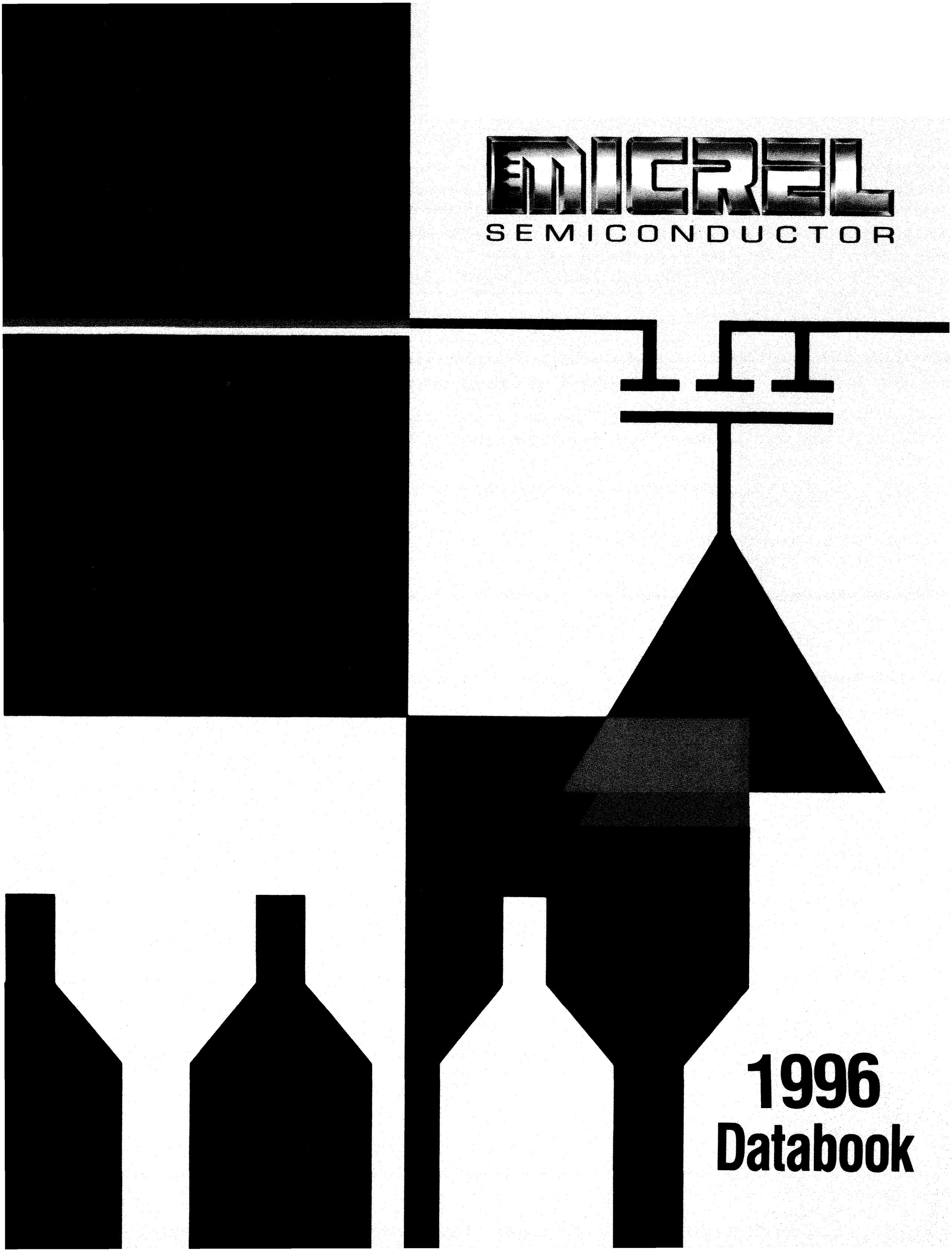
MICREL

SEMICONDUCTOR



1996
Databook

A CORPORATE COMMITMENT TO EXCELLENCE IN SUPPLYING HIGH PERFORMANCE ANALOG POWER ICs:

Micrel Semiconductor was founded in 1978 in the heart of "Silicon Valley." We are a profitable, self-funded, full service semiconductor company. All growth, product development, and acquisitions until December of 1994 were funded through retained earnings. On December 9, 1994, Micrel emerged in an initial public offering as a public company. Micrel is the new leader in power IC products. Our line of low-dropout voltage regulators, power MOSFET drivers, and protected latched drivers is the most extensive in the industry.

Micrel's objective is to be a major supplier of high performance analog power ICs to the personal computer, telecommunications, industrial controls, automotive, office automation, avionics, and military markets. Our rapidly expanding standard product line complements our long standing semiconductor foundry and testing services business.

Micrel's Super ßeta PNP™ LDO Regulators are an example of Micrel's leadership in technology: Super ßeta PNP™ LDO Regulators have the lowest dropout voltage for any high-current voltage regulators available in the industry. Micrel's superb technology provides the *Micrel Advantage* to its customers. Our class 10 wafer fabrication facility is second to none in the markets we serve.

"High Performance Analog Power" is the combining of low-voltage linear and digital functions with high-voltage, high-current output devices. This allows for the further integration of functions previously handled primarily by modules and hybrids. By combining these low-voltage and high-voltage functions in a single monolithic IC, we have dramatically improved both reliability and packaging density. Micrel is dedicated to support this new and exciting high performance analog power semiconductor market. Whether your application is personal computers, telecommunications, industrial controls, automotive, office automation, avionics, or military, Micrel has the solution. We extensively test our products to insure they meet the highest standards of quality and reliability.

Micrel is proud of our success and has established a standard of business performance envied by others in the industry. We are dedicated to service and you have my personal commitment that Micrel will meet or exceed your strictest standard of excellence.

Ray Zinn

Ray Zinn

President and Chief Executive Officer

Micrel, Inc.

Micrel Semiconductor–your source for *High Performance Analog Power ICs™*

Super ßeta PNP and **High Performance Analog Power ICs** are trademarks of Micrel, Inc.

Micrel Semiconductor
1996 Databook

PATENTS

Some products in this book are protected by one or more of the following patents: 4,914,546; 4,951,101; 4,979,001; 5,034,346; 5,045,966; 5,047,820; 5,254,486; 5,355,008; 5,430,403.

LIFE SUPPORT APPLICATIONS POLICY

Micrel products are not authorized for use as critical components in life support devices or systems without the express written approval of the president of Micrel, Incorporated.

As used herein:

(I) Life support devices or systems are devices or systems which, (A) are intended for surgical implant into the body, or (B) support or sustain life, and whose failure to perform, when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.

(II) A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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IttyBitty™ and TinyFET™ Part Identification Index

† early production identification

SMD (Standard Military Drawing) Number Index

IttyBitty and **TinyFET** are a trademarks of Micrel, Inc.

* Summary information. For full details, contact Micrel.

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Section 1: General Information

Corporate History

Introduction

Micrel Semiconductor designs, develops, and manufacturers high-performance analog power integrated circuits. Micrel currently ships over 700 standard products which are used in a wide variety of electronic products, including those in the communications, computer, and industrial markets. Micrel also manufactures custom analog and mixed-signal circuits, and provides wafer foundry services, for a widely diverse range of industries. Standard products are sold through a worldwide network of independent sales representative firms, independent distribution firms, and a direct sales force.

Micrel History

Since its founding in 1978 as an independent test facility of integrated circuits, Micrel has maintained a reputation for excellence, quality and customer responsiveness that is second to none.

In 1981 Micrel acquired its first independent semiconductor processing facility. Initially focusing on custom and specialty fabrication for other IC manufacturers, Micrel eventually expanded to develop its own line of semicustom and standard-product Intelligent Power integrated circuits. In 1993, with the continued success of these ventures, a new 57,000 square feet facility was acquired. This new Class 10 facility has allowed Micrel to extend its process and foundry capabilities with a full complement of CMOS/DMOS/Bipolar/NMOS/PMOS processes. Incorporating metal gate, silicon gate, dual metal, dual poly and features sizes down to 1.5 micron, Micrel is able to offer its customers unique design and fabrication tools.

The ability to combine high-speed/high-density digital, precision, high-performance analog, and high-voltage/high-power devices all on the same monolithic circuit opened new frontiers in semiconductor design. One early example of this capability was the MPD8020 ASIS™ (Applications Specific Integrated System). This semicustom Intelligent Power Array allows users to economically design a proprietary IC by specifying the final interconnect pattern of an array of low-voltage analog and logic CMOS along with customized high-voltage PMOS and high-voltage DMOS power drivers.

As Micrel moved forward toward its goal of becoming an independent supplier of integrated circuits, it expanded its base by entering into agreements to second source products for some major manufacturers. Since then, Micrel has announced numerous proprietary lines of standard products including low-dropout regulators, MOSFET drivers, SMPS regulator and controller ICs, CardBus (PCMCIA card) power controller ICs, latched drivers, display drivers, and many others.

Micrel Today and Beyond

Building on its strength as an innovator in process and test technology, Micrel has expanded and diversified its business by becoming a recognized leader in the high-performance analog power control and management markets.

A successful initial public offering, in December 1994, and ISO9001 compliance are just two additional steps in Micrel's long range strategy to become the preeminent supplier of high performance analog power management and control ICs. By staying close to the customer and the markets they serve, Micrel will remain focused on cost-effective standard product solutions for a changing world.

High-Performance Analog Power ICs

- ***High Performance*** Precision voltages, high technology (Super ßeta PNP™ process, patented circuit techniques, etc.) combined with safety features—such as overcurrent, overvoltage, and overtemperature protection
- ***Analog*** Continuously varying outputs of voltage or current as opposed to digital on/off. Micrel also manufactures mixed-signal (analog plus digital) ICs which take advantage of the best of both.
- ***Power ICs*** High current and/or high voltage

Market Segments

- Power supplies
- Battery-powered computers, cellular phones, and handheld instruments
- Industrial and display systems
- Desktop computers
- Aftermarket automotive
- Avionics
- Plus others

ASIS and **Super ßeta PNP** are trademarks of Micrel, Inc.

Part Identification

Packaged Devices

MIC XXXX -01 A E B Q

Micrel or Standard Prefix

Part Number

Speed /Bonding Option only used when required

Temperature
A = –55°C to +125°C
B = –40°C to +85°C
C = 0°C to +70°C

Qualification Option
H4 = Rad Hard, 1x10^4 rad (Si)
Q = Class B or S

Screening Option
(None) = Industrial
B = Class B **S =** Class S

Package
E = Ceramic Quad
M = 150 mil body SOIC
M5 = SOT-23-5
S = SOT-223
U = TO-263
WM = Wide 300 mil SOIC
Z = TO-92
J = Ceramic DIP
M3 = SOT-23
N = Plastic DIP
SM = SSOP
V = PLCC
WT = TO-247
L = Leadless Chip Carrier
M4 = SOT-143
Q = QFP
T = TO-220
W = Flat-Pack
Y = Dice

Die

(Minimum Order $500)

MIC XXXX A Y P X

Micrel or Industry Standard Prefix

Part Number

Quality
C: Commercial Visual (0°C/+70°C design temperature)
A: Class B Visual, per Mil-Std-883/2010 (–55°C/+125°C design temperature) Wafer Lot Traceability C of C, requires element evaluation, 883/5008, Class B
S: Class S visual per Mil-Std-883/2010 (–55°C/+125°C temperature) Wafter Lot Traceability C of C, requires element evaluation, 883/5008, Class S and Wafer Lot Acceptance 883/5007

Special Processing
H: Radiation Wafer Lot Qualification
L: Backlapped
G: Backlapped and Gold Backed
HG: Rad Hard and Gold Backed

Element Evaluation
Die Form
W: Wafer Form
T: Sticky Tape
P: Waffle Pack

Package
Y: Die are 100% tested at 25°C

Micrel Semiconductor
1849 Fortune Drive
San Jose, CA 95131
USA

TEL: + 1 (408) 944-0800 FAX: + 1 (408) 944-0970

Part Identification

IttyBitty™ and TinyFET™ Part Identification

IttyBitty™, TinyFET™, and other SOT-143/SOT-23/SOT-23-5 packaged devices require an alternate identification scheme due to the small surface area available for marking.

Mark	Part Number	Description	
C10	MIC2660BM5	IttyBitty™ Charge Pump	
D10	MIC4416BM4	IttyBitty™ Low-Side MOSFET Driver	noninverting
D11	MIC4417BM4	IttyBitty™ Low-Side MOSFET Driver	inverting
ML10	*MIC4416BM4*	*IttyBitty™ Low-Side MOSFET Driver*	*early production mark*
H10	MIC5018BM4	IttyBitty™ High-Side MOSFET Driver	noninverting
MH10	*MIC5018BM4*	*IttyBitty™ High-Side MOSFET Driver*	*early production mark*
LA30	MIC5203-3.0BM4	80mA Low-Dropout Regulator	3.0V output
LA33	MIC5203-3.3BM4	80mA Low-Dropout Regulator	3.3V output
LA36	MIC5203-3.6BM4	80mA Low-Dropout Regulator	3.6V output
LA38	MIC5203-3.8BM4	80mA Low-Dropout Regulator	3.8V output
LA40	MIC5203-4.0BM4	80mA Low-Dropout Regulator	4.0V output
LA47	MIC5203-4.7BM4	80mA Low-Dropout Regulator	4.75V output
LA50	MIC5203-5.0BM4	80mA Low-Dropout Regulator	5.0V output
LBAA	MIC5205BM5	150mA Low-Dropout Regulator	adjustable output
LB30	MIC5205-3.0BM5	150mA Low-Dropout Regulator	3.0V output
LB33	MIC5205-3.3BM5	150mA Low-Dropout Regulator	3.3V output
LB36	MIC5205-3.6BM5	150mA Low-Dropout Regulator	3.6V output
LB38	MIC5205-3.8BM5	150mA Low-Dropout Regulator	3.8V output
LB40	MIC5205-4.0BM5	150mA Low-Dropout Regulator	4.0V output
LB50	MIC5205-5.0BM5	150mA Low-Dropout Regulator	5.0V output
P30	MIC94030BM4	TinyFET™ P-Channel MOSFET	
P31	MIC94031BM4	TinyFET™ P-Channel MOSFET	with gate pull-up resistor
R*ab*	LM4040*b*IM3-*x.x* LM4041*b*IM3-*x.x*	Precision Micropower Shunt Voltage Reference	*x.x*: output voltage (volts) *a*: voltage code *b*: tolerance code [see data sheet for details]
T10	MIC1555BM5	IttyBitty™ Timer/Oscillator	
T11	MIC1557BM5	IttyBitty™ Oscillator	

Part Number Cross Reference

Part Number	_Micrel Replacement_
Allegro (Sprague)	
UCN4807A	_MIC4807BN_
UCN5800A	__MIC5800BN__
UCN5800L	__MIC5800BM__
UCN5800R	_MIC5800AJ_
UCN5801A	__MIC5801BN__, _MIC58P01_, _MIC59P50_
UCN5801EP	_MIC5801BV_, _MIC58P01BV_
UCN5801R	_MIC5801AJ_
UCN5821A	__MIC5821BN__
UCN5822A	__MIC5822BN__
UCN5841A	__MIC5841BN__, _MIC58P42_, _MIC59P60_
UCN5841EP	__MIC5841BV__
UCN5841EPTR	__MIC5841BV T&R__
UCN5841LW	__MIC5841BWM__
UCN5841LWTR	__MIC5841BWM T&R__
UCN5842A	__MIC5842BN__, _MIC58P42BN_, _MIC59P60_
UCN5842EP	__MIC5842BV__, _MIC58P42BV_
UCN5842LW	__MIC5842BWM__, _MIC58P42BWM_
UCN5891A	__MIC5891BN__
UCQ5800A	__MIC5800BN__
UCQ5801A	__MIC5801BN__
UCQ5801ABU	__MIC5801AJB__, _MIC58P01AJB_
UCQ5801R	_MIC5801AJ_, _MIC58P01AJ_
UCQ5821A	__MIC5821BN__
UCS5800H883	__5962-8764002CA (MIC5800AJBQ)__
UCS5801H883	__5962-8764001WA (MIC5801AJBQ)__
UCS5822H883	__5962-8764101EA (MIC5822AJBQ)__
Astec	
AS3842...	_MIC38C42..._*, _MIC38HC42..._*
AS3843...	_MIC38C43..._*, _MIC38HC43..._*
AS3844...	_MIC38C44..._*, _MIC38HC44..._*
AS3845...	_MIC38C45..._*, _MIC38HC45..._*
UC3842...	_MIC38C42..._*, _MIC38HC42..._*
UC3843...	_MIC38C43..._*, _MIC38HC43..._*
UC3844...	_MIC38C44..._*, _MIC38HC44..._*
UC3845...	_MIC38C45..._*, _MIC38HC45..._*
Cherry Semiconductor	
CS2843AN8	__MIC38C43BN__*, __MIC38HC43BN__*
CS2843AD8	__MIC38C43BM__*, __MIC38HC43BM__*
CS2843AD14	__MIC38C43-1BM__*, __MIC38HC43-1BM__*
CS3842AD8	__MIC38C42BM__*, __MIC38HC42BM__*
CS3842AD14	__MIC38C42-1BM__*, __MIC38HC42-1BM__*
CS3842AN8	__MIC38C42N__*, __MIC38HC42BN__*
CS3842D8	__MIC38C42BM__*, __MIC38HC42BM__*
CS3842D14	__MIC38C42-1BM__*, __MIC38HC42-1BM__*
CS3842N8	__MIC38C42N__*, __MIC38HC42BN__*
CS3843AD8	__MIC38C43BM__*, __MIC38HC43BM__*
CS3843AD14	__MIC38C43-1BM__*, __MIC38HC43-1BM__*
CS3843AN8	__MIC38C43N__*, __MIC38HC43BN__*
CS3843D8	__MIC38C43BM__*, __MIC38HC43BM__*
CS3843D14	__MIC38C43-1BM__*, __MIC38HC43-1BM__*
CS3843N8	__MIC38C43N__*, __MIC38HC43BN__*

Part Number	_Micrel Replacement_
élantec	
EL7202CN	_MIC1427CN_, _MIC4424BN_
EL7202CS	_MIC1427CM_
EL7212CN	_MIC1426CN_, _MIC4423BN_
EL7212CS	_MIC1426CM_
EL7222CN	_MIC1428CN_, _MIC4425BN_
EL7222CS	_MIC1428CM_
EL7262CN	_MIC4607BN_
EL7262CS	_MIC4607BM_
EL7272CN	_MIC4606BN_
EL7272CS	_MIC4606BM_
Goldstar	
GL3842...	_MIC38C42..._*, _MIC38HC42..._*
GL3843...	_MIC38C43..._*, _MIC38HC43..._*
GL3844...	_MIC38C44..._*, _MIC38HC44..._*
GL3845...	_MIC38C45..._*, _MIC38HC45..._*
Gould AMI	
S4520	_MIC8030_
Harris Semiconductor	
ICL7667CBA	__MIC1426CM__, __MIC4426CM__
ICL7667CPA	__MIC1426CN__, _MIC4423CN_, __MIC4426CN__
ICL7667MJA	_MIC4423AJ_, __MIC4426AJ__
Holt	
HI-8010	_MIC8030_
Linear Technology Corp.	
LT1083CP	_MIC29752BWT_*, _MIC29753BWT_*
LT1084CT	_MIC29502BT_*, _MIC29503BT_*
LT1085CT	_MIC29302BT_*, _MIC29303BT_*
LT1083CP-5	_MIC29750-5.0BWT_*
LT1084CT-5	_MIC29500-5.0BT_*
LT1085CT-5	_MIC29300-5.0BT_*
LT1085CT-12	_MIC29300-12BT_*
LT1086CT	_MIC29152BT_*, _MIC29153BT_*
LT1086-5CT	_MIC29150-5.0BT_*
LT1086-12CT	_MIC29150-12BT_*
LT1172	_MIC2172_*, _MIC3172_*
LT1241MJ8	_MIC18C45AJB_
LT1241CN8	_MIC38C45BN_, _MIC38HC45BN_
LT1241CS8	_MIC38C45BM_, _MIC38HC45BM_
LT1242MJ8	__MIC18C42AJB__*
LT1242CN8	__MIC38C42BN__*, __MIC38HC42BN__*
LT1242CS8	__MIC38C42BM__*, __MIC38HC42BM__*
LT1243CJ8	__MIC38C43AJB__*
LT1243MJ8	__MIC18C43AJB__*
LT1243CN8	__MIC38C43BN__*, __MIC38HC43BN__*
LT1243CS8	__MIC38C43BM__*, __MIC38HC43BM__*
LT1244CJ8	__MIC38C44AJB__*
LT1244MJ8	__MIC18C44AJB__*
LT1244CN8	__MIC38C44BN__*, __MIC38HC44BN__*

Micrel **Equivalent** devices are shown in **boldface**.
Micrel *Similar Replacement* devices are shown in *italic*.
* Indicates Micrel Improved Version devices.

Part Number	*Micrel Replacement*
LT1244CS8	**MIC38C44BM***, **MIC38HC44BM***
LT1245CJ8	**MIC38C45AJB***
LT1245MJ8	**MIC18C45AJB***
LT1245CN8	**MIC38C45BN***, **MIC38HC45BN***
LT1245CS8	**MIC38C45BM***, **MIC38HC45BM***
Linfinity Micro (Silicon General)	
SG1626/2626/3626	**MIC426**, **MIC1426**, **MIC4423**, **MIC4426**
SG1644/2644/3644	**MIC426**, **MIC1426**, **MIC4423**, **MIC4426**
SG3842...	*MIC38C42...**, *MIC38HC42...**
SG3843...	*MIC38C43...**, *MIC38HC43...**
SG3844...	*MIC38C44...**, *MIC38HC44...**
SG3845...	*MIC38C45...**, *MIC38HC45...**
Maxim	
ICL7667	**MIC426**, **MIC1426**, **MIC4423**, **MIC4426**
TSC426	**MIC426**, **MIC1426**, **MIC4423**, **MIC4426**
Motorola	
MH0026	**MIC426**, **MIC1426**, **MIC4423**, **MIC4426**
UC2842AD	**MIC38C42-1BM***, **MIC38HC42-1BM***
UC2842AN	**MIC38C42BN***, **MIC38HC42BN***
UC2842AJ	**MIC38C42AJB***
UC2843AD	**MIC38C43-1BM***, **MIC38HC43-1BM***
UC2843AJ	**MIC38C43AJB***
UC2843AN	**MIC38C43BN***, **MIC38HC43BN***
UC3842AD	**MIC38C42-1BM***, **MIC38HC42-1BM***
UC3842AJ	**MIC38C42AJB***
UC3842AN	**MIC38C42BN***, **MIC38HC42BN***
UC3842D	**MIC38C42-1BM***, **MIC38HC42-1BM***
UC3842DJ	**MIC38C42AJB***
UC3842N	**MIC38C42BN***, **MIC38HC42BN***
UC3843AN	**MIC38C43BN***, **MIC38HC43BN***
UC3843AD	**MIC38C43-1BM***, **MIC38HC43-1BM***
National Semiconductor	
DS0026CJ-8	*MIC4426AJ*
DS0026CN	*MIC4426CN*, *MIC4426CN*
LM2574M-3.3	**LM2574-3.3BWM**, *LM4574-3.3BWM*
LM2574M-5.0	**LM2574-5.0BWM**, *LM4574-5.0BWM*
LM2574M-12	**LM2574-12BWM**
LM2574M-ADJ	**LM2574BWM**, *LM4574BWM*
LM2574N-3.3	**LM2574-3.3BN**, *LM4574-3.3BN*
LM2574N-5.0	**LM2574-5.0BN**
LM2574N-12	**LM2574-12BN**
LM2574N-ADJ	**LM2574BN**, *LM4574BN*
LM2575M-ADJ	**LM2575BWM**
LM2575M-3.3	**LM2575-3.3BWM**
LM2575M-5.0	**LM2575-5.0BWM**
LM2575M-12	**LM2575-12BWM**
LM2575N-ADJ	**LM2575BN**
LM2575N-3.3	**LM2575-3.3BN**
LM2575N-5.0	**LM2575-5.0BN**
LM2575N-12	**LM2575-12BN**
LM2575T-ADJ	**LM2575BT**, *MIC4575BT*
LM2575T-3.3	**LM2575-3.3BT**, *MIC4575-3.3BT*
LM2575T-5.0	**LM2575-5.0BT**, *MIC4575-5.0BT*
LM2575T-12	**LM2575-12BT**
LM2576T-ADJ	**LM2576BT**, *MIC4576BT*
LM2576T-3.3	**LM2576-3.3BT**, *MIC4576-3.3BT*
LM2576T-5.0	**LM2576-5.0BT**, *MIC4576-5.0BT*
LM2576T-12	**LM2576-12BT**
LM2930T-5.0	**MIC2954-03BT***
LM2931AT-5.0	**MIC2954-03BT***
LM2931AZ-5.0	**MIC2950-06BZ***
LM2931T-5.0	**MIC2954-03BT***

Part Number	*Micrel Replacement*
LM2931Z-5.0	**MIC2950-06BZ***
LM2937ET-5.0	**MIC2937A-5.0BT***
LM2937ET-12	**MIC2937A-12BT***
LM2940CT-5.0	**MIC2940A-5.0BT***
LM2940CT-12	**MIC2940A-12BT***
LM2940T-5.0	**MIC2940A-5.0BT***
LM2940T-12	**MIC2940A-12BT***
LM2941CT-5.0	**MIC2941ABT***
LM2941T-5.0	**MIC2941ABT***
LM4040...	**LM4040...**
LM4041...	**LM4041...**
LP2950ACZ-5.0	**LP2950-02BZ**, **MIC2950-05BZ***
LP2950CZ-5.0	**LP2950-03BZ**, **MIC2950-06BZ***
LP2951ACM	**LP2951-02BM**, **MIC2951-02BM***
LP2951ACN	**LP2951-02BN**, **MIC2951-02BN***
LP2951AIT	**MIC2954-02BT***
LP2951ICM	**LP2951-03BM**, **MIC2951-03BM***
LP2951CN	**LP2951-03BN**, **MIC2951-03BN***
LP2951IT	**MIC2954-03BT***
LP2954AIT	**MIC2954-02BT***
LP2954IT	**MIC2954-03BT***
MM5450	**MM5450**
MM5451	**MM5451**
NHM0026	**MIC426**, **MIC1426**, **MIC4423**, **MIC4426**
Phillips	
UC3842...	*MIC38C42...**, *MIC38HC42...**
UC3843...	*MIC38C43...**, *MIC38HC43...**
UC3844...	*MIC38C44...**, *MIC38HC44...**
UC3845...	*MIC38C45...**, *MIC38HC45...**
Samsung	
KA3842B	**MIC38C42BN***, **MIC38HC42BN***
KA3842BD	**MIC38C42-1BM***, **MIC38HC42-1BM***
KA3843B	**MIC38C43BN***, **MIC38HC43BN***
KA3843BD	**MIC38C43-1BM***, **MIC38HC43-1BM***
KA3844B	**MIC38C44BN***, **MIC38HC44BN***
KA3844BD	**MIC38C44-1BM***, **MIC38HC44-1BM***
KA3845B	**MIC38C45BN***, **MIC38HC45BN***
KA3845BD	**MIC38C45-1BM***, **MIC38HC45-1BM***
Semtech	
LM2575T-ADJ	**LM2575BT**
LM2575T-3.3	**LM2575-3.3BT**
LM2575T-5.0	**LM2575-5.0BT**
LM2575T-12	**LM2575-12BT**
LM2575N-ADJ	**LM2575BN**
LM2575N-3.3	**LM2575-3.3BN**
LM2575N-5.0	**LM2575-5.0BN**
LM2575N-12	**LM2575-12BN**
LM2575M-ADJ	**LM2575BWM**
LM2575M-3.3	**LM2575-3.3BWM**
LM2575M-5.0	**LM2575-5.0BWM**
LM2575M-12	**LM2575-12BWM**
LM2576T-ADJ	**LM2576BT**
LM2576T-3.3	**LM2576-3.3BT**
LM2576T-5.0	**LM2576-5.0BT**
LM2576T-12	**LM2576-12BT**

Micrel **Equivalent** devices are shown in **boldface**.
Micrel *Similar Replacement* devices are shown in *italic*.
* Indicates Micrel Improved Version devices.

Part Number	*Micrel Replacement*
SGS-Thomson	
M5450	**MM5450**
M5451	**MM5451**
SGS1626/2626/3626	**MIC426**, **MIC1426**, **MIC4423**, **MIC4426**
UC3842...	*MIC38C42...**, *MIC38HC42...**
UC3843...	*MIC38C43...**, *MIC38HC43...**
UC3844...	*MIC38C44...**, *MIC38HC44...**
UC3845...	*MIC38C45...**, *MIC38HC45...**
Siliconix	
SG1626/2626/3626	**MIC426, MIC1426, MIC4423, MIC4426**
Telcom (Teledyne)	
TC426COA	**MIC426CM**
TC426CPA	**MIC426CN**
TC426EOA	**MIC426BM**
TC426MJA	**MIC426AJ**
TC427COA	**MIC427CM**
TC427CPA	**MIC427CN**
TC427EOA	**MIC427BM**
TC427MJA	**MIC427AJ**
TC428COA	**MIC428CM**
TC428CPA	**MIC428CN**
TC428EOA	**MIC428BM**
TC428MJA	**MIC428AJ**
TC1426COA	**MIC1426CM**
TC1426CPA	**MIC1426CN**
TC1427COA	**MIC1427CM**
TC1427CPA	**MIC1427CN**
TC1428COA	**MIC1428CM**
TC1428CPA	**MIC1428CN**
TC18C42MJA	**MIC18C42AJB***
TC18C43MJA	**MIC18C43AJB***
TC18C44MJA	**MIC18C44AJB***
TC18C45MJA	**MIC18C45AJB***
TC28C42EJA	**MIC18C42AJB***
TC28C42EPA	**MIC38C42BN*, MIC38HC42BN***
TC28C43EJA	**MIC18C43AJB***
TC28C43EPA	**MIC38C43BN*, MIC38HC43BN***
TC28C44EJA	**MIC18C44AJB***
TC28C44EPA	**MIC38C44BN*, MIC38HC44BN***
TC28C45EJA	**MIC18C45AJB***
TC28C45EPA	**MIC38C45BN*, MIC38HC45BN***
TC38C42CPA	**MIC38C42BN*, MIC38HC42BN***
TC38C42CPD	**MIC38C42-1BN*, MIC38HC42-1BN***
TC38C43CPA	**MIC38C43BN*, MIC38HC43BN***
TC38C43CPD	**MIC38C43-1BN*, MIC38HC43-1BN***
TC38C44CPA	**MIC38C44BN*, MIC38HC44BN***
TC38C44CPD	**MIC38C44-1BN*, MIC38HC44-1BN***
TC38C45CPA	**MIC38C45BN*, MIC38HC45BN***
TC38C45CPD	**MIC38C45-1BN*, MIC38HC45-1BN***
TC4401EOA	**MIC4401BM**
TC4401EPA	**MIC4401BN**
TC4401MJA	**MIC4401AJ**
TC4403EPA	**MIC4403BN**
TC4404EPA	*MIC4604BN*
TC4404EOA	*MIC4604BM*
TC4605EPA	*MIC4604BN*
TC4605EOA	*MIC4604BM*
TC4406EPA	*MIC4606BN*
TC4407EPA	*MIC4607BN*
TC4420CPA	**MIC4420CN**
TC4420EPA	**MIC4420BN**
TC4420COA	**MIC4420CM**
TC4420EOA	**MIC4420BM**
TC4420MJA	**MIC4420AJ**
TC4420CAT	**MIC4420CT**
TC4421CPA	**MIC4421CN**
TC4421EPA	**MIC4421BN**
TC4421MJA	**MIC4421AJ**
TC4421CAT	**MIC4421CT**
TC4422CPA	**MIC4422CN**
TC4422EPA	**MIC4422BN**
TC4422MJA	**MIC4422AJ**
TC4422CAT	**MIC4422CT**
TC4423COE	**MIC4423CWM**
TC4423CPA	**MIC4423CN**
TC4423EOE	**MIC4423BWM**
TC4423EPA	**MIC4423BN**
TC4423MJA	**MIC4423AJ**
TC4424COE	**MIC4424CWM**
TC4424CPA	**MIC4424CN**
TC4424EOE	**MIC4424BWM**
TC4424EPA	**MIC4424BN**
TC4424MJA	**MIC4424AJ**
TC4425COE	**MIC4425CWM**
TC4425CPA	**MIC4425CN**
TC4425EOE	**MIC4425BWM**
TC4425EPA	**MIC4425BN**
TC4425MJA	**MIC4425AJ**
TC4426COA	**MIC4426CM**
TC4426CPA	**MIC4426CN**
TC4426EOA	**MIC4426BM**
TC4426EPA	**MIC4426BN**
TC4426MJA	**MIC4426AJ**
TC4427COA	**MIC4427CM**
TC4427CPA	**MIC4427CN**
TC4427EOA	**MIC4427BM**
TC4427EPA	**MIC4427BN**
TC4427MJA	**MIC4427AJ**
TC4428COA	**MIC4428CM**
TC4428CPA	**MIC4428CN**
TC4428EOA	**MIC4428BM**
TC4428EPA	**MIC4428BN**
TC4428MJA	**MIC4428AJ**
TC4429CPA	**MIC4429CN**
TC4429EPA	**MIC4429BN**
TC4429COA	**MIC4429CM**
TC4429EOA	**MIC4429BM**
TC4429MJA	**MIC4429AJ**
TC4429CAT	**MIC4429CT**
TC4467COE	**MIC4467CWM**
TC4467CPD	**MIC4467CN**
TC4467EPD	**MIC4467BN**
TC4467EOE	**MIC4467BWM**
TC4467EJD	**MIC4467AJ**
TC4468COE	**MIC4468CWM**
TC4468CPD	**MIC4468CN**
TC4468EPD	**MIC4468BN**
TC4468EOE	**MIC4468BWM**
TC4468EJD	**MIC4468AJ**
TC4469COE	**MIC4469CWM**
TC4469CPD	**MIC4469CN**
TC4469EPD	**MIC4469BN**
TC4469EOE	**MIC4469BWM**
TC4469EJD	**MIC4469AJ**

Micrel **Equivalent** devices are shown in **boldface**.
Micrel *Similar Replacement* devices are shown in *italic*.
* Indicates Micrel Improved Version devices.

Part Number	*Micrel Replacement*
Texas Instruments	
TL750L05LP	**LP2950-03BZ*, MIC2950-06BZ***
UC2842	**MIC38C42BN*, MIC38HC42BN***
UC2843	**MIC38C43BN*, MIC38HC43BN***
UC2844	**MIC38C44BN*, MIC38HC44BN***
UC2845	**MIC38C45BN*, MIC38HC45BN***
UC3842P	**MIC38C42BN*, MIC38HC42BN***
UC3843P	**MIC38C43BN*, MIC38HC43BN***
UC3844P	**MIC38C44BN*, MIC38HC44BN***
UC3845P	**MIC38C45BN*, MIC38HC45BN***
Unitrode	
UC1842AJ	**MIC18C42AJB***
UC1842J	**MIC18C42AJB***
UC1843AJ	**MIC18C43AJB***
UC1843J	**MIC18C43AJB***
UC1844AJ	**MIC18C44AJB***
UC1844J	**MIC18C44AJB***
UC1845AJ	**MIC18C45AJB***
UC1845J	**MIC18C45AJB***
UC2575T-ADJ	**LM2575BT**
UC2576T-ADJ	**LM2576BT**
UC2576T-5.0	**LM2576-5.0BT**
UC2576T-12	**LM2576-12BT**
UC2842AD	**MIC38C42-1BM*, MIC38HC42-1BM***
UC2842AD8	**MIC38C42BM*, MIC38HC42BM***
UC2842AN	**MIC38C42BN*, MIC38HC42BN***
UC2842D	**MIC38C42-1BM*, MIC38HC42-1BM***
UC2842D8	**MIC38C42BM*, MIC38HC42BM***
UC2842N	**MIC38C42BN*, MIC38HC42BN***
UC2843AD	**MIC38C43-1BM*, MIC38HC43-1BM***
UC2843AD8	**MIC38C43BM*, MIC38HC43BM***
UC2843AN	**MIC38HC43BN*, MIC38HC43BN***
UC2843D	**MIC38C43-1BM*, MIC38HC43-1BM***
UC2843D8	**MIC38C43BM*, MIC38HC43BM***
UC2843N	**MIC38HC43BN*, MIC38HC43BN***
UC2844AD	**MIC38C44-1BM*, MIC38HC44-1BM***
UC2844AD8	**MIC38C44BM*, MIC38HC44BM***
UC2844AN	**MIC38C44BN*, MIC38HC44BN***
UC2844D	**MIC38C44-1BM*, MIC38HC44-1BM***
UC2844D8	**MIC38C44BM*, MIC38HC44BM***
UC2844N	**MIC38C44BN*, MIC38HC44BN***
UC2845AD	**MIC38C45-1BM*, MIC38HC45-1BM***
UC2845AD8	**MIC38C45BM*, MIC38HC45BM***
UC2845AN	**MIC38C45BN*, MIC38HC45BN***
UC2845D	**MIC38C45-1BM*, MIC38HC45-1BM***
UC2845D8	**MIC38C45BM*, MIC38HC45BM***
UC2845N	**MIC38C45BN*, MIC38HC45BN***
UC3842AD	**MIC38C42-1BM*, MIC38HC42-1BM***
UC3842AD8	**MIC38C42BM*, MIC38HC42BM***
UC3842AJ	**MIC18C42AJB***
UC3842AN	**MIC38C42BN*, MIC38HC42BN***
UC3842D	**MIC38C42-1BM*, MIC38HC42-1BM***
UC3842D8	**MIC38C42BM*, MIC38HC42BM***
UC3842J	**MIC18C42AJB***
UC3842N	**MIC38C42BN*, MIC38HC42BN***
UC3843AD	**MIC38C43-1BM*, MIC38HC43-1BM***
UC3843AD8	**MIC38C43BM*, MIC38HC43BM***
UC3843AJ	**MIC18C43AJB***
UC3843AN	**MIC38C43BN*, MIC38HC43BN***
UC3843D	**MIC38C43-1BM*, MIC38HC43-1BM***
UC3843D8	**MIC38C43BM*, MIC38HC43BM***
UC3843J	**MIC18C43AJB***
UC3843N	**MIC38C43BN*, MIC38HC43BN***
UC3844AD	**MIC38C44-1BM*, MIC38HC44-1BM***
UC3844AD8	**MIC38C44BM*, MIC38HC44BM***
UC3844AJ	**MIC18C44AJB***
UC3844AN	**MIC38C44BN*, MIC38HC44BN***
UC3844D	**MIC38C44-1BM*, MIC38HC44-1BM***
UC3844D8	**MIC38C44BM*, MIC38HC44BM***
UC3844J	**MIC18C44AJB***
UC3844N	**MIC38C44BN*, MIC38HC44BN***
UC3845AD	**MIC38C45-1BM*, MIC38HC45-1BM***
UC3845AD8	**MIC38C45BM*, MIC38HC45BM***
UC3845AJ	**MIC18C45AJB***
UC3845AN	**MIC38C45BN*, MIC38HC45BN***
UC3845D	**MIC38C45-1BM*, MIC38HC45-1BM***
UC3845D8	**MIC38C45BM*, MIC38HC45BM***
UC3845J	**MIC18C45AJB***
UC3845N	**MIC38C45BN*, MIC38HC45BN***

Micrel **Equivalent** devices are shown in **boldface**.
Micrel *Similar Replacement* devices are shown in *italic*.
* Indicates Micrel Improved Version devices.

Quality/Reliability Program

Our Philosophy

Product quality and reliability are two of the most critical elements for achieving success in today's semiconductor industry. Micrel has attained success as a semiconductor supplier by designing and processing parts that meet the most strenuous applications and most adverse environments. Micrel has accomplished this by never wavering from the philosophy that quality must be built into each and every device and process.

Micrel considers product reliability to be an expression of the quality philosophy extended over the expected life of each product. Micrel's philosophy begins in the design stage and continues, under strict monitoring and control, throughout the development, production, testing and packaging of each product.

Micrel's specific goal is to produce devices that are without defect from their given specifications for performance and product life. Product testing and comparative studies are ongoing activities at Micrel as we continue our search for new and more effective methods for manufacturing products with built-in quality. The Micrel quality program is in full compliance with MIL-I-45208, MIL-STD-883 paragraph 1.2.1 compliant non-JAN devices, and equipment calibration meets all requirements of MIL-STD-45662.

Quality Program Elements

Quality and reliability in Micrel products are obtained through a number of quality assurance program elements, most of which contain multiple levels of requirements and procedures. These program elements comprise the Micrel Quality Assurance Program.

I. Supplier requirements

Vendor certification of compliance to published specifications is required for process materials, gasses, substrates, masks, etc., as well as for components, parts and materials used in assembly.

II. Fabrication QA is based on a Statistical Process Control (SPC) Program including:

1. Test procedures
2. Document control
    - Specifications/recipes
    - Process change notice (PCN)
    - Engineering change notice (ECN)
3. Critical process-step monitoring
    - Particulates
    - Critical dimensions
    - Electrical performance
4. Extended SPC programs
    - Process Limit Control (PLC)
    - Process on Exception (POE)
5. Outgoing QA
    - Visual Inspection
    - To Micrel Standards
    - To Mil-883 Class B or Class S Requirements

III. Vendor Requirements

Certification of compliance to published Micrel or customer specifications is required for processes, materials, and services from third-party vendors.

IV. Assembly QA Program

1. Test procedures
2. Document control
    - Specifications
    - Control systems
    - Engineering change notices (ECN)
3. Critical-step monitoring
    - Assembly processes
    - Critical dimensions
    - Environmental processes
4. Acceptance Test Procedure
    - Electrical performance
    - Component marking
5. Outgoing QA
    - Visual Inspection
    - To Micrel Standards
    - To Mil-883 Class B or Class S Requirements

Organization

At Micrel, quality assurance management reports directly to the President of the corporation. All quality and reliability issues are independent of the production organizations.

The QA Manager's responsibilities are to establish and maintain effective controls for monitoring Micrel manufacturing and test services, equipment and processes (as well as our suppliers and contractors), to report the findings to the President, and to initiate statistically valid techniques to further improve Micrel quality and reliability levels.

The QA Manager is responsible for implementation and administration of multiple quality-related programs and systems for both commercial and military grade processes and products. Activities under the QA Manager's control include: incoming inspection, in-process quality control, qualification testing, conformance testing, document control, specification review, failure analysis, internal audit, quality procedures training, and ongoing vendor qualification and performance appraisal.

Statistical Process Control

Foremost of the Micrel quality assurance programs is their Statistical Process Control (SPC) methodology. Because of the company's unique mix of proprietary, custom and foundry products, SPC at Micrel is approached on two levels.

Level 1	Traditional SPC utilizing process capability studies, design of experiments, Paretto analysis, histograms and X-bar R charting of critical process steps.
Level 2	Extended SPC methodology adds Process Limit Control (PLC) and Process on Exception (POE) programs as sub-sets to the standard SPC programs.

Micrel's Process Limit Control (PLC) program provides absolute control of wafer runs during processing. Parameters are measured and recorded at every process steps against established limits. When any measurement value is found to exceed a specification limit, the run is immediately stopped and process engineering is notified. Before the run can proceed, engineering must evaluate the data and determine the run disposition during that production shift.

The Process on Exception (POE) program monitors and controls wafers during electrical testing. Wafer probe results are compared against specifications. Any exceptions to either absolute, preferred, or target specifications are noted and detailed reports are generated. Engineering may then exercise some influence over yield issues by determining which electrical performance criteria are critical.

The results of SPC, PLC and POE performance monitoring are reviewed on a monthly basis. Trends are charted, corrective actions are evaluated and process improvements are implemented as a result of the data.

Document Control

Document control is an integral part of the Micrel quality assurance program. It is designed to assure that operating procedures and customer requirements are translated into regulatory written instructions. Document control is responsible for initiating, approving, distributing, revising, recalling, and archiving internal control systems in the form of product run sheets (recipes), process and test specifications, etc.

Micrel's two main specification control methodologies utilize engineering change notice (ECN) and process change notice (PCN) systems.

ECN	The engineering change notice system follows standard industry procedures for process and test specifications, travelers, forms, and drawings.
PCN	The process change notice system is an extension of Micrel's unique, highly-detailed product run sheet (recipe) control system. PCN mechanisms meet the extreme demands for accuracy required in wafer processing.

Packaged product quality is controlled by a detailed set of instructions that are issued and controlled as part of the ECN system. These instructions cover all assembly and back-end processing steps and include the build-diagram, burn-in drawing, test set-up specification, test traveler, etc.

Inspection and Test Points

The flow charts accompanying this section describe the sequential steps of semiconductor processing and fabrication, and the associated test or inspection procedures and documentation.

Equipment Calibration

Micrel maintains a calibration system that conforms to MIL-STD-45662 and ensures measurement accuracy of equipment used to determine product workmanship and acceptability. Major provisions of the program include:

- Qualification of external calibration services,
- References traceable to National Institute of Standards and Technology (NIST). Identification of measurement and test equipment for type (electrical, mechanical, and optical) and frequency of calibration
- Certification history of equipment calibration and recall
- Recall status report history
- Audit history (calibration date stickers and recall designation)

Quality Control

The quality control program includes multiple inspections of material in-process, as well as final acceptance inspection of outgoing finished products. The QC system comprises product integrity characterizations of dimensional, structural, electrical and visual parameters. It also includes environmental and procedural monitoring checks.

The program elements include, but are not necessarily limited to:

- Particulate monitoring
- Temperature and relative humidity monitoring
- Electrostatic discharge monitoring and control
- Specification compliance reviews
- Random monitoring of wafers in-process
- Critical dimension qualification of product lot samples
- Wafer/die electrical sort
- Performance/trend data analysis
- Storage, handling, packaging and identification of raw materials, work-in-progress, and finished goods
- Returned material analysis

Finished product is inspected and tested prior to its shipment to the customer. Random sampling methodology is used to check deliverable wafer, die or part quality against published Micrel workmanship standards and customer specifications.

This final-product quality control program includes systems and procedures that assure the following:

- Correlation and qualification of test equipment to internal and customer specifications
- Manufacturing test operations are proper and complete
- Product lots conform to detailed test requirements for visual, mechanical and electrical performance criteria
- Documentation for each product/lot is proper and complete

New Products and Processes

New products or major process changes must undergo complete evaluation before they are certified at Micrel. Quality Assurance participation and approval is required in new product design reviews, product characterization and reliability studies, and documentation preparation.

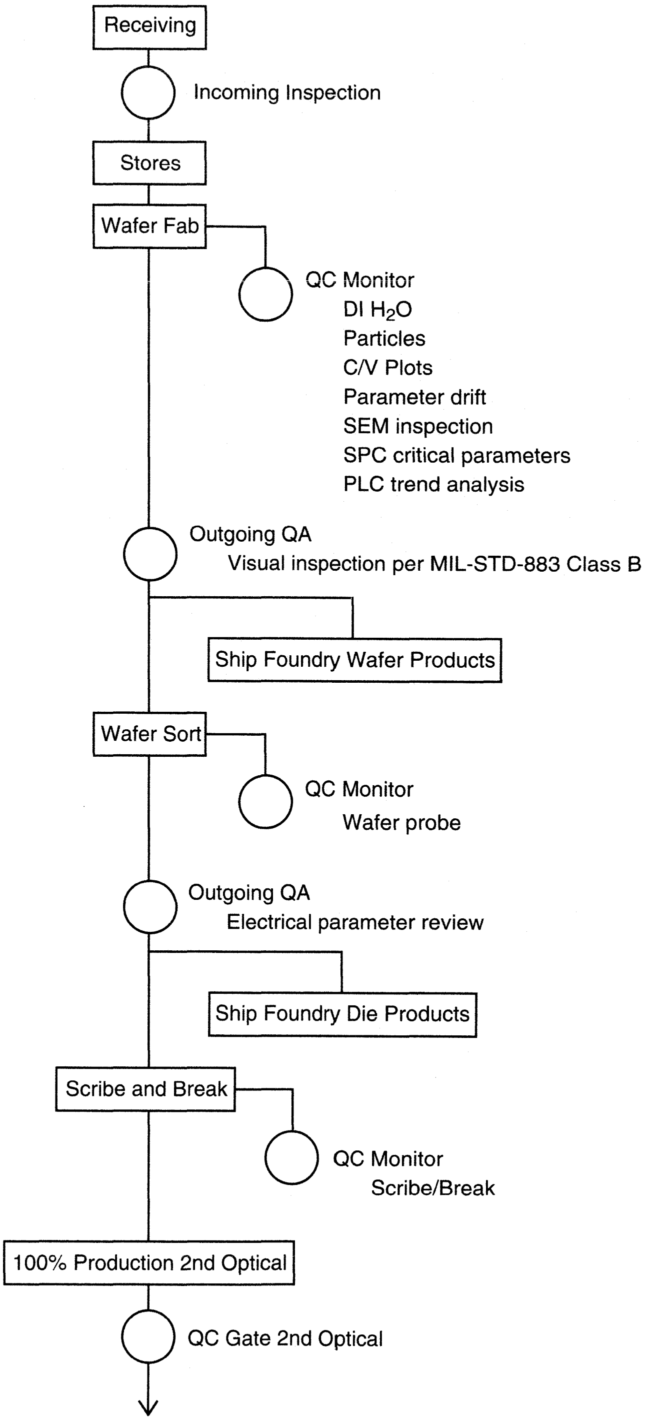
Certification is granted to new products or processes only after rigorous stress-testing, thorough monitoring of critical dimensions, careful failure analysis, and full process/trend data review. New packages are qualified and released for production only after Quality Assurance has determined that all environmental, mechanical and electrical tests are satisfactorily completed.

Complete and proper documentation of all material, process, procedure or packaging changes is required for final Quality Assurance certification.

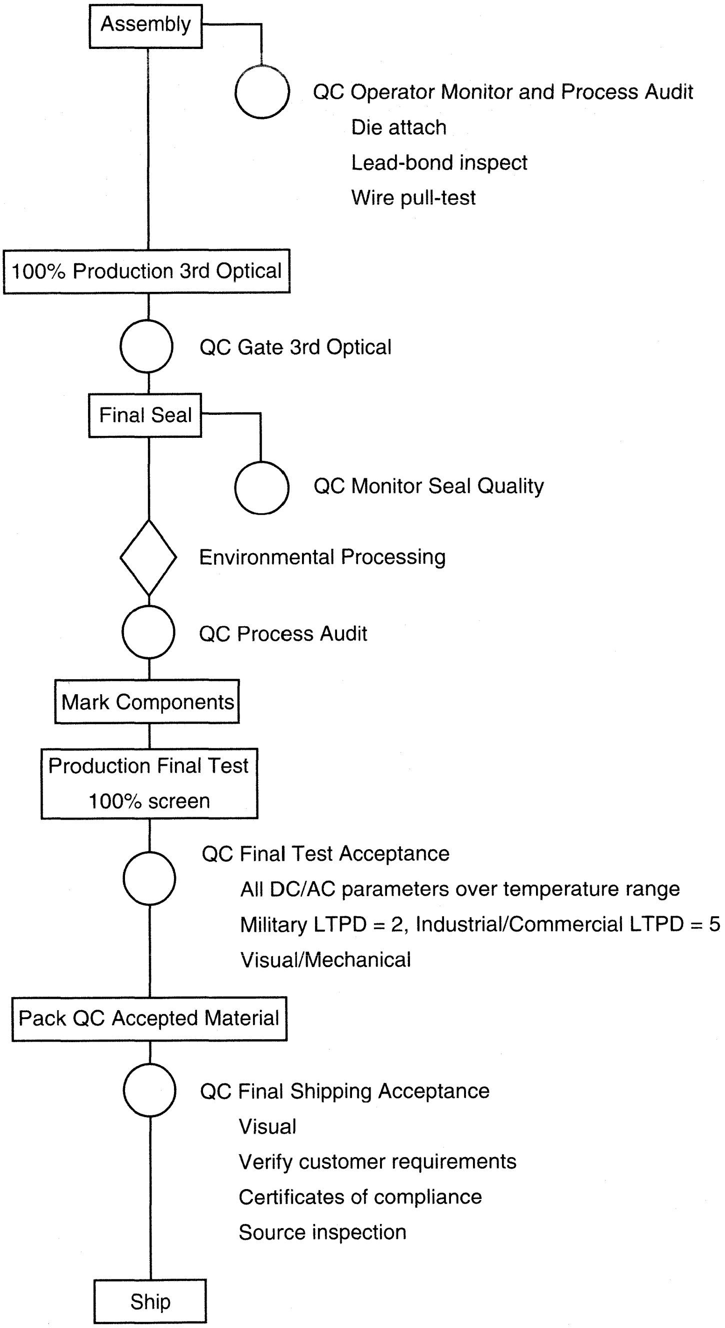
Summary

The Micrel Quality Assurance philosophy — that quality must be built into every process and product — is realized by the company's thorough implementation of the policies, procedures and processes required to ensure that our products and services meet the highest standards for material and workmanship.

Micrel Quality Flow for Semiconductor Circuit Manufacturing



Micrel Quality Flow for Semiconductor Assembly



Customer Returns

Perform analysis, answer and/or generate corrective action request, make disposition of return.

Specification Review

Review internal specifications, verify agreement to customer requirements, issue specification to production.

Reliability Assurance

Qualification — Test each device family in accordance with MIL-STD-883, Method 5004 and 5005, Class B requirements.

Certification — New products and major process changes subjected to accelerated test and process analysis.

Failure Analysis — Performed on all Qualification and Process Monitor failures and customer returns as needed.

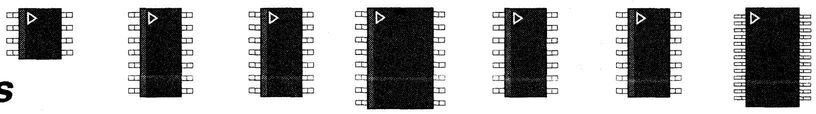
Document Control — Maintains files of all latest drawings and specifications, controls and issues wafer run-sheets, specifications, drawings and ECN numbers, distributes copies to specification control books and user groups.

Table of Contents

Section 2: Computer Peripherals

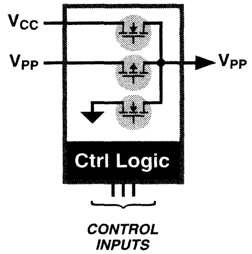
Computer Peripherals Selection Guide

PC Card Slot (PCMCIA) Power Controllers

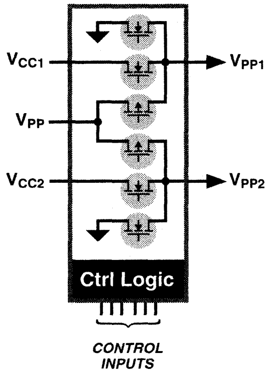


Typical R_{ON}	MIC2557	MIC2558	MIC2559	MIC2560	MIC2561	*NEW* MIC2562A	*NEW* MIC2563A
V_{CC} = 3.3V				40mΩ	110mΩ	100mΩ	100mΩ
V_{CC} = 5V				70mΩ	210mΩ	70mΩ	70mΩ
V_{PP} = 12V	500mΩ	500mΩ	500mΩ	550mΩ	550mΩ	600mΩ	600mΩ
Current Limit				▲	▲	▲	▲
Thermal Shutdown			▲	▲	▲	▲	▲
Charge Pump						▲	▲
Dual		▲	▲				▲
Lowest Cost Applications					▲		
Controlled Switching	▲	▲	▲	▲	▲	▲	▲

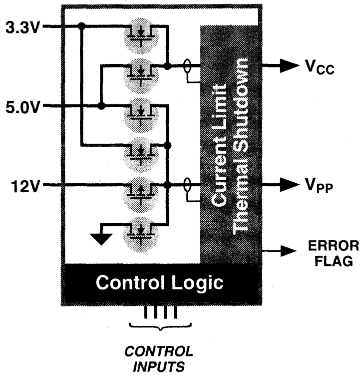
MIC2557



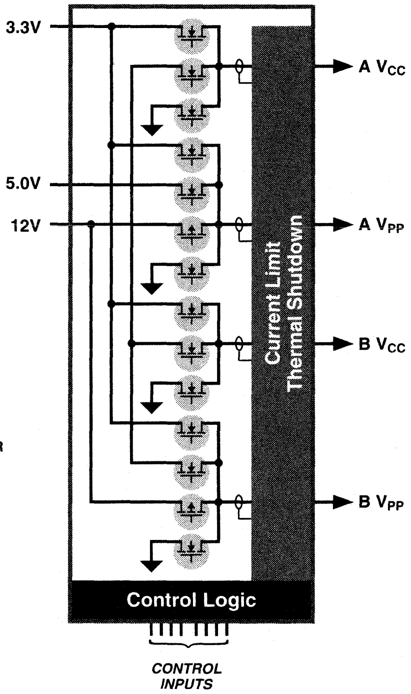
MIC2558
MIC2559



MIC2560
MIC2561
MIC2562A*



MIC2563A*



** 12V supply not required*

MIC2557

PCMCIA Card Socket V_{PP} Switching Matrix

General Description

The MIC2557 switches the four voltages required by PCMCIA (Personal Computer Memory Card International Association) card V_{PP} Pins. The MIC2557 provides selectable 0V, 3.3V, 5.0V, or 12.0V (±5%) from the system power supply to V_{PP1} or V_{PP2}. Output voltage is selected by two digital inputs. Output current ranges up to 120mA. Four control states, V_{PP}, V_{CC}, high impedance, and active logic low are available. An auxiliary control input determines whether the high impedance (open) state or low logic state is asserted.

In either quiescent mode or full operation, the device draws very little current, typically less than 1µA.

The MIC2557 is available in an 8-pin SOIC and an 8-pin plastic DIP.

Applications

- PCMCIA V_{PP} Pin Voltage Switch
- Power Supply Management
- Power Analog Switch

Features

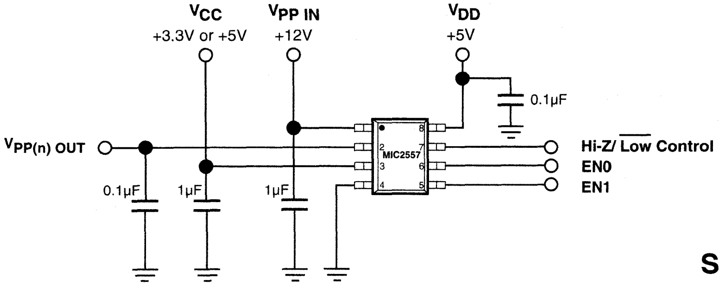
- Complete PCMCIA V_{PP} Switch Matrix in a Single IC
- No External Components Required
- Digital Selection of 0V, V_{CC}, V_{PP}, or High Impedance Output
- No $V_{PP\ OUT}$ Overshoot or Switching Transients
- Break-Before-Make Switching
- Low Power Consumption
- 120mA V_{PP} (12V) Output Current
- Optional Active Source Clamp for Zero Volt Condition
- 3.3V or 5V Supply Operation
- 8-Pin SOIC Package

Ordering Information

Part Number	Temperature Range	Package
MIC2557BM	–40°C to +85°C	8-pin SOIC
MIC2557BM T&R	–40°C to +85°C	8-SOIC Tape & Reel*

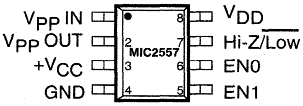
* 2,500 Parts per reel.

Typical Application

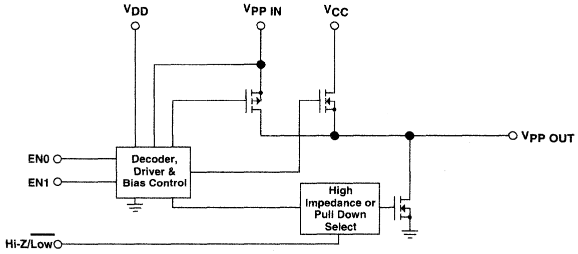


EN1	EN0	Hi-Z/$\overline{\text{Low}}$	$V_{PP\ OUT}$
0	0	0	0V, (Sink current)
0	0	1	Hi-Z (No Connect)
0	1	x	V_{CC} (3.3V or 5.0V)
1	0	x	V_{PP}
1	1	x	Hi-Z (No Connect)

Pin Configuration



Simplified Block Diagram

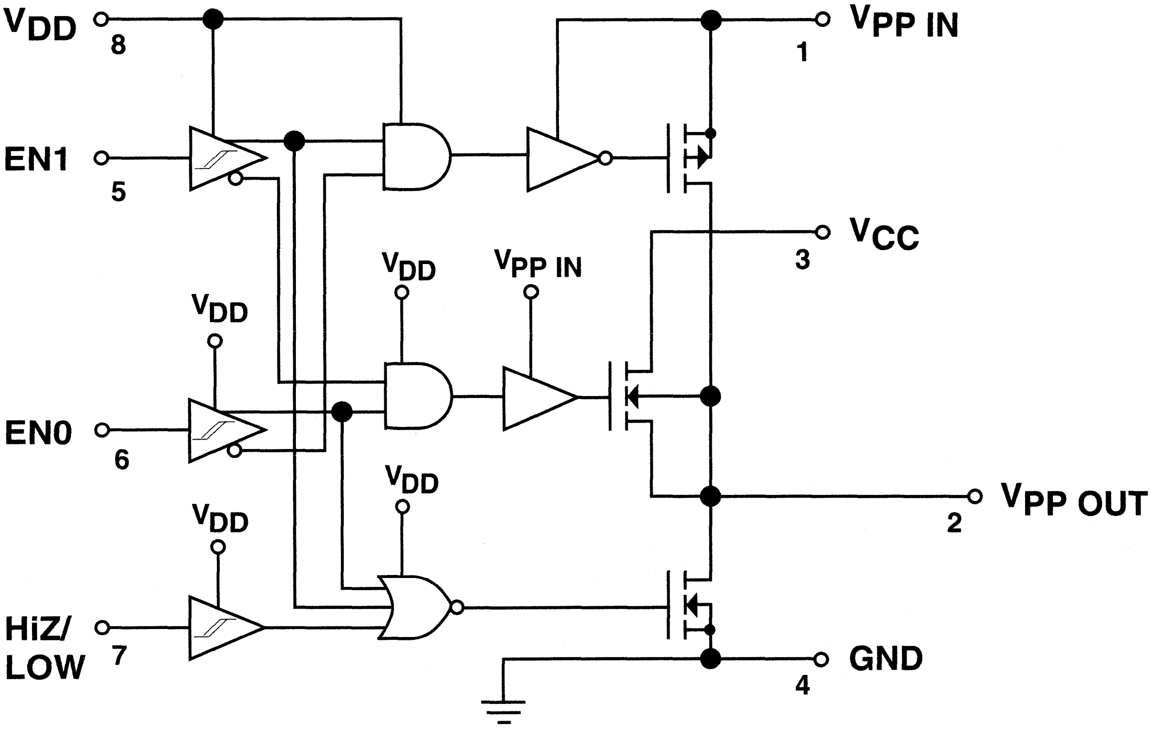


For a dual PCMCIA Card Socket V_{PP} Switching Matrix, see the MIC2558.
For a V_{PP} and V_{CC} Switching Matrix, see the MIC2560.

Absolute Maximum Ratings (Notes 1 and 2)

Power Dissipation, $T_{AMBIENT} \leq 25°C$	
SOIC	800 mW
Derating Factors (To Ambient)	
SOIC	4 mW/°C
Storage Temperature	–65°C to +150°C
Operating Temperature (Die)	125°C
Operating Temperature (Ambient)	–40°C to +85°C
Lead Temperature (10 sec)	300°C
Supply Voltage, $V_{PP\ IN}$	15V
V_{CC}	7.5V
V_{DD}	7.5V
Logic Input Voltages	–0.3V to V_{DD}
Output Current	
$V_{PP\ OUT}$ = 12V	600mA
$V_{PP\ OUT} = V_{CC}$	250mA

Logic Block Diagram



Electrical Characteristics: (Over operating temperature range with $V_{DD} = V_{CC} = 5V$, $V_{PP\ IN} = 12$ V unless otherwise specified.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage	V_{DD} = 3.3V or 5.0V	2.2			V
V_{IL}	Logic 0 Input Voltage	V_{DD} = 3.3V or 5.0V			0.8	V
V_{IN} (Max)	Input Voltage Range		–5		V_{DD}	V
I_{IN}	Input Current	$0\ V < V_{IN} < V_{DD}$			±1	µA
OUTPUT						
V_{OL}	Clamp Low Output Voltage	EN0 = EN1 = HiZ = 0, I_{SINK} = 1.6mA			0.4	V
I_{OUT}, Hi-Z	High Impedance Output Leakage Current	EN0 = EN1 = 0, HiZ = 1 $0 \le V_{PP\ OUT} \le 12V$		1	10	µA
R_{OC}	Clamp Low Output Resistance	Resistance to Ground. I_{SINK} = 2mA EN0 = EN1 =0,HiZ=0		130	250	Ω
R_O	Switch Resistance, $V_{PP\ OUT} = V_{CC}$	$I_{PP\ OUT}$ = –10 mA (Sourcing)		2.5	5	Ω
R_O	Switch Resistance, $V_{PP\ OUT} = V_{PP\ IN}$	$I_{PP\ OUT}$ = –100 mA (Sourcing)		0.5	1	Ω
SWITCHING TIME (See Figure 1)						
t_1	Delay + Rise Time	$V_{PP\ OUT}$ = 0V to 5V (Notes 3, 5)		15	50	µs
t_2	Delay + Rise Time	$V_{PP\ OUT}$ = 5V to 12V (Notes 3, 5)		12	50	µs
t_3	Delay + Fall Time	$V_{PP\ OUT}$ = 12V to 5V (Notes 3, 5)		25	75	µs
t_4	Delay + Fall Time	$V_{PP\ OUT}$ = 5V to 0V (Notes 3, 5)		45	100	µs
t_5	Output Turn-On Delay	$V_{PP\ OUT}$ = Hi-Z to 5V (Notes 4, 5)		10	50	µs
t_6	Output Turn-Off Delay	$V_{PP\ OUT}$ = 5V to Hi-Z (Notes 4, 5)		75	200	ns
POWER SUPPLY						
I_{DD}	V_{DD} Supply Current			–	1	µA
I_{CC}	V_{CC} Supply Current	$I_{PP\ OUT} = 0$		–	1	µA
I_{PP}	I_{PP} Supply Current	$V_{PP\ OUT}$ = 0 V or V_{PP} . I_{PPOUT} = 0.		–	10	µA
		$V_{PP\ OUT1} = V_{PPOUT2} = V_{CC}$		10	40	µA

Electrical Characteristics, (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
POWER SUPPLY, continued						
V_{CC}	Operating Input Voltage				6	V
V_{DD}	Operating Input Voltage		2.8		6	V
$V_{PP\ IN}$	Operating Input Voltage		8.0		14.5	V

NOTE 1: Functional operation above the absolute maximum stress ratings is not implied.

NOTE 2: Static-sensitive device. Store only in conductive containers. Handling personnel and equipment should be grounded to prevent damage from static discharge.

NOTE 3: With R_L = 2.9kΩ and C_{OUT} = 0.1µF on $V_{PP\ OUT}$.

NOTE 4: R_L = 2.9kΩ. R_L is connected to V_{CC} during t_5 , and is connected to ground during t_6.

NOTE 5: Rise and fall times are measured to 90% of the difference between initial and final values.

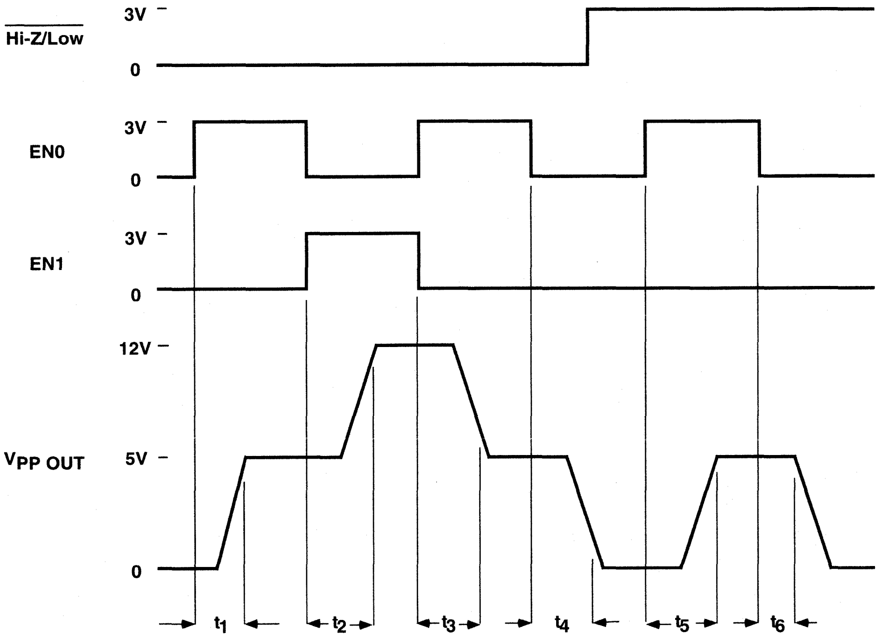


Figure 1. Timing Diagram

Applications Information

PCMCIA V_{PP} control is easily accomplished using the MIC2557 voltage selector/switch IC. Two control bits determine output voltage and standby/operate mode condition. Output voltages of 0V (defined as less than 0.4V), V_{CC} (3.3V or 5V), V_{PP}, or a high impedance state, are available. When either the high impedance or low voltage conditions are selected, the device switches into "sleep" mode, and draws only nanoamperes of leakage current.

The MIC2557 is a low-resistance power MOSFET switching matrix that operates from the computer system main power supply. Device power is obtained from V_{DD}, which may be either 3.3V or 5V, and FET drive is obtained from $V_{PP\ IN}$ (usually +12V). Internal break-before-make switches determine the output voltage and device mode.

Supply Bypassing

For best results, bypass V_{CC} and $V_{PP\ IN}$ at their inputs with 1µF capacitors. $V_{PP\ OUT}$ should have a 0.01µF to 0.1µF capacitor for noise reduction and electrostatic discharge (ESD) damage prevention. Larger values of output capacitor will create large current spikes during transitions, requiring larger bypass capacitors on the V_{CC} and $V_{PP\ IN}$ pins.

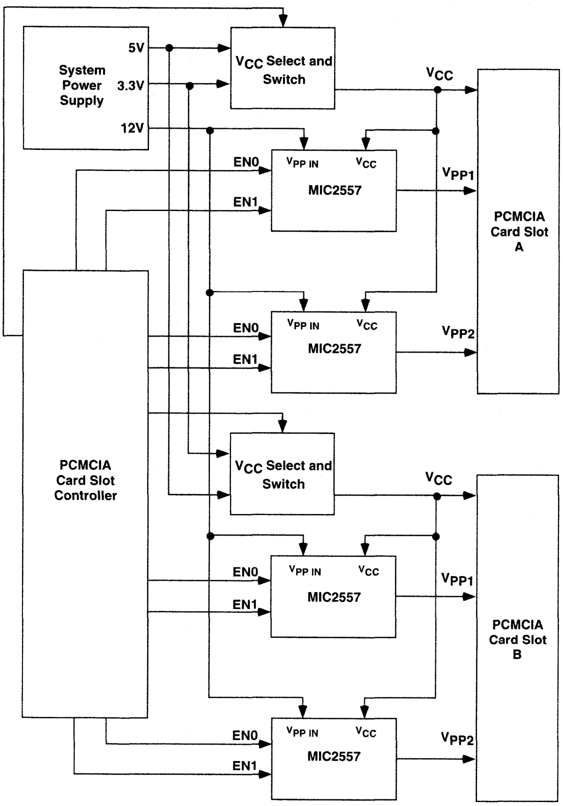


Figure 2. MIC2557 Typical two slot PCMCIA application with dual V_{cc} (5.0V or 3.3V).

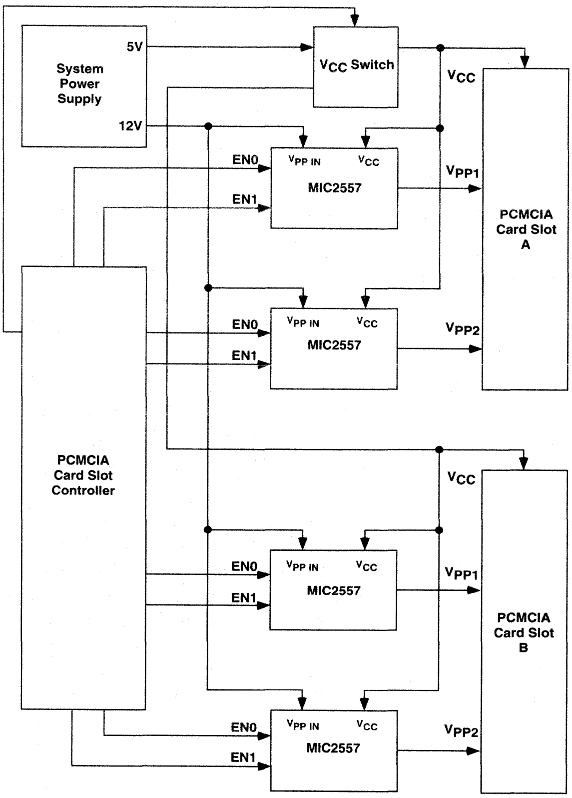


Figure 3. MIC2557 Typical two slot PCMCIA application with single 5.0V V_{CC}.

PCMCIA Implementation

The Personal Computer Memory Card International Association (PCMCIA) specification requires two V_{PP} supply pins per PCMCIA slot. V_{PP} is primarily used for programming Flash (EEPROM) memory cards. The two V_{PP} supply pins may be programmed to different voltages. Fully implementing PCMCIA specifications requires two MIC2557, and a controller. Figure 2 shows this full configuration, supporting both 5.0V and 3.3V V_{CC} operation. Figure 3 is a simplified design with fixed V_{CC} = 5V. Palmtop computers, where size and battery life are tantamount, can sometimes use a compromise implementation, with V_{PP1} tied to V_{PP2} (see Figure 4).

When a memory card is initially inserted, it should receive V_{CC}, usually 5.0V ±5%. The card sends a handshaking data stream to the controller, which then determines whether or not this card requires V_{PP} and if the card is designed for 5.0V or 3.3V V_{CC}. If the card uses 3.3V V_{CC}, the controller commands this change, which is reflected on the V_{CC} pins of both the PCMCIA slot and the MIC2557.

During Flash memory programming, the PCMCIA controller outputs a (1,0) to the MIC2557, which connects $V_{PP\ IN}$ to

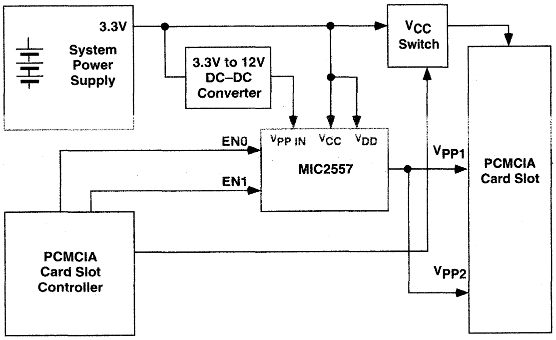


Figure 4. MIC2557 Palmtop application. Note that the V_{PP1} and V_{PP2} pins are combined. Although this does not fully satisfy PCMCIA specifications, it simplifies the circuitry and is acceptable in certain applications.

$V_{PP\ OUT}$. The low ON resistance of the MIC2557 switch requires only a small bypass capacitor on $V_{PP\ OUT}$, with the main filtering action performed by a large filter capacitor on $V_{PP\ IN}$. The $V_{PP\ OUT}$ transition from V_{CC} to 12.0V typically takes 25µS. After programming is completed, the controller outputs a (0,1) to the MIC2557, which then reduces $V_{PP\ OUT}$ to the V_{CC} level. Break-before-make switching action reduces switching transients and lowers maximum current spikes through the switch from the output capacitor.

If no card is inserted, or the system is in sleep mode, the controller outputs either a (0,0) or a (1,1) to the MIC2557. Either input places the switch into its shutdown mode, where only a small leakage current flows.

The HiZ/Low input controls the optional logic low output clamp. With HiZ/Low in the high state and ENO = EN1 = 0, $V_{PP\ OUT}$ enters a high impedance (open) state. With HiZ/Low in the low state and EN0 = EN1 = 0, $V_{PP\ OUT}$ is clamped to ground, providing a logic low signal. The clamp does not require DC bias current for operation.

MOSFET drive and bias voltage is derived from $V_{PP\ IN}$. Internal device control logic is powered from V_{DD}, which should be connected to the same supply voltage as the PCMCIA controller (normally either 3.3V or 5V).

Output Current

MIC2557 output switches are capable of far more current than usually needed in PCMCIA applications. PCMCIA V_{PP} output current is limited primarily by switch resistance voltage drop (**I** x **R**) and the requirement that $V_{PP\ OUT}$ cannot drop more than 5% below nominal. $V_{PP\ OUT}$ will survive output short circuits to ground if $V_{PP\ IN}$ and V_{CC} are current limited by the regulator that supplies these voltages.

MIC2558

PCMCIA Dual Card Socket V_{PP} Switching Matrix

General Description

The MIC2558 Dual V_{PP} Matrix switches the four voltages required by PCMCIA (Personal Computer Memory Card International Association) card V_{PP1} and V_{PP2} Pins. The MIC2558 provides selectable 0V, 3.3V, 5.0V, or 12.0V (±5%) from the system power supply to V_{PP1} and V_{PP2}. Output voltage is selected by two digital inputs per V_{PP} pin. Output current ranges up to 120mA. Four output states, V_{PP}, V_{CC}, high impedance, and active logic low are available, and V_{PP1} is independent of V_{PP2}. An auxiliary control input determines whether the high impedance (open) state or low logic state is asserted.

In standby mode or full operation, the device draws very little quiescent current, typically less than 1µA.

The MIC2558 is available in a 14-pin SOIC and a 14-pin plastic DIP.

Applications

- PCMCIA V_{PP} Pin Voltage Switch
- Power Supply Management

Features

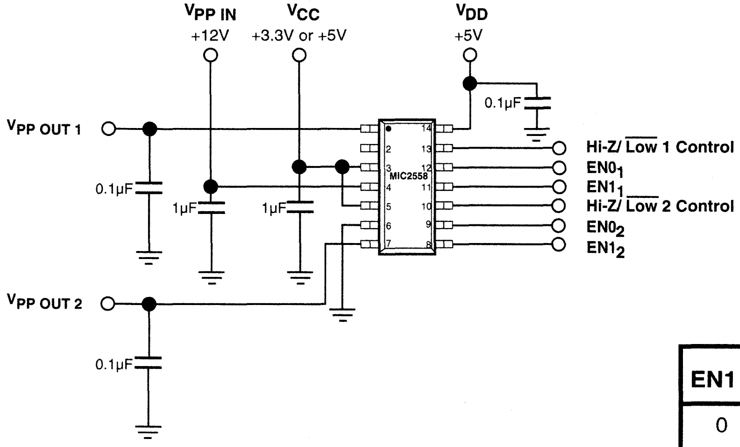
- Complete PCMCIA V_{PP} Switch Matrix in a Single IC
- Dual Matrix allows independent V_{PP1} and V_{PP2}
- Digital Selection of 0V, V_{CC}, V_{PP}, or High Impedance Output
- No V_{PPOUT} Overshoot or Switching Transients
- Break-Before-Make Switching
- Ultra Low Power Consumption
- 120mA V_{PP} (12V) Output Current
- Optional Active Source Clamp for Zero Volt Condition
- 3.3V or 5V Supply Operation
- 14-Pin SOIC Package

Ordering Information

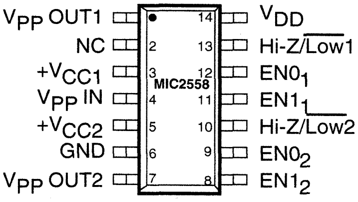
Part Number	Temperature Range	Package
MIC2558BM	–40°C to +85°C	14-pin SOIC
MIC2558BM T&R	–40°C to +85°C	14-SO Tape & Reel*

* 2,500 Parts per reel.

Typical Application



Pin Configuration

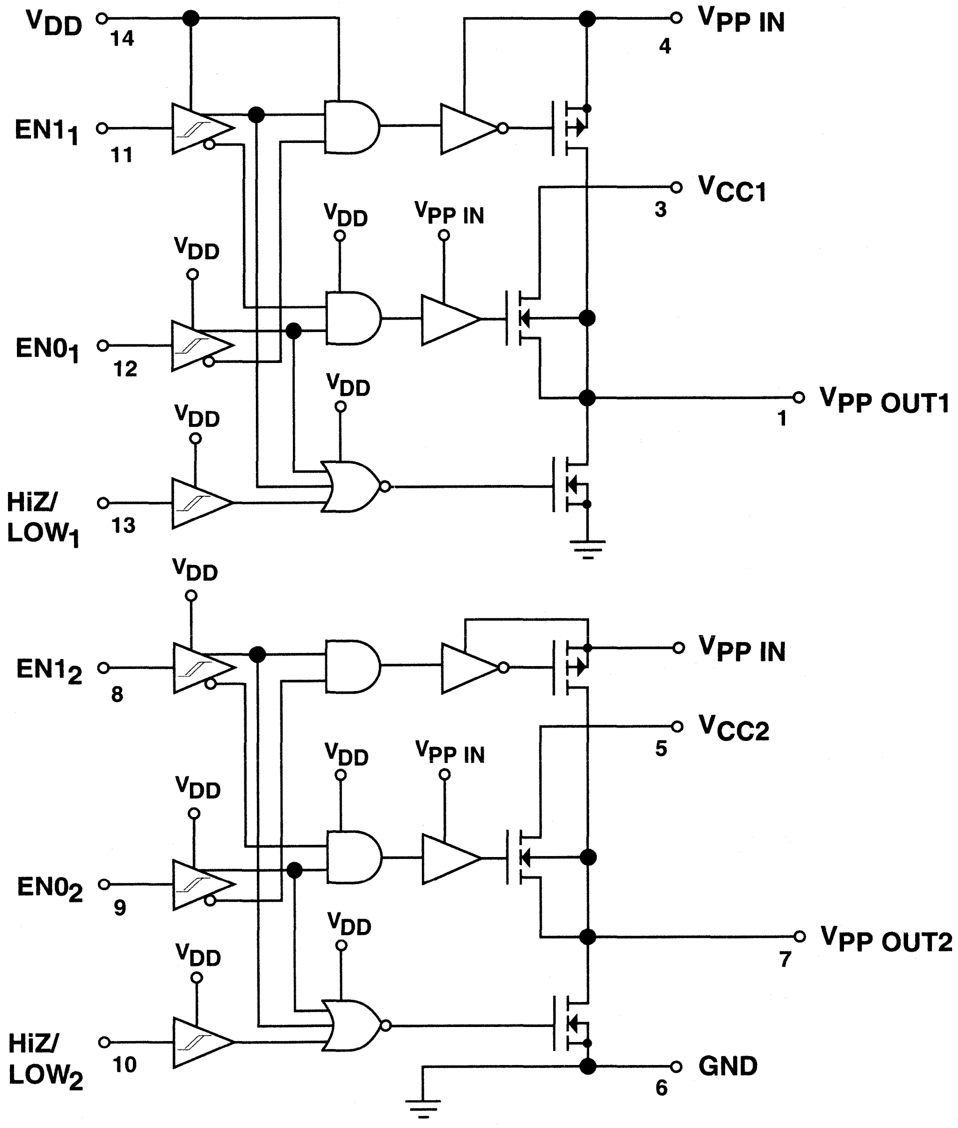


EN1	EN0	Hi-Z/$\overline{Low}$	$V_{PP\ OUT}$
0	0	0	0V, (Sink current)
0	0	1	Hi-Z (No Connect)
0	1	x	V_{CC} (3.3V or 5.0V)
1	0	x	V_{PP}
1	1	x	Hi-Z (No Connect)

Absolute Maximum Ratings (Notes 1 and 2)

Power Dissipation, $T_{AMBIENT} \le 25°C$	
SOIC	800 mW
Derating Factors (To Ambient)	
SOIC	4 mW/°C
Storage Temperature	–65°C to +150°C
Operating Temperature (Die)	125°C
Operating Temperature (Ambient)	–40°C to +85°C
Lead Temperature (10 sec)	300°C
Supply Voltage, $V_{PP\ IN}$	15V
V_{CC}	7.5V
V_{DD}	7.5V
Logic Input Voltages	–0.3V toV_{DD}
Output Current (each Output)	
$V_{PP\ OUT} = 12V$	600mA
$V_{PP\ OUT} = V_{CC}$	250mA

Logic Block Diagram



Electrical Characteristics: (Over operating temperature range with $V_{DD} = V_{CC} = 5V$, $V_{PP\ IN} = 12$ V unless otherwise specified.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.2			V
V_{IL}	Logic 0 Input Voltage				0.8	V
V_{IN} (Max)	Input Voltage Range		–5		V_{DD}	V
I_{IN}	Input Current	$0\ V < V_{IN} < V_{DD}$			±1	µA
EACH OUTPUT						
V_{OL}	Clamp Low Output Voltage	EN0 = EN1 = HiZ = 0, $I_{SINK} = 1.6mA$			0.4	V
I_{OUT}, Hi-Z	High Impedance Output Leakage Current	EN0 = EN1 = 0, HiZ = 1. $0 \le V_{PP\ OUT} \le 12V$		1	10	µA
R_{OC}	Clamp Low Output Resistance	Resistance to Ground. $I_{SINK} = 2mA$ EN0 = EN1 = 0, HiZ = 0.		130	250	Ω
R_O	Switch Resistance, $V_{PP\ OUT} = V_{CC}$	$I_{PP\ OUT} = -10$ mA (Sourcing)		2.5	5	Ω
R_O	Switch Resistance, $V_{PP\ OUT} = V_{PP\ IN}$	$I_{PP\ OUT} = -100$ mA (Sourcing)		0.5	1	Ω
SWITCHING TIME (See Figure 1)						
t_1	Delay + Rise Time	$V_{PP\ OUT} = 0V$ to 5V (Notes 3, 5)		15	50	µs
t_2	Delay + Rise Time	$V_{PP\ OUT} = 5V$ to 12V (Notes 3, 5)		12	50	µs
t_3	Delay + Fall Time	$V_{PP\ OUT} = 12V$ to 5V (Notes 3, 5)		25	75	µs
t_4	Delay + Fall Time	$V_{PP\ OUT} = 5V$ to 0V (Notes 3, 5)		45	100	µs
t_5	Output Turn-On Delay	$V_{PP\ OUT}$ = Hi-Z to 5V (Notes 4, 5)		10	50	µs
t_6	Output Turn-Off Delay	$V_{PP\ OUT}$ = 5V to Hi-Z (Notes 4, 5)		75	200	ns
POWER SUPPLY						
I_{DD}	V_{DD} Supply Current			–	1	µA
I_{CC}	V_{CC} Supply Current	$I_{PP\ OUT} = 0$		–	1	µA
I_{PP}	I_{PP} Supply Current	$V_{PP\ OUT1} = V_{PPOUT2} = 0$ V or V_{PP} . $I_{PPOUT} = 0$.		–	10	µA
		$V_{PP\ OUT1} = V_{PPOUT2} = V_{CC}$		20	80	µA

Electrical Characteristics (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
POWER SUPPLY, continued						
V_{CC}	Operating Input Voltage				6	V
V_{DD}	Operating Input Voltage		2.8		6	V
$V_{PP\ IN}$	Operating Input Voltage		8.0		14.5	V

NOTE 1: Functional operation above the absolute maximum stress ratings is not implied.
NOTE 2: Static-sensitive device. Store only in conductive containers. Handling personnel and equipment should be grounded to prevent damage from static discharge.
NOTE 3: With R_L = 2.9kΩ and C_{OUT} = 0.1µF on $V_{PP\ OUT}$.
NOTE 4: R_L = 2.9kΩ. R_L is connected to V_{CC} during t_5, and is connected to ground during t_6.
NOTE 5: Rise and fall times are measured to 90% of the difference of initial and final values.

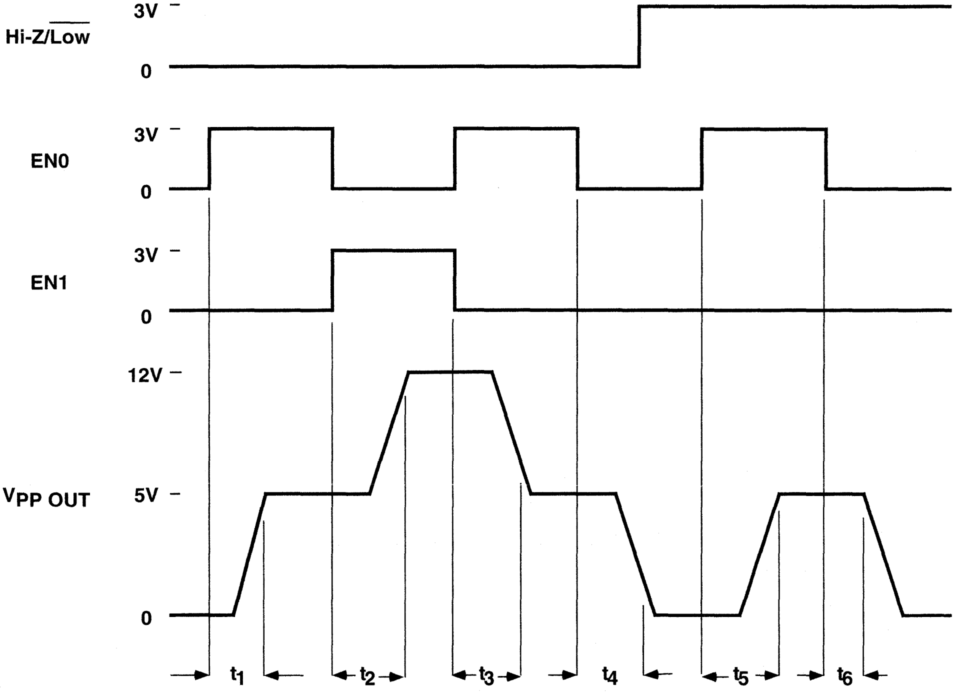


Figure 1. Timing Diagram.

Applications Information

PCMCIA V_{PP1} and V_{PP2} control is easily accomplished using the MIC2558 voltage selector/switch IC. Two control bits per $V_{PP\ OUT}$ pin determine output voltage and standby/operate mode condition. Output voltages of 0V (defined as less than 0.4V), V_{CC} (3.3V or 5V), V_{PP}, or a high impedance state, are available. When either the high impedance or low voltage conditions are selected, the device switches into "sleep" mode and draws only nanoamperes of leakage current.

The MIC2558 is a dual low-resistance power MOSFET switching matrix that operates from the computer system main power supply. Device power is obtained from V_{DD}, which may be either 3.3V or 5V, and FET drive is obtained from $V_{PP\ IN}$ (usually +12V). Internal break-before-make switches determine the output voltage and device mode. V_{PP1} and V_{PP2} are completely indepenent from each other.

Supply Bypassing

For best results, bypass V_{CC} and $V_{PP\ IN}$ inputs with 1µF capacitors. Both $V_{PP\ OUT}$ pins should have a 0.01µF to 0.1µF capacitor for noise reduction and electrostatic discharge (ESD) damage prevention. Larger values of output capacitor will create large current spikes during transitions, requiring larger bypass capacitors on the V_{CC} and $V_{PP\ IN}$ pins.

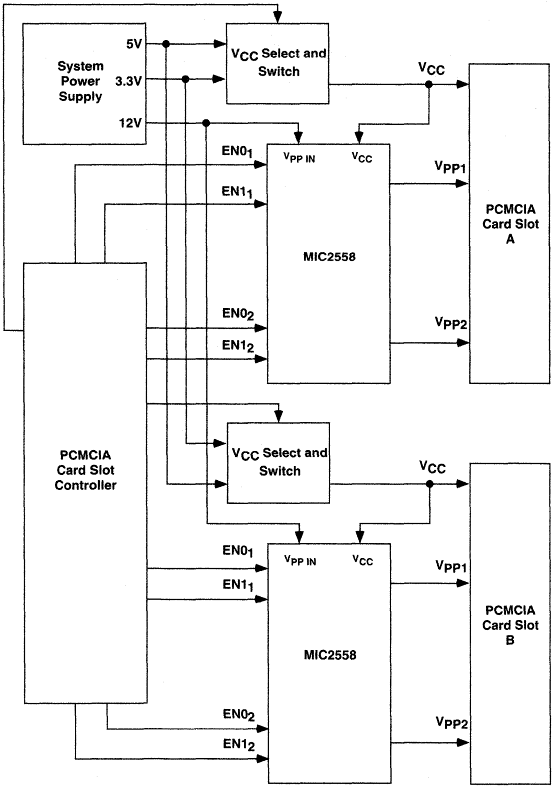


Figure 2. MIC2558 Typical two slot PCMCIA application with dual V_{cc} (5.0V or 3.3V).

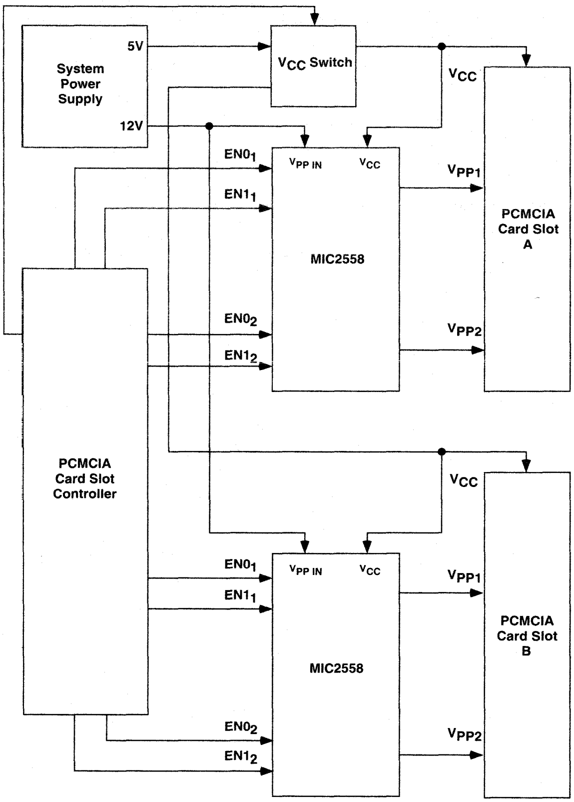


Figure 3. MIC2558 Typical two slot PCMCIA application with single 5.0V V_{cc}.

PCMCIA Implementation

The Personal Computer Memory Card International Association (PCMCIA) specification requires two V_{PP} supply pins per PCMCIA slot. V_{PP} is primarily used for programming Flash (EEPROM) memory cards. The two V_{PP} supply pins may be programmed to different voltages. Fully implementing PCMCIA specifications requires a MIC2558 and a controller. Figure 2 shows this full configuration, supporting both 5.0V and 3.3V V_{CC} operation. Figure 3 is a simplified design with fixed V_{CC} = 5V.

When a memory card is initially inserted, it should receive V_{CC} — usually 5.0V ±5%. The card sends a handshaking data stream to the controller, which then determines whether or not this card requires V_{PP} and if the card is designed for 5.0V or 3.3V V_{CC}. If the card uses 3.3V V_{CC}, the controller commands this change, which is reflected on the V_{CC} pins of both the PCMCIA slot and the MIC2558.

During Flash memory programming, the PCMCIA controller outputs a (1,0) to one or both halves of the MIC2558, which connects $V_{PP\ IN}$ to $V_{PP\ OUT1}$ and/or $V_{PP\ OUT2}$. The low ON resistance of the MIC2558 switch requires only a small bypass capacitor on the $V_{PP\ OUT}$ pins, with the main filtering action performed by a large filter capacitor on $V_{PP\ IN}$. The $V_{PP\ OUT}$ transition from V_{CC} to 12.0V typically takes 25µS. After programming is completed, the controller outputs a (0,1) to the MIC2558, which then reduces $V_{PP\ OUT}$ to the V_{CC} level. Break-before-make switching action reduces switching transients and lowers maximum current spikes through the switch from the output capacitor.

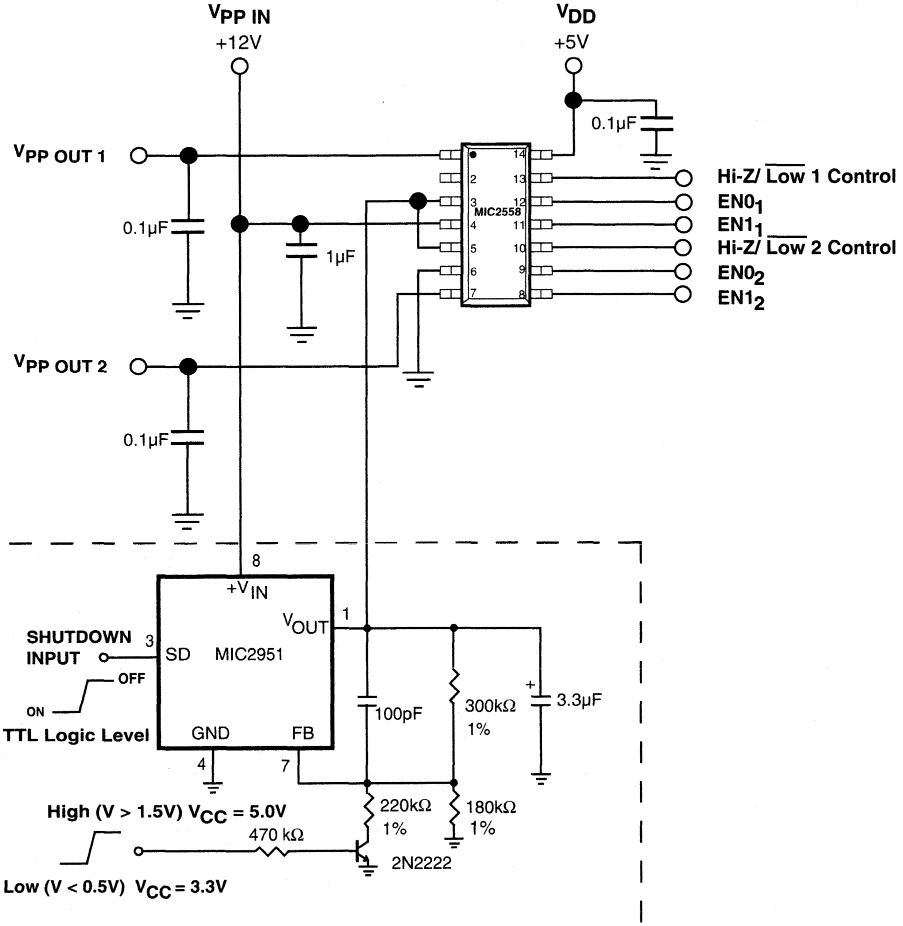
If no card is inserted, or the system is in sleep mode, the controller outputs either a (0,0) or a (1,1) to the MIC2558. Either input places the switch into shutdown mode, where current consumption drops even further.

The HiZ/Low input controls the optional logic low output clamp. With HiZ/Low in the high state and EN0 = EN1 = 0, $V_{PP\ OUT}$ enters a high impedance (open) state. With HiZ/Low in the low state and EN0 = EN1 = 0, $V_{PP\ OUT}$ is clamped to ground, providing a logic low signal. The clamp does not require any DC bias current for operation.

MOSFET drive and bias voltage is derived from $V_{PP\ IN}$. Internal device control logic is powered from V_{DD}, which should be connected to the same supply voltage as the PCMCIA controller (normally either 3.3V or 5V).

Output Current

MIC2558 output switches are capable of far more current than usually needed in PCMCIA applications. PCMCIA V_{PP} output current is limited primarily by switch resistance voltage drop (**I** x **R**) and the requirement that $V_{PP\ OUT}$ cannot drop more than 5% below nominal. $V_{PP\ OUT}$ will survive output short circuits to ground if $V_{PP\ IN}$ or V_{CC} are current limited by the regulator that supplies these voltages.



V_{CC} Switching and Control Block

Figure 3. Full PCMCIA Implementation of V_{PP} and V_{CC} switching using MIC2558 and MIC2951 voltage regulator.

MIC2559

PCMCIA Dual Card Socket V_{PP} Switching Matrix

Preliminary Information

General Description

The MIC2559 Dual V_{PP} Matrix switches the four voltages required by PCMCIA (Personal Computer Memory Card International Association) card V_{PP1} and V_{PP2} Pins. The MIC2559 provides selectable 0V, 3.3V, 5.0V, or 12.0V (±5%) from the system power supply to V_{PP1} and V_{PP2}. Output voltage is selected by two digital inputs per V_{PP} pin. Output current ranges up to 120mA. Four output states, V_{PP}, V_{CC}, high impedance, and active logic low are available, and V_{PP1} is independent of V_{PP2}. An auxiliary control input determines whether the high impedance (open) state or low logic state is asserted.

In standby mode or full operation, the device draws very little quiescent current, typically less than 1µA.

The MIC2559 is available in a 14-pin SOIC.

Applications

- PCMCIA V_{PP} Pin Voltage Switch
- Power Supply Management

Features

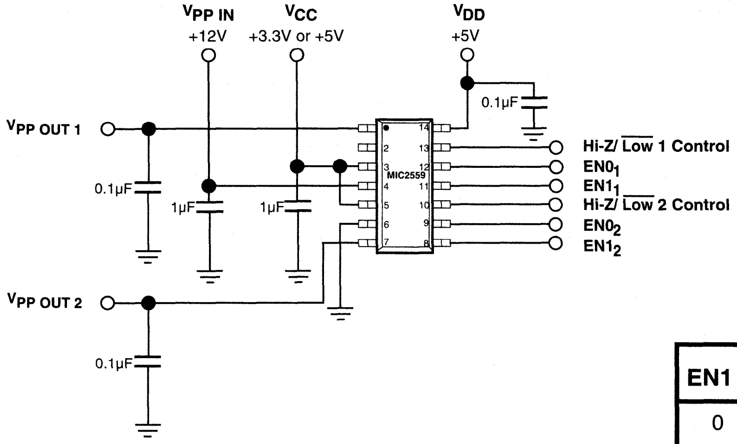
- Complete PCMCIA V_{PP} Switch Matrix in a Single IC
- Dual Matrix allows independent V_{PP1} and V_{PP2}
- Digital Selection of 0V, V_{CC}, V_{PP}, or High Impedance Output
- No V_{PPOUT} Overshoot or Switching Transients
- Break-Before-Make Switching
- Ultra Low Power Consumption
- 120mA V_{PP} (12V) Output Current
- Optional Active Source Clamp for Zero Volt Condition
- 3.3V or 5V Supply Operation
- 14-Pin SOIC Package

Ordering Information

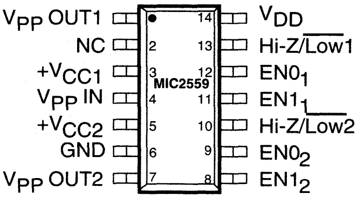
Part Number	Temperature Range	Package
MIC2559BM	–40°C to +85°C	14-pin SOIC
MIC2559BM T&R	–40°C to +85°C	14-SO Tape & Reel*

* 2,500 Parts per reel.

Typical Application



Pin Configuration



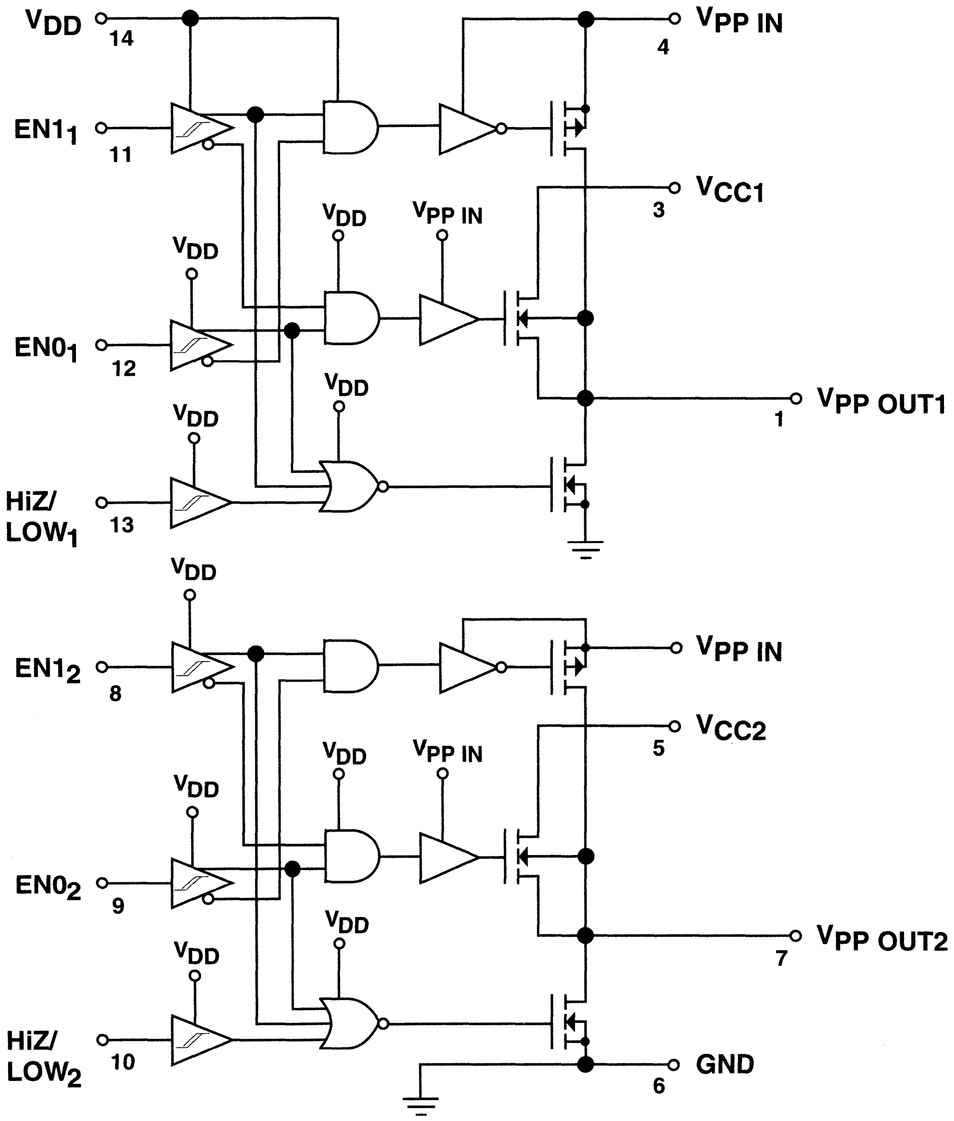
EN1	EN0	Hi-Z/$\overline{\text{Low}}$	$V_{PP\ OUT}$
0	0	0	0V, (Sink current)
0	0	1	Hi-Z (No Connect)
0	1	x	V_{CC} (3.3V or 5.0V)
1	0	x	V_{PP}
1	1	x	Hi-Z (No Connect)

Absolute Maximum Ratings (Notes 1 and 2)

Power Dissipation, $T_{AMBIENT} \leq 25°C$	800 mW
Derating Factors (To Ambient)	4 mW/°C
Storage Temperature	–65°C to +150°C
Operating Temperature (Die)	125°C
Operating Temperature (Ambient)	–40°C to +85°C
Lead Temperature (10 sec)	300°C

Supply Voltage, $V_{PP\ IN}$	15V
V_{CC}	7.5V
V_{DD}	7.5V
Logic Input Voltages	–5V toV_{DD}
Output Current (each Output)	
$V_{PP\ OUT}$ = 12V	600mA
$V_{PP\ OUT} = V_{CC}$	250mA

Logic Block Diagram



Electrical Characteristics: (Over operating temperature range with V_{DD} = V_{CC}= 5V, $V_{PP\ IN}$ = 12 V unless otherwise specified.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.2			V
V_{IL}	Logic 0 Input Voltage				0.8	V
V_{IN} (Max)	Input Voltage Range		–5		V_{DD}	V
I_{IN}	Input Current	$0\ V < V_{IN} < V_{DD}$			±1	µA
EACH OUTPUT						
V_{OL}	Clamp Low Output Voltage	EN0 = EN1 = HiZ = 0, I_{SINK} = 1.6mA			0.4	V
I_{OUT}, Hi-Z	High Impedance Output Leakage Current	EN0 = EN1 = 0, HiZ = 1. $0 \le V_{PP\ OUT} \le 12V$		1	10	µA
R_{OC}	Clamp Low Output Resistance	Resistance to Ground. I_{SINK} = 2mA EN0 = EN1 = 0, HiZ = 0.		130	250	Ω
R_O	Switch Resistance, $V_{PP\ OUT} = V_{CC}$	$I_{PP\ OUT}$ = –100 mA (Sourcing) T_A = –40°C to +60°C		0.8	1.5	Ω
R_O	Switch Resistance, $V_{PP\ OUT} = V_{PP\ IN}$	$I_{PP\ OUT}$ = –100 mA (Sourcing)		0.5	1	Ω
SWITCHING TIME (See Figure 1)						
t_1	Delay + Rise Time	$V_{PP\ OUT}$ = 0V to 5V (Notes 3, 5)		15	50	µs
t_2	Delay + Rise Time	$V_{PP\ OUT}$ = 5V to 12V (Notes 3, 5)		12	50	µs
t_3	Delay + Fall Time	$V_{PP\ OUT}$ = 12V to 5V (Notes 3, 5)		25	75	µs
t_4	Delay + Fall Time	$V_{PP\ OUT}$ = 5V to 0V (Notes 3, 5)		45	100	µs
t_5	Output Turn-On Delay	$V_{PP\ OUT}$ = Hi-Z to 5V (Notes 4, 5)		10	50	µs
t_6	Output Turn-Off Delay	$V_{PP\ OUT}$ = 5V to Hi-Z (Notes 4, 5)		75	200	ns
POWER SUPPLY						
I_{DD}	V_{DD} Supply Current			–	1	µA
I_{CC}	V_{CC} Supply Current	$I_{PP\ OUT}$ = 0		–	1	µA
I_{PP}	I_{PP} Supply Current	$V_{PP\ OUT1} = V_{PPOUT2}$ = 0 V or V_{PP} . I_{PPOUT} = 0.		–	10	µA
		$V_{PP\ OUT1} = V_{PPOUT2} = V_{CC}$		20	80	µA

Electrical Characteristics (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
POWER SUPPLY, continued						
V_{CC}	Operating Input Voltage				6	V
V_{DD}	Operating Input Voltage		2.8		6	V
$V_{PP\ IN}$	Operating Input Voltage		8.0		14.5	V

NOTE 1: Functional operation above the absolute maximum stress ratings is not implied.

NOTE 2: Static-sensitive device. Store only in conductive containers. Handling personnel and equipment should be grounded to prevent damage from static discharge.

NOTE 3: With R_L = 2.9kΩ and C_{OUT} = 0.1µF on $V_{PP\ OUT}$.

NOTE 4: R_L = 2.9kΩ. R_L is connected to V_{CC} during t_5, and is connected to ground during t_6.

NOTE 5: Rise and fall times are measured to 90% of the difference of initial and final values.

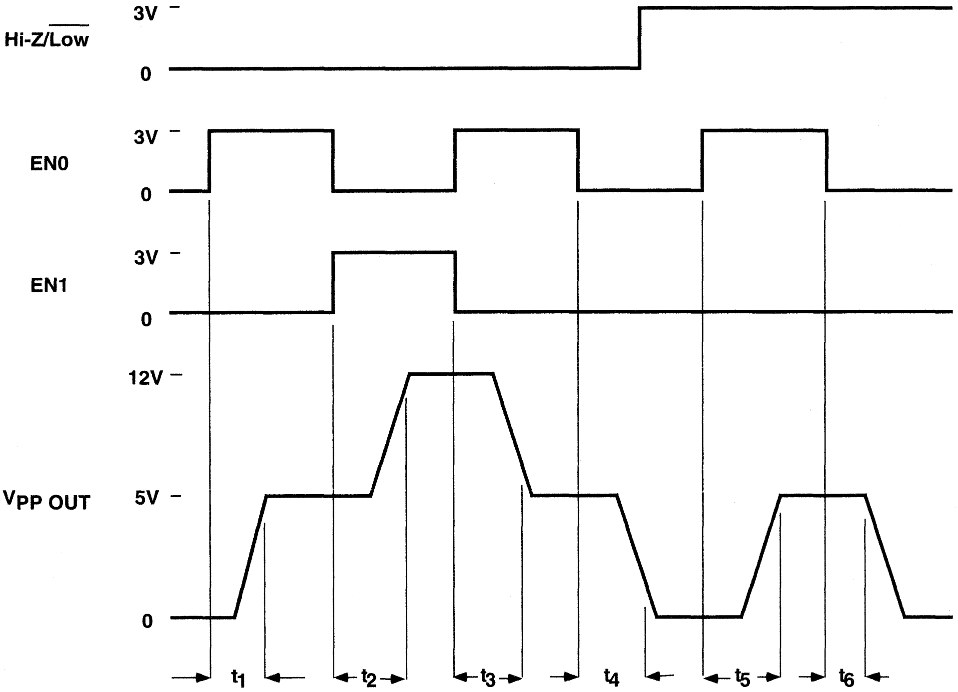


Figure 1. Timing Diagram.

Applications Information

PCMCIA V_{PP1} and V_{PP2} control is easily accomplished using the MIC2559 voltage selector/switch IC. Two control bits per $V_{PP\ OUT}$ pin determine output voltage and standby/operate mode condition. Output voltages of 0V (defined as less than 0.4V), V_{CC} (3.3V or 5V), V_{PP}, or a high impedance state, are available. When either the high impedance or low voltage conditions are selected, the device switches into "sleep" mode and draws only nanoamperes of leakage current.

The MIC2559 is a dual low-resistance power MOSFET switching matrix that operates from the computer system main power supply. Device power is obtained from V_{DD}, which may be either 3.3V or 5V, and FET drive is obtained from $V_{PP\ IN}$ (usually +12V). Internal break-before-make switches determine the output voltage and device mode. V_{PP1} and V_{PP2} are completely indepenent from each other.

Supply Bypassing

For best results, bypass V_{CC} and $V_{PP\ IN}$ inputs with 1µF capacitors. Both $V_{PP\ OUT}$ pins should have a 0.01µF to 0.1µF capacitor for noise reduction and electrostatic discharge (ESD) damage prevention. Larger values of output capacitor will create large current spikes during transitions, requiring larger bypass capacitors on the V_{CC} and $V_{PP\ IN}$ pins.

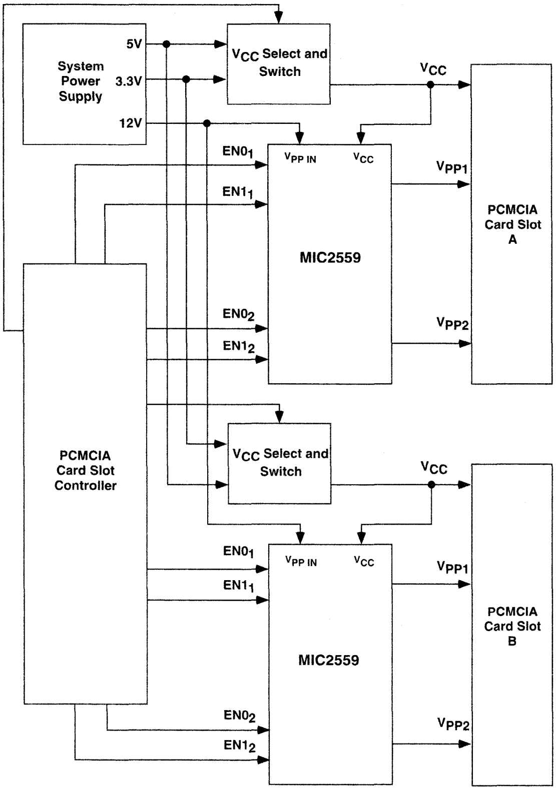


Figure 2. MIC2559 Typical two slot PCMCIA application with dual V_{CC} (5.0V or 3.3V).

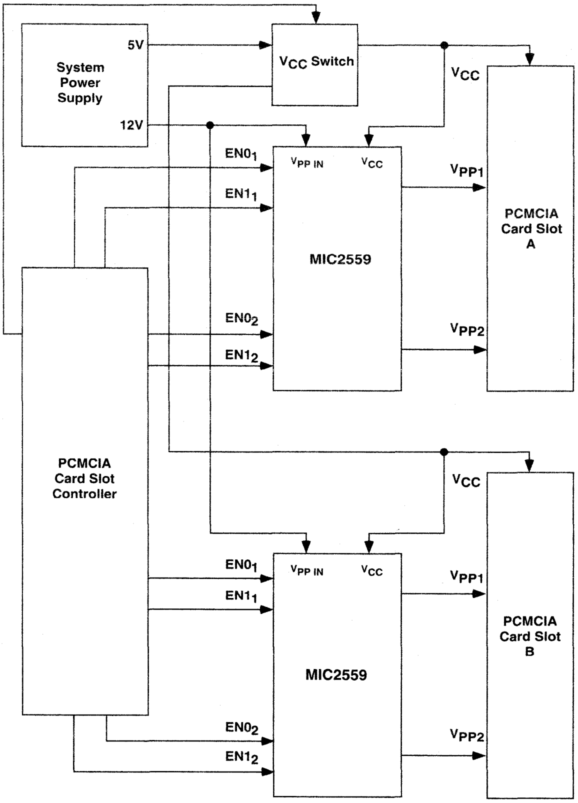


Figure 3. MIC2559 Typical two slot PCMCIA application with single 5.0V V_{CC}.

PCMCIA Implementation

The Personal Computer Memory Card International Association (PCMCIA) specification, version 2.0 (September, 1991), requires two V_{PP} supply pins per PCMCIA slot. V_{PP} is primarily used for programming Flash (EEPROM) memory cards. The two V_{PP} supply pins may be programmed to different voltages. Fully implementing PCMCIA specifications requires a MIC2559 and a controller. Figure 2 shows this full configuration, supporting both 5.0V and 3.3V V_{CC} operation. Figure 3 is a simplified design with fixed $V_{CC} = 5V$.

When a memory card is initially inserted, it should receive V_{CC} — usually 5.0V ±5%. The card sends a handshaking data stream to the controller, which then determines whether or not this card requires V_{PP} and if the card is designed for 5.0V or 3.3V V_{CC}. If the card uses 3.3V V_{CC}, the controller commands this change, which is reflected on the V_{CC} pins of both the PCMCIA slot and the MIC2559.

During Flash memory programming, the PCMCIA controller outputs a (1,0) to one or both halves of the MIC2559, which connects $V_{PP\ IN}$ to $V_{PP\ OUT1}$ and/or $V_{PP\ OUT2}$. The low ON resistance of the MIC2559 switch requires only a small bypass capacitor on the $V_{PP\ OUT}$ pins, with the main filtering action performed by a large filter capacitor on $V_{PP\ IN}$. The $V_{PP\ OUT}$ transition from V_{CC} to 12.0V typically takes 25µS. After programming is completed, the controller outputs a (0,1) to the MIC2559, which then reduces $V_{PP\ OUT}$ to the V_{CC} level. Break-before-make switching action reduces switching transients and lowers maximum current spikes through the switch from the output capacitor.

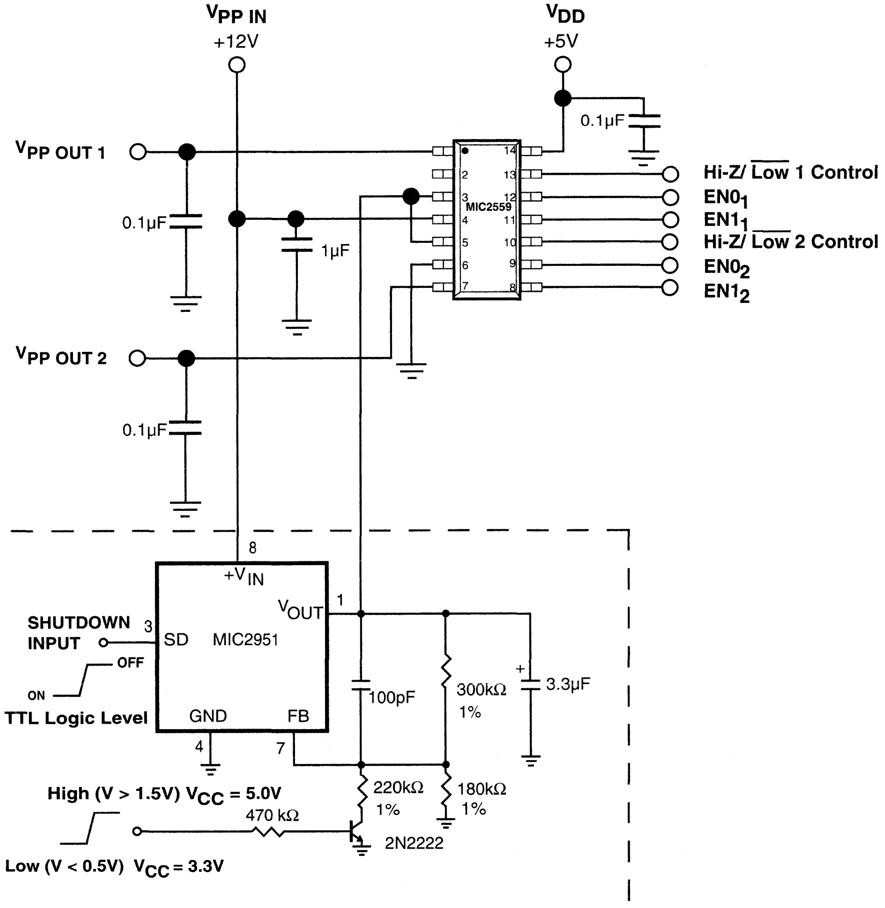
If no card is inserted, or the system is in sleep mode, the controller outputs either a (0,0) or a (1,1) to the MIC2559. Either input places the switch into shutdown mode, where current consumption drops even further.

The HiZ/Low input controls the optional logic low output clamp. With HiZ/Low in the high state and EN0 = EN1 = 0, $V_{PP\ OUT}$ enters a high impedance (open) state. With HiZ/Low in the low state and EN0 = EN1 = 0, $V_{PP\ OUT}$ is clamped to ground, providing a logic low signal. The clamp does not require any DC bias current for operation.

MOSFET drive and bias voltage is derived from $V_{PP\ IN}$. Internal device control logic is powered from V_{DD}, which should be connected to the same supply voltage as the PCMCIA controller (normally either 3.3V or 5V).

Output Current

MIC2559 output switches are capable of far more current than usually needed in PCMCIA applications. PCMCIA V_{PP} output current is limited primarily by switch resistance voltage drop (**I** x **R**) and the requirement that $V_{PP\ OUT}$ cannot drop more than 5% below nominal. $V_{PP\ OUT}$ will survive output short circuits to ground if $V_{PP\ IN}$ or V_{CC} are current limited by the regulator that supplies these voltages.



V_{CC} Switching and Control Block

Figure 3. Full PCMCIA Implementation of V_{PP} and V_{CC} switching using MIC2559 and MIC2951 voltage regulator.

MIC2560

PCMCIA Card Socket V_{CC} & V_{PP} Switching Matrix

General Description

The MIC2560 V_{CC} & V_{PP} Matrix controls PCMCIA (Personal Computer Memory Card International Association) memory card power supply pins, both V_{CC} and V_{PP}. The MIC2560 switches voltages from the system power supply to V_{CC} and V_{PP}. The MIC2560 switches between the three V_{CC} voltages (OFF, 3.3V and 5.0V) and the V_{PP} voltages (OFF, 0V, 3.3V, 5V, or 12.0V) required by PCMCIA cards. Output voltage is selected by two digital inputs for each output and output current ranges up to 1A for V_{CC} and 200mA for V_{PP}.

The MIC2560 provides power management capability under the control of the PC Card controller and features overcurrent and thermal protection of the power outputs, zero current "sleep" mode, suspend mode, low power dynamic mode, and ON/OFF control of the PCMCIA socket power.

The MIC2560 is designed for efficient operation. In standby ("sleep") mode the device draws very little quiescent current, typically 0.01µA. The device and PCMCIA ports are protected by current limiting and overtemperature shutdown. Full cross-conduction lockout protects the system power supply.

Ordering Information

Part Number	Temperature Range	Package
MIC2560-0BWM	–40°C to +70°C	16-pin Wide SOIC
MIC2560-1BWM	–40°C to +70°C	16-pin Wide SOIC
MIC2560-2BWM	–40°C to +70°C	16-pin Wide SOIC

Refer to the Control Logic Table for an explanation of the differences between the three MIC2560 versions.

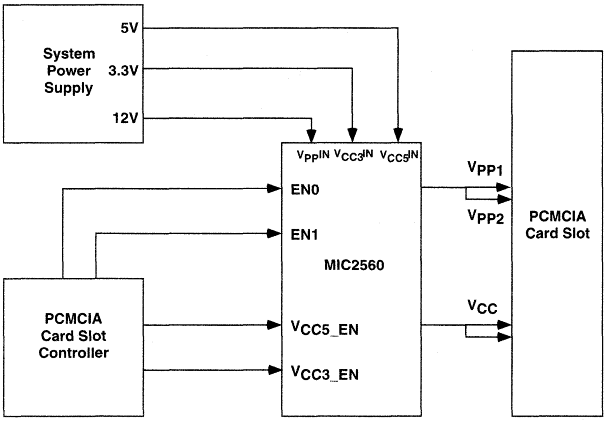
Applications

- PCMCIA Power Supply Pin Voltage Switch
- Font Cards for Printers and Scanners
- Data Collection Systems
- Machine Control Data Input Systems
- Wireless Communications
- Bar Code Data Collection Systems
- Instrumentation Configuration/Datalogging
- Docking Stations (portable and desktop)
- Power Supply Management
- Power Analog Switching

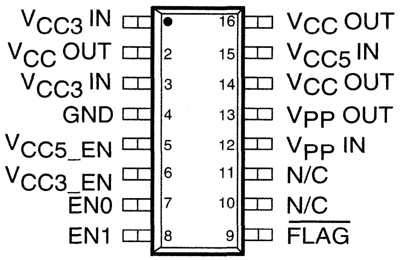
Features

- Complete PCMCIA V_{CC} and V_{PP} Switch Matrix in a Single IC
- No External Components Required
- Logic Compatible with Industry Standard PCMCIA Controllers
- No Voltage Overshoot or Switching Transients
- Break-Before-Make Switching
- Output Current Limit and Over-Temperature Shutdown
- Digital Flag for Error Condition Indication
- Ultra Low Power Consumption
- Digital Selection of V_{CC} and V_{PP} Voltages
- Over 1A V_{CC} Output Current
- 200mA V_{PP} (12V) Output Current
- Options for Direct Compatibility With Industry Standard PCMCIA Controllers
- 16-Pin SOIC Package

Typical Application



Pin Configuration

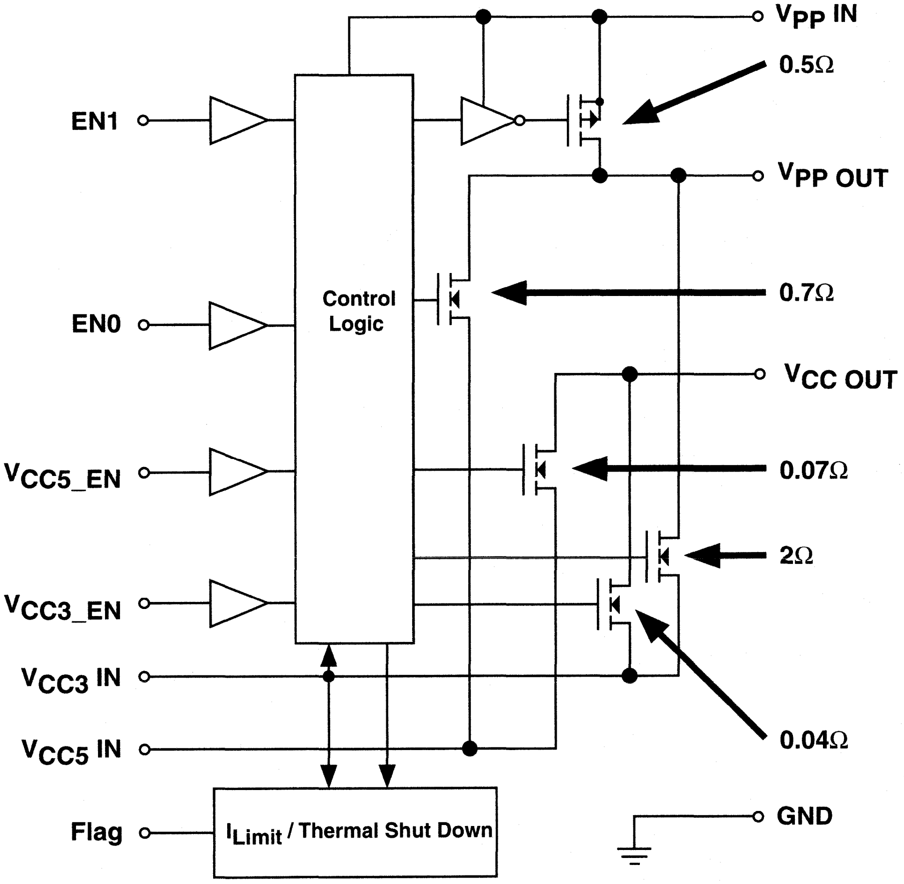


Note: both V_{CC3} IN pins must be connected. All three V_{CC} OUT pins must be connected.

Absolute Maximum Ratings (Notes 1 and 2)

Power Dissipation, $T_{AMBIENT} \le 25°C$	*Internally Limited*
SOIC	800 mW
Derating Factors (To Ambient)	
SOIC	4 mW/°C
Storage Temperature	–65°C to +150°C
Maximum Operating Temperature (Die)	125°C
Operating Temperature (Ambient)	–40°C to +70°C
Lead Temperature (10 sec)	300°C
Supply Voltage, $V_{PP\ IN}$	15V
V_{CC3} IN	V_{CC5} IN
V_{CC5} IN	7.5V
Logic Input Voltages	–0.3V to +15V
Output Current (each Output)	
$V_{PP\ OUT}$	*>200mA, Internally Limited*
$V_{CC\ OUT}$	*>1A, Internally Limited*
$V_{CC\ OUT}$, Suspend Mode	600mA

Logic Block Diagram



Electrical Characteristics: (Over operating temperature range with V_{CC3} IN = 3.3V, V_{CC5} IN = 5.0V, V_{PP} IN = 12V unless otherwise specified.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.2		15	V
V_{IL}	Logic 0 Input Voltage		–0.3		0.8	V
I_{IN}	Input Current	$0\text{ V} < V_{IN} < 5.5\text{V}$			±1	µA
V_{PP} OUTPUT						
$I_{PP\ OUT}$ Hi-Z	High Impedance Output Leakage Current	Shutdown Mode $1\text{V} \le V_{PP\ OUT} \le 12\text{V}$		1	10	µA
I_{PPSC}	Short Circuit Current Limit	$V_{PP\ OUT} = 0$		0.2		A
R_O	Switch Resistance, $I_{PP\ OUT} = -100\text{mA}$ (Sourcing)	Select $V_{PP\ OUT}$ = 12V Select $V_{PP\ OUT}$ = 5V Select $V_{PP\ OUT}$ = 3.3V		0.55 0.7 2	1 1 3	Ω
R_O	Switch Resistance, $I_{PP\ OUT} = 50\mu\text{A}$	Select $V_{PP\ OUT}$ = Clamped to Ground		0.75	2	kΩ
V_{PP} SWITCHING TIME						
t_1	Output Turn-On Rise Time	$V_{PP\ OUT}$ = Hi-Z to 5V		50		µs
t_2	Output Turn-On Rise Time	$V_{PP\ OUT}$ = Hi-Z to 3.3V		40		µs
t_3	Output Turn-On Rise Time	$V_{PP\ OUT}$ = Hi-Z to 12V		300		µs
t_4	Output Rise Time	$V_{PP\ OUT}$ = 3.3V or 5V to 12V		300		µs
V_{CC} OUTPUT						
$I_{CC\ OUT}$ Hi-Z	High Impedance Output Leakage Current (Note 3)	$1\text{V} \le V_{CC\ OUT} \le 5\text{V}$		1	10	µA
I_{CCSC}	Short Circuit Current Limit	$V_{CC\ OUT} = 0$	1	2		A
R_O	Switch Resistance, $V_{CC\ OUT}$ = 5.0V	$I_{CC\ OUT} = -1000\text{mA}$ (Sourcing)		70	100	mΩ
R_O	Switch Resistance, $V_{CC\ OUT}$ = 3.3V	$I_{CC\ OUT} = -1000\text{mA}$ (Sourcing)		40	66	mΩ
R_O	Switch Resistance, $V_{CC\ OUT}$ = Clamped to Ground (MIC2560-2 only)	$I_{CC\ OUT} = 50\mu\text{A}$ (Sinking)		0.75	2	kΩ

Electrical Characteristics (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{CC} SWITCHING TIME						
t_1	Rise Time	$V_{CC\ OUT}$ = 0V to 3.3V, I_{OUT} = 1A	100	600		µs
t_2	Rise Time	$V_{CC\ OUT}$ = 0V to 5.0V, I_{OUT} = 1A	100	500		µs
t_3	Fall Time	$V_{CC\ OUT}$ = 5.0V to 3.3V		300		µs
t_4	Rise Time	$V_{CC\ OUT}$ = Hi-Z to 5V		400		µs
POWER SUPPLY						
I_{CC5}	V_{CC5} IN Supply Current	$I_{CC\ OUT}$ = 0		0.01	10	µA
I_{CC3}	V_{CC3} IN Supply Current	$V_{CC\ OUT}$ = 5V or 3.3V, $I_{CC\ OUT}$ = 0 $V_{CC\ OUT}$ = Hi-Z (Sleep Mode)		30 0.01	50 10	µA
I_{PP} IN	V_{PP} IN Supply Current ($I_{PP\ OUT}$ = 0.)	V_{CC} Active, $V_{PP\ OUT}$ = 5V or 3.3V $V_{PP\ OUT}$ = Hi-Z, 0 or V_{PP}		15 0.01	50 10	µA
V_{CC5} IN	Operating Input Voltage	V_{CC5} IN ≥ V_{CC3} IN	V_{CC3} IN	5.0	6	V
V_{CC3} IN	Operating Input Voltage	V_{CC3} IN ≤ V_{CC5} IN	2.8	3.3	V_{CC5} IN	V
$V_{PP\ IN}$	Operating Input Voltage		8.0	12.0	14.5	V
SUSPEND MODE (NOTE 4)						
I_{CC3}	Active Mode Current	$V_{PP\ IN}$ = 0V, V_{CC5} = V_{CC3} = 3.3V V_{CC3} = Enabled V_{PP} = Disabled (Hi-Z or 0V)		30		µA
R_{ON} V_{CC}	$V_{CC\ OUT}$ R_{ON}	$V_{PP\ IN}$ = 0V, V_{CC5} = V_{CC3} = 3.3V V_{CC3} = Enabled V_{PP} = Disabled (Hi-Z or 0V)		4.5		Ω

NOTE 1: Functional operation above the absolute maximum stress ratings is not implied.

NOTE 2: Static-sensitive device. Store only in conductive containers. Handling personnel and equipment should be grounded to prevent damage from static discharge.

NOTE 3: Leakage current after 1,000 hours at 125°C may increase up to five times the initial limit.

NOTE 4: Suspend mode is a pseudo power-down mode the MIC2560 automatically allows when $V_{PP\ IN}$ = 0V, V_{PP} OUT is deselected, and V_{CC} OUT = 3.3V is selected. Under these conditions, the MIC2560 functions in a reduced capacity mode where V_{CC} output of 3.3V is allowed, but at lower current levels (higher switch ON resistance).

MIC2560-0 Control Logic Table

Pin 5 V_{CC5_EN}	Pin 6 V_{CC3_EN}	Pin 8 EN1	Pin 7 EN0	Pins 2 & 14 V_{CC} OUT	Pin 13 V_{PP} OUT
0	0	0	0	High Z	High Z
0	0	0	1	High Z	High Z
0	0	1	0	High Z	High Z
0	0	1	1	High Z	Clamped to Ground
0	1	0	0	3.3	High Z
0	1	0	1	3.3	3.3
0	1	1	0	3.3	12
0	1	1	1	3.3	Clamped to Ground
1	0	0	0	5	High Z
1	0	0	1	5	5
1	0	1	0	5	12
1	0	1	1	5	Clamped to Ground
1	1	0	0	3.3	High Z
1	1	0	1	3.3	3.3
1	1	1	0	3.3	5
1	1	1	1	3.3	Clamped to Ground

MIC2560-1 Logic (Compatible with Cirrus Logic CL-PD6710 & CL-PD6720 Controllers)

Pin 5 V_{CC5_EN}	Pin 6 V_{CC3_EN}	Pin 8 V_{PP_PGM}	Pin 7 $V_{PP\_}V_{CC}$	Pins 2 & 14 V_{CC} OUT	Pin 13 V_{PP} OUT
0	0	0	0	High Z	Clamped to Ground
0	0	0	1	High Z	High Z
0	0	1	0	High Z	High Z
0	0	1	1	High Z	High Z
0	1	0	0	5	Clamped to Ground
0	1	0	1	5	5
0	1	1	0	5	12
0	1	1	1	5	High Z
1	0	0	0	3.3	Clamped to Ground
1	0	0	1	3.3	3.3
1	0	1	0	3.3	12
1	0	1	1	3.3	High Z
1	1	0	0	High Z	Clamped to Ground
1	1	0	1	High Z	High Z
1	1	1	0	High Z	High Z
1	1	1	1	High Z	High Z

MIC2560-2 Logic (Compatible with Databook Controllers)

Pin 5 $V_{CCSEL0(1)}$	Pin 6 $V_{PPSEL0(1)}$	Pin 7 $V_{CCSEL2(3)}$	Pins 2 & 14 V_{CC} OUT	Pin 13 V_{PP} OUT
0	1	0	Clamped to Ground	Clamped to Ground
1	1	0	3.3V	3.3V
0	0	0	3.3V	12V
1	0	0	3.3V	Clamped to Ground
0	1	1	Clamped to Ground	Clamped to Ground
1	1	1	5V	5V
0	0	1	5V	12V
1	0	1	5V	Clamped to Ground

The Databook DB86184 PCMCIA controller requires two 100kΩ pull-down resistors from pins 5 and 7 to ground and a 100kΩ pull-up resistor from pin 6 to +3.3V (or +5V). Connect MIC2560-2 pin 8 to ground.

Note: other control logic patterns are available. Please contact Micrel for details.

Applications Information

PCMCIA V_{CC} and V_{PP} control is easily accomplished using the MIC2560 voltage selector/switch IC. Four control bits determine $V_{CC\ OUT}$ and $V_{PP\ OUT}$ voltage and standby/operate mode condition. $V_{PP\ OUT}$ output voltages of V_{CC} (3.3V or 5V), V_{PP}, or a high impedance state are available. When the V_{CC} high impedance condition is selected, the device switches into "sleep" mode and draws only nanoamperes of leakage current. An error flag falls low if the output is improper, because of overtemperature or overcurrent faults. Full protection from hot switching is provided which prevents feedback from the $V_{PP\ OUT}$ to the V_{CC} inputs (from 12V to 5V, for example) by locking out the low voltage switch until $V_{PP\ OUT}$ drops below V_{CC}. The V_{CC} output is similarly protected against 5V to 3.3V shoot through.

The MIC2560 is a low-resistance power MOSFET switching matrix that operates from the computer system main power supply. Device logic power is obtained from V_{CC3} and internal MOSFET drive is obtained from the V_{PP} IN pin (usually +12V) during normal operation. If +12V is not available, the MIC2560 automatically switches into "suspend" mode, where $V_{CC\ OUT}$ can be switched to 3.3V, but at higher switch resistance. Internal break-before-make switches determine the output voltage and device mode.

Supply Bypassing

External capacitors are not required for operation. The MIC2560 is a switch and has no stability problems. For best results however, bypass V_{CC3} IN, V_{CC5} IN, and V_{PP} IN inputs with filter capacitors to improve output ripple. As all internal device logic and voltage/current comparison functions are powered from the V_{CC3} IN line, supply bypass of this line is the most critical, and may be necessary in some cases. In the most stubborn layouts, up to 0.47µF may be necessary. Both $V_{CC\ OUT}$ and $V_{PP\ OUT}$ pins may have 0.01µF to 0.1µF capacitors for noise reduction and electrostatic discharge (ESD) damage prevention. Larger values of output capacitor might create current spikes during transitions, requiring larger bypass capacitors on the V_{CC3} IN, V_{CC5} IN, and V_{PP} IN pins.

PCMCIA Implementation

The MIC2560 is designed for compatibility with the Personal Computer Memory Card International Association's (PCMCIA) Specification, revision 2.1 as well as the PC Card Specification, (March 1995), including the CardBus option.

The Personal Computer Memory Card International Association (PCMCIA) specification requires two V_{PP} supply pins per PCMCIA slot. V_{PP} is primarily used for programming Flash (EEPROM) memory cards. The two V_{PP} supply pins may be programmed to different voltages. Fully implementing PCMCIA specifications requires a MIC2560, a MIC2557 PCMCIA V_{PP} Switching Matrix, and a controller. Figure 3 shows this full configuration, supporting both 5.0V and 3.3V V_{CC} operation.

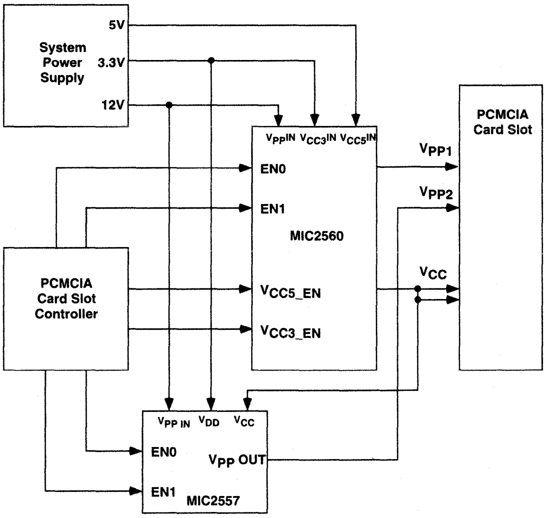


Figure 3. MIC2560 Typical PCMCIA memory card application with dual V_{CC} (5.0V or 3.3V) and separate V_{PP1} and V_{PP2}.

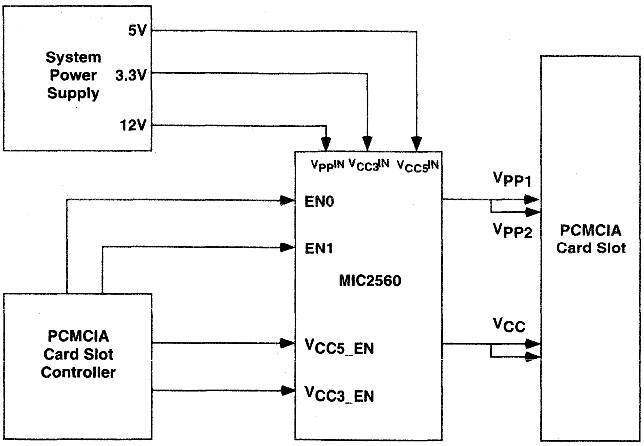


Figure 4. MIC2560 Typical PCMCIA memory card application with dual V_{CC} (5.0V or 3.3V). Note that V_{PP1} and V_{PP2} are driven together.

However, many cost sensitive designs (especially notebook/palmtop computers) connect V_{PP1} to V_{PP2} and the MIC2557 is not required. This circuit is shown in Figure 4.

When a memory card is initially inserted, it should receive V_{CC} — either 3.3V ± 0.3V or 5.0V ±5%. The initial voltage is determined by a combination of mechanical socket "keys" and voltage sense pins. The card sends a handshaking data stream to the controller, which then determines whether or not this card requires V_{PP} and if the card is designed for dual V_{CC}. If the card is compatible with and desires a different V_{CC} level, the controller commands this change by disabling V_{CC}, waiting at least 100ms, and then re-enabling the other V_{CC} voltage.

If no card is inserted or the system is in sleep mode, the controller outputs a (V_{CC3} IN, V_{CC5} IN) = (0,0) to the MIC2560, which shuts down V_{CC}. This also places the switch into a high impedance output shutdown (sleep) mode, where current consumption drops to nearly zero, with only tiny CMOS leakage currents flowing.

During Flash memory programming with standard (+12V) Flash memories, the PCMCIA controller outputs a (1,0) to the EN0, EN1 control pins of the MIC2560, which connects V_{PP} IN to $V_{PP\ OUT}$. The low ON resistance of the MIC2560 switches allow using small bypass capacitors (in some cases, none at all) on the $V_{CC\ OUT}$ and $V_{PP\ OUT}$ pins, with the main filtering action performed by a large filter capacitor on the input supply voltage to V_{PP} IN (usually the main power supply filter capacitor is sufficient). The $V_{PP\ OUT}$ transition from V_{CC} to 12.0V typically takes 250µs. After programming is completed, the controller outputs a (EN1, EN0) = (0,1) to the MIC2560, which then reduces $V_{PP\ OUT}$ to the V_{CC} level for read verification. Break-before-make switching action reduces switching transients and lowers maximum current spikes through the switch from the output capacitor. The flag comparator prevents having high voltage on the $V_{PP\ OUT}$ capacitor from contaminating the V_{CC} inputs, by disabling the low voltage V_{PP} switches until $V_{PP\ OUT}$ drops below the V_{CC} level selected. The lockout delay time varies with the load current and the capacitor on $V_{PP\ OUT}$. With a 0.1µF capacitor and nominal $I_{PP\ OUT}$, the delay is approximately 250µs.

Internal drive and bias voltage is derived from V_{PP} IN. Internal device control logic is powered from V_{CC3} IN. Input logic threshold voltages are compatible with common PCMCIA controllers using either 3.3V or 5V supplies. No pull-up resistors are required at the control inputs of the MIC2560.

Output Current and Protection

MIC2560 output switches are capable of more current than needed in PC Card applications (1A) and meet or exceed all PCMCIA specifications. For system and card protection, output currents are internally limited. For full system protection, long term (millisecond or longer) output short circuits invoke overtemperature shutdown, protecting the MIC2560, the system power supplies, the card socket pins, and the memory card. Overtemperature shutdown typically occurs at a die temperature of 115°C.

Single V_{CC} Operation

For PC Card slots requiring only a single V_{CC}, connect $V_{CC3\ IN}$ and $V_{CC5\ IN}$ together and to the system V_{CC} supply (i.e., Pins 1, 3, and 15 are all connected to system V_{CC}). Either the V_{CC5} switch or the V_{CC3} switch may be used to enable the card slot V_{CC}; generally the V_{CC3} switch is preferred because of its lower ON resistance.

Suspend Mode

An additional feature in the MIC2560 is a pseudo power-down mode, Suspend Mode, which allows operation without a V_{PP} IN supply. In Suspend Mode, the MIC2560 supplies 3.3V to V_{CC} OUT whenever a V_{CC} output of 3.3V is enabled by the PCMCIA controller. This mode allows the system designer the ability to turn OFF the V_{PP} supply generator to save power when it is not specifically required. The PCMCIA card receives V_{CC} at reduced capacity during Suspend Mode, as the switch resistance rises to approximately 4.5Ω.

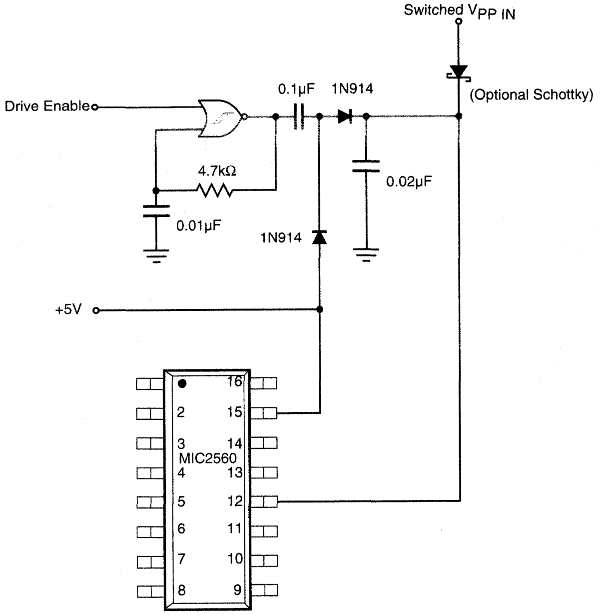


Figure 5. Circuit for generating bias drive for the V_{cc} switches when +12V is not readily available.

High Current V_{cc} Operation Without a +12V Supply

Figure 5 shows the MIC2560 with V_{CC} switch bias provided by a simple charge pump. This enables the system designer to achieve full V_{CC} performance without a +12V supply, which is often helpful in battery powered systems that only provide +12V when it is needed. These on-demand +12V supplies generally have a quiescent current draw of a few milliamperes, which is far more than the microamperes used by the MIC2560. The charge pump of figure 5 provides this low current, using about 100µA when enabled. When $V_{PP\ OUT}$ = 12V is selected, however, the on-demand V_{PP} generator must be used, as this charge pump cannot deliver the current required for Flash memory programming. The Schottky diode may not be necessary, depending on the configuration of the on-demand +12V generator and whether any other loads are on this line.

MIC2561

PCMCIA Card Socket V_{CC} & V_{PP} Switching Matrix

General Description

The MIC2561 V_{CC} & V_{PP} Matrix controls PCMCIA (Personal Computer Memory Card International Association) memory card power supply pins, both V_{CC} and V_{PP}. The MIC2561 switches voltages from the system power supply to V_{CC} and V_{PP}. The MIC2561 switches between the three V_{CC} voltages (OFF, 3.3V and 5.0V) and the V_{PP} voltages (OFF, 0V, 3.3V, 5V, or 12.0V) required by PCMCIA cards. Output voltage is selected by two digital inputs for each output and output current ranges up to 750mA for V_{CC} and 200mA for V_{PP}. For higher V_{CC} output current, please refer to the full-performance MIC2560.

The MIC2561 provides power management capability under the control of the PC Card controller and features overcurrent and thermal protection of the power outputs, zero current "sleep" mode, suspend mode, low power dynamic mode, and ON/OFF control of the PCMCIA socket power.

The MIC2561 is designed for efficient operation. In standby ("sleep") mode the device draws very little quiescent current, typically 0.01µA. The device and PCMCIA port is protected by current limiting and overtemperature shutdown. Full cross-conduction lockout protects the system power supply.

Ordering Information

Part Number	Temperature Range	Package
MIC2561-0BM	0°C to +70°C	14-pin SOIC
MIC2561-1BM	0°C to +70°C	14-pin SOIC

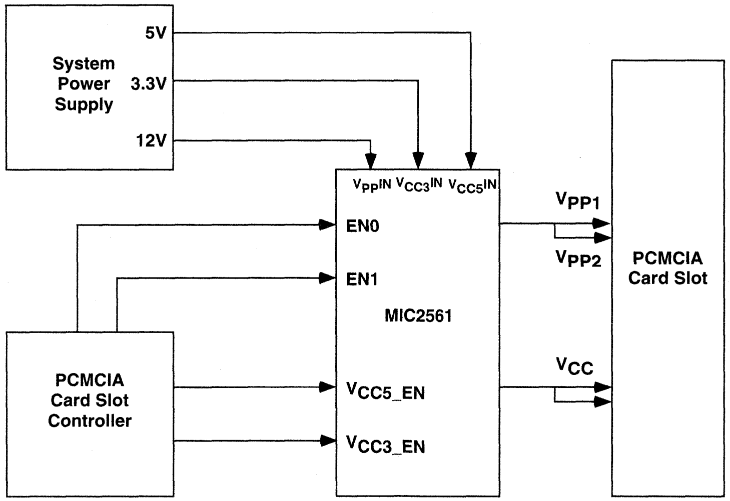
Applications

- PCMCIA Power Supply Pin Voltage Switch
- Data Collection Systems
- Machine Control Data Input Systems
- Wireless Communications
- Bar Code Data Collection Systems
- Instrumentation Configuration/Datalogging
- Docking Stations (portable and desktop)
- Power Supply Management
- Power Analog Switching

Features

- Complete PCMCIA V_{CC} and V_{PP} Switch Matrix in a Single IC
- No External Components Required
- Controlled Switching Times
- Logic Options for Compatible with Industry Standard PCMCIA Controllers
- No Voltage Overshoot or Switching Transients
- Break-Before-Make Switching
- Output Current Limit and Over-Temperature Shutdown
- Digital Flag for Error Condition Indication
- Ultra Low Power Consumption
- Digital Selection of V_{CC} and V_{PP} Voltages
- Over 750mA of V_{CC} Output Current
- 200mA of V_{PP} Output Current
- 14-Pin or 16-Pin SOIC Package

Typical Application

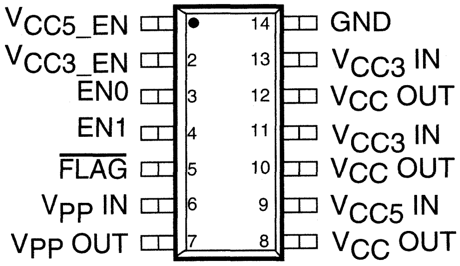


Absolute Maximum Ratings (Notes 1 and 2)

Power Dissipation, $T_{AMBIENT} \le 25°C$	*Internally Limited*
SOIC	800 mW
Derating Factors (To Ambient)	
SOIC	4 mW/°C
Storage Temperature	–65°C to +150°C
Maximum Operating Temperature (Die)	125°C
Operating Temperature (Ambient)	0°C to +70°C
Lead Temperature (10 sec)	300°C

Supply Voltage, $V_{PP\ IN}$	15V
V_{CC3} IN	V_{CC5} IN
V_{CC5} IN	7.5V
Logic Input Voltages	–0.3V to +15V
Output Current (each Output)	
$V_{PP\ OUT}$	*Internally Limited*
$V_{CC\ OUT}$	*Internally Limited*
$V_{CC\ OUT}$, Suspend Mode	600mA

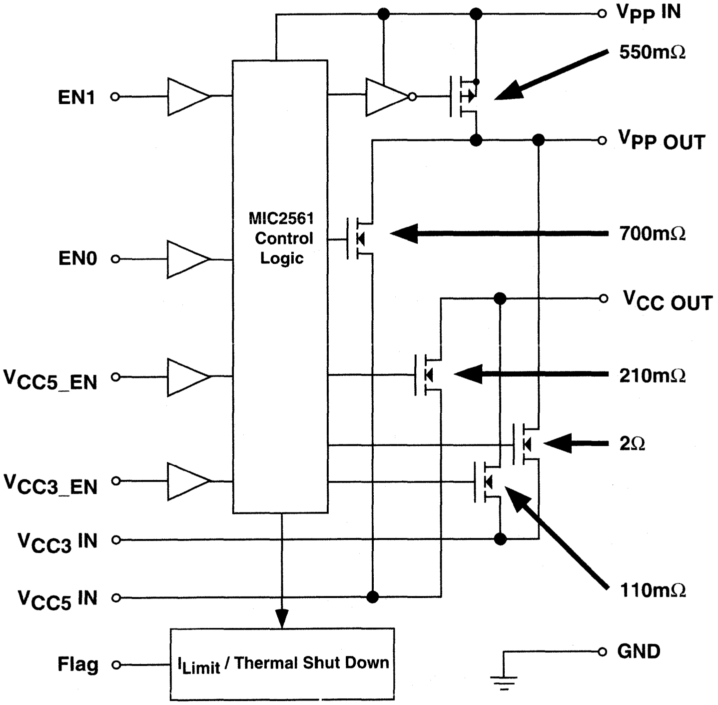
Pin Configuration



14-Pin SO Package

Note: Both V_{CC3} IN pins must be connected. All three V_{CC} OUT pins must be connected.

Logic Block Diagram



Electrical Characteristics: (Over operating temperature range with V_{CC3} IN = 3.3V, V_{CC5} IN = 5.0V, V_{PP} IN = 12V unless otherwise specified.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.2		15	V
V_{IL}	Logic 0 Input Voltage		–0.3		0.8	V
I_{IN}	Input Current	$0\ V < V_{IN} < 5.5V$			±1	µA
V_{PP} OUTPUT						
$I_{PP\ OUT}$ Hi-Z	High Impedance Output Leakage Current	Shutdown Mode $0 \le V_{PP\ OUT} \le 12V$		0.1	50	µA
I_{PPSC}	Short Circuit Current Limit	$V_{PP\ OUT} = 0$		0.2		A
R_O	Switch Resistance, $I_{PP\ OUT} = -1000mA$ (Sourcing)	Select $V_{PP\ OUT} = 12V$ Select $V_{PP\ OUT} = 5V$ Select $V_{PP\ OUT} = 3.3V$		0.55 0.7 2	1 1 3	Ω
R_O	Switch Resistance, $I_{PP\ OUT} = 50\mu A$ (Sinking)	Select $V_{PP\ OUT}$ = Clamped to Ground		0.75	2	kΩ
V_{PP} SWITCHING TIME (See Figure 1)						
t_1	Output Turn-On Rise Time	$V_{PP\ OUT}$ = Hi-Z to 5V		50		µs
t_2	Output Turn-On Rise Time	$V_{PP\ OUT}$ = Hi-Z to 3.3V		40		µs
t_3	Output Turn-On Rise Time	$V_{PP\ OUT}$ = Hi-Z to 12V		300		µs
t_4	Output Rise Time	$V_{PP\ OUT}$ = 3.3V or 5V to 12V		30		µs
t_5	Output Turn-Off Delay	$V_{PP\ OUT}$ = 12V to 3.3V or 5V		25	75	µs
t_6	Output Turn-Off Delay	$V_{PP\ OUT}$ = 5V to Hi-Z		75	200	ns
V_{CC} OUTPUT						
$I_{CC\ OUT}$ Hi-Z	High Impedance Output Leakage Current	$1 \le V_{CC\ OUT} \le 5V$		0.1	10	µA
I_{CCSC}	Short Circuit Current Limit	$V_{CC\ OUT} = 0$		1.5	2	A
R_O	Switch Resistance, $V_{CC\ OUT} = 5.0V$	$I_{CC\ OUT} = -650$ mA (Sourcing)		210	300	mΩ
R_O	Switch Resistance, $V_{CC\ OUT} = 3.3V$	$I_{CC\ OUT} = -650$ mA (Sourcing)		110	185	mΩ

Electrical Characteristics (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{CC} SWITCHING TIME						
t_1	Rise Time (10% to 90%)	$V_{CC\ OUT}$ = 0V to 3.3V, I_{OUT} = 750mA	70	140		µs
t_2	Rise Time (10% to 90%)	$V_{CC\ OUT}$ = 0V to 5.0V	50	60		µs
t_3	Fall Time (note 3)	$V_{CC\ OUT}$ = 5.0V to 0V or 3.3V to 0V		40		µs
t_4	Rise Time	$V_{CC\ OUT}$ = Hi-Z to 5V		60		µs
POWER SUPPLY						
I_{CC5}	V_{CC5} IN Supply Current	$I_{CC\ OUT}$ = 0		0.01	10	µA
I_{CC3}	V_{CC3} IN Supply Current	$V_{CC\ OUT}$ = 5V or 3.3V, $I_{CC\ OUT}$ = 0 $V_{CC\ OUT}$ = Hi-Z (Sleep Mode)		30 0.01	100 10	µA
I_{PP} IN	V_{PP} IN Supply Current $I_{PP\ OUT}$ =0	V_{CC} Active, $V_{PP\ OUT}$ = 5V or 3.3V $V_{PP\ OUT}$ = HiZ, 0, or V_{PP}		15 0.01	30 10	µA
V_{CC5} IN	Operating Input Voltage	V_{CC5} IN ≥ V_{CC3} IN	V_{CC3} IN	5.0	6	V
V_{CC3} IN	Operating Input Voltage	V_{CC3} IN ≤ V_{CC5} IN	2.8	3.3	V_{CC5} IN	V
$V_{PP\ IN}$	Operating Input Voltage		8.0	12.0	14.5	V
SUSPEND MODE (NOTE 6)						
I_{CC3}	Suspend Mode Active Current (from V_{CC3})	$V_{PP\ IN}$ = 0V, V_{CC5} = V_{CC3} = 3.3V V_{CC5} = Enabled V_{PP} = Disabled (Hi-Z or 0V)		30	100	µA
R_{ON} V_{CC}	$V_{CC\ OUT}$ R_{ON}	$V_{PP\ IN}$ = 0V, V_{CC5} = V_{CC3} = 3.3V V_{CC3} = Enabled V_{PP} = Disabled (Hi-Z or 0V)		4.5	6	Ω

NOTE 1: Functional operation above the absolute maximum stress ratings is not implied.

NOTE 2: Static-sensitive device. Store only in conductive containers. Handling personnel and equipment should be grounded to prevent damage from static discharge.

NOTE 3: From 90% of V_{OUT} to 10% of V_{OUT}. R_L = 2.1kΩ

NOTE 6: Suspend mode is a pseudo power-down mode the MIC2561 automatically allows when $V_{PP\ IN}$ = 0V, V_{PP} OUT is deselected, and V_{CC} OUT = 3.3V is selected. Under these conditions, the MIC2561 functions in a reduced capacity mode where V_{CC} output of 3.3V is allowed, but at lower current levels (higher switch ON resistance).

MIC2561-0 Control Logic Table

Pin 5 V_{CC5_EN}	Pin 6 V_{CC3_EN}	Pin 8 EN1	Pin 7 EN0	Pins 2 & 14 V_{CC} OUT	Pin 13 V_{PP} OUT
0	0	0	0	High Z	High Z
0	0	0	1	High Z	High Z
0	0	1	0	High Z	High Z
0	0	1	1	High Z	Clamped to Ground
0	1	0	0	3.3	High Z
0	1	0	1	3.3	3.3
0	1	1	0	3.3	12
0	1	1	1	3.3	Clamped to Ground
1	0	0	0	5	High Z
1	0	0	1	5	5
1	0	1	0	5	12
1	0	1	1	5	Clamped to Ground
1	1	0	0	3.3	High Z
1	1	0	1	3.3	3.3
1	1	1	0	3.3	5
1	1	1	1	3.3	Clamped to Ground

MIC2561-1 Logic (Compatible with Cirrus Logic CL-PD6710 & CL-PD6720 Controllers)

Pin 5 V_{CC5_EN}	Pin 6 V_{CC3_EN}	Pin 8 V_{PP_PGM}	Pin 7 $V_{PP\_}V_{CC}$	Pins 2 & 14 V_{CC} OUT	Pin 13 V_{PP} OUT
0	0	0	0	High Z	Clamped to Ground
0	0	0	1	High Z	High Z
0	0	1	0	High Z	High Z
0	0	1	1	High Z	High Z
0	1	0	0	5	Clamped to Ground
0	1	0	1	5	5
0	1	1	0	5	12
0	1	1	1	5	High Z
1	0	0	0	3.3	Clamped to Ground
1	0	0	1	3.3	3.3
1	0	1	0	3.3	12
1	0	1	1	3.3	High Z
1	1	0	0	High Z	Clamped to Ground
1	1	0	1	High Z	High Z
1	1	1	0	High Z	High Z
1	1	1	1	High Z	High Z

Pin numbers shown are for the 16-pin wide SO package (BWM version)

Note: other control logic patterns are available. Please contact Micrel for details.

Applications Information

PCMCIA V_{CC} and V_{PP} control is easily accomplished using the MIC2561 voltage selector/switch IC. Four control bits determine $V_{CC\ OUT}$ and $V_{PP\ OUT}$ voltage and standby/operate mode condition. $V_{PP\ OUT}$ output voltages of V_{CC} (3.3V or 5V), V_{PP}, or a high impedance state are available. When the V_{CC} high impedance condition is selected, the device switches into "sleep" mode and draws only nanoamperes of leakage current. An error flag falls low if the output is improper, because of overtemperature or overcurrent faults. Full protection from hot switching is provided which prevents feedback from the $V_{PP\ OUT}$ to the V_{CC} inputs (from 12V to 5V, for example) by locking out the low voltage switch until $V_{PP\ OUT}$ drops below V_{CC}. The V_{CC} output is similarly protected against 5V to 3.3V shoot through.

The MIC2561 is a low-resistance power MOSFET switching matrix that operates from the computer system main power supply. Device logic power is obtained from V_{CC3} and internal MOSFET drive is obtained from the V_{PP} IN pin (usually +12V) during normal operation. If +12V is not available, the MIC2561 automatically switches into "suspend" mode, where $V_{CC\ OUT}$ can be switched to 3.3V, but at higher switch resistance. Internal break-before-make switches determine the output voltage and device mode.

Supply Bypassing

External capacitors are not required for operation. The MIC2561 is a switch and has no stability problems. For best results however, bypass V_{CC3} IN, V_{CC5} IN, and V_{PP} IN inputs with filter capacitors to improve output ripple. As all internal device logic and voltage/current comparison functions are powered from the V_{CC3} IN line, supply bypass of this line is the most critical, and may be necessary in some cases. In the most stubborn layouts, up to 0.47µF may be necessary. Both $V_{CC\ OUT}$ and $V_{PP\ OUT}$ pins may have 0.01µF to 0.1µF capacitors for noise reduction and electrostatic discharge (ESD) damage prevention. Larger values of output capacitor might create current spikes during transitions, requiring larger bypass capacitors on the V_{CC3} IN, V_{CC5} IN, and V_{PP} IN pins.

PCMCIA Implementation

The Personal Computer Memory Card International Association (PCMCIA) specification requires two V_{PP} supply pins per PCMCIA slot. V_{PP} is primarily used for programming Flash (EEPROM) memory cards. The two V_{PP} supply pins may be programmed to different voltages. Fully implementing PCMCIA specifications requires a MIC2561, a MIC2557 PCMCIA V_{PP} Switching Matrix, and a controller. Figure 3 shows this full configuration, supporting both 5.0V and 3.3V V_{CC} operation.

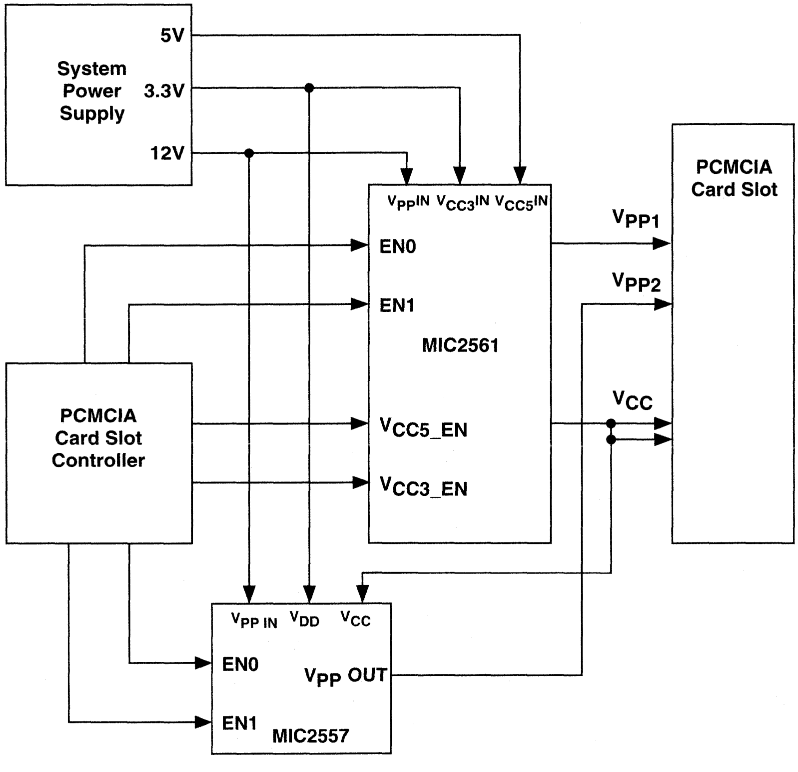


Figure 3. MIC2561 Typical PCMCIA memory card application with dual V_{CC} (5.0V or 3.3V) and separate V_{PP1} and V_{PP2}.

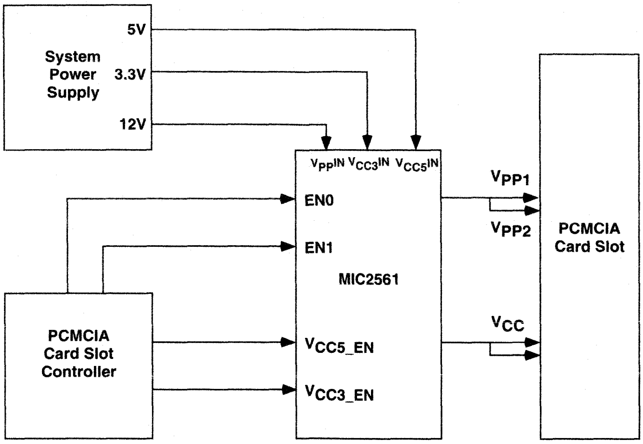


Figure 4. MIC2561 Typical PCMCIA memory card application with dual V_{CC} (5.0V or 3.3V). Note that V_{PP1} and V_{PP2} are driven together.

However, many cost sensitive designs (especially notebook/palmtop computers) connect V_{PP1} to V_{PP2} and the MIC2557 is not required. This circuit is shown in Figure 4.

When a memory card is initially inserted, it should receive V_{CC} — either 3.3V ± 0.3V or 5.0V ±5%. The initial voltage is determined by a combination of mechanical socket "keys" and voltage sense pins. The card sends a handshaking data stream to the controller, which then determines whether or not this card requires V_{PP} and if the card is designed for dual V_{CC}. If the card is compatible with and desires a different V_{CC} level, the controller commands this change by disabling V_{CC}, waiting at least 100ms, and then re-enabling the other V_{CC} voltage.

If no card is inserted or the system is in sleep mode, the controller outputs a (V_{CC3} IN, V_{CC5} IN) = (0,0) to the MIC2561, which shuts down V_{CC}. This also places the switch into a high impedance output shutdown (sleep) mode, where current consumption drops to nearly zero, with only tiny CMOS leakage currents flowing.

During Flash memory programming with standard (+12V) Flash memories, the PCMCIA controller outputs a (1,0) to the EN0, EN1 control pins of the MIC2561, which connects V_{PP} IN to $V_{PP\ OUT}$. The low ON resistance of the MIC2561 switches allow using small bypass capacitors (in some cases, none at all) on the $V_{CC\ OUT}$ and $V_{PP\ OUT}$ pins, with the main filtering action performed by a large filter capacitor on the input supply voltage to V_{PP} IN (usually the main power supply filter capacitor is sufficient). The $V_{PP\ OUT}$ transition from V_{CC} to 12.0V typically takes 15μs. After programming is completed, the controller outputs a (EN1, EN0) = (0,1) to the MIC2561, which then reduces $V_{PP\ OUT}$ to the V_{CC} level for read verification. Break-before-make switching action reduces switching transients and lowers maximum current spikes through the switch from the output capacitor. The flag comparator prevents having high voltage on the $V_{PP\ OUT}$ capacitor from contaminating the V_{CC} inputs, by disabling the low voltage V_{PP} switches until $V_{PP\ OUT}$ drops below the V_{CC} level selected. The lockout delay time varies with the load current and the capacitor on $V_{PP\ OUT}$. With a 0.1μF capacitor and nominal $I_{PP\ OUT}$, the delay is approximately 250μs.

Internal drive and bias voltage is derived from V_{PP} IN. Internal device control logic is powered from V_{CC3} IN. Input logic threshold voltages are compatible with common PCMCIA controllers using either 3.3V or 5V supplies. No pull-up resistors are required at the control inputs of the MIC2561.

Output Current and Protection

MIC2561 output switches are capable of more current than needed in PCMCIA applications and meet or exceed all PCMCIA specifications. For system and card protection, output currents are internally limited. For full system protection, long term (millisecond or longer) output short circuits invoke overtemperature shutdown, protecting the MIC2561, the system power supplies, the card socket pins, and the memory card. The MIC2561 overtemperature shutdown occurs at a die temperature of 110°C.

Suspend Mode

An additional feature in the MIC2561 is a pseudo power-down mode, Suspend Mode, which allows operation without a V_{PP} IN supply. In Suspend Mode, the MIC2561 supplies 3.3V to V_{CC} OUT whenever a V_{CC} output of 3.3V is enabled by the PCMCIA controller. This mode allows the system designer the ability to turn OFF the V_{PP} supply generator to save power when it is not specifically required. The PCMCIA card receives V_{CC} at reduced capacity during Suspend Mode, as the switch resistance rises to approximately 4.5Ω.

High Current V_{CC} Operation Without a +12V Supply

Figure 5 shows the MIC2561 with V_{CC} switch bias provided by a simple charge pump. This enables the system designer to achieve full V_{CC} performance without a +12V supply, which is often helpful in battery powered systems that only provide +12V when it is needed. These on-demand +12V

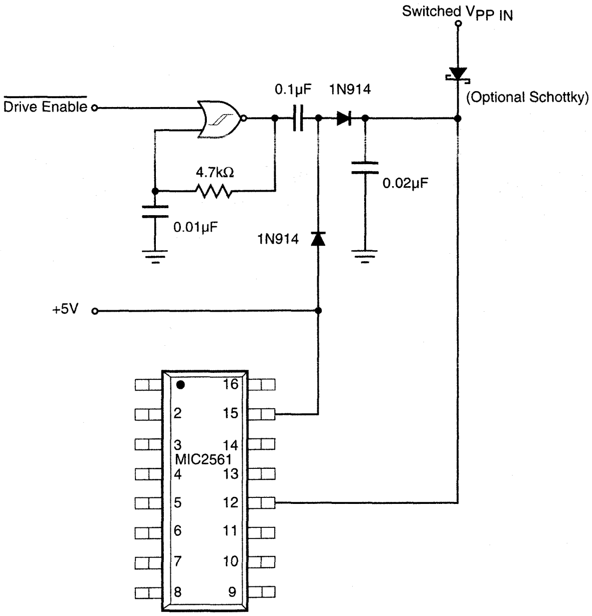


Figure 5. Circuit for generating bias drive for the V_{CC} switches when +12V is not readily available.

supplies generally have a quiescent current draw of a few milliamperes, which is far more than the microamperes used by the MIC2561. The charge pump of Figure 5 provides this low current, using about 100µA when enabled. When $V_{PP\ OUT}$ = 12V is selected, however, the on-demand V_{PP} generator must be used, as this charge pump cannot deliver the current required for Flash memory programming. The Schottky diode may not be necessary, depending on the configuration of the on-demand +12V generator and whether any other loads are on this line.

MIC2562A

PCMCIA/CardBus Socket Power Controller

Preliminary Information

General Description

The MIC2562A PCMCIA (Personal Computer Memory Card International Association) and CardBus Power Controller handles all PC Card slot power supply pins, both V_{CC} and V_{PP}. The MIC2562A switches between the three V_{CC} voltages (0V, 3.3V and 5.0V) and the V_{PP} voltages (OFF, 0V, 3.3V, 5V, or 12.0V) required by PC Cards. The MIC2562A switches voltages from the system power supply to V_{CC} and V_{PP}. Output voltage is selected by two digital inputs each and output current ranges up to 1A for V_{CC} and 250mA for V_{PP}.

The MIC2562A provides power management capability controlled by the PC Card logic controller. Voltage rise and fall times are well controlled. Medium current V_{PP} and high current V_{CC} output switches are self-biasing: ***no +12V supply is required for 3.3V or 5V output.***

The MIC2562A is designed for efficient operation. In standby (sleep) mode the device draws very little quiescent current, typically 0.3µA. The device and PCMCIA port is protected by current limiting and overtemperature shutdown. Full cross-conduction lockout protects the system power supply.

The MIC2562A is an improved version of the MIC2562, offering lower ON-resistance and a V_{CC} pull-down clamp in the OFF mode. It is available in a 14-pin 0.150" SOIC.

Ordering Information

Part Number	Temperature Range	Package
MIC2562A-0BM	–40°C to +85°C	14-pin Narrow SOIC
MIC2562A-1BM	–40°C to +85°C	14-pin Narrow SOIC

Note: see the logic table inside for a description of the differences between the logic options

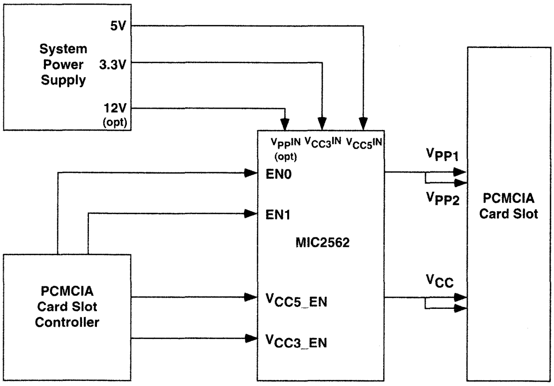
Applications

- PC Card Power Supply Pin Voltage Switch
- CardBus Slot Power Supply Control
- Data Collection Systems
- Machine Control Data Input Systems
- Wireless Communications
- Bar Code Data Collection Systems
- Instrumentation Configuration/Datalogging
- Docking Stations (portable and desktop)
- Power Supply Management
- Analog Power Switching

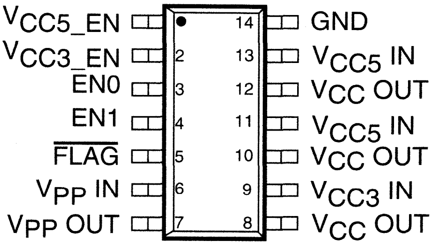
Features

- High Efficiency, Low Resistance Switches Require No 12V Bias Supply
- No External Components Required
- Output Current Limit and Overtemperature Shutdown
- Open-Drain Flag for Error Condition Indication
- Ultra Low Power Consumption
- Complete PC Card/CardBus V_{CC} and V_{PP} Switch Matrix in a Single Package
- Logic Compatible with Industry Standard PC Card Logic Controllers
- No Voltage Shoot-Through or Switching Transients
- Break-Before-Make Switching
- Digital Selection of V_{CC} and V_{PP} Voltages
- Over 1A V_{CC} Output Current
- Over 200mA V_{PP} Output Current
- Small 14-Pin SOIC Package

Typical Application



Pin Configuration

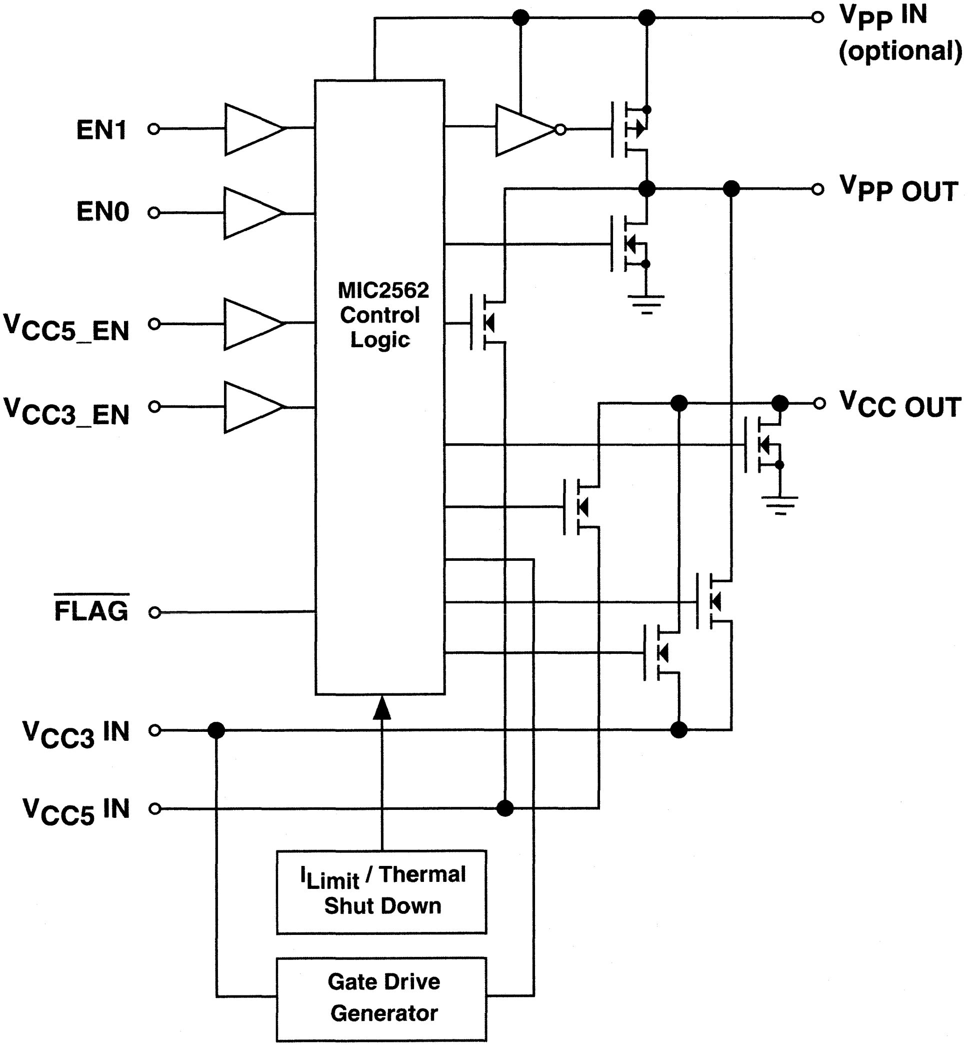


14 Pin S.O. Package
Both V_{CC5} IN pins must be connected.
All three V_{CC} OUT pins must be connected.

Absolute Maximum Ratings (Notes 1 and 2)

Power Dissipation, $T_{AMBIENT} \leq 25°C$	*Internally Limited*
SOIC	800 mW
Derating Factors (To Ambient)	
SOIC	4 mW/°C
Storage Temperature	–65°C to +150°C
Operating Temperature (Die)	125°C
Lead Temperature (10 sec)	300°C
Supply Voltage, $V_{PP\ IN}$	15V
V_{CC3} IN	7.5V
V_{CC5} IN	7.5V
FLAG Pull-up Voltage	7.5V
Logic Input Voltages	–0.3V to +10V
Output Current (each Output)	
$V_{PP\ OUT}$	*>200mA, Internally Limited*
$V_{CC\ OUT}$	*>1A, Internally Limited*

Logic Block Diagram



Electrical Characteristics: (Over operating temperature range with V_{CC3} IN = 3.3V, V_{CC5} IN = 5.0V, V_{PP} IN = 12V, unless otherwise specified.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
DIGITAL INPUTS						
V_{IH}	Logic 1 Input Voltage		2.2		7.5	V
V_{IL}	Logic 0 Input Voltage		−0.3		0.8	V
I_{IN}	Input Current	$0\text{ V} < V_{IN} < 5.5\text{V}$			±1	µA
V_{PP} OUTPUT						
$I_{PP\ OUT}$ Hi-Z	High Impedance Output Leakage Current	Shutdown Mode $0 \le V_{PP\ OUT} \le 12\text{V}$		1	10	µA
I_{PPSC}	Short Circuit Current Limit	$V_{PP\ OUT} = 0$	0.2	0.4		A
R_O	Switch Resistance,	Select $V_{PP\ OUT} = 5\text{V}$ Select $V_{PP\ OUT} = 3.3\text{V}$ $I_{PP\ OUT} = -100\text{mA}$ (Sourcing)		1.8 3.3	2.5 5	Ω
R_O	Switch Resistance, Select $V_{PP\ OUT} = 12\text{V}$	$V_{PP\ IN} = 12\text{V}$ $I_{PP\ OUT} = -100\text{ mA}$ (Sourcing)		0.6	1	Ω
R_O	Switch Resistance, Select $V_{PP\ OUT} = 0\text{V}$	Select $V_{PP\ OUT}$ = clamped to ground $I_{PP\ OUT} = 50\mu\text{A}$ (Sinking)		2500	3900	Ω
V_{PP} SWITCHING TIME (See Figure 1)						
t_1 t_2 t_3	Output Turn-ON Delay (Note 3)	$V_{PP\ OUT}$ = Hi-Z to 10% of 3.3V $V_{PP\ OUT}$ = Hi-Z to 10% of 5V $V_{PP\ OUT}$ = Hi-Z to 10% of 12V		5 10 70	50 50 250	µs
t_4 t_5 t_6	Output Rise Time (Note 3)	$V_{PP\ OUT}$ = 10% to 90% of 3.3V $V_{PP\ OUT}$ = 10% to 90% of 5V $V_{PP\ OUT}$ = 10% to 90% of 12V	100 100 100	200 300 225	800 1000 800	µs
t_7 t_8 t_9 t_{10}	Output Transition Timing (Note 3)	$V_{PP\ OUT}$ = 3.3V to 90% of 12V $V_{PP\ OUT}$ = 5V to 90% of 12V $V_{PP\ OUT}$ = 12V to 90% of 3.3V $V_{PP\ OUT}$ = 12V to 90% of 5V	100 100 100 100	250 200 200 350	1000 800 800 1200	µs
t_{14} t_{15} t_{16}	Output Turn-Off Delay Time (Note 3)	$V_{PP\ OUT}$ = 3.3V to Hi-Z $V_{PP\ OUT}$ = 5V to Hi-Z $V_{PP\ OUT}$ = 12V to Hi-Z		200 200 200	1000 1000 1000	ns
t_{11} t_{12} t_{13}	Output Turn-OFF Fall Time (Note 3)	$V_{PP\ OUT}$ = 90% to 10% of 3.3V $V_{PP\ OUT}$ = 90% to 10% of 5V $V_{PP\ OUT}$ = 90% to 10% of 12V		50 50 300	1000 1000 2000	ns

Electrical Characteristics (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{CC} OUTPUT						
I_{CCSC}	Short Circuit Current Limit	$V_{CC\ OUT} = 0$	1	1.5		A
R_O	Switch Resistance	Select $V_{CC\ OUT} = 3.3V$ $I_{CC\ OUT} = -1A$ (Sourcing)		100	150	mΩ
		Select $V_{CC\ OUT} = 5V$ $I_{CC\ OUT} = -1A$ (Sourcing)		70	100	mΩ
		Select $V_{CC\ OUT}$ = clamped to ground $I_{CC\ OUT} = 0.1mA$ (Sinking)		500	3900	Ω
V_{CC} SWITCHING TIME (See Figure 2)						
t_1	Output Turn ON Delay Time	$V_{CC\ OUT}$ = 0V to 10% of 3.3V		300	1500	µs
t_2	(Note 4)	$V_{CC\ OUT}$ = 0V to 10% of 5.0V		750	3000	
t_3	Output Rise Time (Note 4)	$V_{CC\ OUT}$ = 10% to 90% of 3.3V	200	700	2500	µs
t_4		$V_{CC\ OUT}$ = 10% to 90% of 5V	200	1500	6000	
t_7	Output Turn-Off Delay (Notes 4, 5)	$V_{CC\ OUT} = 3.3V$		2.4	8	ms
t_8		$V_{CC\ OUT} = 5V$		2.8	8	
t_5	Output Fall Time (Note 4)	$V_{CC\ OUT}$ = 90% to 10% of 3.3V	100	240	1000	µs
t_6		$V_{CC\ OUT}$ = 90% to 10% of 5.0V	100	600	2000	
POWER SUPPLY						
I_{CC5}	$V_{CC5\ IN}$ Supply Current (5V)	$V_{CC\ OUT}$ = 5V or 3.3V, $I_{CC\ OUT} = 0$		8	50	µA
		$V_{CC\ OUT} = 0V$ (Sleep Mode)		0.2	10	
I_{CC3}	$V_{CC3\ IN}$ Supply Current (3.3V)	$V_{CC\ OUT}$ = 5V or 3.3V, $I_{CC\ OUT} = 0$		40	100	µA
	(Note 6)	$V_{CC\ OUT} = 0V$ (Sleep Mode)		0.1	10	
I_{PP} IN	$V_{PP\ IN}$ Supply Current (12V)	$V_{PP\ OUT}$ = 3.3V or 5V. $I_{PP\ OUT} = 0$		0.3	4	µA
	(Note 7)	$V_{PP\ OUT}$ = Hi-Z, 0 or V_{PP}		0.3	4	
V_{CC5}	Operating Input Voltage (5V)	$V_{CC5\ IN}$ not required for operation	—	5.0	6	V
V_{CC3}	Operating Input Voltage (3.3V)	(Note 6)	3.0	3.3	6	V
$V_{PP\ IN}$	Operating Input Voltage (12V)	$V_{PP\ IN}$ not required for operation (Note 8)	—	12.0	14.5	V

Electrical Characteristics (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
THERMAL SHUTDOWN						
T_{SD}	Thermal Shutdown Temperature			130		°C
FLAG OUTPUT						
V_O OK	FLAG Threshold Voltage (Note 9)	FLAG High (OK) Threshold voltage		$V_{CC} - 1$ $V_{PP} - 1$		V

NOTE 1: Functional operation above the absolute maximum stress ratings is not implied.

NOTE 2: Static-sensitive device. Store only in conductive containers. Handling personnel and equipment should be grounded to prevent damage from static discharge.

NOTE 3: $R_L = 100\Omega$ connected to ground.

NOTE 4: $R_L = 10\Omega$ connected to ground.

NOTE 5: Delay from commanding Hi Z or 0V to beginning slope. Does not apply to current limit or overtemperature shutdown conditions.

NOTE 6: The MIC2562A uses $V_{CC3\ IN}$ for operation. For single 5V supply systems, connect 5V to both $V_{CC3\ IN}$ and V_{CC5IN}. See Applications Information for further details.

NOTE 7: $V_{PP\ IN}$ is not required for operation.

NOTE 8: $V_{PP\ IN}$ must be either high impedance or greater than or approximately equal to the highest voltage V_{CC} in the system. For example, if both 3.3V and 5V are connected to the MIC2562A, $V_{PP\ IN}$ must be either 5V, 12V, or high impedance.

NOTE 9: A 10kΩ pull-up resistor is connected between FLAG and V_{CC3} IN.

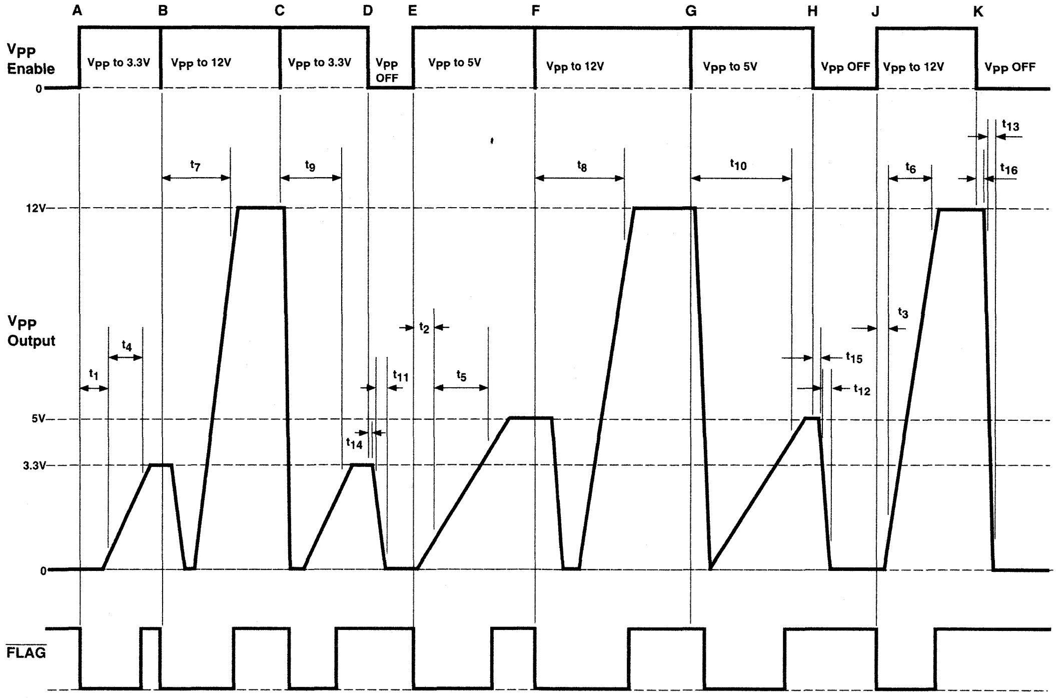


Figure 1. MIC2562A V_{PP} Timing Diagram. V_{PP} Enable is shown generically: refer to the timing tables (below). At time "A" V_{PP} = 3.3V is selected. At B, V_{PP} is set to 12V. At C, V_{PP} = 3.3V (from 12V). At D, V_{PP} is disabled. At E, V_{PP} is programmed to 5V. At F, V_{PP} is set to 12V. At G, V_{PP} is programmed to 5V. At H, V_{PP} is disabled. At J, V_{PP} is set to 12V. And at K, V_{PP} is again disabled. $R_L = 100\Omega$ for all measurements. Load capacitance is negligible.

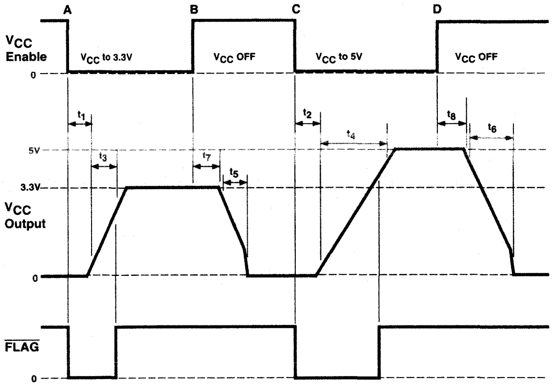


Figure 2. MIC2562A V_{CC} Timing Diagram. V_{CC} Enable is shown generically: refer to the timing tables (below) for specific control logic input. At time A, V_{CC} is programmed to 3.3V. At B, V_{CC} is disabled. At C, V_{CC} is programmed to 5V. And at D, V_{CC} is disabled. R_L = 10Ω. FLAG pull-up resistor is 10kΩ to V_{CC3} IN.

MIC2562A-0 Control Logic Table

V_{CC5_EN}	V_{CC3_EN}	EN1	EN0	V_{CC} OUT	V_{PP} OUT
0	0	0	0	Clamped to Ground	High Z
0	0	0	1	Clamped to Ground	High Z
0	0	1	0	Clamped to Ground	High Z
0	0	1	1	Clamped to Ground	Clamped to Ground
0	1	0	0	3.3	High Z
0	1	0	1	3.3	3.3
0	1	1	0	3.3	12
0	1	1	1	3.3	Clamped to Ground
1	0	0	0	5	High Z
1	0	0	1	5	5
1	0	1	0	5	12
1	0	1	1	5	Clamped to Ground
1	1	0	0	3.3	High Z
1	1	0	1	3.3	3.3
1	1	1	0	3.3	5
1	1	1	1	3.3	Clamped to Ground

MIC2562A-1 Control Logic (compatible with Cirrus Logic CL-PD6710 & PD672x-series Controllers)

V_{CC5_EN}	V_{CC3_EN}	V_{PP_PGM}	V_{PP_VCC}	V_{CC} OUT	V_{PP} OUT
0	0	0	0	Clamped to Ground	Clamped to Ground
0	0	0	1	Clamped to Ground	High Z
0	0	1	0	Clamped to Ground	High Z
0	0	1	1	Clamped to Ground	High Z
0	1	0	0	5	Clamped to Ground
0	1	0	1	5	5
0	1	1	0	5	12
0	1	1	1	5	High Z
1	0	0	0	3.3	Clamped to Ground
1	0	0	1	3.3	3.3
1	0	1	0	3.3	12
1	0	1	1	3.3	High Z
1	1	0	0	Clamped to Ground	Clamped to Ground
1	1	0	1	Clamped to Ground	High Z
1	1	1	0	Clamped to Ground	High Z
1	1	1	1	Clamped to Ground	High Z

Applications Information

PC Card V_{CC} and V_{PP} control is easily accomplished using the MIC2562A PC Card/CardBus Slot V_{CC} & V_{PP} Power Controller IC. Four control bits determine $V_{CC\ OUT}$ and $V_{PP\ OUT}$ voltage and standby/operate mode condition. V_{CC} outputs of 3.3V and 5V at the maximum allowable PC Card current are supported. $V_{PP\ OUT}$ output voltages of V_{CC} (3.3V or 5V), V_{PP}, 0V, or a high impedance state are available. When the V_{CC} clamped to ground condition is selected, the device switches into “sleep” mode and draws only nanoamperes of leakage current. An error flag alerts the user if the output voltage is too low because of overtemperature or overcurrent faults. Protection from hot switching is provided which prevents feedback from the $V_{CC\ OUT}$ (from 5V to 3.3V, for example) by locking out the low voltage switch until the initial switch's gate voltage drops below the desired lower V_{CC}.

The MIC2562A operates from the computer system main power supply. Device logic and internal MOSFET drive is generated internally by charge pump voltage multipliers powered from V_{CC3} IN. Switching speeds are carefully controlled to prevent damage to sensitive loads and meet all PC Card Specification speed requirements.

Supply Bypassing

External capacitors are not required for operation. The MIC2562A is a switch and has no stability problems. For best results however, bypass V_{CC3} IN, V_{CC5} IN, and V_{PP} IN inputs with 1µF capacitors to improve output ripple. As all internal device logic and comparison functions are powered from the V_{CC3} IN line, the power supply quality of this line is the most important, and a bypass capacitor may be necessary for some layouts. Both $V_{CC\ OUT}$ and $V_{PP\ OUT}$ pins may use 0.01µF to 0.1µF capacitors for noise reduction and electrostatic discharge (ESD) damage prevention. Larger values of output capacitors are not necessary.

PC Card Slot Implementation

The MIC2562A is designed for full compatibility with the Personal Computer Memory Card International Association's (PCMCIA) PC Card Specification, (March 1995), including the CardBus option. One MIC2562A is required for each PC Card slot.

When a memory card is initially inserted, it should receive V_{CC} — either 3.3V ± 0.3V or 5.0V ±5%. The initial voltage is determined by a combination of mechanical socket “keys” and voltage sense pins. The card sends a handshaking data stream to the controller, which then determines whether or not this card requires V_{PP} and if the card is designed for dual V_{CC}. If the card is compatible with and desires a different V_{CC} level, the controller commands this change by disabling V_{CC}, waiting at least 100ms, and then re-enabling the other V_{CC} voltage.

V_{CC} switches are turned ON and OFF slowly. If commanded to immediately switch from one V_{CC} to the other (without turning OFF and waiting 100ms first), enhancement of the second switch begins after the first is OFF, realizing break-before-make protection. V_{PP} switches are turned ON slowly and OFF quickly, which also prevents cross conduction.

If no card is inserted or the system is in sleep mode, the slot logic controller outputs a (V_{CC3} IN, V_{CC5} IN) = (0,0) to the MIC2562A, which shuts down V_{CC}. This also places the switch into a high impedance output shutdown (sleep) mode, where current consumption drops to nearly zero, with only tiny CMOS leakage currents flowing.

Internal device control logic and MOSFET drive and bias voltage is powered from V_{CC3} IN. The high voltage bias is generated by an internal charge pump quadrupler. Systems without 3.3V may connect V_{CC3} IN to 5V. Input logic threshold voltages are compatible with common PC Card logic controllers using either 3.3V or 5V supplies.

The PC Card Specification defines two V_{PP} supply pins per card slot. The two V_{PP} supply pins may be programmed to different voltages. V_{PP} is primarily used for programming FLASH memory cards. Implementing two independent V_{PP} voltages is easily accomplished with the MIC2562A and a MIC2557 PCMCIA V_{PP} Switching Matrix. Figure 3 shows this full configuration, supporting independent V_{PP} and both 5.0V and 3.3V V_{CC} operation. However, few logic controllers support multiple V_{PP}—most systems connect V_{PP1} to V_{PP2} and the MIC2557 is not required. This circuit is shown in Figure 4.

During Flash memory programming with standard (+12V) Flash memories, the PC Card slot logic controller outputs a (0,1) to the EN0, EN1 control pins of the MIC2562A, which connects V_{PP} IN (nominally +12V) to $V_{PP\ OUT}$. The low ON resistance of the MIC2562A switch allows using a small bypass capacitor on the $V_{PP\ OUT}$ pins, with the main filtering action performed by a large filter capacitor on V_{PP} IN (usually the main power supply filter capacitor is sufficient). Using a small-value capacitor such as 0.1µF on the output causes little or no timing delays. The $V_{PP\ OUT}$ transition from V_{CC} to 12.0V typically takes 250µs. After programming is completed, the controller outputs a (EN1, EN0) = (0,1) to the MIC2562A, which then reduces $V_{PP\ OUT}$ to the V_{CC} level. Break-before-make switching action and controlled rise times reduces switching transients and lowers maximum current spikes through the switch.

Figure 5 shows MIC2562A configuration for situations where only a single +5V V_{CC} is available.

Output Current and Protection

MIC2562A output switches are capable of passing the maximum current needed by any PC Card. The MIC2562A meets or exceeds all PCMCIA specifications. For system and card protection, output currents are internally limited. For full system protection, long term (millisecond or longer) output short circuits invoke overtemperature shutdown, protecting the MIC2562A, the system power supplies, the card socket pins, and the PC Card. A final protective feature is the error FLAG, which signals the PC Card slot logic controller when a fault condition exists, allowing the controller to notify the user that the card inserted has a problem. The open-drain FLAG monitors the voltage level on both $V_{CC\ OUT}$ and $V_{PP\ OUT}$ and activates (pulls low) when either output is 1V below its programmed level or an overtemperature fault exists.

This FLAG signals output voltage transitions as well as fault conditions. Refer to Figures 1 and 2 for details.

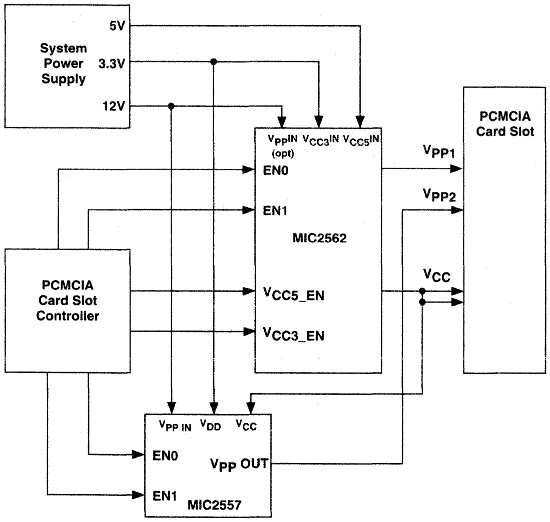


Figure 3. MIC2562A PC Card slot power control application with dual V_{CC} (5V and 3.3V) and separate V_{PP1} and V_{PP2}.

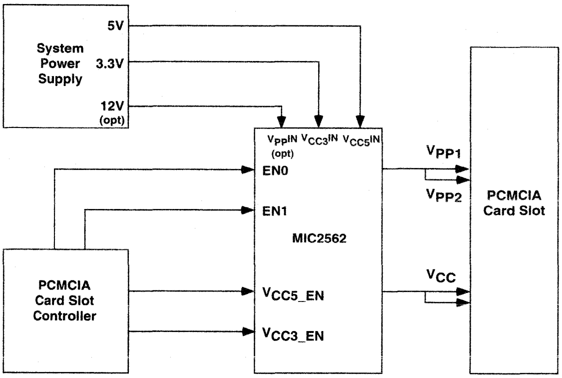


Figure 4. Typical MIC2562A PC Card slot power control application with dual V_{CC} (5V and 3.3V). Note that V_{PP1} and V_{PP2} are driven together.

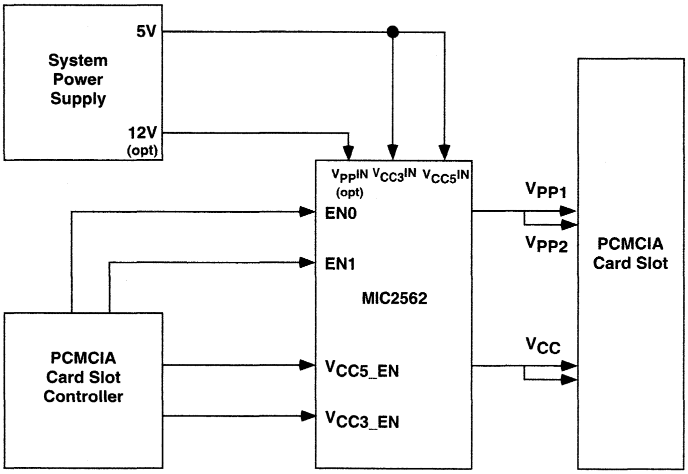


Figure 5. PC Card slot power control application without an available 3.3V V_{CC}. Note that $V_{CC3\,IN}$ and $V_{CC5\,IN}$ are driven together. The MIC2562A is powered by the $V_{CC3\,IN}$ line. In this configuration, $V_{CC\,OUT}$ will be 5V when either V_{CC3} or V_{CC5} is enabled from the logic table. Take advantage of the lower switch resistance of the V_{CC5} switch by using the V_{CC5_EN} control as your main V_{CC} switch.

MIC2563A

Dual Slot PCMCIA/CardBus Power Controller

Preliminary Information

General Description

The MIC2563A Dual Slot PCMCIA (Personal Computer Memory Card International Association) and CardBus Power Controller handles all PC Card slot power supply pins, both V_{CC} and V_{PP}. The MIC2563A switches between the three V_{CC} voltages (0V, 3.3V and 5.0V) and the V_{PP} voltages (OFF, 0V, 3.3V, 5V, or 12.0V) required by PC Cards. The MIC2563A switches voltages from the system power supply to V_{CC} and V_{PP}. Output voltage is selected by two digital inputs each and output current ranges up to 1A for V_{CC} and 250mA for V_{PP}.

The MIC2563A provides power management capability controlled by the PC Card logic controller. Voltage rise and fall times are well controlled. Medium current V_{PP} and high current V_{CC} output switches are self-biasing: ***no +12V supply is required for 3.3V or 5V output.***

The MIC2563A is designed for efficient operation. In standby (sleep) mode the device draws very little quiescent current, typically 0.3µA. The device and PCMCIA port is protected by current limiting and overtemperature shutdown. Full cross-conduction lockout protects the system power supplies.

The MIC2563A is an improved version of the MIC2563, offering lower ON-resistances and a V_{CC} pulldown clamp in the OFF mode. It is available in a 28-pin SSOP.

Applications

- Dual Slot PC Card Power Supply Pin Voltage Switch
- CardBus Slot Power Supply Control
- Data Collection Systems
- Machine Control Data Input Systems
- Wireless Communications
- Bar Code Data Collection Systems
- Instrumentation Configuration/Datalogging
- Docking Stations (portable and desktop)
- Power Supply Management
- Power Analog Switching

Features

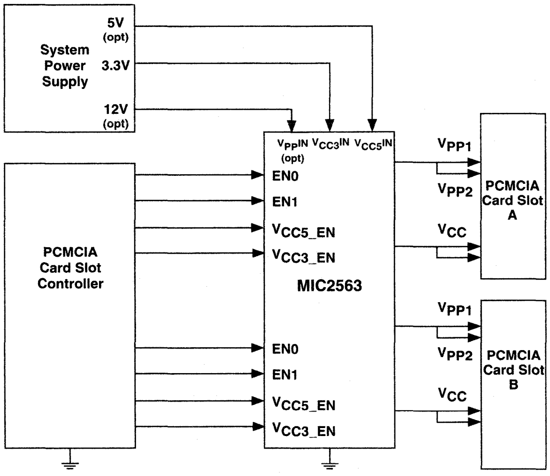
- Single Package Controls Two PC Card Slots
- High Efficiency, Low Resistance Switches Require No 12V Bias Supply
- No External Components Required
- Output Current Limit and Overtemperature Shutdown
- Ultra Low Power Consumption
- Complete Dual Slot PC Card/CardBus V_{CC} and V_{PP} Switch Matrix in a Single Package
- Logic Compatible with Industry Standard PC Card Logic Controllers
- No Voltage Shoot-Through or Switching Transients
- Break-Before-Make Switching
- Digital Selection of V_{CC} and V_{PP} Voltages
- Over 1A V_{CC} Output Current for Each Section
- Over 250mA V_{PP} Output Current for Each Section
- 28-Pin SSOP Package

Ordering Information

Part Number	Temperature Range	Package
MIC2563A-0BSM	–40°C to +85°C	28-pin SSOP
MIC2563A-1BSM	–40°C to +85°C	28-pin SSOP

Note: see the logic table inside for a description of the differences between the logic options

Typical Application

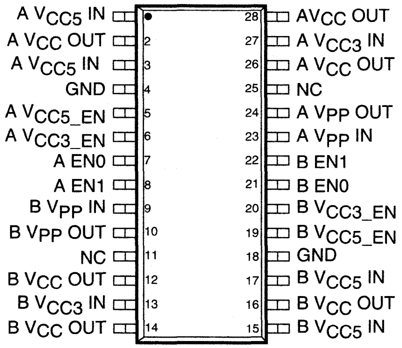


Absolute Maximum Ratings (Notes 1 and 2)

Power Dissipation, $T_{AMBIENT} \leq 25°C$	*Internally Limited*
SSOP	800 mW
Derating Factors (To Ambient)	
SSOP	4 mW/°C
Storage Temperature	−65°C to +150°C
Operating Temperature (Die)	125°C
Lead Temperature (10 sec)	300°C

Supply Voltage, $V_{PP\ IN}$	15V
V_{CC3} IN	7.5V
V_{CC5} IN	7.5V
Logic Input Voltages	−0.3V to +10V
Output Current (each Output)	
$V_{PP\ OUT}$	*>200mA, Internally Limited*
$V_{CC\ OUT}$	*>1A, Internally Limited*

Pin Configuration



28 Pin SSOP Package

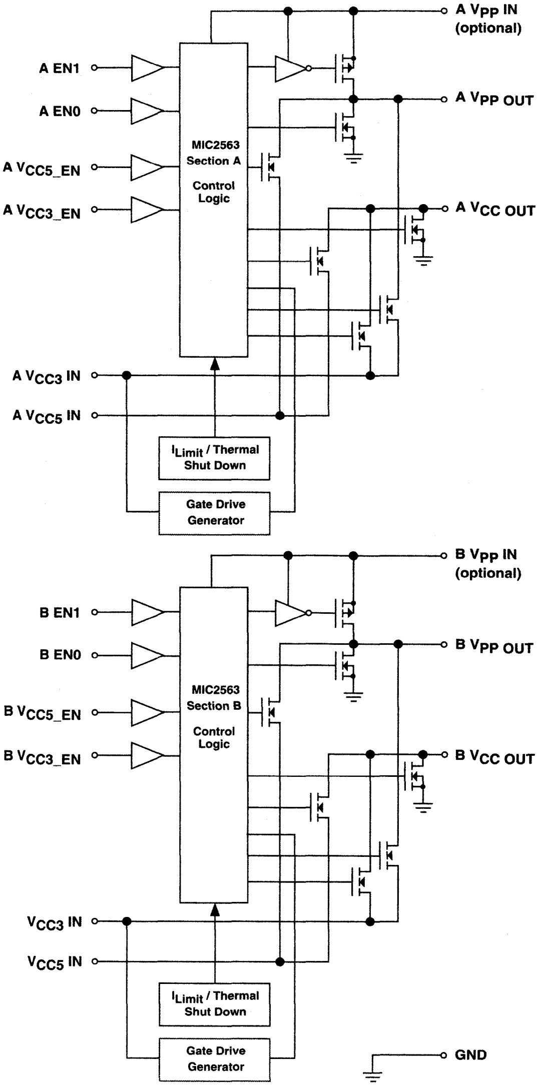
Connect all pins with the same name together for proper operation.

MIC2563A-1 Redefined Pin Assignment

Function	Pin Number	
	Slot A	Slot B
VPP_VCC	7	21
VPP_PGM	8	22

Some pin names for the MIC2563A-1 are different from the MIC2563A-0. This table shows the differences. All other pin names are identical to the MIC2563A-0 as shown in the **Pin Configuration**, above.

Logic Block Diagram



Electrical Characteristics:

(Over operating temperature range with V_{CC3} IN = 3.3V, V_{CC5} IN = 5.0V, V_{PP} IN = 12V, unless otherwise specified.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
DIGITAL INPUTS						
V_{IH}	Logic 1 Input Voltage		2.2		7.5	V
V_{IL}	Logic 0 Input Voltage		–0.3		0.8	V
I_{IN}	Input Current	$0\ V < V_{IN} < 5.5V$			±1	µA
V_{PP} OUTPUT						
$I_{PP\ OUT}$ Hi-Z	High Impedance Output Leakage Current	Shutdown Mode $0 \le V_{PP\ OUT} \le 12V$		1	10	µA
I_{PPSC}	Short Circuit Current Limit	$V_{PP\ OUT} = 0$	0.2	0.3		A
R_O	Switch Resistance	Select $V_{PP\ OUT}$ = 5V Select $V_{PP\ OUT}$ = 3.3V $I_{PP\ OUT} = -100mA$ (Sourcing)		1.8 3.3	2.5 5	Ω
R_O	Switch Resistance, Select $V_{PP\ OUT}$ = 12V	$V_{PP\ IN}$ = 12V $I_{PP\ OUT} = -100$ mA (Sourcing)		0.6	1	Ω
R_O	Switch Resistance, Select $V_{PP\ OUT}$ = 0V	Select $V_{PP\ OUT}$ = clamped to ground $I_{PP\ OUT} = 50µA$ (Sinking)		2500	3900	Ω
V_{PP} SWITCHING TIME (See Figure 1)						
t_1 t_2 t_3	Output Turn-ON Delay (Note 3)	$V_{PP\ OUT}$ = Hi-Z to 10% of 3.3V $V_{PP\ OUT}$ = Hi-Z to 10% of 5V $V_{PP\ OUT}$ = Hi-Z to 10% of 12V		5 10 70	50 50 250	µs
t_4 t_5 t_6	Output Rise Time (Note 3)	$V_{PP\ OUT}$ = 10% to 90% of 3.3V $V_{PP\ OUT}$ = 10% to 90% of 5V $V_{PP\ OUT}$ = 10% to 90% of 12V	100 100 100	200 300 225	800 1000 800	µs
t_7 t_8 t_9 t_{10}	Output Transition Timing (Note 3)	$V_{PP\ OUT}$ = 3.3V to 90% of 12V $V_{PP\ OUT}$ = 5V to 90% of 12V $V_{PP\ OUT}$ = 12V to 90% of 3.3V $V_{PP\ OUT}$ = 12V to 90% of 5V	100 100 100 100	250 200 200 350	1000 800 800 1200	µs
t_{14} t_{15} t_{16}	Output Turn-Off Delay Time (Notes 3, 5)	$V_{PP\ OUT}$ = 3.3V to Hi-Z $V_{PP\ OUT}$ = 5V to Hi-Z $V_{PP\ OUT}$ = 12V to Hi-Z		200 200 200	1000 1000 1000	ns
t_{11} t_{12} t_{13}	Output Turn-OFF Fall Time (Note 3)	$V_{PP\ OUT}$ = 90% to 10% of 3.3V $V_{PP\ OUT}$ = 90% to 10% of 5V $V_{PP\ OUT}$ = 90% to 10% of 12V		50 50 300	1000 1000 2000	ns

Electrical Characteristics (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{CC} OUTPUT						
I_{CCSC}	Short Circuit Current Limit	$V_{CC\ OUT} = 0$	1	1.5		A
R_O	Switch Resistance	Select $V_{CC\ OUT} = 3.3V$ $I_{CC\ OUT} = -1A$ (Sourcing)		100	150	mΩ
		Select $V_{CC\ OUT} = 5V$ $I_{CC\ OUT} = -1A$ (Sourcing)		70	100	mΩ
		Select $V_{CC\ OUT}$ = clamped to ground $I_{CC\ OUT} = 0.1mA$ (Sinking)		500	3900	Ω
V_{CC} SWITCHING TIME (See Figure 2)						
t_1	Output Turn ON Delay Time	$V_{CC\ OUT}$ = 0V to 10% of 3.3V		300	1500	µs
t_2	(Note 4)	$V_{CC\ OUT}$ = 0V to 10% of 5.0V		750	3000	
t_3	Output Rise Time (Note 4)	$V_{CC\ OUT}$ = 10% to 90% of 3.3V	200	700	2500	µs
t_4		$V_{CC\ OUT}$ = 10% to 90% of 5V	200	1500	6000	
t_7	Output Turn-Off Delay (Notes 4, 5)	$V_{CC\ OUT} = 3.3V$		2.4	8	ms
t_8		$V_{CC\ OUT} = 5V$		2.8	8	
t_5	Output Fall Time (Note 4)	$V_{CC\ OUT}$ = 90% to 10% of 3.3V	100	240	1000	µs
t_6		$V_{CC\ OUT}$ = 90% to 10% of 5.0V	100	600	2000	
POWER SUPPLY						
I_{CC5}	$V_{CC5\ IN}$ Supply Current (5V)	$V_{CC\ OUT}$ = 5V or 3.3V, $I_{CC\ OUT} = 0$		8	50	µA
		$V_{CC\ OUT} = 0V$ (Sleep Mode)		0.2	10	
I_{CC3}	$V_{CC3\ IN}$ Supply Current (3.3V)	$V_{CC\ OUT}$ = 5V or 3.3V, $I_{CC\ OUT} = 0$		40	100	µA
	(Note 6)	$V_{CC\ OUT} = 0V$ (Sleep Mode)		0.1	10	
I_{PP} IN	$V_{PP\ IN}$ Supply Current (12V)	$V_{PP\ OUT}$ = 3.3V or 5V. $I_{PP\ OUT} = 0$		0.3	4	µA
	(Note 7)	$V_{PP\ OUT}$ = Hi-Z, 0 or V_{PP}		0.3	4	
V_{CC5}	Operating Input Voltage (5V)	$V_{CC5\ IN}$ not required for operation	—	5.0	6	V
V_{CC3}	Operating Input Voltage (3.3V)	(Note 6)	3.0	3.3	6	V
$V_{PP\ IN}$	Operating Input Voltage (12V)	$V_{PP\ IN}$ not required for operation (Note 8)	—	12.0	14.5	V

Electrical Characteristics (continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
THERMAL SHUTDOWN						
T_{SD}	Thermal Shutdown Temperature			130		°C

NOTE 1: Functional operation above the absolute maximum stress ratings is not implied.

NOTE 2: Static-sensitive device. Store only in conductive containers. Handling personnel and equipment should be grounded to prevent damage from static discharge.

NOTE 3: R_L = 100Ω connected to ground.

NOTE 4: R_L = 10Ω connected to ground.

NOTE 5: Delay from commanding Hi Z or 0V to beginning slope. Does not apply to current limit or overtemperature shutdown conditions.

NOTE 6: The MIC2563A uses $V_{CC3\ IN}$ for operation. For single 5V supply systems, connect 5V to both $V_{CC3\ IN}$ and V_{CC5IN}. See Applications Information for further details.

NOTE 7: $V_{PP\ IN}$ is not required for operation.

NOTE 8: $V_{PP\ IN}$ must be either high impedance or greater than or approximately equal to the highest voltage V_{CC} in the system. For example, if both 3.3V and 5V are connected to the MIC2563A, $V_{PP\ IN}$ must be either 5V, 12V, or high impedance.

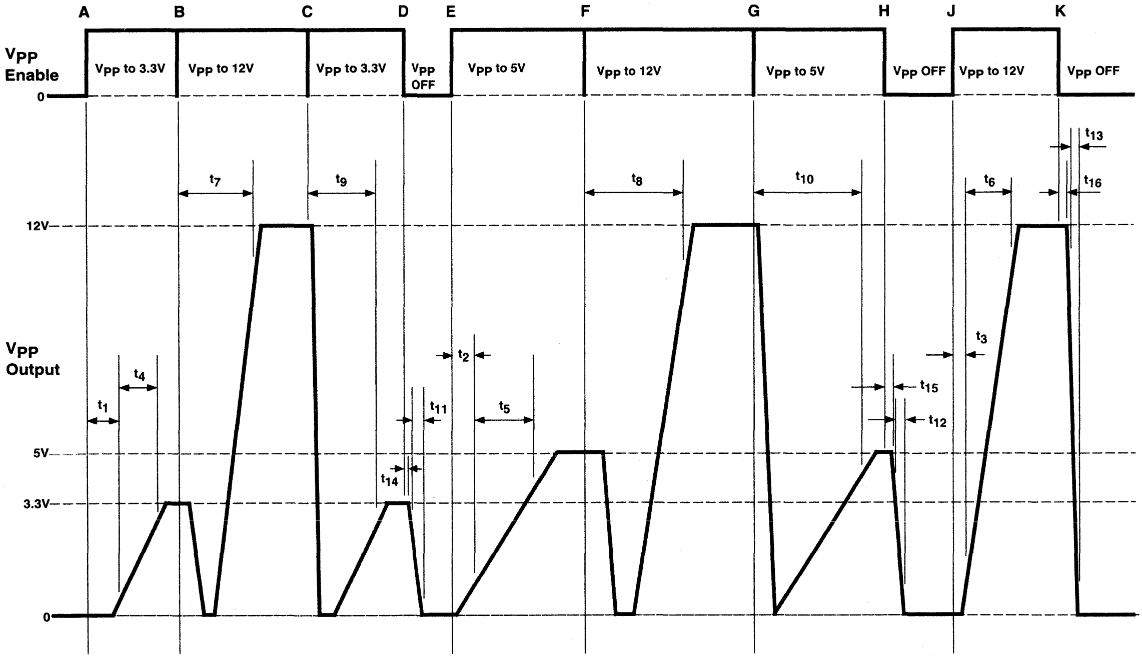


Figure 1. MIC2563A V_{PP} Timing Diagram. V_{PP} Enable is shown generically: refer to the timing tables (below). At time "A" V_{PP} = 3.3V is selected. At B, V_{PP} is set to 12V. At C, V_{PP} = 3.3V (from 12V). At D, V_{PP} is disabled. At E, V_{PP} is programmed to 5V. At F, V_{PP} is set to 12V. At G, V_{PP} is programmed to 5V. At H, V_{PP} is disabled. At J, V_{PP} is set to 12V. And at K, V_{PP} is again disabled. R_L = 100Ω for all measurements. Load capacitance is negligible.

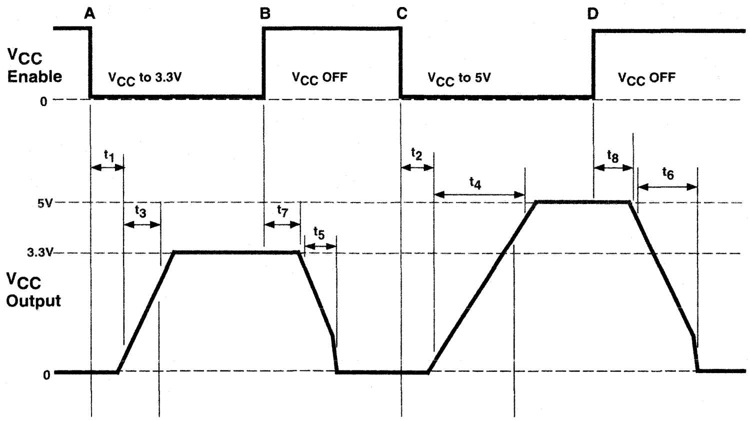


Figure 2. MIC2563A V_{CC} Timing Diagram. V_{CC} Enable is shown generically: refer to the timing tables (below) for specific control logic input. At time A, V_{CC} is programmed to 3.3V. At B, V_{CC} is disabled. At C, V_{CC} is programmed to 5V. And at D, V_{CC} is disabled. $R_L = 10\Omega$

MIC2563A-0 Control Logic Table

V_{CC5_EN}	V_{CC3_EN}	EN1	EN0	V_{CC} OUT	V_{PP} OUT
0	0	0	0	Clamped to Ground	High Z
0	0	0	1	Clamped to Ground	High Z
0	0	1	0	Clamped to Ground	High Z
0	0	1	1	Clamped to Ground	Clamped to Ground
0	1	0	0	3.3	High Z
0	1	0	1	3.3	3.3
0	1	1	0	3.3	12
0	1	1	1	3.3	Clamped to Ground
1	0	0	0	5	High Z
1	0	0	1	5	5
1	0	1	0	5	12
1	0	1	1	5	Clamped to Ground
1	1	0	0	3.3	High Z
1	1	0	1	3.3	3.3
1	1	1	0	3.3	5
1	1	1	1	3.3	Clamped to Ground

MIC2563A-1 Control Logic (compatible with Cirrus Logic CL-PD6710 & PD672x-series Controllers)

V_{CC5_EN}	V_{CC3_EN}	V_{PP_PGM}	V_{PP_VCC}	V_{CC} OUT	V_{PP} OUT
0	0	0	0	Clamped to Ground	Clamped to Ground
0	0	0	1	Clamped to Ground	High Z
0	0	1	0	Clamped to Ground	High Z
0	0	1	1	Clamped to Ground	High Z
0	1	0	0	5	Clamped to Ground
0	1	0	1	5	5
0	1	1	0	5	12
0	1	1	1	5	High Z
1	0	0	0	3.3	Clamped to Ground
1	0	0	1	3.3	3.3
1	0	1	0	3.3	12
1	0	1	1	3.3	High Z
1	1	0	0	Clamped to Ground	Clamped to Ground
1	1	0	1	Clamped to Ground	High Z
1	1	1	0	Clamped to Ground	High Z
1	1	1	1	Clamped to Ground	High Z

Applications Information

PC Card power control for two sockets is easily accomplished using the MIC2563A PC Card/CardBus Slot V_{CC} & V_{PP} Power Controller IC. Four control bits per socket determine $V_{CC\ OUT}$ and $V_{PP\ OUT}$ voltage and standby/operate mode condition. V_{CC} outputs of 3.3V and 5V at the maximum allowable PC Card current are supported. $V_{PP\ OUT}$ output voltages of V_{CC} (3.3V or 5V), V_{PP}, 0V, or a high impedance state are available. When the V_{CC} clamped to ground condition is selected, the device switches into "sleep" mode and draws only nanoamperes of leakage current. Full protection from hot switching is provided which prevents feedback from the $V_{CC\ OUT}$ (from 5V to 3.3V, for example) by locking out the low voltage switch until the initial switch's gate voltage drops below the desired lower V_{CC}.

The MIC2563A operates from the computer system main power supply. Device logic and internal MOSFET drive is generated internally by charge pump voltage multipliers powered from $V_{CC3\ IN}$. Switching speeds are carefully controlled to prevent damage to sensitive loads and meet all PC Card Specification timing requirements.

Supply Bypassing

External capacitors are not required for operation. The MIC2563A is a switch and has no stability problems. For best results however, bypass V_{CC3} IN, V_{CC5} IN, and V_{PP} IN inputs with 1µF capacitors to improve output ripple. As all internal device logic and comparison functions are powered from the V_{CC3} IN line, the power supply quality of this line is the most important, and a bypass capacitor may be necessary for some layouts. Both $V_{CC\ OUT}$ and $V_{PP\ OUT}$ pins may use 0.01µF to 0.1µF capacitors for noise reduction and electrostatic discharge (ESD) damage prevention.

PC Card Slot Implementation

The MIC2563A is designed for full compatibility with the Personal Computer Memory Card International Association's (PCMCIA) PC Card Specification, (March 1995), including the CardBus option.

When a memory card is initially inserted, it should receive V_{CC} — either 3.3V ± 0.3V or 5.0V ±5%. The initial voltage is determined by a combination of mechanical socket "keys" and voltage sense pins. The card sends a handshaking data stream to the controller, which then determines whether or not this card requires V_{PP} and if the card is designed for dual V_{CC}. If the card is compatible with and desires a different V_{CC} level, the controller commands this change by disabling V_{CC}, waiting at least 100ms, and then re-enabling the other V_{CC} voltage.

V_{CC} switches are turned ON and OFF slowly. If commanded to immediately switch from one V_{CC} to the other (without turning OFF and waiting 100ms first), enhancement of the second switch begins after the first is OFF, realizing break-before-make protection. V_{PP} switches are turned ON slowly and OFF quickly, which also prevents cross conduction.

If no card is inserted or the system is in sleep mode, the slot logic controller outputs a (V_{CC3} IN, V_{CC5} IN) = (0,0) to the MIC2563A, which shuts down V_{CC}. This also places the switch into a high impedance output shutdown (sleep) mode, where current consumption drops to nearly zero, with only tiny CMOS leakage currents flowing.

Internal device control logic and MOSFET drive and bias voltage is powered from V_{CC3} IN. The high voltage bias is generated by an internal charge pump quadrupler. Systems without 3.3V may connect V_{CC3} IN to 5V. Input logic threshold voltages are compatible with common PC Card logic controllers using either 3.3V or 5V supplies.

The PC Card Specification defines two V_{PP} supply pins per card slot. The two V_{PP} supply pins may be programmed to different voltages. V_{PP} is primarily used for programming FLASH memory cards. Implementing two independent V_{PP} voltages is easily accomplished with the MIC2563A and a MIC2557 PCMCIA V_{PP} Switching Matrix. Figure 3 shows this full configuration, supporting independent V_{PP} and both 5.0V and 3.3V V_{CC} operation. However, few logic controllers support multiple V_{PP}—most systems connect V_{PP1} to V_{PP2} and the MIC2557 is not required. This circuit is shown in Figure 4.

During Flash memory programming with standard (+12V) Flash memories, the PC Card slot logic controller outputs a (0 , 1) to the EN0, EN1 control pins of the MIC2563A, which connects V_{PP} IN (nominally +12V) to $V_{PP\ OUT}$. The low ON resistance of the MIC2563A switch allows using a small bypass capacitor on the $V_{PP\ OUT}$ pins, with the main filtering action performed by a large filter capacitor on V_{PP} IN (usually the main power supply filter capacitor is sufficient). Using a small-value capacitor such as 0.1µF on the output causes little or no timing delays. The $V_{PP\ OUT}$ transition from V_{CC} to 12.0V typically takes 250µs. After programming is completed, the controller outputs a (EN1, EN0) = (0,1) to the MIC2563A, which then reduces $V_{PP\ OUT}$ to the V_{CC} level. Break-before-make switching action and controlled rise times reduces switching transients and lowers maximum current spikes through the switch.

Figure 5 shows MIC2563A configuration for situations where only a single +5V V_{CC} is available.

Output Current and Protection

MIC2563A output switches are capable of passing the maximum current needed by any PC Card. The MIC2563A meets or exceeds all PCMCIA specifications. For system and card protection, output currents are internally limited. For full system protection, long term (millisecond or longer) output short circuits invoke overtemperature shutdown, protecting the MIC2563A, the system power supplies, the card socket pins, and the PC Card.

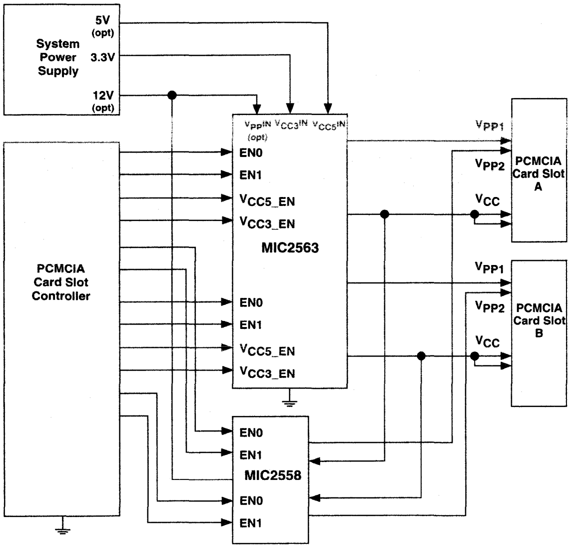


Figure 3. PC Card slot power control application with dual V_{CC} (5.0V or 3.3V) and separate V_{PP1} and V_{PP2}.

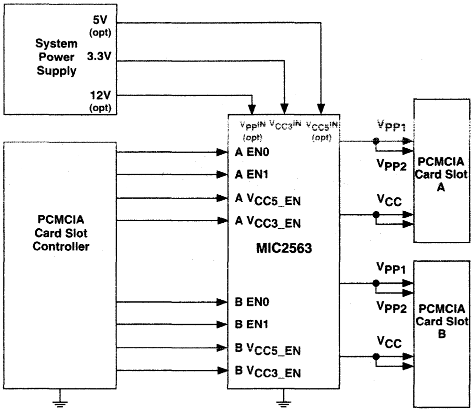


Figure 4. Typical PC Card slot power control application with dual V_{CC} (5.0V or 3.3V). Note that V_{PP1} and V_{PP2} are driven together.

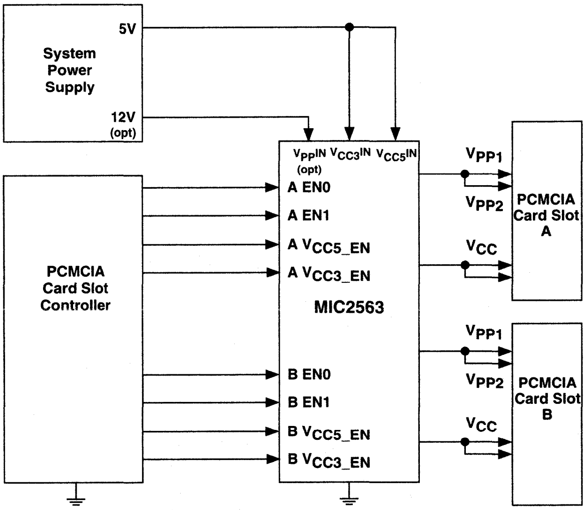


Figure 5. PC Card slot power control application without a 3.3V V_{CC} supply. Note that $V_{CC3\,IN}$ and $V_{CC5\,IN}$ lines are driven together. The MIC2563A is powered from the $V_{CC3\,IN}$ line. In this configuration, $V_{CC\,OUT}$ will be 5V when either V_{CC3} or V_{CC5} is enabled.

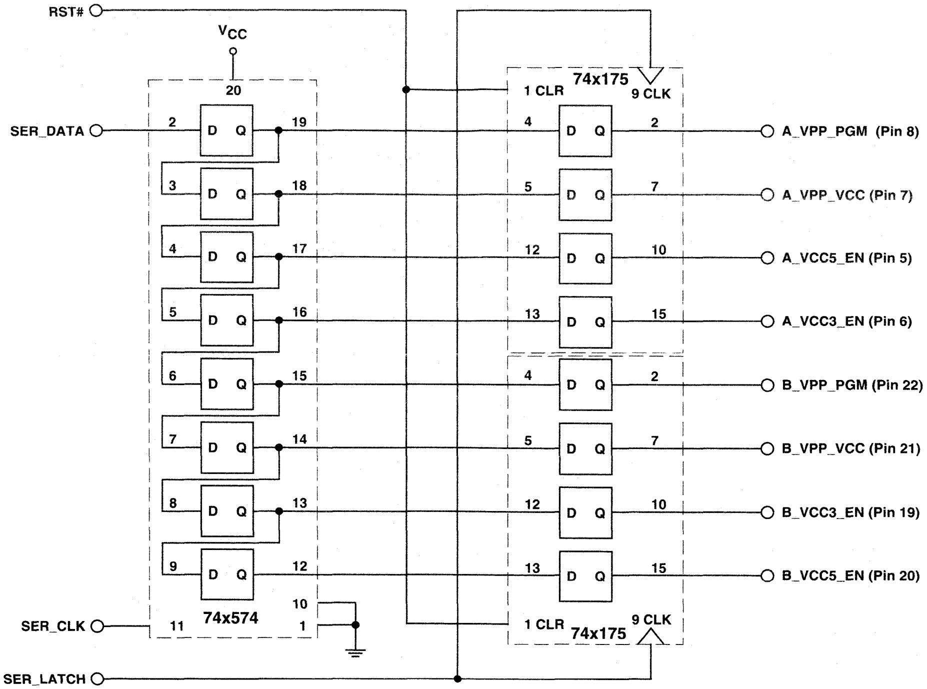


Figure 6. Interfacing the MIC2563A with a serial-output data controller. Pinouts shown are for the MIC2563A-1 and a three-wire serial controller.

Serial Control

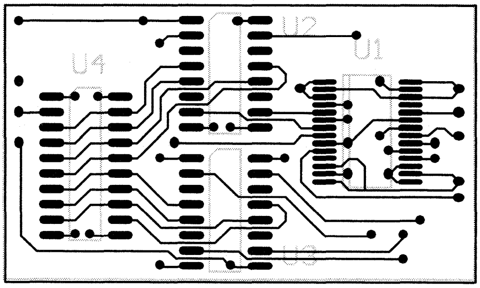
Figure 6 shows conversion from a three-wire serial interface, such as used by the Cirrus Logic CL-PD6730, to the standard eight-line parallel interface used by the MIC2563A-1. This interface requires three common, low cost 7400-series logic ICs:

- 74x574 Octal D Flip-Flop
- 74x175 Quad Flip-Flop with Latches (two needed)

Either 3.3V or 5V logic devices may be used, depending upon the control voltage employed by the slot logic controller. Pin numbers in parenthesis refer to the MIC2563A-1BSM. Gerber™ files for this P.C. board layout are available to Micrel customers. Please contact Micrel directly.

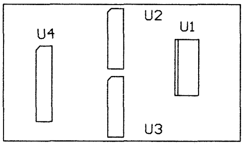
Another serial-to-parallel solution for this application is the 74HC594, 8-bit shift register with output registers. This device contains the eight D flip-flops plus has latched outputs suitable for this purpose.

Serial Control Adapter P.C. Board Layout



Component Key

U1 .... MIC2563
U2, U3....... 74x175
U4 .... 74x574



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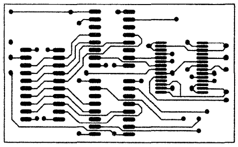
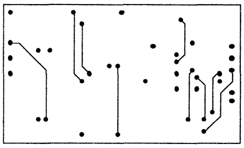
Top Overlay



95090201.PCB
Top Layer



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Bottom Layer

MIC2565

Dual Serial PCMCIA/CardBus Power Controller

Advance Information

General Description

The MIC2565 Dual Slot PCMCIA (Personal Computer Memory Card International Association) and CardBus Power Controller handles all PC Card slot power supply pins, both V_{CC} and V_{PP}. The MIC2565 switches between the V_{CC} voltages (OFF, 0V, 3.3V and 5.0V) and the V_{PP} voltages (OFF, 0V, 3.3V, 5V, or 12.0V) required by PC Cards. The MIC2565 switches voltages from the system power supply to the socket V_{CC} and V_{PP} pins. Output current ranges up to 1A for V_{CC} and 250mA for V_{PP}.

The MIC2565 provides power management capability controlled by the PC Card logic controller. Voltage rise and fall times are well controlled. Medium current V_{PP} and high current V_{CC} output switches are self-biasing: ***no +12V supply is required for 3.3V or 5V output.***

The MIC2565 employs the new industry standard two-wire bidirectional serial control bus. This SMBus™-based protocol allows full control of the power outputs and feeds slot power status back to the logic controller.

The MIC2565 is designed for efficient operation. In standby (sleep) mode the device draws very little quiescent current, typically 0.3µA. The device and PCMCIA port is protected by current limiting and overtemperature shutdown. Full cross-conduction lockout protects the system power supplies.

The MIC2565 is available in a 28-pin SSOP.

Applications

- Dual Slot PC Card Power Supply Pin Voltage Switch
- Dual CardBus Slot Power Supply Control
- Dual Zoom Video Port Power Supply Control
- Wireless Communications
- Bar Code Data Collection Systems
- Docking Stations (portable and desktop)
- Power Supply Management
- Power Analog Switching

Features

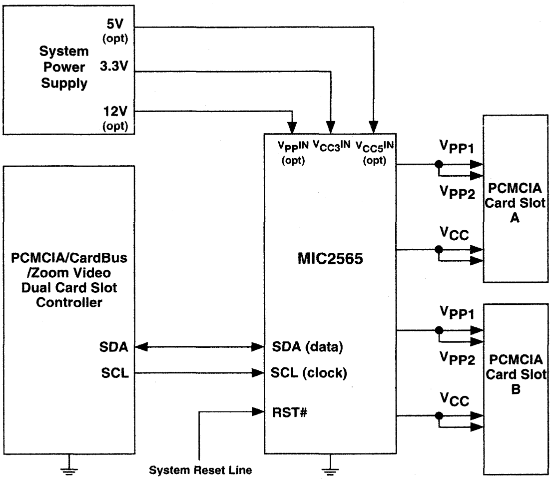
- Single Package Controls Two PC Card Slots
- High Efficiency, Low Resistance Switches Require No 12V Bias Supply
- Bidirectional Two-Wire Serial Control Bus Compatible with the New Industry Standard (SMBus)
- No External Components Required
- Output Current Limit and Overtemperature Shutdown
- Ultra Low Power Consumption
- Complete Dual Slot PC Card/CardBus V_{CC} and V_{PP} Switch Matrix in a Single Package
- No Voltage Shoot-Through or Switching Transients
- Break-Before-Make Switching
- Independent Selection of V_{CC} and V_{PP} Voltages
- Over 1A V_{CC} Output Current for Each Slot
- Over 250mA V_{PP} Output Current for Each Slot
- 28-Pin SSOP Package

Ordering Information

Part Number	Temperature Range	Package
MIC2565BSM	–40°C to +85°C	28-pin SSOP

SMBus is a trademark of Intel, Inc.

Typical Application



MIC5204

SCSI-II Active Terminator

Preliminary Information

General Description

The MIC5204 is an active terminator designed to comply with SCSI-II specifications. The MIC5204 is enabled by a CMOS or TTL compatible logic signal. When disabled, power consumption drops nearly to zero and the output goes into a high impedance state. Key MIC5204 features include protection against reversed battery, current limiting, and over-temperature shutdown.

Features

- ± 1% Output voltage accuracy
- Guaranteed 1A output
- Low quiescent current
- Low dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Current and thermal limiting
- Zero OFF mode current
- Logic-controlled electronic shutdown
- Available in SO-8 and SOT-223 packages

Applications

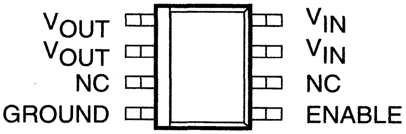
- SCSI–II Active Terminator
- Desktop, Laptop, Notebook, and Palmtop Computers
- Intelligent Instrumentation
- Printers
- Disk Drives
- Voltage Reference

Ordering Information

Part Number	Temperature Range*	Package
MIC5204BM	–40°C to +125°C	SO-8
MIC5204BS	–40°C to +125°C	SOT-223

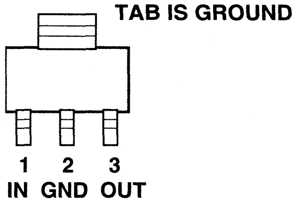
** Junction Temperature*

Pin Configuration



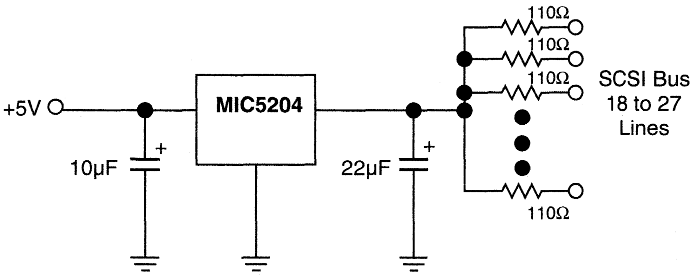
MIC5204BM

Both V_{IN} and both V_{OUT} pins must be tied together. ENABLE must be pulled high for operation.



MIC5204-xxBS

Typical Application



Absolute Maximum Ratings

Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its specified **Operating Ratings.**

Power Dissipation	Internally Limited
Lead Temperature (Soldering, 5 seconds)	260°C
Operating Junction Temperature Range	–40°C to +125°C
Input Supply Voltage	–20V to +20V
ENABLE Input Voltage	–0.3V to +20V
ESD Rating	> 2000V

Recommended Operating Conditions

Input Voltage	3V to 6V
Operating Junction Temperature Range	–40°C to +125°C
ENABLE Input Voltage	–0.3V to V_{CC}

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C and limits in **boldface** apply over the junction temperature range of –40°C to +125°C. Unless otherwise specified, $V_{IN} = V_{OUT} + 1V$, I_L = 1mA, C_L = 3.3µF, and $V_{ENABLE} \geq 2.0V$

Symbol	Parameter	Conditions	Min	Typical	Max	Units
V_O	Output Voltage Accuracy		2.8215 **2.793**		2.8785 **2.907**	V
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temperature Coef.	(Note 2)		**20**	**100**	ppm/°C
$\frac{\Delta V_O}{V_{IN}}$	Line Regulation	$V_{IN} = V_{OUT}$ + 1 V to 6V		0.004	0.10 **0.40**	%
$\frac{\Delta V_O}{I_L}$	Load Regulation	I_L = 0.1mA to 100mA (Note 3)		0.04	0.16 **0.30**	%
$V_{IN} - V_O$	Dropout Voltage (Note 4)	I_L = 100µA		30 **75**		mV
		I_L = 50mA		190 **240**		
		I_L = 100mA		210 **350**		
		I_L = 750mA		600 **1000**		
		I_L = 1000mA		750 **1200**		
I_Q	Quiescent Current	$V_{ENABLE} \leq 0.7V$ (Shutdown)		0.01		µA
I_{GND}	Ground Pin Current	$V_{ENABLE} \geq 2.0V$, I_L = 100µA		130		µA
		I_L = 20mA		240		
		I_L = 30mA		300		
		I_L = 50mA		450		
		I_L = 100mA		900		
PSRR	Ripple Rejection			70		dB
I_{GNDDO}	Ground Pin Current at Dropout	V_{IN} = 0.5V less than designed V_{OUT} I_L = 100µA (Note 5)		270	**330**	µA
I_{LIMIT}	Current Limit	V_{OUT} = 0V		**1.5**		A
$\frac{\Delta V_O}{\Delta P_D}$	Thermal Regulation	(Note 6)		0.05		%/W
e_n	Output Noise			30		µV

ENABLE Input

V_{IL}	Input Voltage Level					
	Logic Low	OFF			**0.7**	V
	Logic High	ON	**2.0**			
I_{IL}	ENABLE Input Current	$V_{IL} \leq 0.7V$		0.01		µA
I_{IH}		$V_{IH} \geq 2.0V$		15	**50**	

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions. The maximum allowable power dissipation is a function of the maximum junction temperature, $T_{J\,(MAX)}$, the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using: $P_{(MAX)} = (T_{J(MAX)} - T_A)\ \theta_{JA}$. Exceeding the maximum allowable power dissipation will result in excessive die temperature, and the regulator will go into thermal shutdown. The θ_{JC} of the MIC5204BS is 15°C/W and θ_{JA} for the MIC5204BM is 160°C/W mounted on a PC board (see "Thermal Considerations" section for further details).

Note 2: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

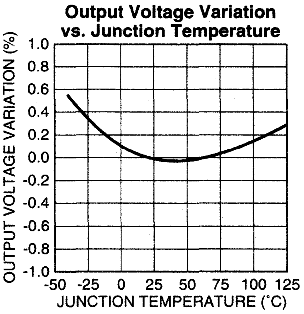
Note 3: Regulation is measured at constant junction temperature using low duty cycle pulse testing. Parts are tested for load regulation in the load range from 0.1mA to 100mA. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

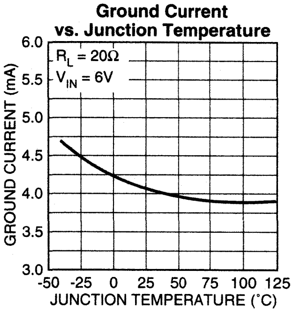
Note 4: Dropout Voltage is defined as the input to output differential at which the output voltage drops 2% below its nominal value measured at 1V differential.

Note 5: Ground pin current is the regulator quiescent current plus pass transistor base current. The total current drawn from the supply is the sum of the load current plus the ground pin current.

Note 6: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 1A load pulse at V_{IN} = 6V for T = 10ms.

Typical Characteristics





Applications Information

External Capacitors

A 2.2µF capacitor is recommended between the MIC5204 output and ground to prevent oscillations due to instability. Larger values serve to improve the regulator's transient response. Most types of tantalum or aluminum electrolytics will be adequate; film types will work. Many aluminum electrolytics have electrolytes that freeze at about –30°C, so solid tantalums are recommended for operation below –25°C. The important parameters of the capacitor are an effective series resistance of about 5Ω or less and a resonant frequency above 500kHz. The value of this capacitor may be increased without limit.

A 1µF capacitor should be placed from the MIC5204 input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the input.

The MIC5204 will remain stable and in regulation with no load in addition to the internal voltage divider.

Thermal Considerations

Part I. Layout

The MIC5204BM (8-pin surface mount package) has the following thermal characteristics when mounted on a single layer copper-clad printed circuit board.

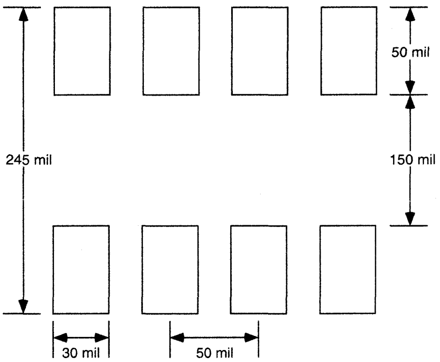
PC Board Dielectric	θ_{JA}
FR4	160°C/W
Ceramic	120°C/W

Multi-layer boards having a ground plane, wide traces near the pads, and large supply bus lines provide better thermal conductivity. The "worst case" value of 160°C/W assumes no ground plane, minimum trace widths, and a FR4 material board.

Part II. Nominal Power Dissipation and Die Temperature

The MIC5204BM at a 25°C ambient temperature will operate reliably at up to 625mW power dissipation when mounted in the "worst case" manner described above. At an ambient temperature of 55°C, the device may safely dissipate 440mW. These power levels are equivalent to a die temperature of 125°C, the recommended maximum temperature for non-military grade silicon integrated circuits. In normal SCSI terminator applications, the average power dissipation is very small and this minimum geometry heat sink is suitable. The total dissipation does not approact the 400mW to 625mW range described above.

For MIC5204BS (SOT-223 package) heat sink characteristics, please refer to Micrel Application Hint 17, "P.C. Board Heat Sinking". As with the SO-8, average power dissipation in SCSI terminator applications is low and a minimum pad size is generally adequate.



Minimum recommended board pad size, SO-8.

Application Note 8

Interfacing the MIC2557/8 to PCMCIA Controllers

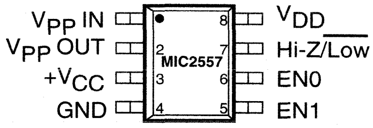
by Bob Wolbert

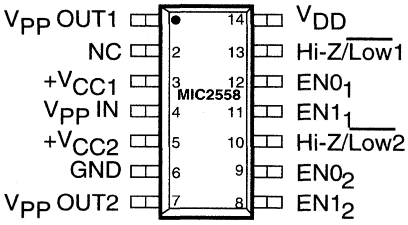
General Description

The MIC2557 and MIC2558 provide "Programming and Peripheral" voltage (V_{PP}) switching for PCMCIA card sockets. They have simple logic compatible inputs and easily interface with industry standard PCMCIA controllers. This note gives circuit examples for several PCMCIA controllers. For controllers supporting dual V_{CC} (3.3V and 5.0V), two simple high current V_{CC} switch matrices are shown.

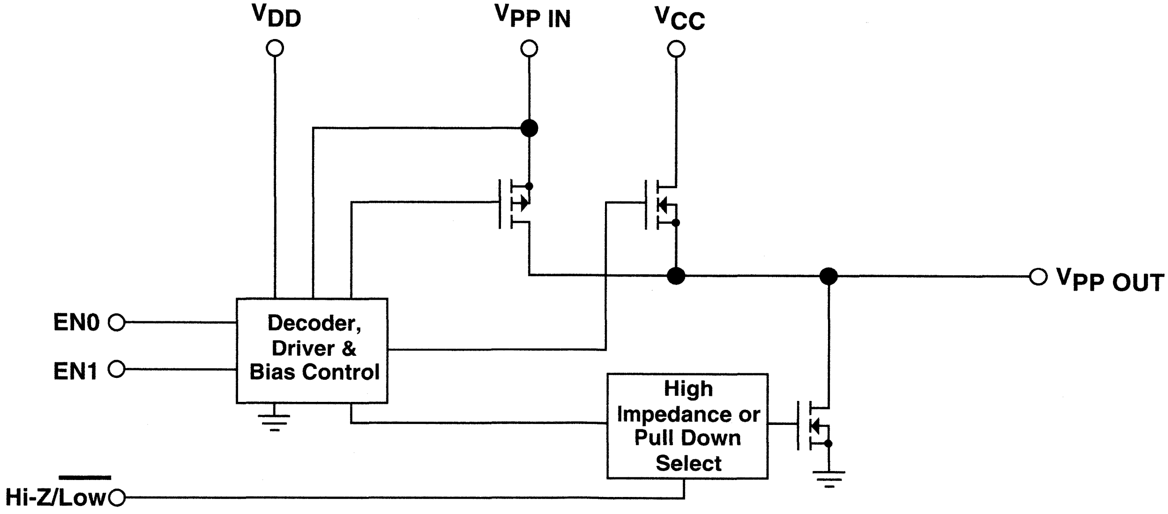
PCMCIA
PC Card
MEMBER COMPANY

Pin Configuration





MIC2557 (½ MIC2558) Block Diagram



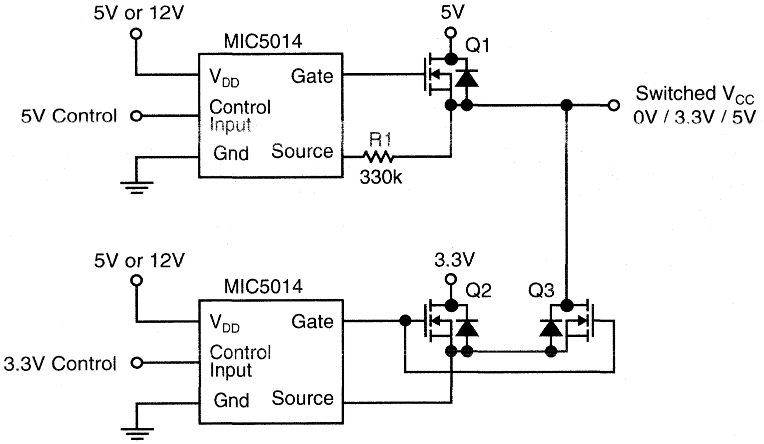


Figure 1. PCMCIA Compatible Dual V_{CC} Switch Matrix. This circuit uses power MOSFETs driven by two MIC5014 high side MOSFET drivers to select between 3.3V and 5V V_{CC}. MOSFET "body diodes" are shown for information.

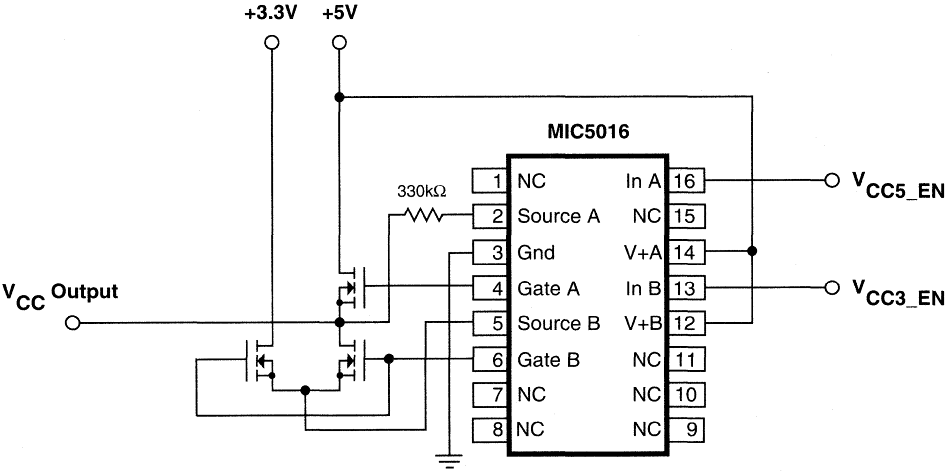


Figure 2. PCMCIA Compatible Dual V_{CC} Switch Matrix. This circuit uses power MOSFETs driven by a single MIC5016 high side MOSFET drivers to select between 3.3V and 5V V_{CC}.

V_{CC} Switching

Figures 1 and 2 show the MIC5014 and MIC5016 high side power MOSFET drivers configured as a V_{CC} select matrix. Both circuits operate identically; the MIC5016 is a dual MIC5014. For convenience, we will discuss the circuit operation referring to Figure 1. Initially, both MOSFET drivers are OFF and the MOSFET gates are clamped low, placing the V_{CC} output in the high impedance condition. A TTL High level on V_{CC5_EN} enables Q1, and 5V appears on $V_{CC\ OUT}$. Likewise, when V_{CC3_EN} is High, Q2 and Q3 are ON and 3.3V appears on the output. V_{CC5_EN} and V_{CC3_EN} are mutually exclusive: circuit damage might occur if both switches are commanded ON simultaneously.

The inherent "body diode" of the power MOSFET, shown in Figure 1, creates circuit problems that are dealt with by adding another MOSFET, Q3, connected in the reverse direction. Without Q3, whenever the 5V supply is enabled, current would flow from $V_{CC\,OUT}$ through the body diode of Q2 into the 3.3V supply, thereby contaminating the low voltage supply. Q3's reverse direction connects its body diode anode to anode with Q2 and eliminates reverse current. When V_{CC3_EN} is High and the MIC5014 enhances the MOSFET gates, both Q2 and Q3 are ON, and 3.3V appears on $V_{CC\ OUT}$. The enhanced channel shorts out the body diodes, so no diode forward voltage drop is evident. The ON resistance of Q3 is slightly higher in its reverse direction than in normal operation, but with reasonably sized MOSFETs, the voltage drop is small. Although a Schottky diode would provide the required protection, its forward voltage drop is much too large and would prevent the 3.3V switch from meeting its ±5% accuracy requirement.

Cirrus Logic CL-PD6710

The Cirrus Logic CL-PD6710 provides support for a single PCMCIA socket. Key features include full support for dual V_{CC} voltages (3.3V and 5.0V). The CL-PD6710 assumes V_{PP1} is tied to V_{PP2}. The MIC2557, in a small 8-pin surface mount package, provides V_{PP} power control for this single socket. V_{CC} switching is accomplished using the circuit of (either) Figure 1 or Figure 2. Note that no additional components are required, although filter capacitors are recommended for best performance.

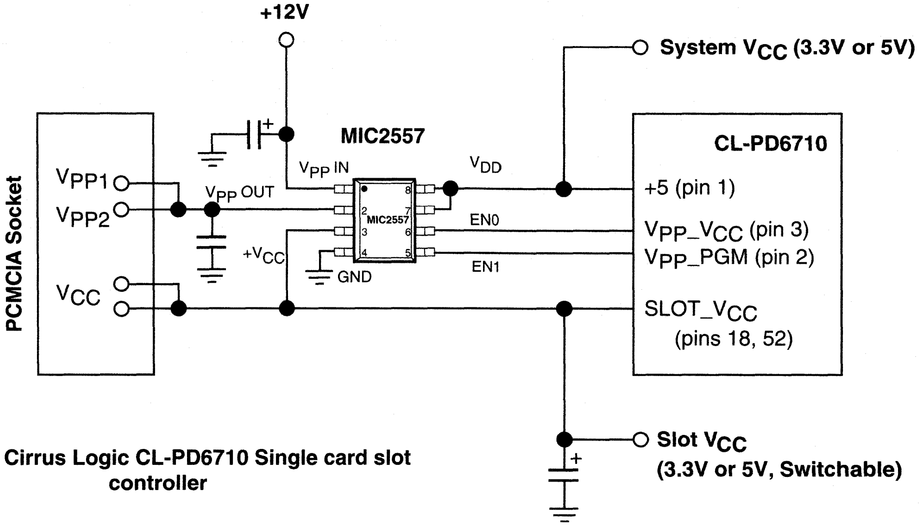


Figure 3. Cirrus Logic CL-PD6710 Single card slot controller

CL-PD6710 & CL-PD6720 Control Logic

V_{CC5_EN}	V_{CC3_EN}	V_{PP_PGM} (EN1)	V_{PP_VCC} (EN0)	V_{CC} OUT	V_{PP} OUT
0	0	0	0	High Z	Clamped to Ground
0	0	0	1	High Z	High Z
0	0	1	0	High Z	High Z
0	0	1	1	High Z	High Z
0	1	0	0	5	Clamped to Ground
0	1	0	1	5	5
0	1	1	0	5	12
0	1	1	1	5	High Z
1	0	0	0	3.3	Clamped to Ground
1	0	0	1	3.3	3.3
1	0	1	0	3.3	12
1	0	1	1	3.3	High Z
1	1	0	0	High Z	Clamped to Ground
1	1	0	1	High Z	High Z
1	1	1	0	High Z	High Z
1	1	1	1	High Z	High Z

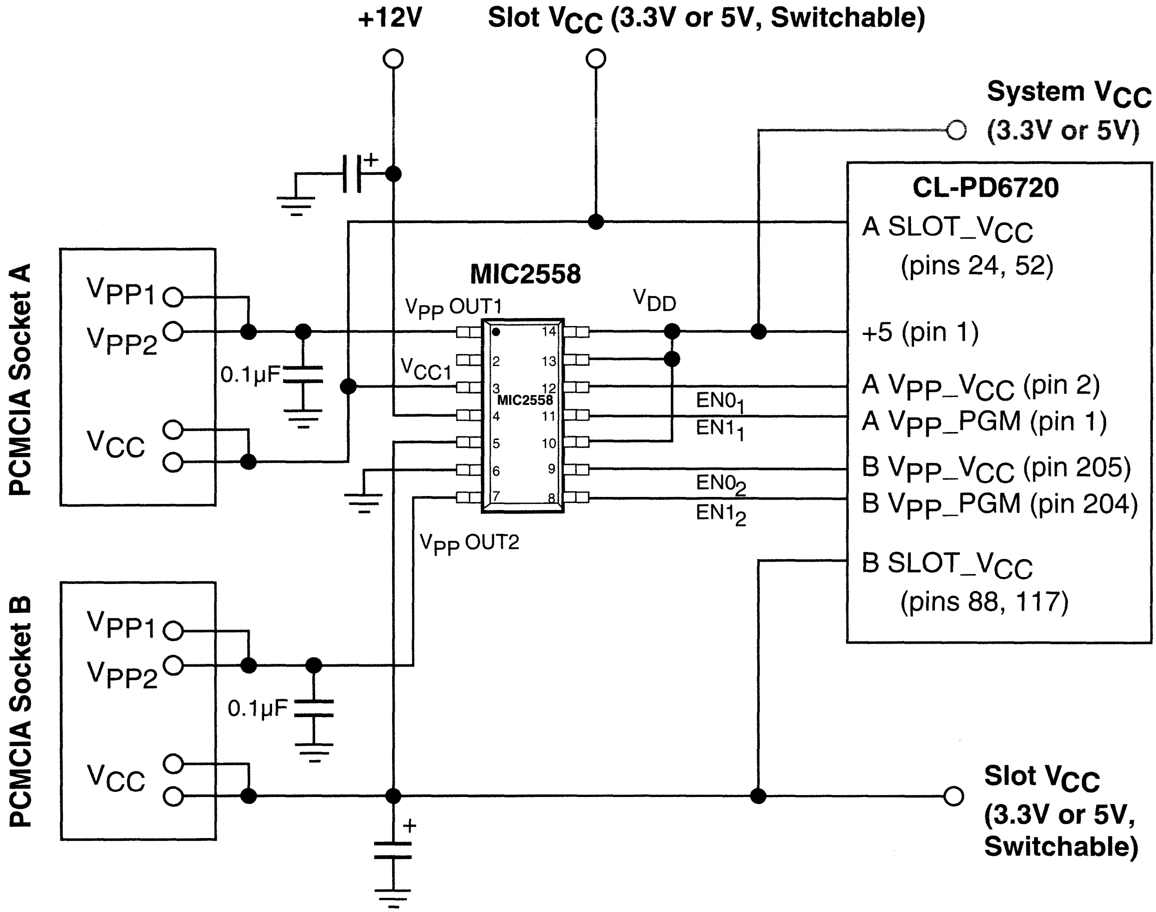
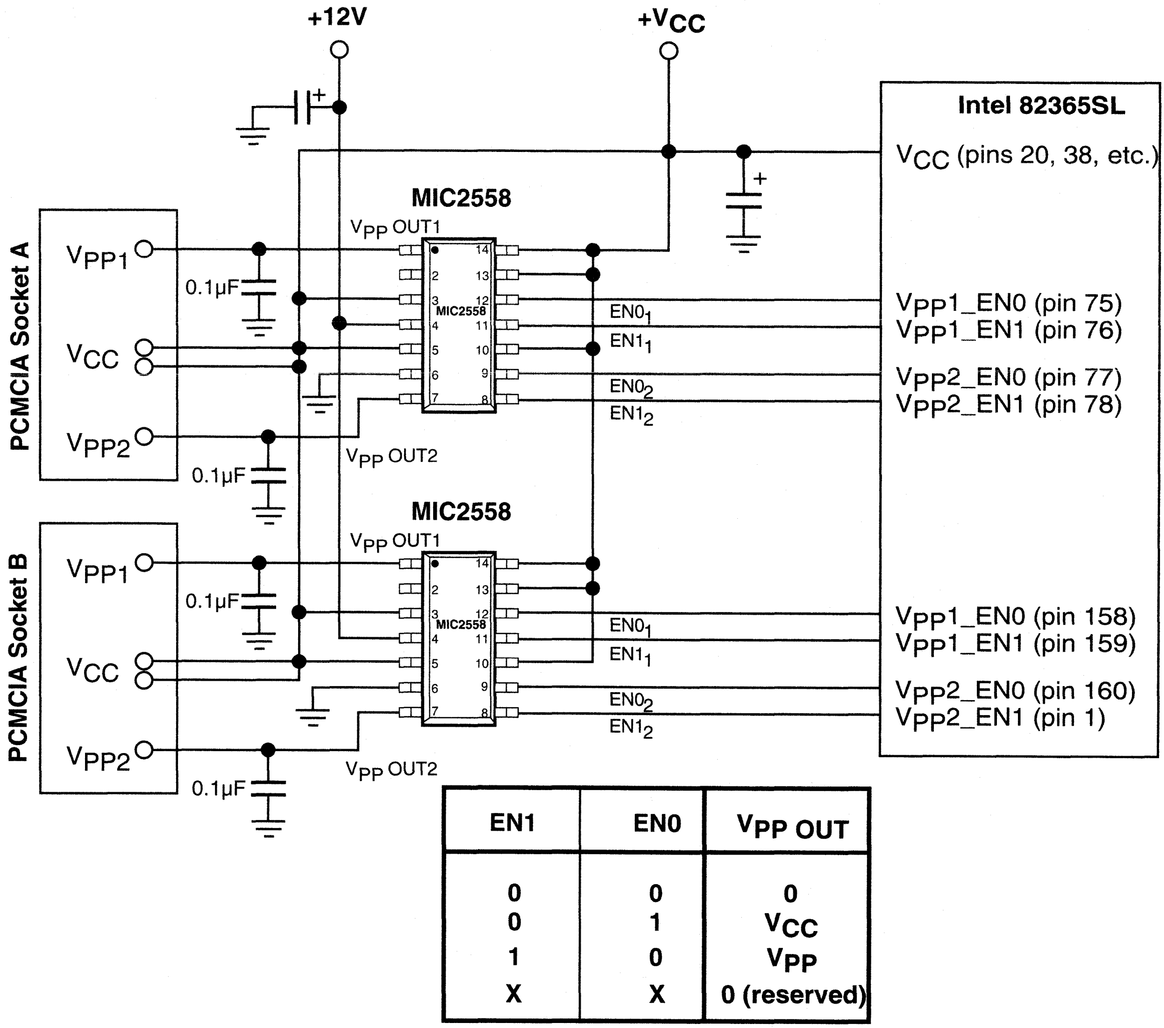


Figure 4. Cirrus Logic CL-PD6720 dual slot PCMCIA controller

Cirrus Logic CL-PD6720

As shown in Figure 4, the Cirrus Logic CL-PD6720 provides support for two PCMCIA sockets. Key features include full support for dual V_{CC} voltages. The CL-PD6720 assumes V_{PP1} is tied directly to V_{PP2}. The MIC2558, in a small 14-pin surface mount package, provides all necessary V_{PP} power control for both sockets. V_{CC} switching is accomplished using the circuit of (either) Figure 1 or Figure 2. No additional components are necessary, but filter capacitors are recommended for best performance.

A complete dual slot PCMCIA power control subsystem using this controller appears as Figure 8.



EN1	EN0	V_{PP} OUT
0	0	0
0	1	V_{CC}
1	0	V_{PP}
X	X	0 (reserved)

Figure 5. Intel 82365SL "PC Card Interface Controller (PCIC)" implementation

Intel 82365SL

The Intel 82365SL supports fully independent V_{PP1} and V_{PP2} for two PCMCIA slots. Two MIC2558 allow the necessary voltage combinations for all four V_{PP} pins. No additional components are necessary, although filter capacitors are recommended for best performance. The Intel 82365SL does not support dual V_{CC} selection, so no other power control is required. V_{CC} ON/OFF is supported, and may be implemented by a simple V_{CC} switch consisting of a MIC5014 and a single power MOSFET (per slot). Refer to Figure 6 for details on this ON/OFF V_{CC} switch.

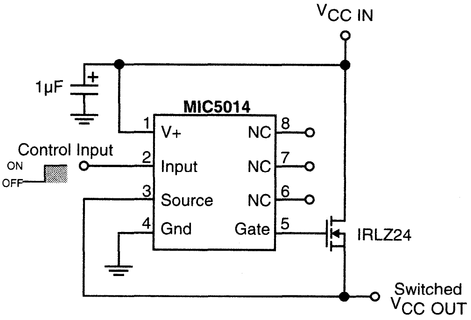


Figure 6. V_{CC} ON/OFF Switch for use with the Intel 82365SL.

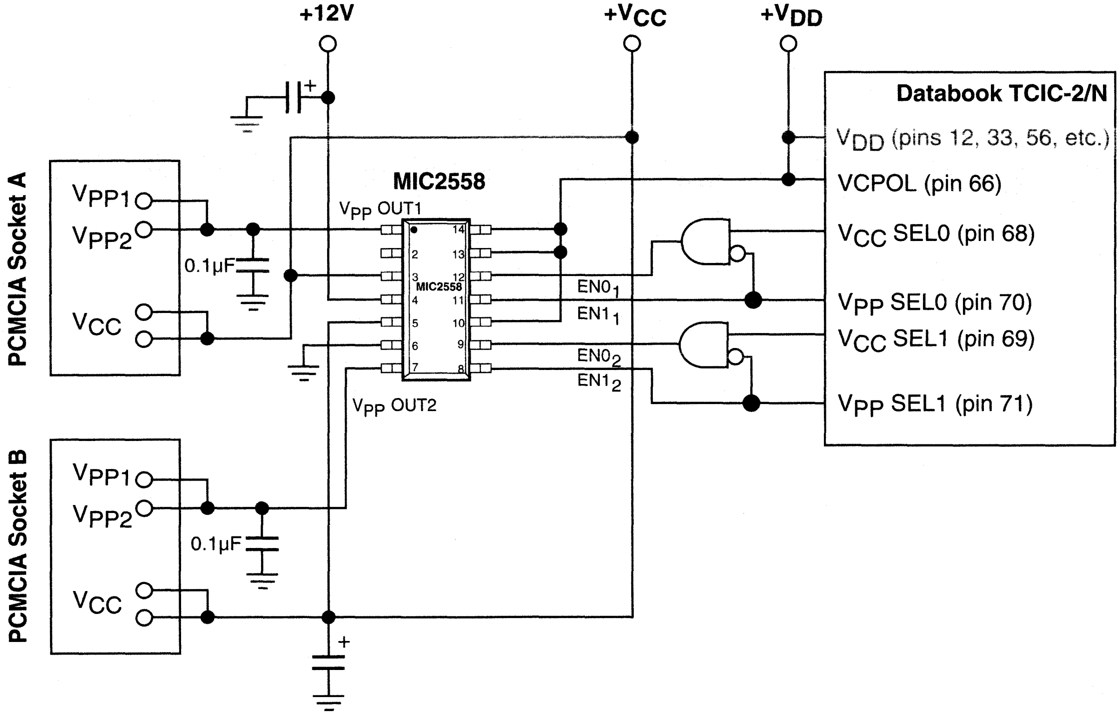


Figure 7. Databook TCIC-2/N family PCMCIA controller interfacing with the MIC2558.

V_{PP} SEL	V_{CC} SEL	EN1	EN0	V_{PP} OUT
0	0	0	0	0
0	1	0	1	V_{CC}
1	1	1	0	V_{PP}
1	0	X	X	0 (illegal)

Databook TCIC-2/N Control Logic

Databook TCIC-2/N Family

The Databook TCIC-2/N family of PCMCIA controllers has V_{PP} and V_{CC} voltage enable signals a bit different than provided by the other controllers. A logic gate is necessary to complete the interface between the TCIC-2/N and the MIC2558. The TCIC-2/N has a pin, VCPOL, which controls the polarity of the output enable signals. When VCPOL is tied to V_{DD}, the control signals are active high, and with VCPOL low, the control outputs are active low. The configuration shown uses the active high option.

Complete PCMCIA Power Control Circuitry Using MIC2558 and Cirrus Logic CL-PD6720

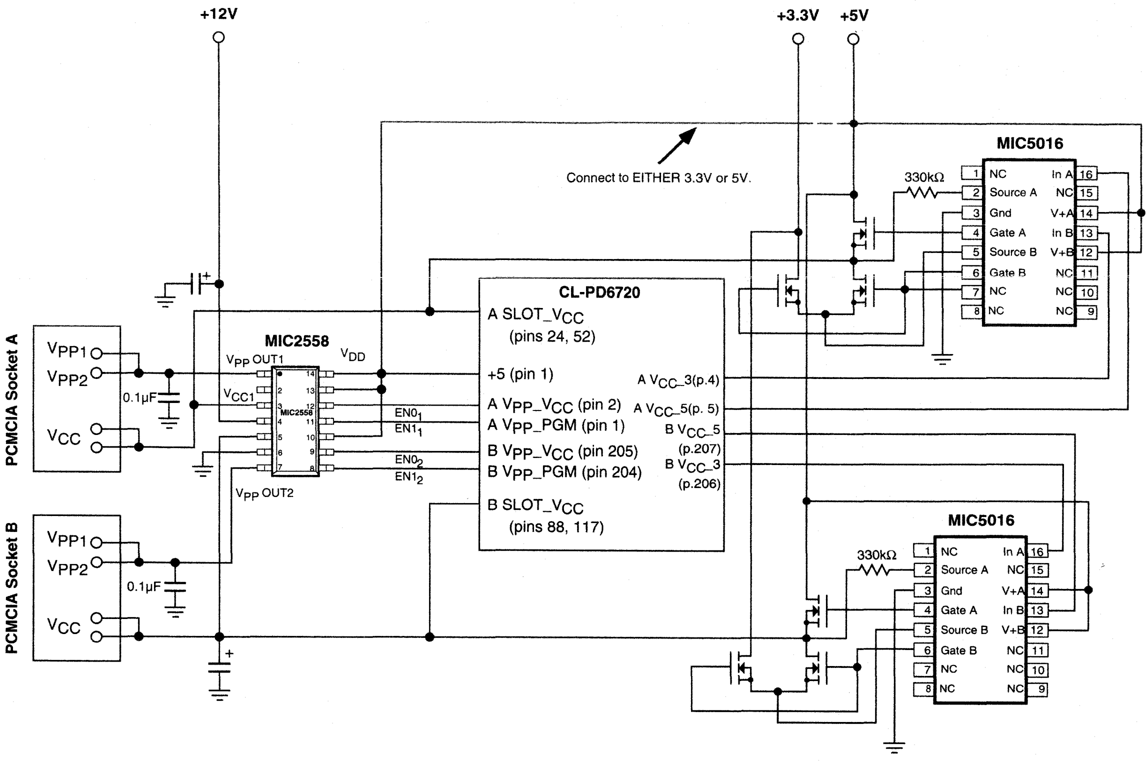


Figure 8. Complete dual slot PCMCIA power control system using MIC2558 and Cirrus Logic CL-PD6720

Figure 7 shows a complete dual slot PCMCIA power control implementation for dual V_{CC} systems. CL-PD6720 pin 1 ("+5V") is connected to 5V if available, and to 3.3V if the logic lines are powered from this voltage. This pin, and the MIC2558 V_{DD} pin (pin 14) set up reference levels for the logic input pins (and output pins on the CL-PD6720).

As of the time of this writing, the PCMCIA field is quite dynamic. Please contact Micrel for the latest information on PCMCIA controller compatibility and new Micrel devices designed for this application.

Application Note 11

Interfacing PC Card Power Controllers to Logic Controllers

General Description

This application note describes the interface connections between Micrel PCMCIA Power Controllers and industry standard logic controllers from Cirrus Logic, Data Book, Intel, and Vadem. Combining one or two Micrel PC Card Power Controller s and one of these controllers produces a complete PCMCIA-compatible PC Card slot. In most cases, no other components are necessary.

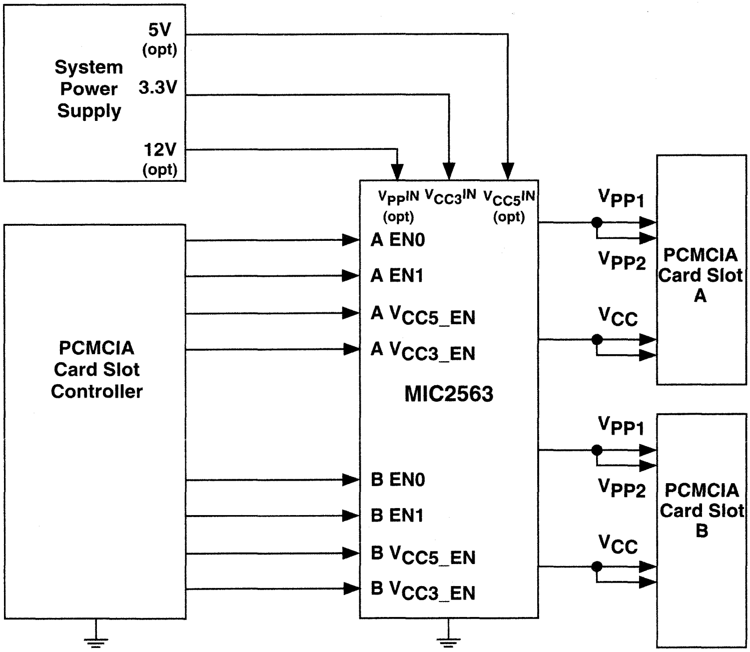
This note concentrates on the power control subsystem only. For full details on designing-with and operating the PC Card logic controllers, please refer to the respective manufacturer's literature. For detailed specifications and additional information on the MIC2560, MIC2561, MIC2562, and MIC2563 please see their datasheets earlier in this section.

Overview

The MIC2560 is a fully-protected PC Card Power Controller that meets all PCMCIA specifications. It provides full control of both V_{CC} and V_{PP} for one PC Card slot. It features industry-leading ON resistances and is available in different control logic configurations for "glueless" compatibility with the major industry-standard PC Card logic controllers.

The MIC2561 is also a fully protected card slot controller, similar to the MIC2560, but has higher ON resistances, enabling its use in price-sensitive applications. It is available in the same MIC2560 pinout as well as in a smaller package that is less than half the size of the MIC2560.

The MIC2562 is a new design, providing full functionality from a 3.3V supply. The new MIC2563 is a dual version of the MIC2562 in a SSOP package.



This note details the connections between the PCMCIA slot logic controller and Micrel PC Card Power Controllers.

Cirrus Logic Controllers

PC Card logic controllers from Cirrus Logic are compatible with Micrel's "–1" option of PC Card power controllers. Tables 1, 2, and 3 show pin connections between three popular Cirrus Logic controllers and the MIC2560-1 and MIC2561-1.

Figure 1 is a schematic of a typical two slot PC Card implementation using the CL-PD6720 and the MIC2560-1.

CL-PD6710		MIC2560-1BWM MIC2561-1BWM		MIC2561-1BM MIC2562-1BM
Pin Name	**Pin #**	**Pin Name**	**Pin #**	**Pin #**
VCC_5	6	V_{CC5_EN}	5	1
VCC_3	5	V_{CC3_EN}	6	2
VPP_VCC	3	V_{PP_VCC}	7	3
VPP_PGM	2	V_{PP_PGM}	8	4

Table 1. CL-PD6710 single slot controller and MIC2560-1/MIC2561-1 pin equivalencies.

CL-PD6720			MIC2560-1BWM MIC2561-1BWM		MIC2561-1BM MIC2562-1BM	MIC2563-1BSM	
Pin Name	**Pin #**		**Pin Name**	**Pin #**	**Pin #**	**Pin #**	
	Slot A	**Slot B**				**Slot A**	**Slot B**
VCC_5	5	207	V_{CC5_EN}	5	1	5	19
VCC_3	4	206	V_{CC3_EN}	6	2	6	20
VPP_VCC	2	205	V_{PP_VCC}	7	3	7	21
VPP_PGM	1	204	V_{PP_PGM}	8	4	8	22

Table 2. CL-PD6720 dual slot controller and MIC2560-1/MIC2561-1 pin equivalencies.

CL-PD6729			MIC2560-1BWM MIC2561-1BWM		MIC2561-1BM MIC2562-1BM	MIC2563-1BSM	
Pin Name	**Pin #**		**Pin Name**	**Pin #**	**Pin #**	**Pin #**	
	Slot A	**Slot B**				**Slot A**	**Slot B**
VCC_5	130	138	V_{CC5_EN}	5	1	5	19
VCC_3	129	136	V_{CC3_EN}	6	2	6	20
VPP_VCC	128	135	V_{PP_VCC}	7	3	7	21
VPP_PGM	127	134	V_{PP_PGM}	8	4	8	22

Table 3. CL-PD6729 dual slot controller and MIC2560-1/MIC2561-1 pin equivalencies.

Cirrus Logic CL-PD6720 Application Circuit

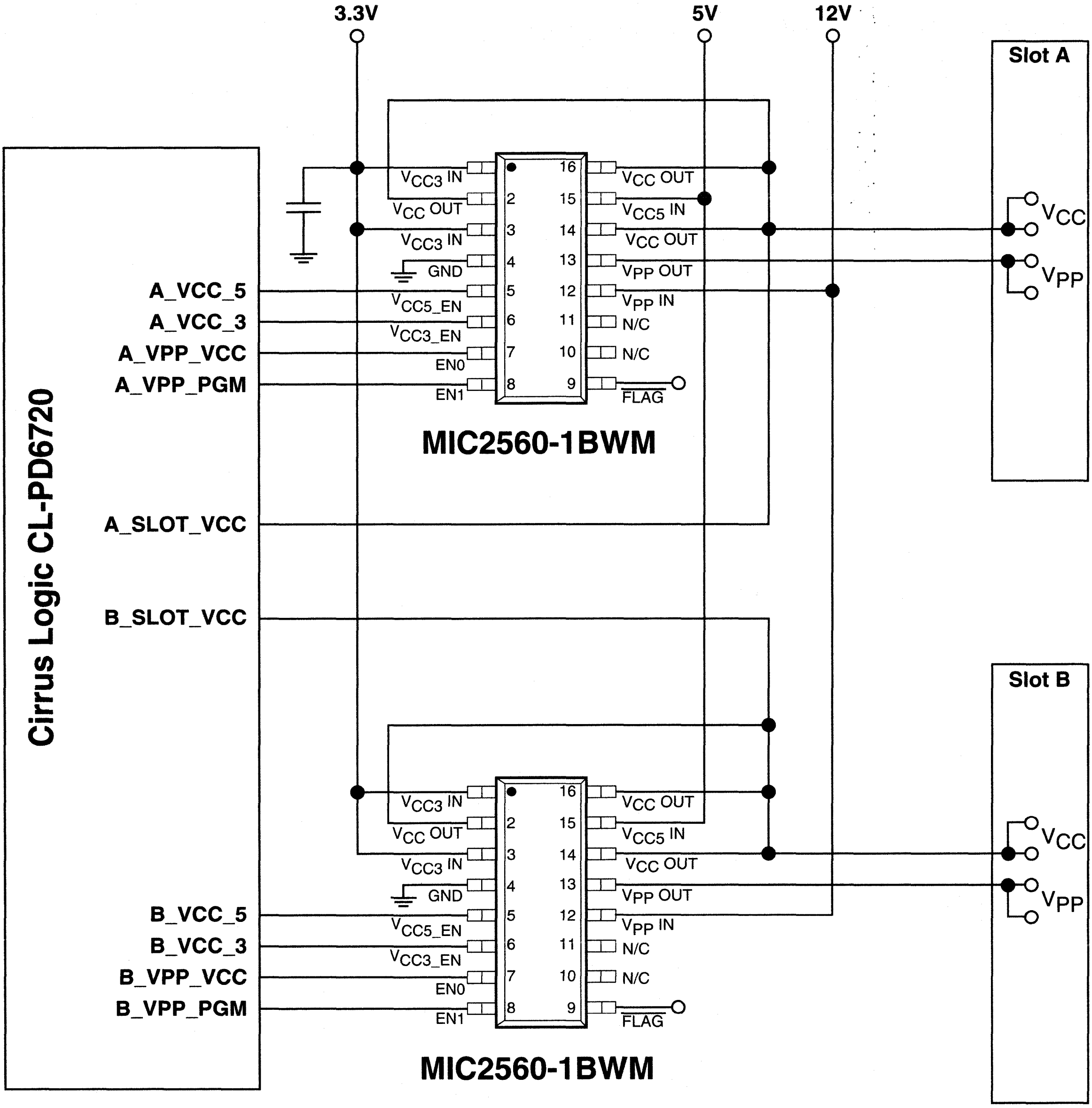


Figure 1. A typical two slot PC Card (PCMCIA) implementation using the Cirrus Logic CL-PD6720 and two MIC2560-1. The lower cost MIC2561-1BWM may be directly substituted for the MIC2560-1 in this circuit. The MIC2561-1BM will also work: refer to Table 2 for pin connection changes.

Data Book Controllers

Micrel's option "–2" PC Card power controllers are designed to interface with Data Book logic controllers. The Data Book devices have individually programmable power supply control pin polarity, which is determined at power-up. Resistors are used to force positive polarity for proper interfacing with the MIC2560-2. Refer to the control logic shown in Table 4 for details. When V_{CC} is deselected (OFF), a MIC2560-2 internal clamp actively pulls-down the output, insuring zero volts on the socket. This clamp has an ON resistance of approximately 1.2kΩ. The Databook DB86184 PCMCIA controller requires 100kΩ pull-down resistors from VCCSEL0, VCCSEL1, VPPSEL0, and VPPSEL1 to ground and 100kΩ pull-up resistors from VCCSEL2 and VCCSEL3 to +3.3V (or +5V). MIC2560-2 pin 8 should be connected to ground.

While not required, a 0.1µF capacitor from V_{CC3} IN to ground provides decoupling for the current sense amplifier.

Pin 5 V_{CCSEL1}	Pin 6 V_{CCSEL2}	Pin 7 V_{PPSEL}	Pins 2 & 14 $V_{CC\ OUT}$	Pin 13 $V_{PP\ OUT}$
0	1	0	Clamped to Ground	Clamped to Ground
1	1	0	3.3V	3.3V
0	0	0	3.3V	12V
1	0	0	3.3V	Clamped to Ground
0	1	1	Clamped to Ground	Clamped to Ground
1	1	1	5V	5V
0	0	1	5V	12V
1	0	1	5V	Clamped to Ground

Table 4. MIC2560-2 Logic

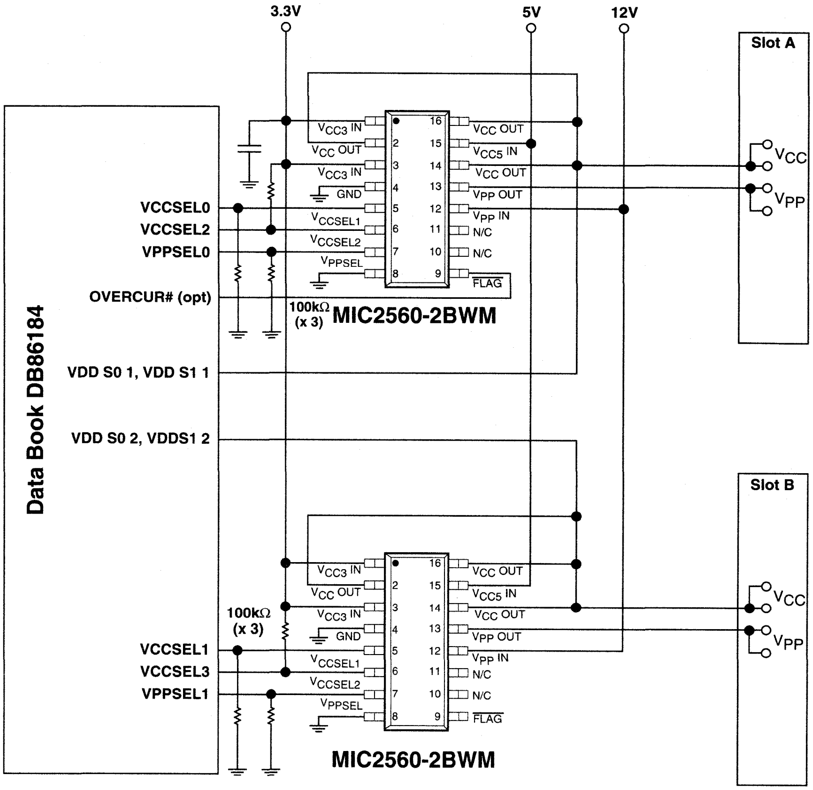


Figure 2. The Data Book DB86184 and two MIC2560-2BWM in a typical two slot application.

Intel Controllers

Intel PC Card logic controllers generally interface with the option "–0", MIC2560-0 and MIC2561-0. The older Intel 82365 supports two V_{PP} pins per slot, but only one V_{CC} level (5V). Use the MIC2558 PCMCIA Dual Card Slot V_{PP} Switching Matrix to control the additional V_{PP} for each socket. Since the MIC2558 has separate V_{CC} inputs, full independence between V_{PP2} of slot A and V_{PP2} of slot B is maintained. Since only 5V is available for V_{CC} OUT, connect all MIC2560/MIC2561 V_{CC} inputs together. These inputs, including both $V_{CC3\ IN}$ pins, are rated to 6V, so no damage will occur. Take advantage of the lower ON resistance of the 3.3V V_{CC} switch by using the V_{CC3_EN} control as the V_{CC} enable. Figure 3 shows this configuration.

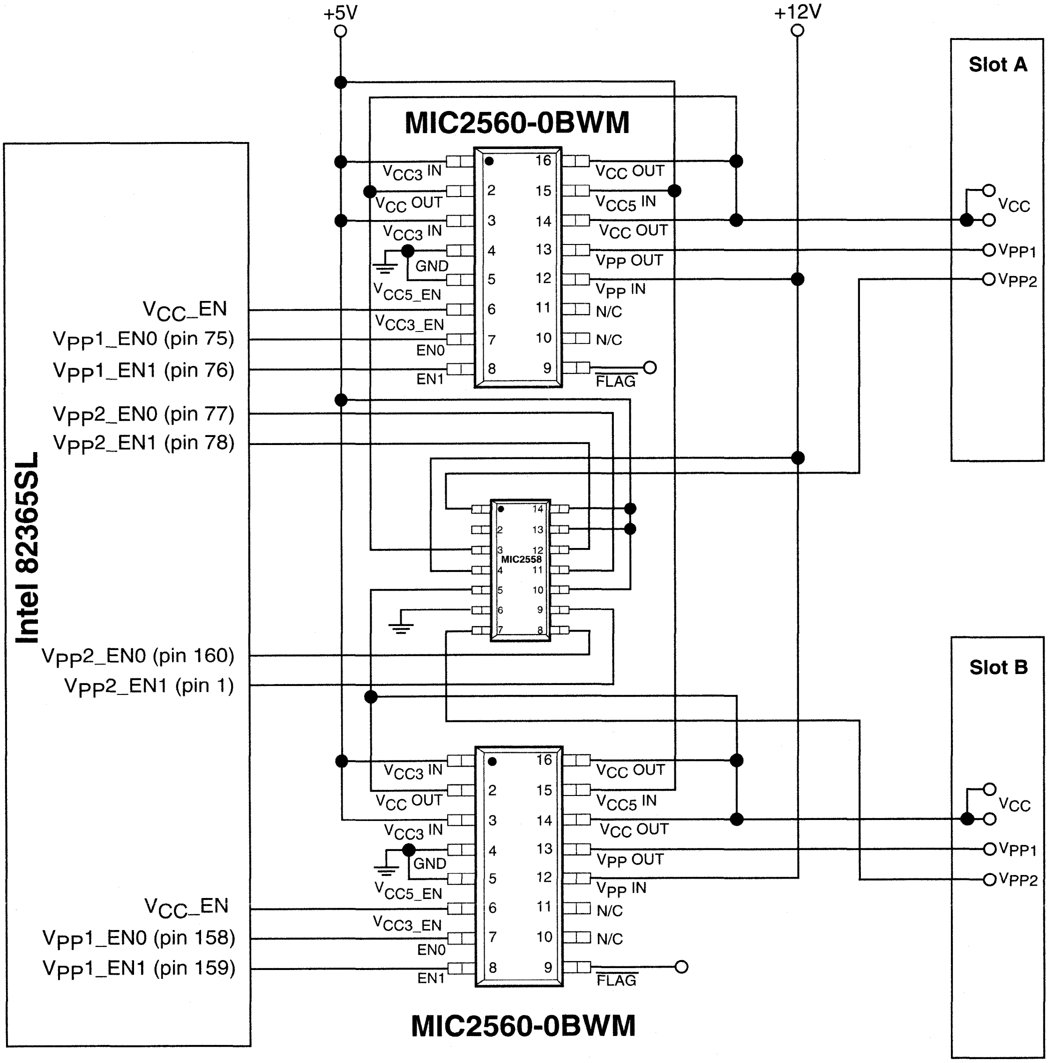


Figure 3. A two slot configuration using the Intel 82365 controller and the MIC2560-0. Note that this Intel controller does not support 3.3V supplies: for best results, connect the +5V supply to all V_{CC} pins (both V_{CC3} IN pins and the V_{CC5} IN pin.

Interfacing with the Intel PPEC PCI to PCMCIA logic controller

The Intel PPEC (PCI to PCMCIA Enhanced IDE Controller) is a dual slot, dual V_{CC} controller that does not provide latched data outputs for power control. Thus, an external latch is required. This latch is easily implemented using a 74273 or equivalent Octal D Flip-Flop. One octal latch supplies two slots (two MIC2560-0 or MIC2561-0). Figure 4 and Table 5 illustrate this system.

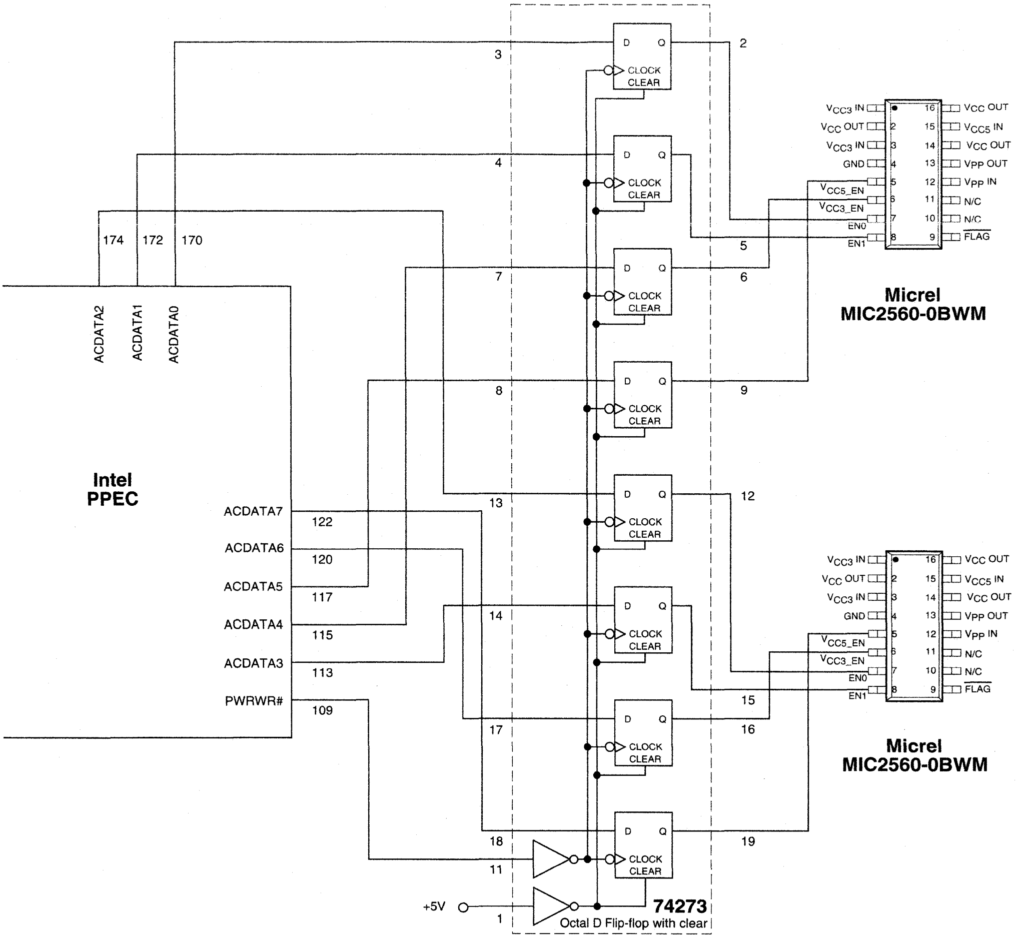


Figure 4. A dual slot system using the Intel PPEC controller and the MIC2560-0/MIC2561-0.

Table 5. Power control signals for Figure 4.

Intel PPEC			74273		MIC2560-0	
Power Signal	Pin Name	Pin #	Pin # In	Pin # Out	Pin Name	Pin #
A-EN0	ACDATA0	170	3	2	EN0	7
A-EN1	ACDATA1	172	4	5	EN1	8
A-VCC3V	ACDATA4	115	7	6	V_{CC3_EN}	6
A-VCC5V	ACDATA5	117	8	9	V_{CC5_EN}	5
B-EN0	ACDATA2	174	13	12	EN0	7
B-EN1	ACDATA3	113	14	15	EN1	8
B-VCC3V	ACDATA6	120	17	16	V_{CC3_EN}	6
B-VCC5V	ACDATA7	122	18	19	V_{CC5_EN}	5

Omega Micro Controllers

The MIC2560, MIC2561, MIC2562, and MIC2563 are compatible with Omega Micro logic controllers, including the 82C722GX ISA to PCMCIA (use the "–1" option, shown in Figure 5) and the 82C094 PCI to PCMCIA (use the "–0" option, shown in Figure 6) controllers. Both controllers support dual V_{CC} voltages to dual slots. The 82C094 offers a serial control output: the Omega Micro 82C28 converts this serial output into the latched parallel control required by Micrel MIC256x-0 Power Controllers.

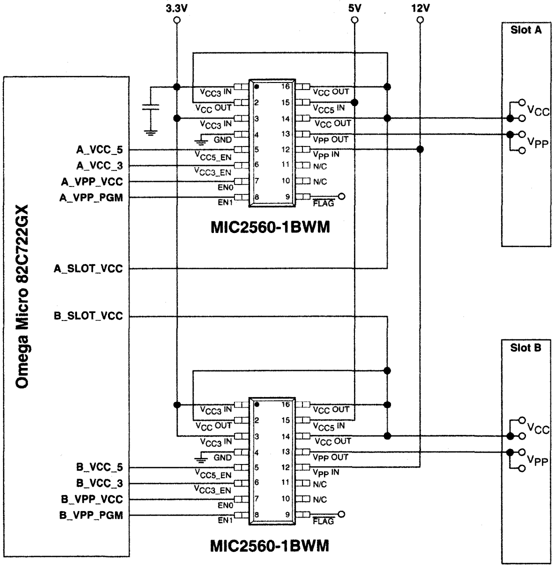
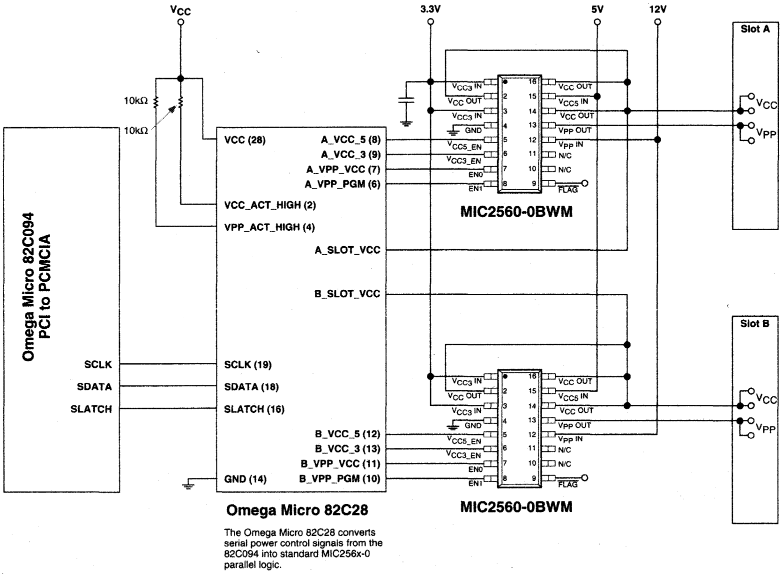


Figure 5. The Omega Micro 82C722GX and two MIC256x-1 (or one MIC2563-1) adapt the ISA bus to two PCMCIA sockets.



The Omega Micro 82C28 converts serial power control signals from the 82C094 into standard MIC256x-0 parallel logic.

Figure 6. The Omega Micro 82C094 and two MIC256x-0 (or one MIC2563-0) adapt the PCI bus to PCMCIA. An Omega Micro 82C28 converts serial output from the 82C094 to the parallel control needed by the MIC256x-0.

Opti Controllers

The Opti 82C852 is logic compatible with Micrel "–1" option logic power controllers. Figure 7 shows a typical single-slot PC Card implementation using the Opti 82C852 and the MIC2560-1 power controller. The MIC2561-1 and MIC2562-1 are also directly compatible with the 82C852.

Figure 8 shows the Opti 82C824 dual-slot logic controller interfacing with the MIC2563A-1. Two MIC2560-1, MIC2561-1, or two MIC2562A-1 power controllers are also compatible with the 82C824.

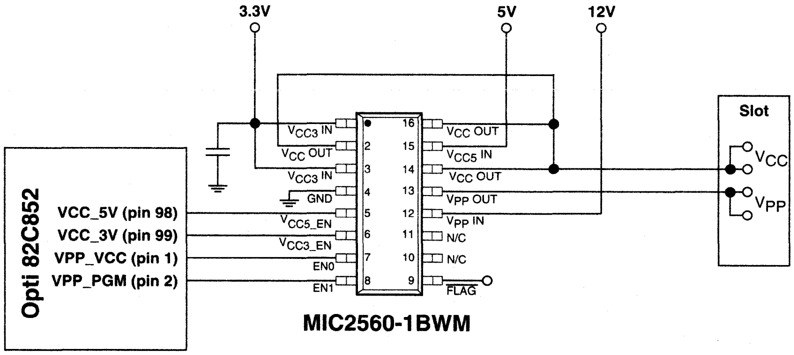


Figure 7. The Opti 82C852 is a single slot PC Card logic controller that directly interfaces with Micrel MIC2560-1, MIC2561-1, or MIC2562-1 power controllers.

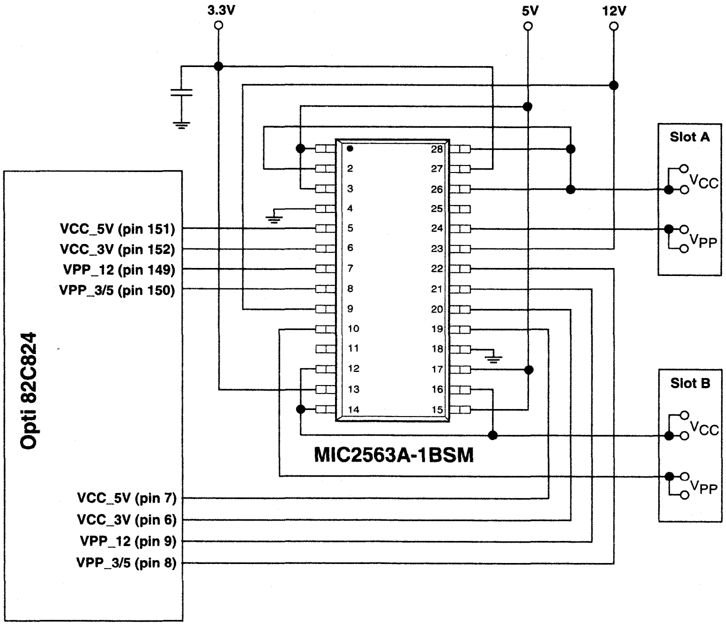


Figure 8. The Opti 82C824 dual slot CardBus controller/docking station that works with the MIC2563 forming a two-IC solution for two PC Card slots.

Vadem Controllers

The MIC2560-0, MIC2561-0, MIC2562-0, and MIC2563-0 are compatible with Vadem logic controllers, including the VG-365, VG-465, VG-468, and VG-469. The VG-365, VG-465, and VG-468 are straight forward implementations; the VG-469 with its flexible voltage control scheme requires a strapping option for voltage control. Refer to Vadem's design literature for full details. Table 6 shows the VG-469 V_{CC} strapping options for positive pin polarity.

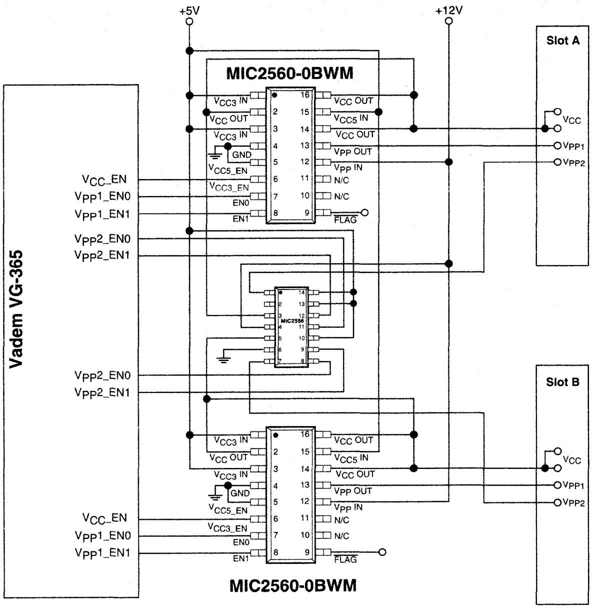


Figure 7. A dual slot PC Card system using the Vadem VG-365 and the MIC256x-0. One MIC2563-0 may replace the two MIC2560-0 shown in this schematic.

D1 Reg 2F/6F	D0 Reg 2F/6F	V_{CC_EN1}	V_{CC_EN0}	V_{CC} OUT
1	0	0	0	Hi-Z
1	1	0	1	3.3V
0	0	1	0	5V
0	1	1	1	3.3V

Table 6. Vadem VG-469 flexible voltage control strapping scheme for the MIC2560-0, MIC2561-0, MIC2562-0, or the MIC2563-0.

Serial-Interface Logic Controllers

With the advent of the CardBus option, logic controllers need more and more pins to handle the extra functions. Some of the eight pins previously reserved for power control are now employed for these new functions. Converting from a parallel control bus to a serial bus is one answer: this change frees up to six pins. However; the control logic inside the power controller must be significantly more complex to handle serial data protocols.

Existing parallel bus power controllers may be adapted for serial control operation. A typical circuit consists of two main blocks: a serial to-parallel converter and an eight-bit latch.

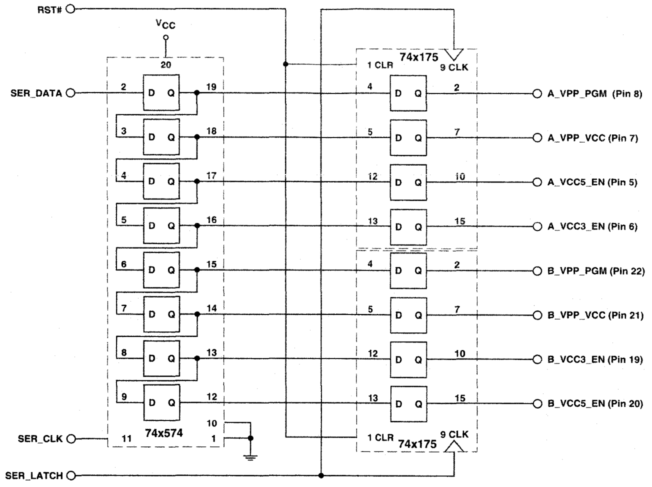


Figure 6. Interfacing the MIC2563A with a serial-output data controller. Pinouts shown are for the MIC2563A-1 and a three-wire serial controller.

Serial Control

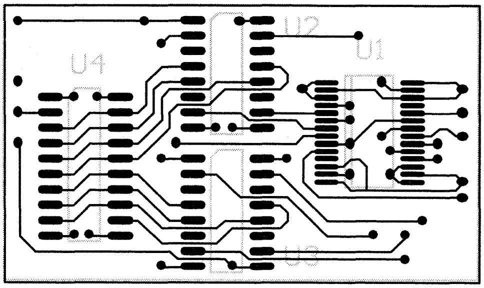
Figure 6 shows conversion from a three-wire serial interface, such as used by the Cirrus Logic CL-PD6730, to the standard eight-line parallel interface used by the MIC2563A-1. It is compatible with any of Micrel's "-1" controllers. This interface requires three common, low cost 7400-series logic ICs:

- 74x574 Octal D Flip-Flop
- 74x175 Quad Flip-Flop with Latches (two needed)

Either 3.3V or 5V logic devices may be used, depending upon the control voltage employed by the slot logic controller. Pin numbers in parenthesis refer to the MIC2563A-1BSM. Gerber™ files for this P.C. board layout are available to Micrel customers. Please contact Micrel directly.

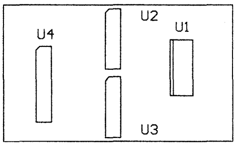
Another serial-to-parallel solution for this application is the 74HC594, 8-bit shift register with output registers. This device contains the eight D flip-flops plus has latched outputs suitable for this purpose.

Serial Control Adapter P.C. Board Layout



Component Key

U1 .... MIC2563
U2, U3 .... 74x175
U4 .... 74x574



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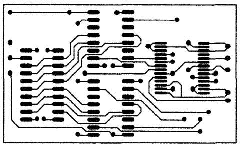

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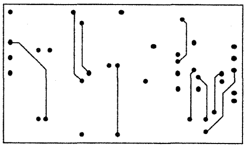


95090201.PCB
Bottom Layer

Application Hint 15

A High Current V_{CC} Switching Matrix

by Brenda Kovacevic

Introduction

Some applications require a multiplexer that can deliver two or more supply voltages at 1A or greater. An example is the V_{CC} multiplexer for the PCMCIA interface. A low cost multiplexer for high current loads can be made using the Micrel MIC5014 and a few discrete power MOSFETs. A simple 3.3V and 5V switch is shown in Figure 1. Since low cost discrete MOSFETs are available with ON resistances of a few milliohms, these multiplexers can manage currents exceeding several tens of amperes.

The MIC5014

Making this solution possible is the MIC5014 MOSFET driver. This driver is designed to provide gate enhancement above the positive rail for an N-channel FET. N-channel FETs have the advantages of lower cost and lower $R_{DS(ON)}$ than similar P-channel FETs. The MIC5014 consumes a maximum of 1μA in the OFF state and typically 100μA in the ON state while powered from a 5V supply. The MIC5014 does not require its supply to be the input logic supply since the control input threshold is approximately 1.2V and is independent of supply voltage. Likewise, the MIC5014 does not require its supply to be the MOSFET drain supply voltage because the voltage supplied to the gate is regulated and will not exceed 16V above the source voltage and is also independent of the supply voltage. The MIC5014 is available in an 8-pin SOIC package which helps minimizes the size of the complete switch matrix.

The Switch Matrices

Figure 1 shows the basic switching matrix configurations. Q1 through Q3 can be any low impedance N-channel power FETs. Table 1 shows the expected V_{OUT} for several FETs with different $R_{DS(ON)}$ values.

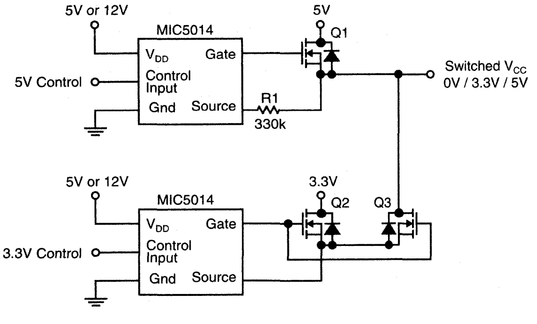


Figure 1. Switch Matrix for 0V, 3.3V, and 5V

Each FET has its body internally connected to its source, resulting in an intrinsic diode between the body and the drain known as a "body diode." Figure 1 shows that the body diode does not present a problem for the Q1 switch, because it is always reverse biased. If Q3 were not in the circuit and the source of Q2 connected directly to the output, then Q2's body diode would be reverse biased when both Q1 and Q2 are OFF and the output voltage is zero. However, Q2's body diode would be forward biased when Q1 is ON and the 5V supply would be shorted to the 3.3V supply through Q1 and the forward biased body diode of Q2. Similarly, if Q2 were not in the circuit and the source of Q3 connected to 3.3V, then Q3's body diode would be reverse biased when Q1 is ON but forward biased when both Q1 and Q3 are OFF and the load would be held one diode drop below 3.3V. With two MOSFETs connected back to back, both body diodes will be reverse biased when all switches are OFF as long as the output voltage remains positive with respect to ground. Although Q3 conducts current in the reverse direction when it is ON, the body diode will not conduct because it is shorted by Q3's ON resistance.

FET Part Number	$R_{DS(ON)}$	V_{OUT} at 1A	
		5.0V Input	3.3V Input
IRFZ20	100mΩ	4.9V	3.1V
IRFZ30	50mΩ	4.95V	3.20V
SMP06N06-14	14mΩ	4.99V	3.27V

Table 1. Power FETs and Expected Output Voltages at 1A

Low Current PCMCIA V_{PP} Switching Matrices

If V_{PP} programming currents are switched, the new MIC2557/2558 devices provide all level shifting, timing, and high current switches for this function in one package. The MIC2557 serves as a single channel and is available in an 8-pin SOIC package (see Figure 2). The MIC2558 is a dual channel device, and is available in a 14-pin SOIC package (see Figure 3). See the MIC2557 or MIC2558 data sheets for full details.

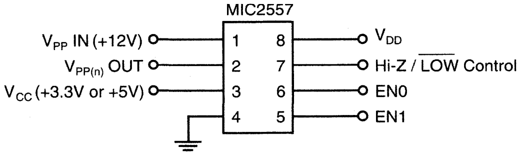


Figure 2. Typical MIC2557 Application

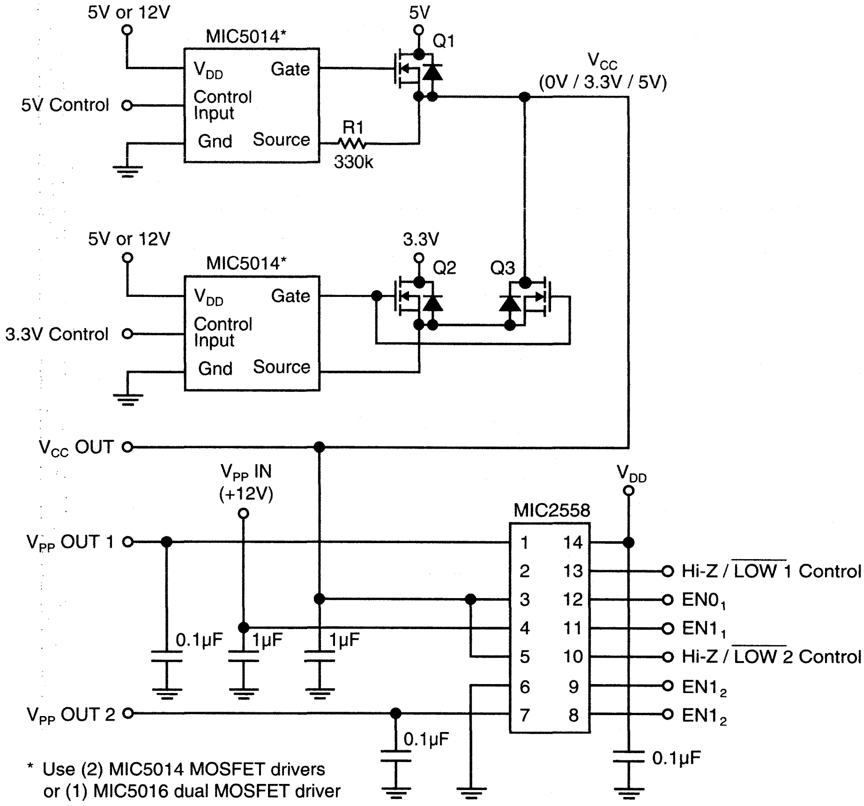


Figure 3. Full PCMCIA V_{PP} and V_{CC} Circuit using MIC5014 (or MIC5016) and MIC2558

Table of Contents

Section 3: Low-Dropout Linear Voltage Regulators

Low-Dropout Voltage Regulator Selector Guide

Device	V_{OUT}						Accu-racy	I_{OUT} (mA)	Dropout Voltage @ I (Max. @ 25°C)	Features						Package
	3.0	3.3	4.85	5.0	12	Adjust.				I_{LIM}	Therm Protect	Error Flag	Logic Control	Reverse Supply	Load Dump	
MIC5203	•	•	●	•			3.0%	80	450mV	•	•		•	•		SOT-143
MIC5200	•	•	•	•			1.0%	100	450mV	•	•		•	•		SO-8, SOT-223
MIC5202	•	•	•	•			1.0%	100	450mV	•	•		•	•		SO-8
								dual								
LP2950				•			0.5%	100	450mV	•	•					TO-92
							1.0%		@ 100mA							
LP2951			•	•		1.2 to 29	0.5%			•	•	•	•			P DIP, SO-8
							1.0%									
MIC2950				•			0.5%	150	300mV	•	•			•	•	TO-92
							1.0%		@ 100mA							
MIC2951		•	•	•		1.2 to 29	0.5%			•	•	•	•	•	•	P DIP, SO-8
							1.0%									
MIC5205	•	•	■	•		1.2 to 16	1.0%	150	450mV	•	•		•	•		SOT-23-5
MIC5201	•	•		•		1.2 to 16	1.0%	200	450mV	•	•		•	•		SO-8, SOT-223
MIC2954				•		1.2 to 29	0.5%	250	500mV	•	•	•	•	•	•	TO-92, TO-220
							1.0%		@ 250mA							SOT-223, SO-8
MIC2920A		•	•	•	•		1.0%	400	450mV	•	•			•	•	TO-220, SOT-223
MIC29201		•	•	•	•				@ 250mA	•	•	•	•	•	•	TO-220-5, TO-263-5
MIC29202						1.2 to 26			370mV typ.	•	•		•	•	•	TO-220-5, TO-263-5
MIC29203						1.2 to 26				•	•	•		•	•	TO-220-5, TO-263-5
MIC29204						1.2 to 26				•	•	•	•	•	•	P DIP, CerDIP, SO-8
MIC2937A		•		•	•		1.0%	750	450mV	•	•			•	•	TO-220, TO-263
									@ 500mA							
MIC29371		•		•	•				325mV typ	•	•	•	•	•	•	TO-220-5, TO-263-5
MIC29372						1.2 to 26				•	•		•	•	•	TO-220-5, TO-263-5
MIC29373						1.2 to 26				•	•	•		•	•	TO-220-5, TO-263-5
MIC2940A		•		•	•		1.0%	1250	450mV	•	•			•	•	TO-220, TO-263
MIC2941A						1.2 to 26				•	•		•	•	•	TO-220-5, TO-263-5

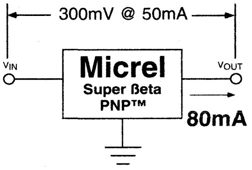
● = 3.6V, 3.8V, 4.0V, 4.75V; ■ = 3.6V, 3.8V, 4.0V

Low-Dropout Voltage Regulator Selector Guide

Device	V_{OUT}						Accuracy	I_{OUT} (A)	Dropout	Features						Package
	3.0	3.3	4.85	5.0	12	Adjust.			Voltage @ I (Max. @ 25°C)	I_{LIM}	Therm Protect	Error Flag	Logic Control	Reverse Supply	Load Dump	
MIC29150		•		•	•		1%	1.5A	450mV	•	•			•	•	TO-220, TO-263
MIC29151		•		•	•		1%	1.5A	450mV	•	•	•	•	•	•	TO-220, TO-263
MIC29152						1.2 to 26	1%	1.5A	450mV	•	•		•	•	•	TO-220, TO-263
MIC29153						1.2 to 26	1%	1.5A	450mV	•	•	•		•	•	TO-220, TO-263
MIC29300		•		•	•		1%	3A	450mV	•	•			•	•	TO-220, TO-263
MIC29301		•		•	•		1%	3A	450mV	•	•	•	•	•	•	TO-220, TO-263
MIC29302						1.2 to 26	1%	3A	450mV	•	•		•	•	•	TO-220, TO-263
MIC29303						1.2 to 26	1%	3A	450mV	•	•	•		•	•	TO-220, TO-263
MIC29310		•		•				3A	1V	•	•					TO-220
MIC29312						1.2 to 16		3A	1V	•	•		•			TO-220
MIC29500		•		•			1%	5A	450mV	•	•			•	•	TO-220
MIC29501		•		•			1%	5A	450mV	•	•	•	•	•	•	TO-220, TO-263
MIC29502						1.2 to 26	1%	5A	450mV	•	•		•	•	•	TO-220, TO-263
MIC29503						1.2 to 26	1%	5A	450mV	•	•	•		•	•	TO-220, TO-263
MIC29510		•		•				5A	1V	•	•					TO-220
MIC29512						1.2 to 16		5A	1V	•	•		•			TO-220
MIC29710		•		•				7.5A	1V	•	•					TO-220
MIC29712						1.2 to 16		7.5A	1V	•	•		•			TO-220
MIC29750		•		•			1%	7.5A	450mV	•	•			•	•	TO-247
MIC29751		•		•			1%	7.5A	450mV	•	•	•	•	•	•	TO-247
MIC29752						1.2 to 26	1%	7.5A	450mV	•	•		•	•	•	TO-247
MIC29753						1.2 to 26	1%	7.5A	450mV	•	•	•		•	•	TO-247
MIC5156		•		•		1.2 to 36	1%	①	①	•		•	•			**SOIC, P DIP, CerDIP**
MIC5157		②		②	②		1%	①	①	•		•	•			① Max. I_{OUT} and dropout determined by choice of extermal MOSFET
MIC5158				③		③	1%	①	①	•		•	•			② Selectable: 3.3V/5V/12V ③ Selectable: 5V/adjustable

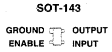
Micrel Super ßeta PNP™ LDO Regulator Family

MIC5203

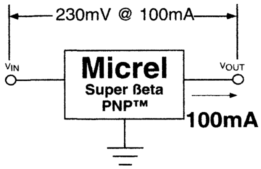


- Guaranteed 80mA output
- 3.0V, 3.3V, 3.6V, 3.8V, 4.0V, 4.75V, and 5.0V fixed
- 300mV typical dropout at 50mA
- Super ßeta PNP™ provides minimum ground current
- Available in SOT-143 package

MIC5203

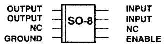


MIC5200/5202

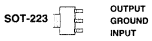


- Guaranteed 100mA output
- 3.0V, 3.3V, and 5.0V fixed
- 230mV typical dropout at 100mA
- Super ßeta PNP™ provides minimum ground current
- MIC5200 Single is available in SO-8 and SOT-223 packages
- MIC5202 dual is available in SO-8

MIC5200



MIC5200



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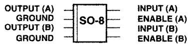
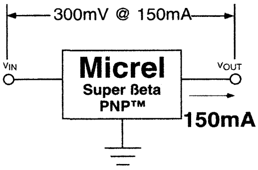
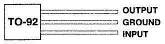


MIC2950



- Guaranteed 150mA output
- 3.3V, 4.85V, 5.0V fixed or adjustable
- 300mV typical dropout at 150mA
- Super ßeta PNP™ provides minimum ground current
- Available in SO-8, DIP, and TO-92 packages

MIC2950



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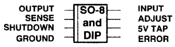

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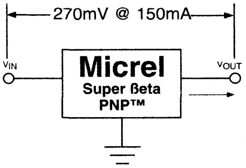
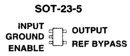
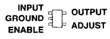


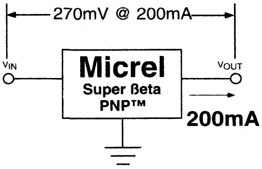
- Guaranteed 150mA output
- 3.0, 3.3V, 3.6, 3.8, 4.0V, 5.0V or adjustable
- 270mV typical dropout at 150mA
- Super ßeta PNP™ provides minimum ground current
- Available in SOT-23-5 package

MIC5205



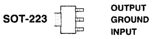


MIC5201



- Guaranteed 200mA output
- 3.0V, 3.3V, 4.5V, 5.0V, or adjustable
- 270mV typical dropout at 200mA
- Super ßeta PNP™ provides minimum ground current
- Available in SO-8 and SOT-223 packages

MIC5201



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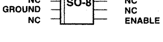
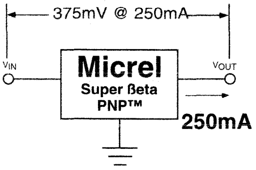
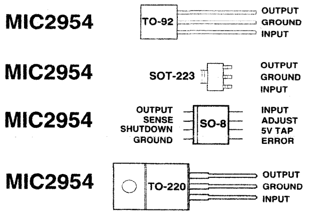


Micrel Super ßeta PNP™ LDO Regulator Family

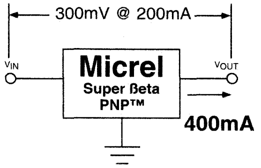
MIC2954



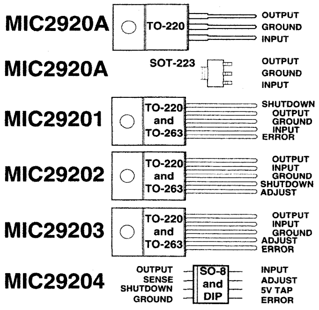
- Guaranteed 250mA output
- 5.0V fixed or adjustable
- <450mV dropout at 250mA
- Super ßeta PNP™ provides minimum ground current
- Available in SO-8, SOT-223, TO-220, and TO-92 packages



MIC2920A



- Guaranteed 400mA output
- 3.3V, 5V, 12V fixed or adjustable
- 450mV typical dropout at 400mA
- Super ßeta PNP™ provides minimum ground current
- Available in SO-8, DIP, TO-220, TO-263, and SOT-223 packages



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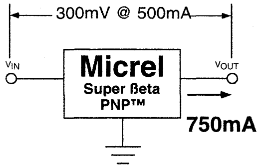
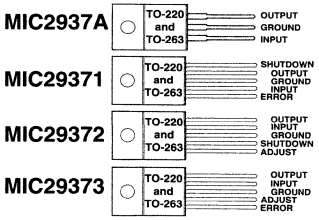


- Guaranteed 750mA output
- 3.3V, 5V, 12V fixed or adjustable
- 370mV typical dropout at 750mA
- Super ßeta PNP™ provides minimum ground current
- Available in TO-220 and TO-263 packages



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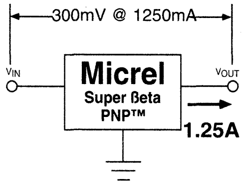
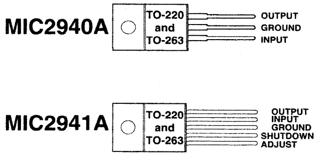
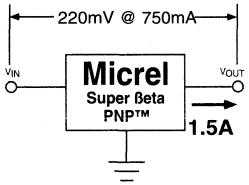


- Guaranteed 1250mA output
- 3.3V, 5V, 12V fixed or adjustable
- 300mV typical dropout at 1.25A
- Super ßeta PNP™ provides minimum ground current
- Available in TO-220 and TO-263 packages

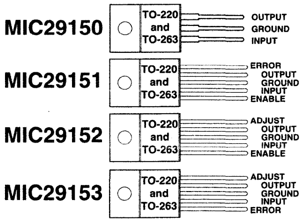


Micrel Super ßeta PNP™ LDO Regulator Family

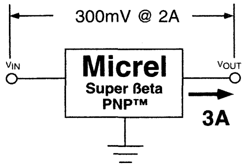
MIC29150



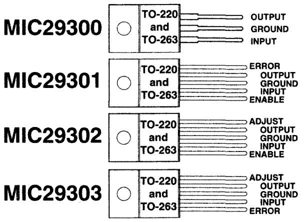
- Guaranteed 1.5A output
- 3.3V, 5V, 12V fixed or adjustable
- <450mV dropout at 1.5A
- Zero power shutdown mode
- Super ßeta PNP™ provides minimum ground current
- Available in TO-220 and TO-263 packages



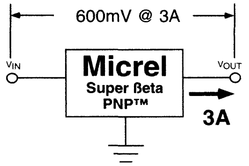
MIC29300



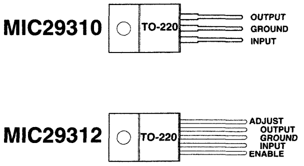
- Guaranteed 3A output
- 3.3V, 5V,12V fixed or adjustable
- Input range to 26V
- 370mV typical dropout at 3A
- Zero power shutdown mode
- Super ßeta PNP™ provides minimum ground current
- Available in TO-220 and TO-263 packages



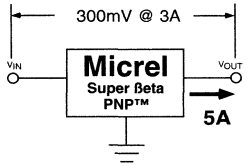
MIC29310



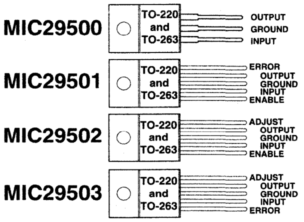
- Guaranteed 3A output
- 3.3V, 5V fixed or adjustable
- 600mV typical dropout at 3A
- Zero power shutdown mode
- Input range to 16V
- Available in TO-220-3 and -5 packages



MIC29500

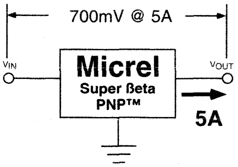


- Guaranteed 5A output
- 3.3V, 5V fixed or adjustable
- Input range to 26V
- 370mV typical dropout at 5A
- Zero power shutdown mode
- Super ßeta PNP™ provides minimum ground current
- Available in TO-220 and TO-263 packages

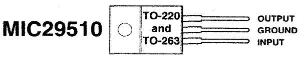


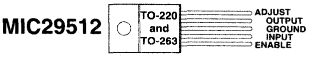
Micrel Super ßeta PNP™ LDO Regulator Family

MIC29510

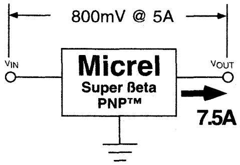


- Guaranteed 5A output
- 3.3V, 5V fixed or adjustable
- 700mV typical dropout at 5A
- Zero power shutdown mode
- Input range to 16V
- Available in TO-220-3 and -5 packages

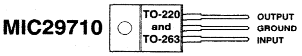


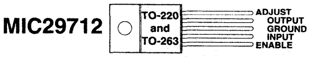


MIC29710

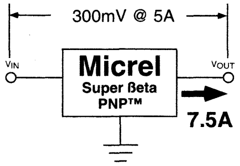


- Guaranteed 7.5A output
- 3.3V and 5V fixed or adjustable
- 700mV typical dropout at 7.5A
- Zero power shutdown mode
- Input range to 16V
- Available in TO-220-3 and -5 packages

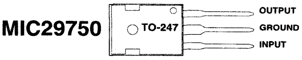


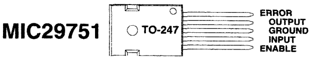


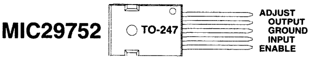
MIC29750



- Guaranteed 7.5A output
- 3.3V, 5V fixed or adjustable
- 240mV typical dropout at 7.5A
- Zero power shutdown mode
- Super ßeta PNP™ provides minimum ground current
- Available in TO-247-3 and -5 packages

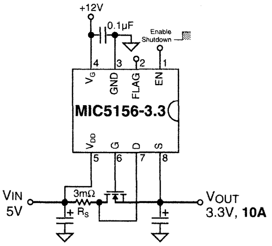




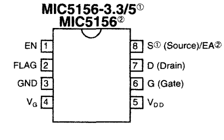


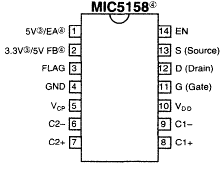
MIC5156/5157/5158

Super LDO™ Regulator Controller



- 6mA typical operating current
- <1µA typical standby current
- 3.3V, 5V fixed output (MIC5156)
- 3.3V, 5V, 12V fixed output (MIC5157)
- 1.3V to 36V adjustable output (MIC5156/8)
- 1% initial output voltage tolerance
- Enable/shutdown control
- Internal gate-to-source protective clamp
- DIP and SOIC packages





MIC2920A/29201/29202/29203/29204

400mA Low-Dropout Voltage Regulator

Preliminary Information

General Description

The MIC2920A family are "bulletproof" efficient voltage regulators with very low drop out voltage (typically 40mV at light loads and 370mV at 250mA), and very low quiescent current (140μA typical). The quiescent current of the MIC2920A increases only slightly in dropout, thus prolonging battery life. Key MIC2920A features include protection against reversed battery, fold-back current limiting, and automotive "load dump" protection (60V positive transient).

The MIC2920 is available in several configurations. The MIC2920A-xx devices are three pin fixed voltage regulators available in 3.3V, 4.85V, 5V, and 12V outputs. The MIC29201 is a fixed regulator offering logic compatible ON/OFF switching input and an error flag output. This flag may also be used as a power-on reset signal. A logic-compatible shutdown input is provided on the adjustable MIC29202, which enables the regulator to be switched on and off. The MIC29203 is a five pin adjustable version that includes an error flag output that warns of a low output voltage, which is often due to failing batteries on the input. The eight pin DIP and SOIC adjustable version, the MIC29204, includes both shutdown and error flag pins, and may be pin-strapped for 5V output, or programmed from 1.24 V to 26 V with the use of two external resistors.

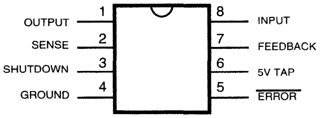
Features

- High output voltage accuracy
- Guaranteed 400mA output
- Low quiescent current
- Low dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Current and thermal limiting
- Input can withstand –20V reverse battery and +60V positive transients
- Error flag warns of output dropout
- Logic-controlled electronic shutdown
- Output programmable from 1.24V to 26V (MIC29202/MIC29203/MIC29204)
- Available in TO-220, TO-220-5, DIP, CerDIP, and Surface Mount TO-263-5, SOT-223, and SO-8 packages.

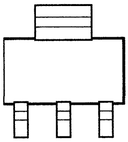
Applications

- Battery Powered Equipment
- Cellular Telephones
- Laptop, Notebook, and Palmtop Computers
- PCMCIA V_{CC} and V_{PP} Regulation/Switching
- Bar Code Scanners
- Automotive Electronics
- SMPS Post-Regulator/ DC to DC Modules
- Voltage Reference
- High Efficiency Linear Power Supplies

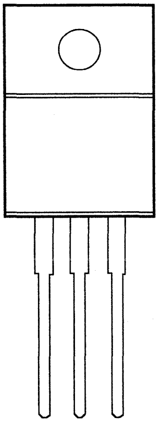
Pin Configuration



SO/DIP Packages
(MIC29204BJ/M/N)

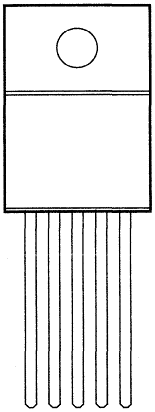


1 2 3
IN GND OUT
MIC2920A-xxBS



1 2 3
INPUT GROUND OUTPUT

TO-220 Package
(MIC2920A-xxBT)

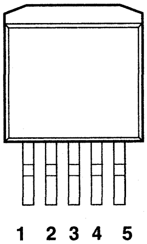


1 2 3 4 5

TO-220-5 Package
(MIC29201/29202/29203BT)

Five Lead Package Pin Functions:

	MIC29201	MIC29202	MIC29203
1)	Error	Adjust	Error
2)	Input	Shutdown	Adjust
3)	Ground	Ground	Ground
4)	Output	Input	Input
5)	Shutdown	Output	Output



1 2 3 4 5

TO-263-5 Package
(MIC29201/29202/29203BU)

The TAB is Ground on the SOT-223, TO-220, and TO-263 packages.

Ordering Information

Part Number	Voltage	Temperature Range*	Package
MIC2920A-3.3BS	3.3	–40°C to +125°C	SOT-223
MIC2920A-3.3BT	3.3	–40°C to +125°C	TO-220
MIC2920A-4.8BS	4.85	–40°C to +125°C	SOT-223
MIC2920A-4.8BT	4.85	–40°C to +125°C	TO-220
MIC2920A-5.0BS	5.0	–40°C to +125°C	SOT-223
MIC2920A-5.0BT	5.0	–40°C to +125°C	TO-220
MIC2920A-12BS	12	–40°C to +125°C	SOT-223
MIC2920A-12BT	12	–40°C to +125°C	TO-220
MIC29201-3.3BT	3.3	–40°C to +125°C	TO-220-5
MIC29201-3.3BU	3.3	–40°C to +125°C	TO-263-5
MIC29201-4.8BT	4.85	–40°C to +125°C	TO-220-5
MIC29201-4.8BU	4.85	–40°C to +125°C	TO-263-5
MIC29201-5.0BT	5.0	–40°C to +125°C	TO-220-5
MIC29201-5.0BU	5.0	–40°C to +125°C	TO-263-5
MIC29201-12BT	12	–40°C to +125°C	TO-220-5
MIC29201-12BU	12	–40°C to +125°C	TO-263-5
MIC29202BT	Adj	–40°C to +125°C	TO-220-5
MIC29202BU	Adj	–40°C to +125°C	TO-263-5
MIC29203BT	Adj	–40°C to +125°C	TO-220-5
MIC29203BU	Adj	–40°C to +125°C	TO-263-5
MIC29204BM	5 and Adj	–40°C to +125°C	SO-8
MIC29204BN	5 and Adj	–40°C to +125°C	8-pin PDIP

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, contact your local Micrel representative/distributor for availability and specifications.

Power Dissipation (Note 1)	Internally Limited
Lead Temperature (Soldering, 5 seconds)	260°C
Storage Temperature Range	–65°C to +150°C
Operating Junction Temperature Range	–40°C to +125°C
Thermal Characteristics:	
SOT–223 θ_{JC}	15°C/W
TO-220 θ_{JC}	3°C/W
TO-263 θ_{JC}	3°C/W
8-Pin CerDIP θ_{JA}	130°C/W
8-Pin Plastic DIP θ_{JA}	105°C/W
8-Pin SOIC θ_{JA}	See Note 1
Input Supply Voltage	–20V to +60V
Operating Input Supply Voltage	2V† to 26V
Adjust Input Voltage (Notes 9 and 10)	–1.5V to +26V
Shutdown Input Voltage	–0.3V to +30V
Error Comparator Output Voltage	–0.3V to +30V

† Across the full operating temperature, the minimum input voltage range for full output current is 4.3V to 26V. Output will remain in-regulation at lower output voltages and low current loads down to an input of 2V at 25°C.

* Junction temperatures

Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$ and limits in **boldface** apply over the full operating temperature range. Unless otherwise specified, $V_{IN} = V_{OUT} + 1V$, $I_L = 1mA$, $C_L = 10\mu F$. Adjustable version are set for an output of 5V. The MIC29202 $V_{SHUTDOWN} \leq 0.7V$. The eight pin MIC29204 is configured with the Adjust pin tied to the 5V Tap, the Output is tied to Output Sense ($V_{OUT} = 5V$), and $V_{SHUTDOWN} \leq 0.7V$.

Symbol	Parameter	Conditions	Min	Typical	Max	Units
V_O	Output Voltage Accuracy	Variation from factory trimmed V_{OUT}	−1 **−2**		1 **2**	%
		$1mA \leq I_L \leq 400mA$, across temp. range	**−2.5**		**2.5**	
		MIC2920A-12 and 29201-12 only	−1.5 **−3**		1.5 **3**	
		$1mA \leq I_L \leq 400mA$, across temp. range	**−4**		**4**	
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temperature Coef.	(Note 2)		20	**100**	ppm/°C
		$V_{OUT} > 10V$ only		80	**350**	
$\frac{\Delta V_O}{V_O}$	Line Regulation	$V_{IN} = V_{OUT} + 1V$ to 26V		0.03	0.10 **0.40**	%
$\frac{\Delta V_O}{V_O}$	Load Regulation	$I_L = 1$ to 250mA (Note 3)		0.04	0.16 **0.30**	%
$V_{IN} - V_O$	Dropout Voltage (Note 4)	$I_L = 1mA$		100	150 **180**	mV
		$I_L = 100mA$		250		
		$V_{OUT} > 10V$ only		350		
		$I_L = 250mA$		370		
		$V_{OUT} > 10V$ only		500		
		$I_L = 400mA$		450	600 **750**	
I_{GND}	Ground Pin Current (Note 5)	$I_L = 1mA$		140	200 **300**	µA
		$I_L = 100mA$		1.3	2 **2.5**	mA
		$I_L = 250mA$		5	9 **12**	
		$I_L = 400mA$		13	15	
I_{GNDDO}	Ground Pin Current at Dropout (Note 5)	$V_{IN} = 0.5V$ less than designed V_{OUT} ($V_{OUT} \geq 3.3V$) $I_O = 1mA$		180	**400**	µA
I_{LIMIT}	Current Limit	$V_{OUT} = 0V$ (Note 6)		425	1000 **1200**	mA
$\frac{\Delta V_O}{\Delta P_D}$	Thermal Regulation	(Note 7)		0.05	0.2	%/W
e_n	Output Noise Voltage (10Hz to 100kHz) $I_L = 100mA$	$C_L = 10\mu F$		400		µV RMS
		$C_L = 100\mu F$		260		

Electrical Characteristics (Continued)

MIC29202, MIC29203, MIC29204

Parameter	Conditions	Min	Typ	Max	Units
Reference Voltage	MIC29202/29203	1.223 **1.210**	1.235	1.247 **1.260**	V
Reference Voltage	MIC29202/29203 (Note 8)	**1.204**		**1.266**	V
Reference Voltage	MIC29204	1.210 **1.200**	1.235	1.260 **1.270**	V
Reference Voltage	MIC29204 (Note 8)	**1.185**		**1.285**	V
Adjust Pin Bias Current			20	40 **60**	nA
Reference Voltage Temperature Coefficient	(Note 7)		20		ppm/°C
Adjust Pin Bias Current Temperature Coefficient			0.1		nA/°C
Error Comparator	**MIC29201, MIC29203, MIC29204**				
Output Leakage Current	$V_{OH} = 26V$		0.01	1.00 **2.00**	µA
Output Low Voltage	$V_{IN} = 4.5V$ $I_{OL} = 250\mu A$		150	250 **400**	mV
Upper Threshold Voltage	(Note 9)	40 **25**	60		mV
Lower Threshold Voltage	(Note 9)		75	95 **140**	mV
Hysteresis	(Note 9)		15		mV
Shutdown Input	**MIC29201, MIC29202, MIC29204**				
Input Logic Voltage	 Low (ON) High (OFF)	 **2.0**	1.3	 **0.7**	V
Shutdown Pin Input Current	$V_{SHUTDOWN} = 2.4V$		30	50 **100**	µA
	$V_{SHUTDOWN} = 26V$		450	600 **750**	µA
Regulator Output Current in Shutdown	(Note 10)		3	10 **20**	µA

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions. The maximum allowable power dissipation is a function of the maximum junction temperature, $T_{J\,(MAX)}$, the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using: $P_{(MAX)} = (T_{J(MAX)} - T_A) / \theta_{JA}$. Exceeding the maximum allowable power dissipation will result in excessive die temperature, and the regulator will go into thermal shutdown. The junction to ambient thermal resistance of the MIC29204BM is 160°C/W mounted on a PC board.

Note 2: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 3: Regulation is measured at constant junction temperature using low duty cycle pulse testing. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

Note 4: Dropout Voltage is defined as the input to output differential at which the output voltage drops 100mV below its nominal value measured at 1V differential. At low values of programmed output voltage, the minimum input supply voltage of 4.3V over temperature must be taken into account. The MIC2920A operates down to 2V of input at reduced output current at 25°C.

Note 5: Ground pin current is the regulator quiescent current. The total current drawn from the supply is the sum of the load current plus the ground pin current.

Note 6: The MIC2920A features fold-back current limiting. The short circuit ($V_{OUT} = 0V$) current limit is less than the maximum current with normal output voltage.

Note 7: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 200mA load pulse at $V_{IN} = 20V$ (a 4W pulse) for T = 10ms.

Note 8: $V_{REF} \leq V_{OUT} \leq (V_{IN} - 1\ V)$, $4.3V \leq V_{IN} \leq 26V$, $1\ mA < I_L \leq 400\ mA$, $T_J \leq T_{J\ MAX.}$

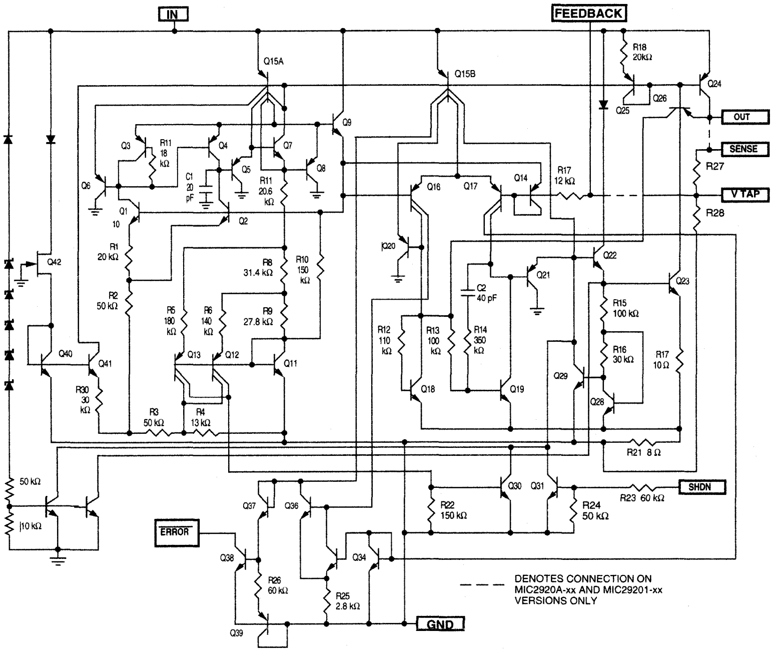
Note 9: Comparator thresholds are expressed in terms of a voltage differential at the Adjust terminal below the nominal reference voltage measured at 6V input. To express these thresholds in terms of output voltage change, multiply by the error amplifier gain = V_{OUT}/V_{REF} = (R1 + R2)/R2. For example, at a programmed output voltage of 5V, the Error output is guaranteed to go low when the output drops by 95 mV x 5V/1.235 V = 384 mV. Thresholds remain constant as a percent of VOUT as VOUT is varied, with the dropout warning occurring at typically 5% below nominal, 7.7% guaranteed.

Note 10: $V_{SHUTDOWN} \geq 2V$, $V_{IN} \leq 26V$, $V_{OUT} = 0$, with Adjust pin tied to 5V Tap or to the R1, R2 junction (see Figure 3) with R1 ≥ 150kΩ.

Note 11: When used in dual supply systems where the regulator load is returned to a negative supply, the output voltage must be diode clamped to ground.

Note 12: Maximum positive supply voltage of 60V must be of limited duration (< 100ms) and duty cycle (≤ 1%). The maximum continuous supply voltage is 26V.

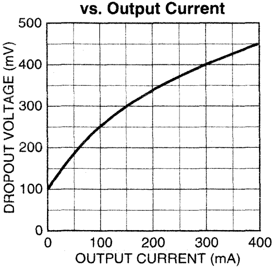
Schematic Diagram



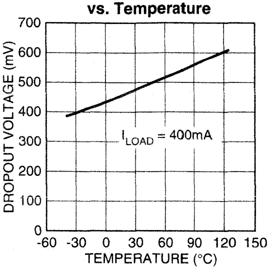
— — — DENOTES CONNECTION ON MIC2920A-xx AND MIC29201-xx VERSIONS ONLY

Typical Characteristics

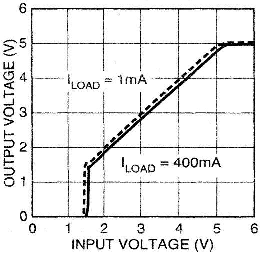
Dropout Voltage vs. Output Current



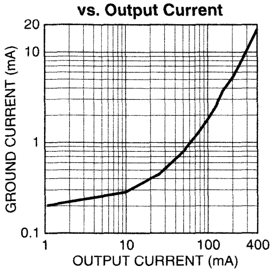
Dropout Voltage vs. Temperature



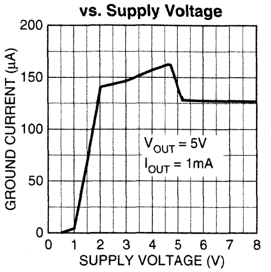
Dropout Characteristics



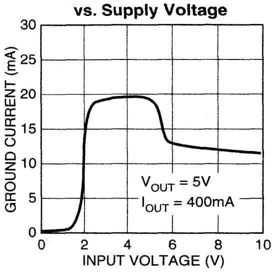
Ground Current vs. Output Current



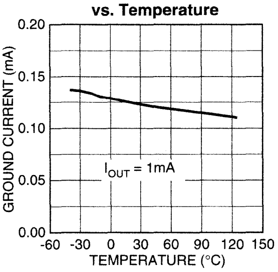
Ground Current vs. Supply Voltage



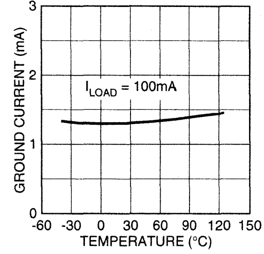
Ground Current vs. Supply Voltage



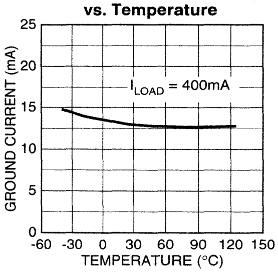
Ground Current vs. Temperature



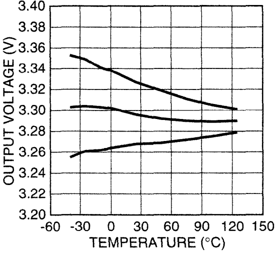
Ground Current vs. Temperature



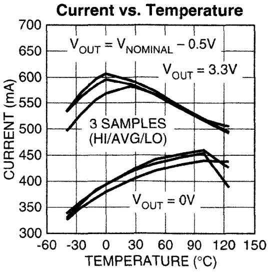
Ground Current vs. Temperature



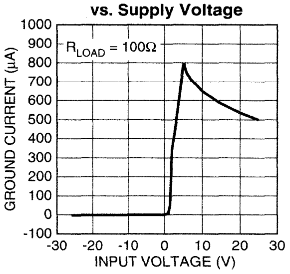
Fixed 3.3V Output Voltage vs. Temperature



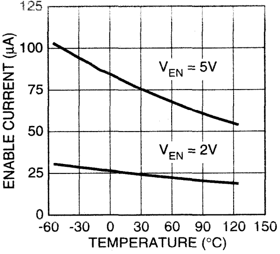
Short Circuit and Maximum Current vs. Temperature



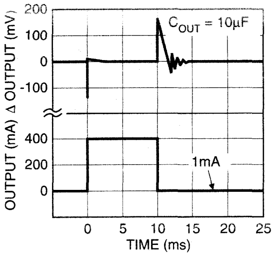
Ground Current vs. Supply Voltage



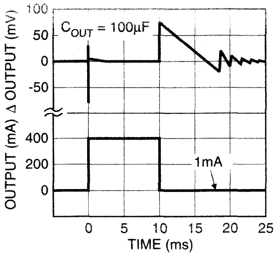
MIC29201/2 Shutdown Current vs. Temperaure



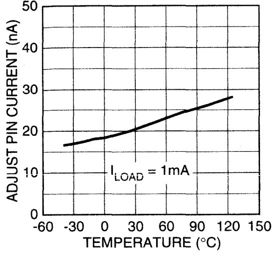
Load Transient



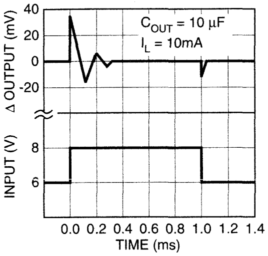
Load Transient



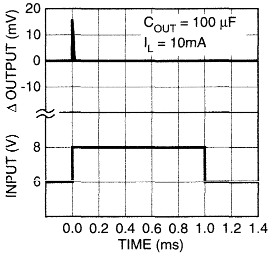
MIC29202/3 Adjust Pin Current vs. Temperature



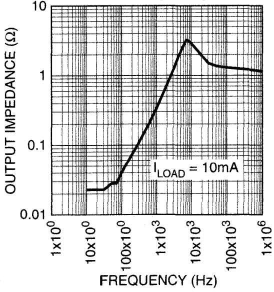
Line Transient



Line Transient



Output Impedance vs. Frequency



Applications Information

External Capacitors

A 10µF (or greater) capacitor is required between the MIC2920A output and ground to prevent oscillations due to instability. Most types of tantalum or aluminum electrolytics will be adequate; film types will work, but are costly and therefore not recommended. Many aluminum electrolytics have electrolytes that freeze at about –30°C, so solid tantalums are recommended for operation below –25°C. The important parameters of the capacitor are an effective series resistance of about 5Ω or less and a resonant frequency above 500kHz. The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for output stability. The capacitor can be reduced to 2.2µF for current below 10mA or 1µF for currents below 1 mA. Adjusting the MIC29202/29203/29204 to voltages below 5V runs the error amplifier at lower gains so that more output capacitance is needed. For the worst-case situation of a 500mA load at 1.23V output (Output shorted to Adjust) a 47µF (or greater) capacitor should be used.

The MIC2920A/29201 will remain in regulation with a minimum load of 1mA. When setting the output voltage of the MIC29202/29203/29204 versions with external resistors, the current through these resistors may be included as a portion of the minimum load.

A 1µF capacitor should be placed from the MIC2920A input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the input.

Stray capacitance to the MIC29202/29203/29204 Adjust terminal can cause instability. This may especially be a problem when using high value external resistors to set the output voltage. Adding a 100pF capacitor between Output and Adjust and increasing the output capacitor to at least 3.3µF will remedy this.

Error Detection Comparator Output (MIC29201/MIC29203/MIC29204)

A logic low output will be produced by the comparator whenever the MIC29201/29203/29204 output falls out of regulation by more than approximately 5%. This figure is the comparator's built-in offset of about 75mV divided by the 1.235V reference voltage. (Refer to the block diagram on Page 1). This trip level remains "5% below normal" regardless of the programmed output voltage of the MIC29201/29203/29204. For example, the error flag trip level is typically 4.75V for a 5V output or 11.4V for a 12V output. The out of regulation condition may be due either to low input voltage, extremely high input voltage, current limiting, or thermal limiting.

Figure 1 is a timing diagram depicting the $\overline{\text{ERROR}}$ signal and the regulated output voltage as the MIC29201/29203/29204 input is ramped up and down. The $\overline{\text{ERROR}}$ signal becomes valid (low) at about 1.3V input. It goes high at about 5V input (the input voltage at which $V_{OUT} = 4.75$). Since the MIC29201/29203/29204's dropout voltage is load-dependent (see curve in Typical Performance Characteristics), the input voltage trip point (about 5V) will vary with the load current. The output voltage trip point (approximately 4.75V) does not vary with load.

The error comparator has an NPN open-collector output which requires an external pull-up resistor. Depending on system requirements, this resistor may be returned to the 5V output or some other supply voltage. In determining a value for this resistor, note that while the output is rated to sink 250µA, this sink current adds to battery drain in a low battery condition. Suggested values range from 100k to 1MΩ. The resistor is not required if this output is unused.

Programming the Output Voltage (MIC29202/MIC29203/29204)

The MIC239202/29203/29204 may be programmed for any output voltage between its 1.235V reference and its 26V maximum rating, using an external pair of resistors, as shown in Figure 3.

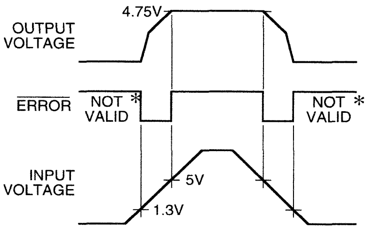
The complete equation for the output voltage is

$$V_{OUT} = V_{REF} \times \{ 1 + R_1/R_2 \} - |I_{FB}| R_1$$

where V_{REF} is the nominal 1.235 reference voltage and I_{FB} is the Adjust pin bias current, nominally 20nA. The minimum recommended load current of 1 µA forces an upper limit of 1.2MΩ on the value of R_2, if the regulator must work with no load (a condition often found in CMOS in standby), I_{FB} will produce a –2% typical error in V_{OUT} which may be eliminated at room temperature by trimming R_1. For better accuracy, choosing R_2 = 100k reduces this error to 0.17% while increasing the resistor program current to 12 µA. Since the MIC29202/29203/29204 typically draws 110µA at no load with SHUTDOWN open-circuited, this is a negligible addition. The MIC29204 may be pin-strapped for 5V using the internal voltage divider by tying Pin 1 (output) to Pin 2 (sense) and Pin 7 (Adjust) to Pin 6 (V Tap).

Reducing Output Noise

In reference applications it may be advantageous to reduce the AC noise present at the output. One method is to reduce the regulator bandwidth by increasing the size of the output



* SEE APPLICATIONS INFORMATION

Figure 1. $\overline{\text{ERROR}}$ Output Timing

capacitor. This is relatively inefficient, as increasing the capacitor from 1 µF to 220 µF only decreases the noise from 430µV to 160µV_{RMS} for a 100kHz bandwidth at 5V output. Noise can be reduced fourfold by a bypass capacitor across R_1, since it reduces the high frequency gain from 4 to unity. Pick

$$C_{BYPASS} \cong \frac{1}{2\pi R_1 \bullet 200\ \text{Hz}}$$

or about 0.01 µF. When doing this, the output capacitor must be increased to 10 µF to maintain stability. These changes reduce the output noise from 430 µV to 100 µV rms for a 100 kHz bandwidth at 5V output. With the bypass capacitor added, noise no longer scales with output voltage so that improvements are more dramatic at higher output voltages.

Automotive Applications

The MIC2920A is ideally suited for automotive applications for a variety of reasons. It will operate over a wide range of input voltages with very low dropout voltages (40mV at light loads), and very low quiescent currents (100µA typical). These features are necessary for use in battery powered systems, such as automobiles. It is a "bulletproof" device with the ability to survive both reverse battery (negative transients up to 20V below ground), and load dump (positive transients up to 60V) conditions. A wide operating temperature range with low temperature coefficients is yet another reason to use these versatile regulators in automotive designs.

Typical Applications

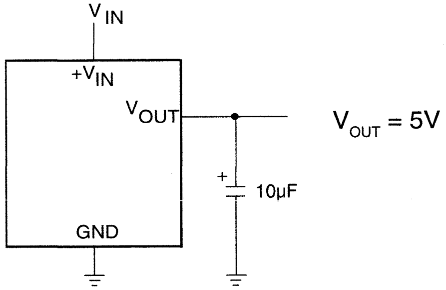
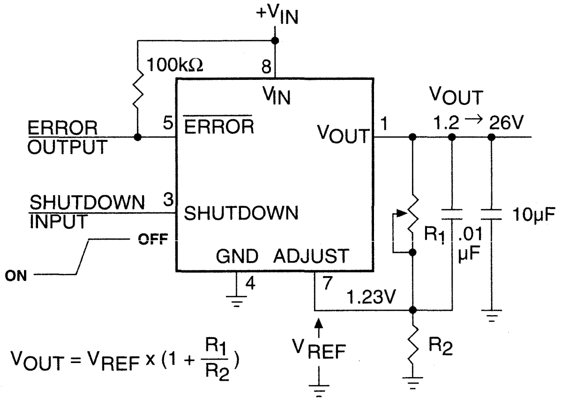
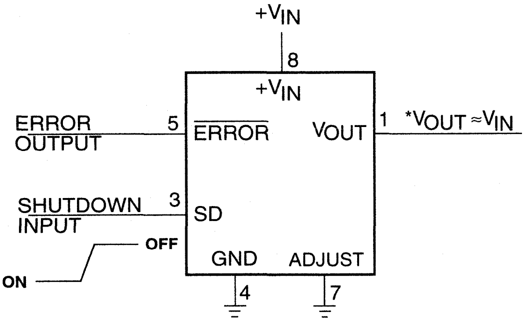


Figure 2. MIC2920A-5.0 Fixed +5V Regulator



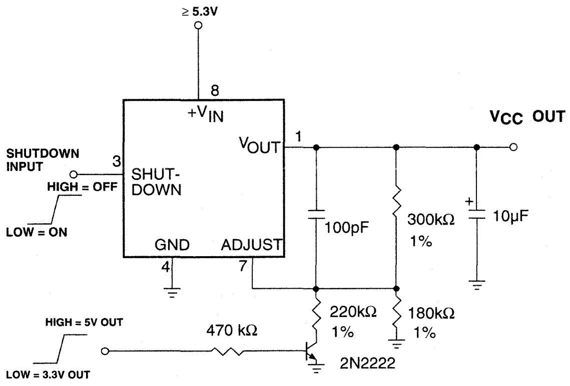
NOTE: PINS 2 AND 6 ARE LEFT OPEN

Figure 3. MIC29202/29203/29204 Adjustable Regulator. Pinout is for MIC29204.



*MINIMUM INPUT-OUTPUT VOLTAGE RANGES FROM 40mV TO 400mV, DEPENDING ON LOAD CURRENT.

Figure 4. MIC29204 Wide Input Voltage Range Current Limiter



PIN 3 LOW= ENABLE OUTPUT. Q1 ON = 3.3V, Q1 OFF = 5.0V.

Figure 5. MIC29202/29203/29204 5.0V or 3.3V Selectable Regulator with Shutdown. Pinout is for MIC29204.

MIC2937A/29371/29372/29373

750mA Low-Dropout Voltage Regulator

Preliminary Information

General Description

The MIC2937A family are "bulletproof" efficient voltage regulators with very low dropout voltage (typically 40mV at light loads and 300mV at 500mA), and very low quiescent current (160µA typical). The quiescent current of the MIC2937A increases only slightly in dropout, thus prolonging battery life. Key MIC2937A features include protection against reversed battery, fold-back current limiting, and automotive "load dump" protection (60V positive transient).

The MIC2937 is available in several configurations. The MIC2937A-xx devices are three pin fixed voltage regulators with 3.3V, 5V, and 12V outputs available. The MIC29371 is a fixed regulator offering logic compatible ON/OFF switching input and an error flag output. This flag may also be used as a power-on reset signal. A logic-compatible shutdown input is provided on the adjustable MIC29372, which enables the regulator to be switched on and off. The MIC29373 is a five pin adjustable version that includes an error flag output that warns of a low output voltage, which is often due to failing batteries on the input.

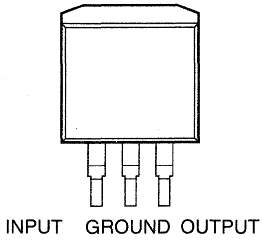
Features

- High output voltage accuracy
- Guaranteed 750mA output
- Low quiescent current
- Low dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Current and thermal limiting
- Input can withstand –20V reverse battery and +60V positive transients
- Error flag warns of output dropout
- Logic-controlled electronic shutdown
- Output programmable from 1.24V to 26V(MIC29372/MIC29373)
- Available in TO-220, TO-263, TO-220-5, and TO-263-5 packages.

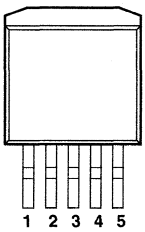
Applications

- Battery Powered Equipment
- Cellular Telephones
- Laptop, Notebook, and Palmtop Computers
- PCMCIA V_{CC} and V_{PP} Regulation/Switching
- Bar Code Scanners
- Automotive Electronics
- SMPS Post-Regulator/ DC to DC Modules
- High Efficiency Linear Power Supplies

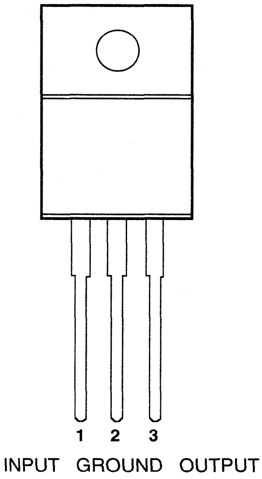
Pin Configuration



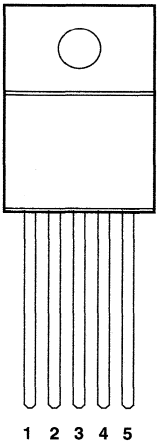
TO-263 Package (MIC2937A-xxBU)



TO-263-5 Package (MIC29371/29372/29373BU)



TO-220 Package (MIC2937A-xxBT)



TO-220-5 Package (MIC29371/29372/29373BT)

Five Lead Package Pin Functions:

	MIC29371	MIC29372	MIC29373
1)	Error	Adjust	Error
2)	Input	Shutdown	Adjust
3)	Ground	Ground	Ground
4)	Output	Input	Input
5)	Shutdown	Output	Output

The TAB is Ground on the TO-220 and TO-263 packages.

Ordering Information

Part Number	Voltage	Temperature Range*	Package
MIC2937A-3.3BU	3.3	–40°C to +125°C	TO-263-3
MIC2937A-3.3BT	3.3	–40°C to +125°C	TO-220
MIC2937A-5.0BU	5.0	–40°C to +125°C	TO-263-3
MIC2937A-5.0BT	5.0	–40°C to +125°C	TO-220
MIC2937A-12BU	12	–40°C to +125°C	TO-263-3
MIC2937A-12BT	12	–40°C to +125°C	TO-220
MIC29371-3.3BT	3.3	–40°C to +125°C	TO-220-5
MIC29371-3.3BU	3.3	–40°C to +125°C	TO-263-5
MIC29371-5.0BT	5.0	–40°C to +125°C	TO-220-5
MIC29371-5.0BU	5.0	–40°C to +125°C	TO-263-5
MIC29371-12BT	12	–40°C to +125°C	TO-220-5
MIC29371-12BU	12	–40°C to +125°C	TO-263-5
MIC29372BT	Adj	–40°C to +125°C	TO-220-5
MIC29372BU	Adj	–40°C to +125°C	TO-263-5
MIC29373BT	Adj	–40°C to +125°C	TO-220-5
MIC29373BU	Adj	–40°C to +125°C	TO-263-5

* Junction temperatures

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, contact your local Micrel representative/distributor for availability and specifications.

Power Dissipation (Note 1) .... Internally Limited
Lead Temperature (Soldering, 5 seconds) .... 260°C
Storage Temperature Range .... –65°C to +150°C
Operating Junction Temperature Range .... –40°C to +125°C
TO-220 θ_{JC} .... 2.5°C/W
TO-263 θ_{JC} .... 2.5°C/W
Input Supply Voltage .... –20V to +60V
Operating Input Supply Voltage .... 2V† to 26V
Adjust Input Voltage (Notes 9 and 10) .... –1.5V to +26V
Shutdown Input Voltage .... –0.3V to +30V
Error Comparator Output Voltage .... –0.3V to +30V

† Across the full operating temperature, the minimum input voltage range for full output current is 4.3V to 26V. Output will remain in-regulation at lower output voltages and low current loads down to an input of 2V at 25°C.

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C and limits in **boldface** apply over the full operating temperature range. Unless otherwise specified, $V_{IN} = V_{OUT}$ + 1V, I_L = 5mA, C_L = 10µF. The MIC29372 and MIC29373 are programmed for a 5V output voltage, and $V_{SHUTDOWN}$ ≤ 0.6V (MIC29271-xx and MIC29372 only).

Symbol	Parameter	Conditions	Min	Typical	Max	Units
V_O	Output Voltage Accuracy	Variation from factory trimmed V_{OUT}	−1		1	%
			−2		**2**	
		5mA ≤ I_L ≤ 500mA	**−2.5**		**2.5**	
		MIC2937A-12 and 29371-12 only:	−1.5		1.5	
			−3		**3**	
		5mA ≤ I_L ≤ 500mA	**−4**		**4**	
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temperature Coef.	(Note 2)		20	**100**	ppm/°C
		Output voltage > 10V		80	**350**	
$\frac{\Delta V_O}{V_O}$	Line Regulation	$V_{IN} = V_{OUT}$ + 1V to 26V		0.03	0.10	%
					0.40	
$\frac{\Delta V_O}{V_O}$	Load Regulation	I_L = 5 to 500mA		0.04	0.16	%
		(Note 3)			**0.30**	
$V_{IN} - V_O$	Dropout Voltage (Note 4)	I_L = 5mA		80	150	mV
					180	
		I_L = 100mA		200		
		Output voltage > 10V		240		
		$_L$ = 500mA		300		
		Output voltage > 10V		420		
		I_L = 750mA		370	600	
					750	
I_{GND}	Ground Pin Current (Note 5)	I_L = 5mA		160	250	µA
					300	
		I_L = 100mA		1	2.5	mA
					3	
		I_L = 500mA		8	13	
					16	
		I_L = 750mA		15	25	
I_{GNDDO}	Ground Pin Current at Dropout (Note 5)	V_{IN} = 0.5V less than designed V_{OUT} (V_{OUT} ≥ 3.3V) I_O = 5mA		200	**500**	µA
I_{LIMIT}	Current Limit	V_{OUT} = 0V		1.1	1.5	A
		(Note 6)			**2**	
$\frac{\Delta V_O}{\Delta P_D}$	Thermal Regulation	(Note 7)		0.05	0.2	%/W
e_n	Output Noise Voltage (10Hz to 100kHz) I_L = 100mA	C_L = 10µF		400		µV RMS
		C_L = 100µF		260		

Electrical Characteristics (Continued)

MIC29372/MIC29373

Parameter	Conditions	Min	Typical	Max	Units
Reference Voltage		1.223 **1.210**	1.235	1.247 **1.260**	V V max
Reference Voltage	(Note 8)	**1.204**		**1.266**	V
Adjust Pin Bias Current			20	40 **60**	nA
Reference Voltage Temperature Coefficient	(Note 7)		20		ppm/°C
Adjust Pin Bias Current Temperature Coefficient			0.1		nA/°C
Error Comparator	**MIC29371/29373**				
Output Leakage Current	V_{OH} = 30V		0.01	1.00 **2.00**	µA
Output Low Voltage	V_{IN} = 4.5V I_{OL} = 250µA		150	250 **400**	mV
Upper Threshold Voltage	(Note 9)	40 **25**	60		mV
Lower Threshold Voltage	(Note 9)		75	95 **140**	mV
Hysteresis	(Note 9)		15		mV
Shutdown Input	**MIC29371/MIC29372**				
Input Logic Voltage Low (ON)			1.3	**0.7**	V
	High (OFF)	**2.0**			
Shutdown Pin Input Current	$V_{SHUTDOWN}$ = 2.4V		30	50 **100**	µA
	$V_{SHUTDOWN}$ = 30V		450	600 **750**	µA
Regulator Output Current in Shutdown	(Note 10)		3	10 **20**	µA

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions. The maximum allowable power dissipation is a function of the maximum junction temperature, $T_{J\,(MAX)}$, the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using: $P_{(MAX)} = (T_{J(MAX)} - T_A) / \theta_{JA}$. Exceeding the maximum allowable power dissipation will result in excessive die temperature, and the regulator will go into thermal shutdown.

Note 2: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 3: Regulation is measured at constant junction temperature using low duty cycle pulse testing. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

Note 4: Dropout Voltage is defined as the input to output differential at which the output voltage drops 100 mV below its nominal value measured at 1V differential. At low values of programmed output voltage, the minimum input supply voltage of 4.3V over temperature must be taken into account. The MIC2937A operates down to 2V of input at reduced output current at 25°C.

Note 5: Ground pin current is the regulator quiescent current. The total current drawn from the source is the sum of the load current plus the ground pin current.

Note 6: The MIC2937A features fold-back current limiting. The short circuit ($V_{OUT} = 0V$) current limit is less than the maximum current with normal output voltage.

Note 7: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 200mA load pulse at $V_{IN} = 20V$ (a 4W pulse) for T = 10ms.

Note 8: $V_{REF} \leq V_{OUT} \leq (V_{IN} - 1\ V)$, $4.3V \leq V_{IN} \leq 26V$, $5mA < I_L \leq 750\ mA$, $T_J \leq T_{J\ MAX.}$

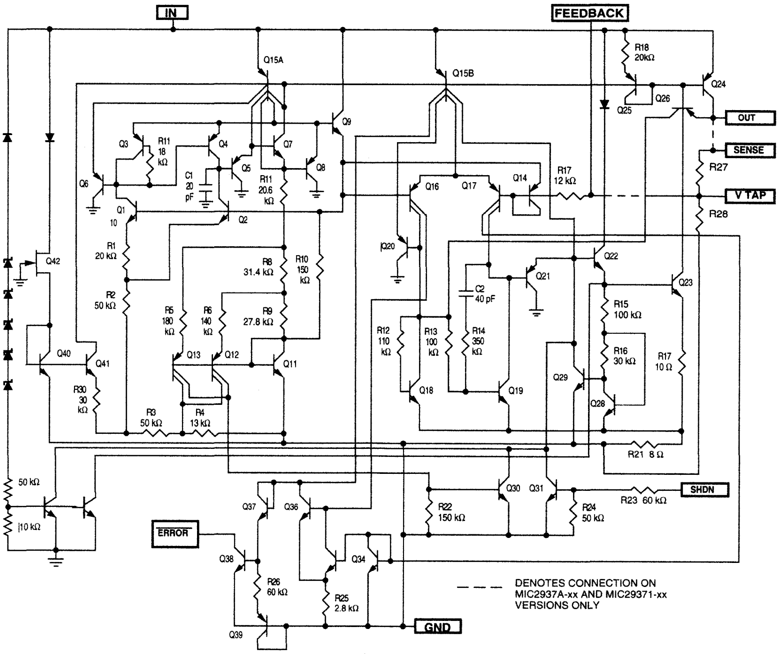
Note 9: Comparator thresholds are expressed in terms of a voltage differential at the Adjust terminal below the nominal reference voltage measured at 6V input (for a 5V regulator). To express these thresholds in terms of output voltage change, multiply by the error amplifier gain $= V_{OUT}/V_{REF} = (R1 + R2)/R2$. For example, at a programmed output voltage of 5V, the Error output is guaranteed to go low when the output drops by 95 mV x 5V/1.235 V = 384 mV. Thresholds remain constant as a percent of VOUT as VOUT is varied, with the dropout warning occurring at typically 5% below nominal, 7.7% guaranteed.

Note 10: Circuit of Figure 3 with R1 ≥ 150kΩ. $V_{SHUTDOWN} \geq 2V$ and $V_{IN} \leq 26V, V_{OUT} = 0$.

Note 11: When used in dual supply systems where the regulator load is returned to a negative supply, the output voltage must be diode clamped to ground.

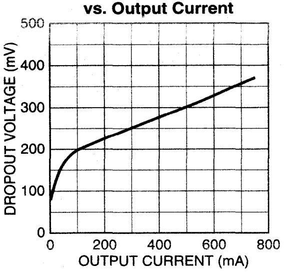
Note 12: Maximum positive supply voltage of 60V must be of limited duration (< 100ms) and duty cycle (≤ 1%). The maximum continuous supply voltage is 26V.

Schematic Diagram

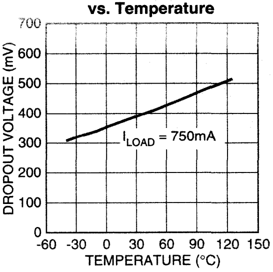


Typical Characteristics

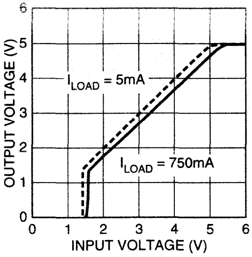
Dropout Voltage vs. Output Current



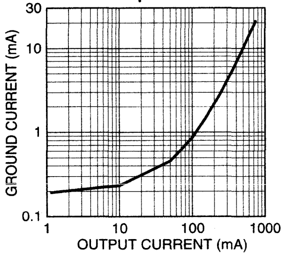
Dropout Voltage vs. Temperature



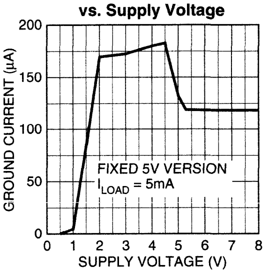
Dropout Characteristics



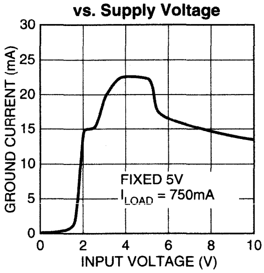
Ground Current vs. Output Current



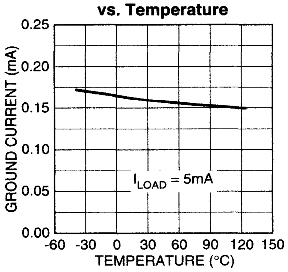
Ground Current vs. Supply Voltage



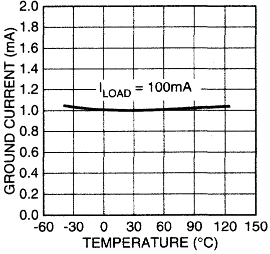
Ground Current vs. Supply Voltage



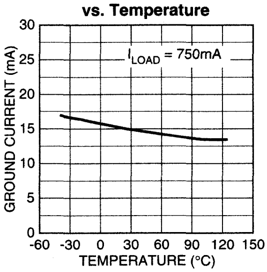
Ground Current vs. Temperature



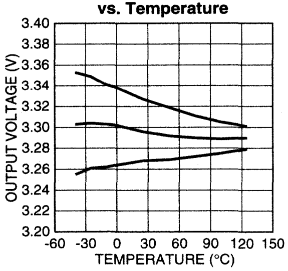
Ground Current vs. Temperature



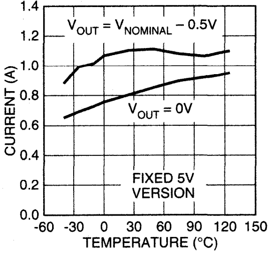
Ground Current vs. Temperature



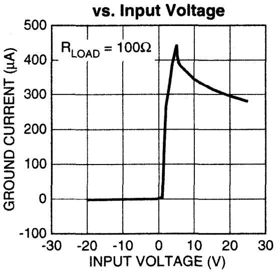
Fixed 3.3V Output Voltage vs. Temperature



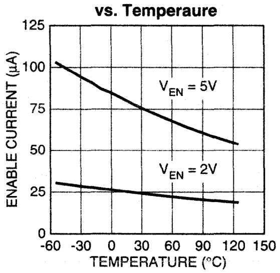
Short Circuit and Maximum Current vs. Temperature



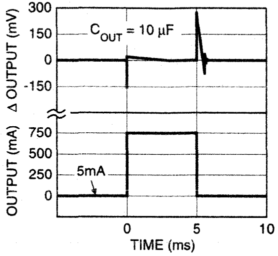
Ground Current vs. Input Voltage



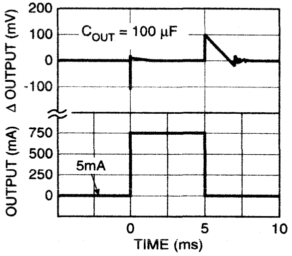
MIC29371/2 Shutdown Current vs. Temperaure



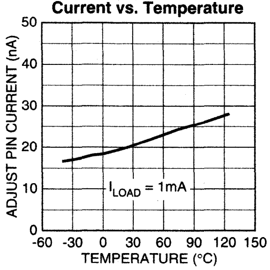
Load Transient



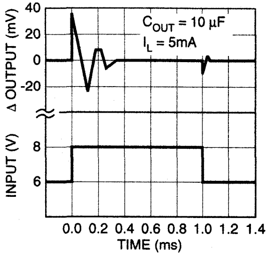
Load Transeint



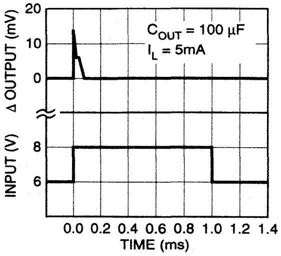
MIC29372/3 Adjust Pin Current vs. Temperature



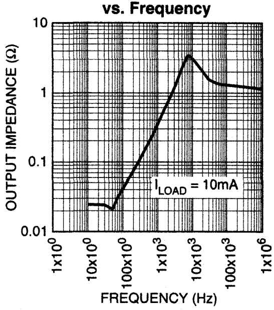
Line Transient



Line Transient



Output Impedance vs. Frequency



Applications Information

External Capacitors

A 10µF (or greater) capacitor is required between the MIC2937A output and ground to prevent oscillations due to instability. Most types of tantalum or aluminum electrolytics will be adequate; film types will work, but are costly and therefore not recommended. Many aluminum electrolytics have electrolytes that freeze at about –30°C, so solid tantalums are recommended for operation below –25°C. The important parameters of the capacitor are an effective series resistance of about 5Ω or less and a resonant frequency above 500kHz. The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for output stability. The capacitor can be reduced to 0.5µF for current below 10mA or 0.15µF for currents below 1 mA. Adjusting the MIC29372/29373 to voltages below 5V runs the error amplifier at lower gains so that more output capacitance is needed. For the worst-case situation of a 750mA load at 1.23V output (Output shorted to Adjust) a 22µF (or greater) capacitor should be used.

The MIC2937A/29371 will remain in regulation with a minimum load of 5mA. When setting the output voltage of the MIC29372/29373 version with external resistors, the current through these resistors may be included as a portion of the minimum load.

A 1µF capacitor should be placed from the input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the input.

Stray capacitance to the MIC29372/29373 Adjust terminal (pin 7) can cause instability. This may especially be a problem when using high value external resistors to set the output voltage. Adding a 100pF capacitor between Output and Adjust and increasing the output capacitor to at least 22µF will remedy this.

Error Detection Comparator Output (MIC29371/MIC29373)

A logic low output will be produced by the comparator whenever the MIC29371/29373 output falls out of regulation by more than approximately 5%. This figure is the comparator's built-in offset of about 75mV divided by the 1.235V reference voltage. (Refer to the block diagram on Page 1). This trip level remains "5% below normal" regardless of the programmed output voltage of the MIC29371/29373. For example, the error flag trip level is typically 4.75V for a 5V output or 11.4V for a 12V output. The out of regulation condition may be due either to low input voltage, extremely high input voltage, current limiting, or thermal limiting.

Figure 1 is a timing diagram depicting the $\overline{\text{ERROR}}$ signal and the regulated output voltage as the MIC29371/29373 input is ramped up and down. The $\overline{\text{ERROR}}$ signal becomes valid (low) at about 1.3V input. It goes high at about 5V input (the input voltage at which V_{OUT} = 4.75). Since the MIC29371/29373's dropout voltage is load-dependent (see curve in Typical Performance Characteristics), the input voltage trip point (about 5V) will vary with the load current. The output voltage trip point (approximately 4.75V) does not vary with load.

The error comparator has an NPN open-collector output which requires an external pull-up resistor. Depending on system requirements, this resistor may be returned to the 5V output or some other supply voltage. In determining a value for this resistor, note that while the output is rated to sink 250µA, this sink current adds to battery drain in a low battery condition. Suggested values range from 100k to 1MΩ. The resistor is not required if this output is unused.

Programming the Output Voltage (MIC29372/MIC29373)

The MIC29372/29373 may programmed for any output voltage between its 1.235V reference and its 26V maximum rating. An external pair of resistors is required, as shown in Figure 3.

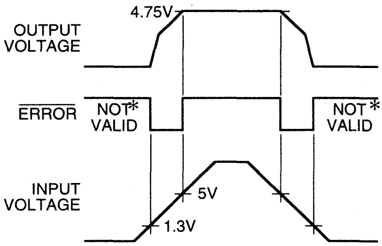
The complete equation for the output voltage is

$$V_{OUT} = V_{REF} \times \{ 1 + R_1/R_2 \} - |I_{FB}| R_1$$

where V_{REF} is the nominal 1.235 reference voltage and I_{FB} is the Adjust pin bias current, nominally 20nA. The minimum recommended load current of 1µA forces an upper limit of 1.2MΩ on the value of R_2, if the regulator must work with no load (a condition often found in CMOS in standby), I_{FB} will produce a –2% typical error in V_{OUT} which may be eliminated at room temperature by trimming R_1. For better accuracy, choosing R_2 = 100k reduces this error to 0.17% while increasing the resistor program current to 12µA. Since the MIC29372/29273 typically draws 100µA at no load with SHUTDOWN open-circuited, this is a negligible addition.

Reducing Output Noise

In reference applications it may be advantageous to reduce the AC noise present at the output. One method is to reduce the regulator bandwidth by increasing the size of the output capacitor. This is relatively inefficient, as increasing the capacitor from 1µF to 220µF only decreases the noise from 430µV to 160µV_{RMS} for a 100kHz bandwidth at 5V output. Noise can be reduced by a factor of four with the adjustable



* SEE APPLICATIONS INFORMATION

Figure 1. $\overline{\text{ERROR}}$ Output Timing

regulators with a bypass capacitor across R_1, since it reduces the high frequency gain from 4 to unity. Pick

$$C_{BYPASS} \cong \frac{1}{2\pi R_1 \cdot 200\ \text{Hz}}$$

or about 0.01µF. When doing this, the output capacitor must be increased to 10µF to maintain stability. These changes reduce the output noise from 430µV to $100\mu V_{RMS}$ for a 100 kHz bandwidth at 5V output. With the bypass capacitor added, noise no longer scales with output voltage so that improvements are more dramatic at higher output voltages.

Automotive Applications

The MIC2937A is ideally suited for automotive applications for a variety of reasons. It will operate over a wide range of input voltages with very low dropout voltages (40mV at light loads), and very low quiescent currents (100µA typical). These features are necessary for use in battery powered systems, such as automobiles. It is a "bulletproof" device with the ability to survive both reverse battery (negative transients up to 20V below ground), and load dump (positive transients up to 60V) conditions. A wide operating temperature range with low temperature coefficients is yet another reason to use these versatile regulators in automotive designs.

Typical Applications

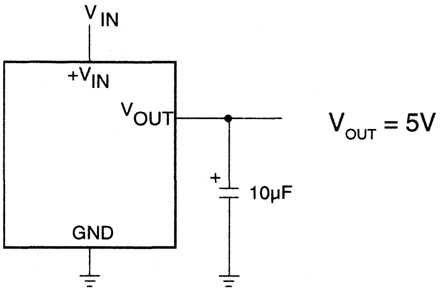
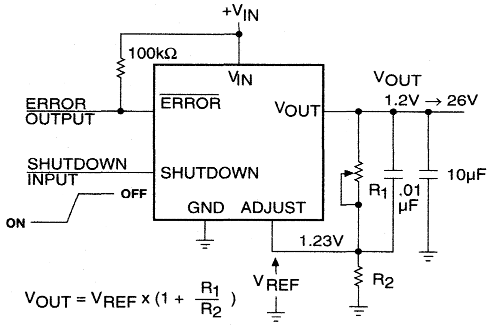
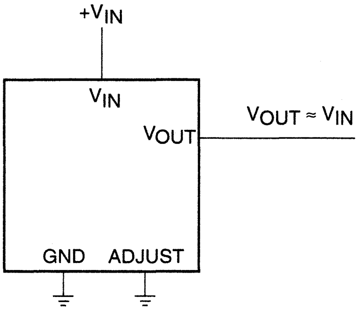


Figure 2. MIC2937A-5.0 Fixed +5V Regulator



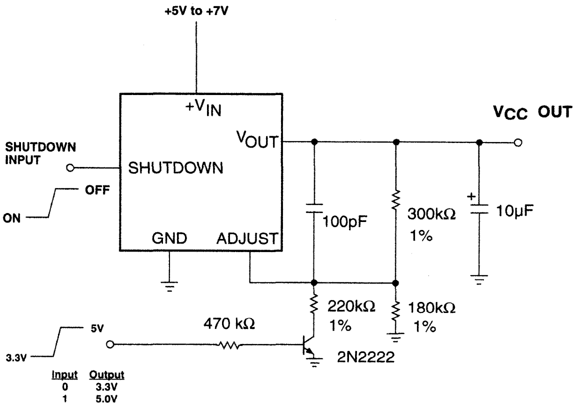
ERROR OUTPUT ON MIC29373 ONLY
SHUTDOWN INPUT ON MIC29372 ONLY

Figure 3. MIC29372/29373 Adjustable Regulator



*MINIMUM INPUT-OUTPUT VOLTAGE RANGES FROM 40mV TO 400mV, DEPENDING ON LOAD CURRENT.

Figure 4. MIC29372/29373 Wide Input Voltage Range Current Limiter



SHUTDOWN PIN LOW= ENABLE OUTPUT. Q1 ON = 3.3V, Q1 OFF = 5.0V.

Figure 5. MIC29372 5.0V or 3.3V Selectable Regulator with Shutdown.

MIC2940A/2941A

1.25A Low-Dropout Voltage Regulator

Preliminary Information

General Description

The MIC2940A and MIC2941A are "bulletproof" efficient voltage regulators with very low dropout voltage (typically 40mV at light loads and 350mV at 1A), and low quiescent current (240µA typical). The quiescent current of the MIC2940A increases only slightly in dropout, thus prolonging battery life. Key MIC2940A features include protection against reversed battery, fold-back current limiting, and automotive "load dump" protection (60V positive transient).

The MIC2940 is available in both fixed voltage (3.3V, 5V, and 12V) and adjustable voltage configurations. The MIC2940A-xx devices are three pin fixed voltage regulators. A logic-compatible shutdown input is provided on the adjustable MIC2941A, which enables the regulator to be switched on and off.

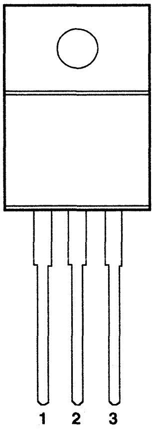
Features

- High output voltage accuracy
- Guaranteed 1.25A output
- Low quiescent current
- Low dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Current and thermal limiting
- Input can withstand –20V reverse battery and +60V positive transients
- Logic-controlled electronic shutdown
- Output programmable from 1.24V to 26V(MIC2941A)
- Available in TO-220, TO-263, TO-220-5, and TO-263-5 packages.

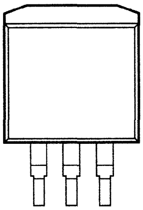
Applications

- Battery Powered Equipment
- Cellular Telephones
- Laptop, Notebook, and Palmtop Computers
- PCMCIA V_{CC} and V_{PP} Regulation/Switching
- Bar Code Scanners
- Automotive Electronics
- SMPS Post-Regulator/ DC to DC Modules
- Voltage Reference
- High Efficiency Linear Power Supplies

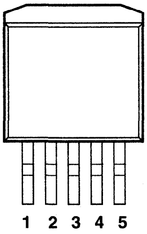
Pin Configuration



TO-220 Package
(MIC2940A-xxBT)



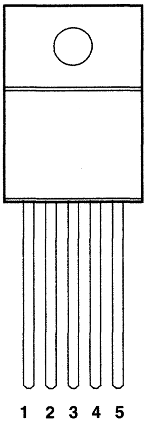
TO-263 Package
(MIC2940A-xxBU)



TO-263-5 Package
(MIC2941ABU)

MIC2941A Pinout

1) Adjust
2) Shutdown
3) Ground
4) Input
5) Output



TO-220-5 Package
(MIC2941ABT)

The Tab is Ground on TO-220 and TO-263 packages

Ordering Information

Part Number	Voltage	Temperature Range*	Package
MIC2940A-3.3BT	3.3	–40°C to +125°C	TO-220
MIC2940A-3.3BU	3.3	–40°C to +125°C	TO-263
MIC2940A-5.0BT	5.0	–40°C to +125°C	TO-220
MIC2940A-5.0BU	5.0	–40°C to +125°C	TO-263
MIC2940A-12BT	12	–40°C to +125°C	TO-220
MIC2940A-12BU	12	–40°C to +125°C	TO-263
MIC2941ABT	Adj	–40°C to +125°C	TO-220-5
MIC2941ABU	Adj	–40°C to +125°C	TO-263-5

* Junction temperatures

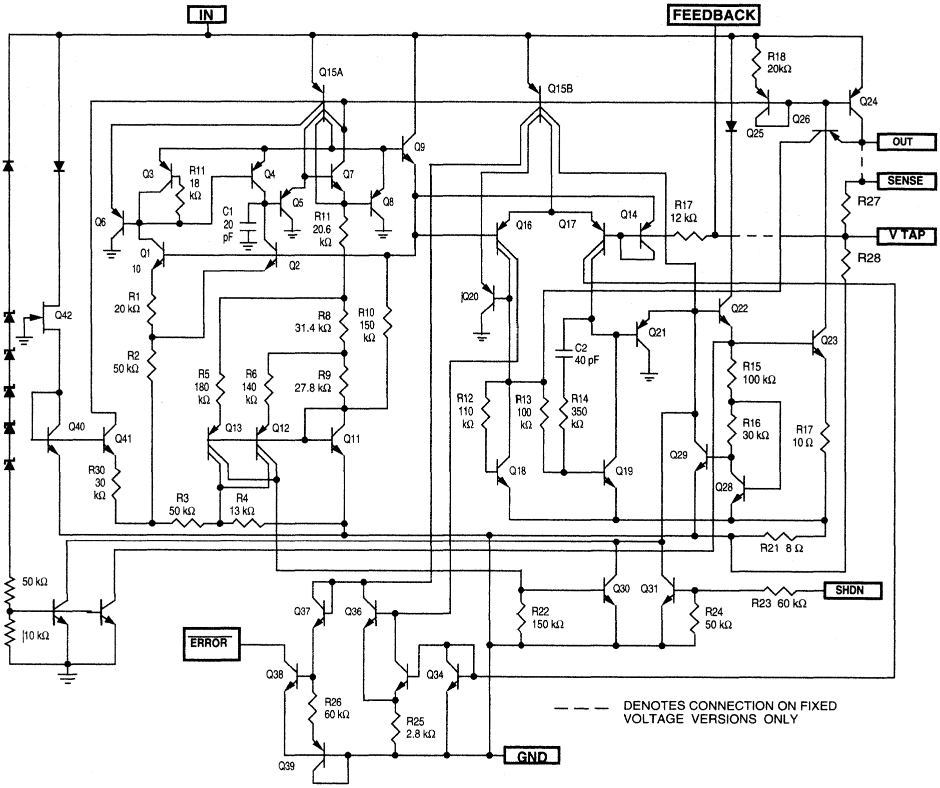
Absolute Maximum Ratings

If Military/Aerospace specified devices are required, contact your local Micrel representative/distributor for availability and specifications.

Power Dissipation (Note 1)	Internally Limited
Lead Temperature (Soldering, 5 seconds)	260°C
Storage Temperature Range	–65°C to +150°C
Operating Junction Temperature Range	–40°C to +125°C
TO-220 θ_{JC}	2 °C/W
TO-263 θ_{JC}	2 °C/W
Input Supply Voltage	–20V to +60V
Operating Input Supply Voltage	2V† to 26V
Adjust Input Voltage (Notes 9 and 10)	–1.5V to +26V
Shutdown Input Voltage	–0.3V to +30V
Error Comparator Output Voltage	–0.3V to +30V

† Across the full operating temperature, the minimum input voltage range for full output current is 4.3V to 26V. Output will remain in-regulation at lower output voltages and low current loads down to an input of 2V at 25°C.

Schematic Diagram



— — — DENOTES CONNECTION ON FIXED VOLTAGE VERSIONS ONLY

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C and limits in **boldface** apply over the full operating temperature range. Unless otherwise specified, $V_{IN} = V_{OUT}$ + 1V, I_L = 1000mA, C_L = 10µF. The MIC2941A is programmed to output 5V and has $V_{SHUTDOWN} \leq 0.6V$.

Symbol	Parameter	Conditions	Min	Typical	Max	Units
V_O	Output Voltage Accuracy		–1		1	%
			–2		**2**	
		5 mA ≤ I_L ≤ 1A	**–2.5**		**2.5**	
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temperature Coef.	(Note 2)		**20**	**100**	ppm/°C
$\frac{\Delta V_O}{V_O}$	Line Regulation	$V_{IN} = V_{OUT}$ + 1V to 26V		0.03	0.10	%
					0.40	
$\frac{\Delta V_O}{V_O}$	Load Regulation	I_L = 5mA to 1A (Note 3)		0.04	0.16	%
					0.20	
$V_{IN} - V_O$	Dropout Voltage (Note 4)	I_L = 5mA		60	150	mV
					180	
		I_L = 250mA		200	250	
					320	
		I_L = 1000mA		350	450	
					600	
		I_L = 1250mA		400	600	
I_{GND}	Ground Pin Current (Note 5)	I_L = 5mA		240	350	µA
					500	
		I_L = 250mA		3	4.5	mA
					6	
		I_L = 1000mA		22	35	
					45	
		I_L = 1250mA		35	70	
I_{GNDDO}	Ground Pin Current at Dropout (Note 5)	V_{IN} = 0.5V less than designed V_{OUT} ($V_{OUT} \geq 3.3V$) I_L = 5mA		330	**600**	µA
I_{LIMIT}	Current Limit	V_{OUT} = 0V (Note 6)		1.6	2.4	A
					3	
$\frac{\Delta V_O}{\Delta P_D}$	Thermal Regulation	(Note 7)		0.05	0.2	%/W
e_n	Output Noise Voltage (10Hz to 100kHz) I_L = 100mA	C_L = 10µF		400		µV RMS
		C_L = 33µF		260		

Electrical Characteristics (MIC2941A Only)

Parameter	Conditions	Min	Typical	Max	Units
Reference Voltage		1.223 **1.210**	1.235	1.247 **1.260**	V V max
Reference Voltage		**1.204**		**1.266**	V
Adjust Pin Bias Current			20	40 **60**	nA
Reference Voltage Temperature Coefficient	(Note 8)		20		ppm/°C
Adjust Pin Bias Current Temperature Coefficient			0.1		nA/°C
Shutdown Input					
Input Logic Voltage			1.3		V
	Low (ON)			**0.7**	
	High (OFF)	**2.0**			
Shutdown Pin Input Current	$V_{SHUTDOWN} = 2.4V$		30	50 **100**	µA
	$V_{SHUTDOWN} = 26V$		450	600 **750**	µA
Regulator Output Current in Shutdown	(Note 10)		3	30 **60**	µA

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions. The maximum allowable power dissipation is a function of the maximum junction temperature, $T_{J\,(MAX)}$, the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using: $P_{(MAX)} = (T_{J(MAX)} - T_A) / \theta_{JA}$. Exceeding the maximum allowable power dissipation will result in excessive die temperature, and the regulator will go into thermal shutdown.

Note 2: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 3: Regulation is measured at constant junction temperature using low duty cycle pulse testing. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

Note 4: Dropout Voltage is defined as the input to output differential at which the output voltage drops 100 mV below its nominal value measured at 1V differential. At low values of programmed output voltage, the minimum input supply voltage of 4.3V over temperature must be taken into account.

Note 5: Ground pin current is the regulator quiescent current. The total current drawn from the source is the sum of the load current plus the ground pin current.

Note 6: The MIC2940A features fold-back current limiting. The short circuit ($V_{OUT} = 0V$) current limit is less than the maximum current with normal output voltage.

Note 7: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 200mA load pulse at $V_{IN} = 20V$ (a 4W pulse) for T = 10ms.

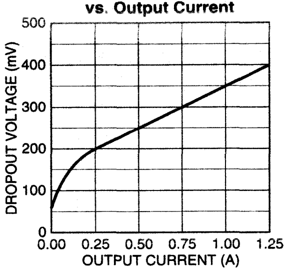
Note 8: $V_{REF} \le V_{OUT} \le (V_{IN} - 1\ V)$, $4.3V \le V_{IN} \le 26V$, $5mA < I_L \le 1.25A$, $T_J \le T_{J\,MAX}$.

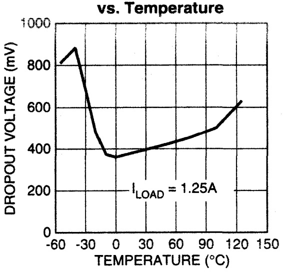
Note 9: Circuit of Figure 3 with R1 ≥ 150kΩ. $V_{SHUTDOWN} \ge 2\ V$ and $V_{IN} \le 26\ V, V_{OUT} = 0$.

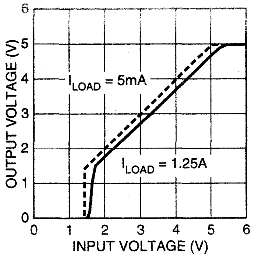
Note 10: When used in dual supply systems where the regulator load is returned to a negative supply, the output voltage must be diode clamped to ground.

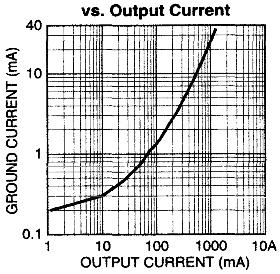
Note 11: Maximum positive supply voltage of 60 V must be of limited duration (< 100 ms) and duty cycle (≤ 1%). The maximum continuous supply voltage is 26V.

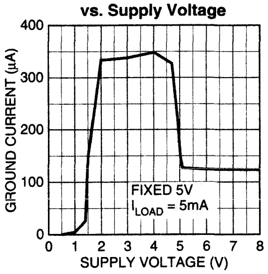
Typical Characteristics

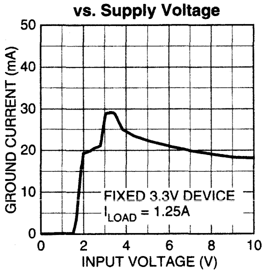

Dropout Voltage vs. Output Current

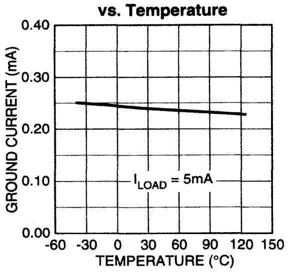

Dropout Voltage vs. Temperature

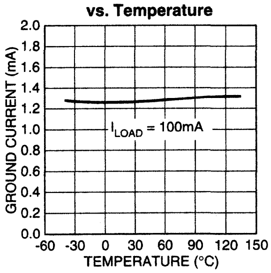

Dropout Characteristics

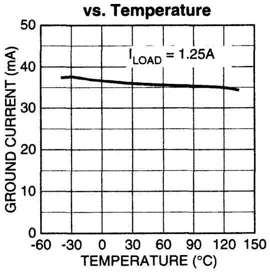

Ground Current vs. Output Current

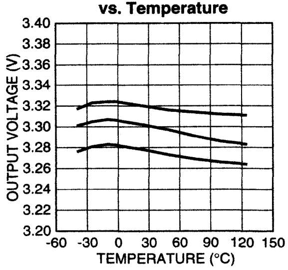

Ground Current vs. Supply Voltage

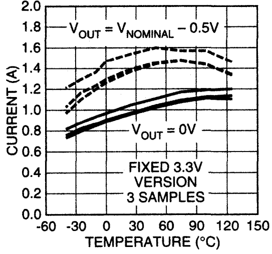

Ground Current vs. Supply Voltage

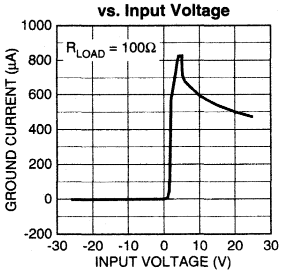

Ground Current vs. Temperature

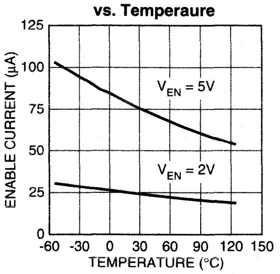

Ground Current vs. Temperature


Ground Current vs. Temperature

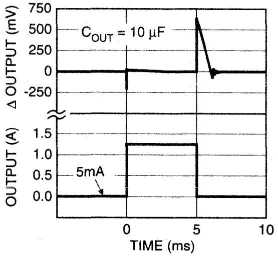

Fixed 3.3V Output Voltage vs. Temperature


Short Circuit and Maximum Current vs. Temperature

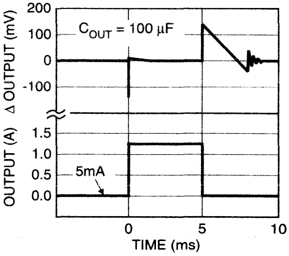

Ground Current vs. Input Voltage



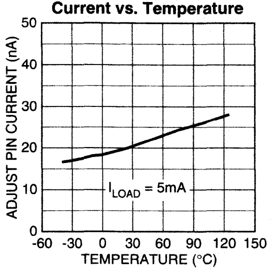
MIC29401/2 Shutdown Current vs. Temperaure



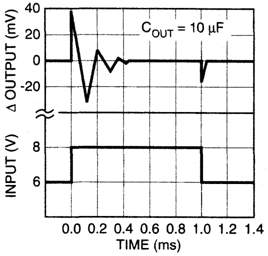
Load Transient



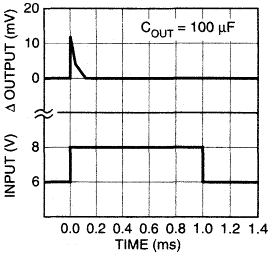
Load Transient



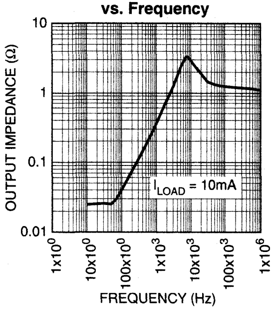
MIC29402/3 Adjust Pin Current vs. Temperature



Line Transient



Line Transient



Output Impedance vs. Frequency

Applications Information

External Capacitors

A 10µF (or greater) capacitor is required between the MIC2940A output and ground to prevent oscillations due to instability. Most types of tantalum or aluminum electrolytics will be adequate; film types will work, but are costly and therefore not recommended. Many aluminum electrolytics have electrolytes that freeze at about –30°C, so solid tantalums are recommended for operation below –25°C. The important parameters of the capacitor are an effective series resistance of about 5Ω or less and a resonant frequency above 500kHz. The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for output stability. The capacitor can be reduced to 3.3µF for current below 100mA or 2.2µF for currents below 10 mA. Adjusting the MIC2941A to voltages below 5V runs the error amplifier at lower gains so that more output capacitance is needed. For the worst-case situation of a 1.25A load at 1.23V output (Output shorted to Adjust) a 22µF (or greater) capacitor should be used.

The MIC2940A will remain stable and in regulation with load currents ranging from 5mA on up to the full 1.25A rating. The external resistors of the MIC2941A version may be scaled to draw this minimum load current.

A 0.22µF capacitor should be placed from the MIC2940A input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the input.

Stray capacitance to the MIC2941A Adjust terminal can cause instability. This may especially be a problem when using high value external resistors to set the output voltage. Adding a 100pF capacitor between Output and Adjust and increasing the output capacitor to at least 22µF will remedy this.

Programming the Output Voltage (MIC2941A)

The MIC2941A may be programmed for any output voltage between its 1.235V reference and its 26V maximum rating. An external pair of resistors is required, as shown in Figure 3.

The complete equation for the output voltage is

$$V_{OUT} = V_{REF} \times \{ 1 + R_1/R_2 \} - |I_{FB}| R_1$$

where V_{REF} is the nominal 1.235 reference voltage and I_{FB} is the Adjust pin bias current, nominally 20nA. The minimum recommended load current of 1 µA forces an upper limit of 1.2MΩ on the value of R_2, if the regulator must work with no load (a condition often found in CMOS in standby), I_{FB} will produce a –2% typical error in V_{OUT} which may be eliminated at room temperature by trimming R_1. For better accuracy, choosing R_2 = 100kΩ reduces this error to 0.17% while increasing the resistor program current to 12 µA. Since the MIC2941A typically draws 100 µA at no load with SHUTDOWN open-circuited, this is a negligible addition.

Reducing Output Noise

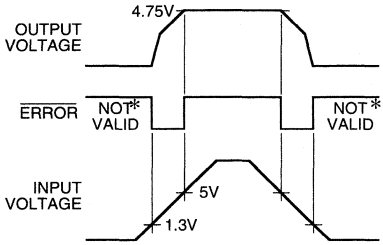
In reference applications it may be advantageous to reduce the AC noise present at the output. One method is to reduce the regulator bandwidth by increasing the size of the output capacitor. This is relatively inefficient, as increasing the capacitor from 1 µF to 220 µF only decreases the noise from 430µV to 160µV_{RMS} for a 100kHz bandwidth at 5V output. Noise can be reduced by a factor of four with the MIC2941A by adding a bypass capacitor across R_1, since it reduces the high frequency gain from 4 to unity. Pick

$$C_{BYPASS} \cong \frac{1}{2\pi R_1 \bullet 200\ \text{Hz}}$$

or about 0.01 µF. When doing this, the output capacitor must be increased to 22 µF to maintain stability. These changes reduce the output noise from 430 µV to 100 µV rms for a 100 kHz bandwidth at 5V output. With the bypass capacitor added, noise no longer scales with output voltage so that improvements are more dramatic at higher output voltages.

Automotive Applications

The MIC2940A is ideally suited for automotive applications for a variety of reasons. It will operate over a wide range of input voltages with very low dropout voltages (40mV at light loads), and very low quiescent currents (240µA typical). These features are necessary for use in battery powered systems, such as automobiles. It is a "bulletproof" device with the ability to survive both reverse battery (negative transients up to 20V below ground), and load dump (positive transients up to 60V) conditions. A wide operating temperature range with low temperature coefficients is yet another reason to use these versatile regulators in automotive designs.



* SEE APPLICATIONS INFORMATION

Figure 1. $\overline{\text{ERROR}}$ Output Timing

Typical Applications

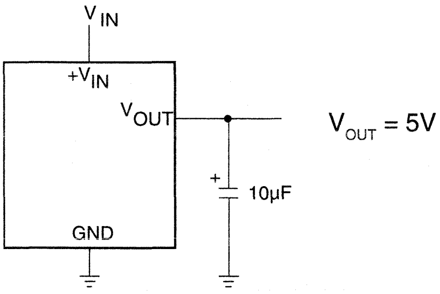


Figure 2. MIC2940A-5.0 Fixed +5V Regulator

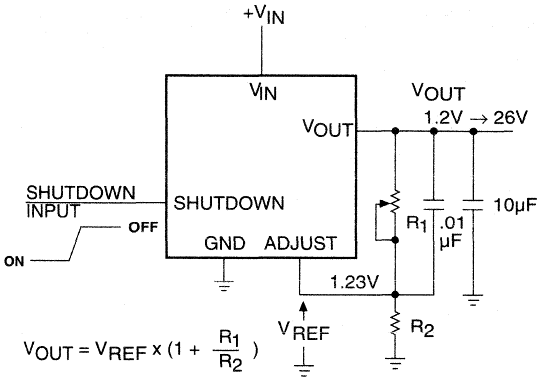
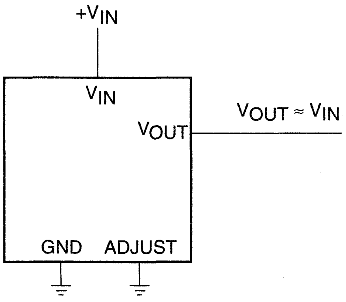
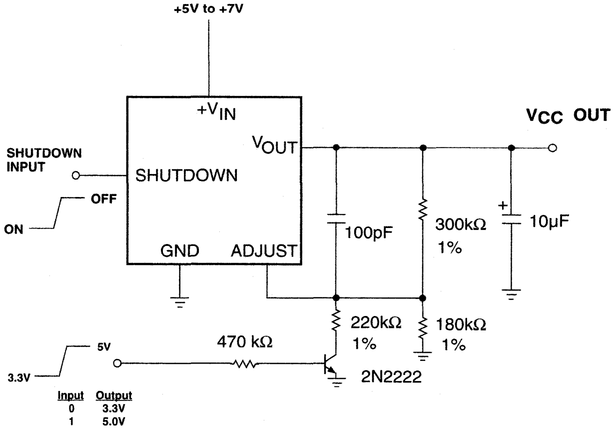


Figure 3. MIC2941A Adjustable Regulator



*MINIMUM INPUT-OUTPUT VOLTAGE RANGES FROM 40mV TO 400mV, DEPENDING ON LOAD CURRENT.

Figure 4. MIC2941A Wide Input Voltage Range Current Limiter



ADJUST PIN LOW= ENABLE OUTPUT. Q1 ON = 3.3V, Q1 OFF = 5.0V.

Figure 5. MIC2941A 5.0V or 3.3V Selectable Regulator with Shutdown.

LP2950/2951

100mA Low-Dropout Voltage Regulator

General Description

The LP2950 and LP2951 are micropower voltage regulators with very low dropout voltage (typically 40mV at light loads and 380mV at 100mA), and very low quiescent current (75µA typical). The quiescent current of the LP2950/LP2951 increases only slightly in dropout, thus prolonging battery life. This feature, among others, makes the LP2950 and LP2951 ideally suited for use in battery-powered systems.

Available in a 3-Pin TO-92 package, the LP2950 is pin-compatible with the older 5V regulators. Additional system functions, such as programmable output voltage and logic-controlled shutdown, are available in the 8-pin DIP and 8-pin SOIC versions of the LP2951.

Applications

- Automotive Electronics
- Voltage Reference
- Avionics

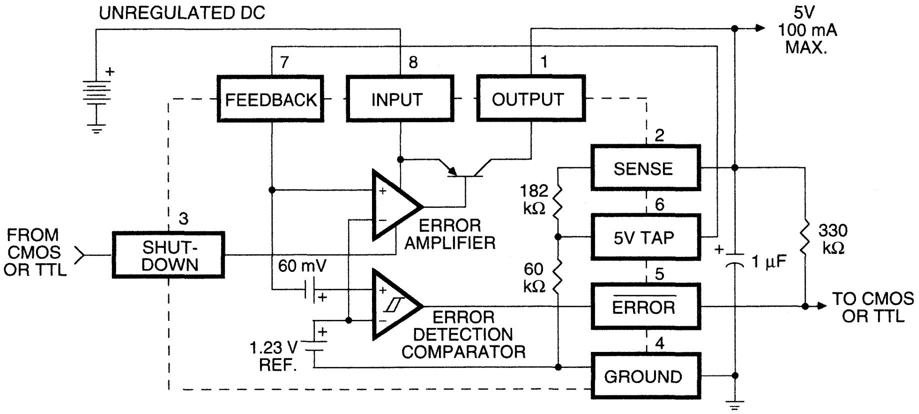
Features

- High accuracy 5V, guaranteed 100 mA output
- Extremely low quiescent current
- Low dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Use as regulator or reference
- Needs only 1µF for stability
- Current and thermal limiting

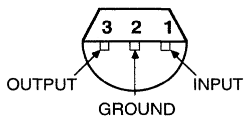
LP2951 Versions Only

- Error flag warns of output dropout
- Logic-controlled electronic shutdown
- Output programmable from 1.24 to 29V

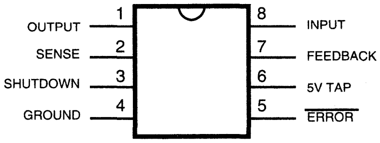
Block Diagram and Pin Configurations



LP2950 and LP2951 Block Diagram (Pin Numbers Refer to LP2951)



TO-92 Plastic Package Bottom View (BZ)



DIP and SO Packages (BN and BM)

See MIC2950 for a part with 1) higher output (150 mA), 2) transient protection (60V), and 3) reverse input protection to –20V)

Additional features available with the LP2951 also include an error flag output that warns of a low output voltage, which is often due to failing batteries on the input. This may also be used as a power-on reset. A logic-compatible shutdown input is also available which enables the regulator to be switched on and off. This part may also be pin-strapped for a 5V output, or programmed from 1.24V to 29V with the use of two external resistors.

The LP2950 is available as either an -02 or -03 version. The -02 and -03 versions are guaranteed for junction temperatures from –40°C to +125°C; the -02 version has a tighter output and reference voltage specification range over temperature. The LP2951 is available as an -01, -02 , or -03 version. The -01 version is guaranteed for junction temperatures from –55°C to +150°C, and has slightly different specifications limits over the full operating temperature range.

The LP2950 and LP2951 have a tight initial tolerance (0.5% typical), a very low output voltage temperature coefficient which allows use as a low-power voltage reference, and extremely good load and line regulation (0.05% typical). This greatly reduces the error in the overall circuit, and is the result of careful design techniques and process control.

Ordering Information

Part Number	Voltage	Temperature Range*	Package	Accuracy
LP2950-02BZ	5.0V	–40°C to +125°C	3-Pin TO-92 plastic	0.5%
LP2950-03BZ	5.0V	–40°C to +125°C	3-Pin TO-92 plastic	1.0%
LP2951-02BM	5.0V	–40°C to +125°C	8-Pin SOIC	0.5%
LP2951-03BM	5.0V	–40°C to +125°C	8-Pin SOIC	1.0%
LP2951-02BN	5.0V	–40°C to +125°C	8-Pin Plastic DIP	0.5%
LP2951-03BN	5.0V	–40°C to +125°C	8-Pin Plastic DIP	1.0%
LP2951-4.8BM	4.85V	–40°C to +125°C	8-Pin SOIC	1.0%

* Junction temperatures

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, contact your local Micrel representative/distributor for availability and specifications.

Power dissipation	Internally Limited
Lead Temperature (Soldering, 5 seconds)	260°C
Storage Temperature Range	–65°C to +150°C
Operating Junction Temperature Range (Note 8)	
LP2951-01	–55°C to +150°C
LP2950-02/LP2950-03, LP2951-02/LP2951-03	–40°C to +125°C
Input Supply Voltage	–0.3V to +30V
Feedback Input Voltage (Notes 9 and 10)	–1.5V to +30V
Shutdown Input Voltage (Note 9)	–0.3V to +30V
Error Comparator Output Voltage (Note 9)	–0.3V to +30V

ESD Rating is to be determined.

Electrical Characteristics **Note 1** T_A = 25°C except as noted.

Parameter	Condition	Min	Typ	Max	Units
Output Voltage T_J = 25°C	LP2951-01 (±0.5%)	4.975	5.000	5.025	V
	LP295x-02 (±0.5%)	4.975	5.000	5.025	V
	LP295x-03 (±1%)	4.950	5.000	5.050	V
	LP2951-4.8 (±1%)	4.802	4.850	4.899	V
Output Voltage −25°C ≤ T_J ≤ +85°C	LP295x-02 (±0.5%)	4.950		5.050	V
	LP295x-03 (±1%)	4.925		5.075	V
	LP2951-4.8 (±1%)	4.777		4.872	V
Output Voltage Over Full Temperature Range	LP2951-01 (±0.5%), –55°C to +160°C	**4.940**		**5.060**	V
	LP295x-02 (±0.5%), –40°C to +125°C	**4.940**		**5.060**	V
	LP295x-03 (±1%), –40°C to +125°C	**4.900**		**5.100**	V
	LP2951-4.8 (±1%), –40°C to +125°C	**4.753**		**4.947**	V
Output Voltage Over Load Variation	LP2951-01 (±0.5%), 100µA ≤ I_L ≤ 100mA, $T_J \leq T_{J(max)}$	**4.925**		**5.075**	V
	LP295x-02 (±0.5%), 100µA ≤ I_L ≤ 100mA, $T_J \leq T_{J(max)}$	**4.930**		**5.070**	V
	LP295x-03 (±1%), 100µA ≤ I_L ≤ 100mA, $T_J \leq T_{J(max)}$	**4.880**		**5.120**	V
	LP2951-4.8 (±1%), 100µA ≤ I_L ≤ 100mA, $T_J \leq T_{J(max)}$	**4.733**		**4.967**	V
Output Voltage Temperature Coefficient	LP2951-01 (±0.5%), Note 12		**20**	**120**	ppm/°C
	LP295x-02 (±0.5%), Note 12		**20**	**100**	ppm/°C
	LP295x-03 (±1%), Note 12		**50**	**150**	ppm/°C
	LP2951-4.8 (±1%), Note 12		**50**	**150**	ppm/°C
Line Regulation	LP2951-01 (±0.5%), Notes 14, 15		0.03	0.10 **0.50**	% %
	LP295x-02 (±0.5%), Notes 14, 15		0.03	0.10 **0.20**	% %
	LP295x-03 (±1%), Notes 14, 15		0.04	0.20 **0.40**	% %
	LP2951-4.8 (±1%), Notes 14, 15		0.04	0.20 **0.40**	% %
Load Regulation	LP2951-01 (±0.5%), Note 14, 100µA ≤ I_L ≤ 100mA		0.04	0.10 **0.30**	% %
	LP295x-02 (±0.5%), Note 14, 100µA ≤ I_L ≤ 100mA		0.04	0.10 **0.20**	% %
	LP295x-03 (±1%), Note 14, 100µA ≤ I_L ≤ 100mA		0.10	0.20 **0.30**	% %
	LP2951-4.8 (±1%), Note 14, 100µA ≤ I_L ≤ 100mA		0.10	0.20 **0.30**	% %
Dropout Voltage	Note 5, I_L = 100µA		50	80 **150**	mV mV
	Note 5, I_L = 100mA		380	450 **600**	mV mV
Ground Current	I_L = 100µA		100	150 **200**	µA µA
	I_L = 100mA		8	12 **14**	mA mA
Dropout Current	V_{IN} = 4.5V, I_L = 100µA		180	250 **310**	µA µA

Parameter	Condition	Min	Typ	Max	Units
Current Limit	V_{OUT} = 0V		160	200 **220**	mA mA
Thermal Regulation	Note 13		0.05	0.20	%/W
Output Noise	10Hz to 100kHz, C_L = 1μF		430		μV_{RMS}
	10Hz to 100kHz, C_L = 200μF		160		μV_{RMS}
	10Hz to 100kHz, C_L = 3.3μF, 0.01μF bypass Feedback to Output		100		μV_{RMS}
Reference Voltage	LP2951-01 (±0.5%)	1.220 **1.200**	1.235	1.250 **1.260**	V V
	LP295x-02 (±0.5%)	1.220 **1.200**	1.235	1.250 **1.260**	V V
	LP295x-03 (±1%)	1.210 **1.200**	1.235	1.260 **1.270**	V V
	LP2951-4.8 (±1%)	1.210 **1.200**	1.235	1.260 **1.270**	V V
Reference Voltage	LP2951-01 (±0.5%), Note 7	**1.190**		**1.270**	V
	LP295x-02 (±0.5%), Note 7	**1.190**		**1.270**	V
	LP295x-03 (±1%), Note 7	**1.185**		**1.285**	V
	LP2951-4.8 (±1%), Note 7	**1.185**		**1.285**	V
Feedback Bias Current			20	40 **60**	nA nA
Reference Voltage	LP2951-01 (±0.5%), Note 12		20		ppm/°C
	LP295x-02 (±0.5%), Note 12		20		ppm/°C
	LP295x-03 (±1%), Note 12		50		ppm/°C
	LP2951-4.8 (±1%), Note 12		50		ppm/°C
Feedback Bias Current Temperature Coefficient			0.1		nA/°C
Output Leakage Current	V_{OH} = 30V		0.01	1.00 **2.00**	μA μA
Output Low Voltage (Flag)	V_{IN} = 4.5V, I_{OL} = 200μA		150	250 **400**	mV mV
Upper Threshold Voltage	Note 6	40 **25**	60	40	mV mV
Lower Threshold Voltage	Note 6		75	95 **140**	mV mV
Hysteresis	Note 6		15		mV
Input Logic Voltage	LP2951-01 (±0.5%) Low High	 **2.0**	1.3	 **0.6**	V V V
	LP295x-02 (±0.5%) Low High	 **2.0**	1.3	 **0.7**	V V V
	LP295x-03 (±1%) Low High	 **2.0**	1.3	 **0.7**	V V V
	LP2951-4.8 (±1%) Low High	 **2.0**	1.3	 **0.7**	V V V

Parameter	Condition	Min	Typ	Max	Units
Shutdown Input Current	$V_{SHUTDOWN} = 2.4V$		30	50 **100**	µA µA
	$V_{SHUTDOWN} = 30V$		450	600 **750**	µA µA
Regulator Output Current in Shutdown	Note 11		3	10 **20**	µA µA

Note 1: Boldface limits apply at temperature extremes.

Note 2: Unless otherwise specified all limits guaranteed for $T_J = 25°C$, $V_{IN} = 6V$, $I_L = 100\mu A$ and $C_L = 1\mu F$. Additional conditions for the 8-pin versions are Feedback tied to 5V Tap and Output tied to Output Sense ($V_{OUT} = 5V$) and $V_{SHUTDOWN} \le 0.8V$.

Note 3: Guaranteed and 100% production tested.

Note 4: Guaranteed but not 100% production tested. These limits are not used to calculate outgoing AQL levels.

Note 5: Dropout voltage is defined as the input to output differential at which the output voltage drops 100mV below its nominal value measured at 1V differential. At very low values of programmed output voltage, the minimum input supply voltage of 2V (2.3V over temperature) must be taken into account.

Note 6: Comparator thresholds are expressed in terms of a voltage differential at the Feedback terminal below the nominal reference voltage measured at 6V input. To express these thresholds in terms of output voltage change, multiply by the error amplifier gain = $V_{OUT} / V_{REF} = (R1 + R2)/R2$. For example, at a programmed output voltage of 5V, the Error output is guaranteed to go low when the output drops by 95mV x 5V/1.235V = 384mV. Thresholds remain constant as a percent of V_{OUT} as V_{OUT} is varied, with the dropout warning occurring at typically 5% below nominal, 7.5% guaranteed.

Note 7: $V_{REF} \le V_{OUT} \le (V_{IN} - 1\ V)$, $2.3V \le V_{IN} \le 30V$, $100\mu A < I_L \le 100mA$, $T_J \le T_{JMAX}$.

Note 8: The junction-to-ambient thermal resistance of the TO-92 package is 180°C/W with 0.4" leads and 160°C/W with 0.25" leads to a PC board. The thermal resistance of the 8-pin DIP package is 105°C/W junction-to-ambient when soldered directly to a PC board. Junction-to-ambient thermal resistance for the SOIC (M) package is 160°C/W.

Note 9: May exceed input supply voltage.

Note 10: When used in dual-supply systems where the output terminal sees loads returned to a negative supply, the output voltage should be diode-clamped to ground.

Note 11: $V_{SHUTDOWN} \ge 2V$, $V_{IN} \le 30\ V$, $V_{OUT} = 0$, with Feedback pin tied to 5V Tap.

Note 12: Output or reference voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

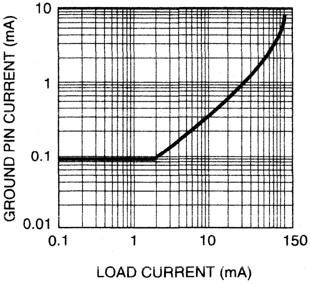
Note 13: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 50mA load pulse at $V_{IN} = 30V$ (1.25W pulse) for t = 10ms.

Note 14: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered in the specification for thermal regulation.

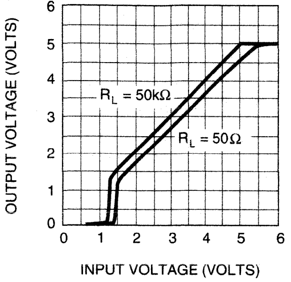
Note 15: Line regulation for the LP2951 is tested at 150°C for $I_L = 1mA$. For $I_L = 100\mu A$ and $T_J = 125°C$, line regulation is guaranteed by design to 0.2%. See Typical Performance Characteristics for line regulation versus temperature and load current.

Typical Performance Characteristics

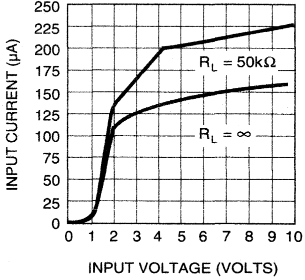
Quiescent Current



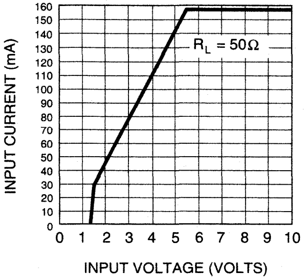
Dropout Characteristics



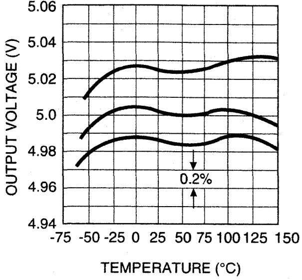
Input Current



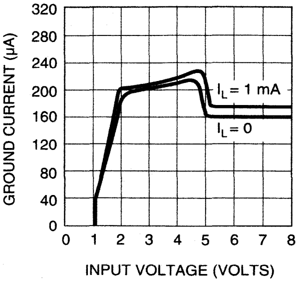
Input Current



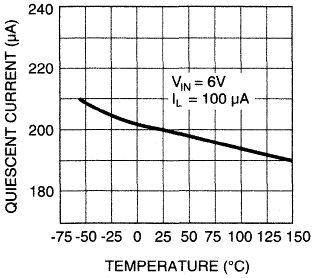
Output Voltage vs. Temperature of 3 Representative Units



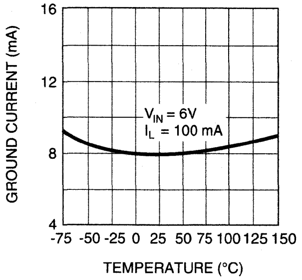
Ground Current



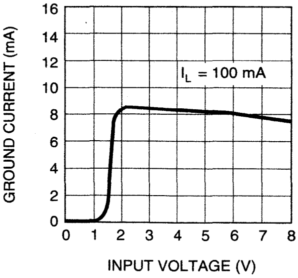
Quiescent Current



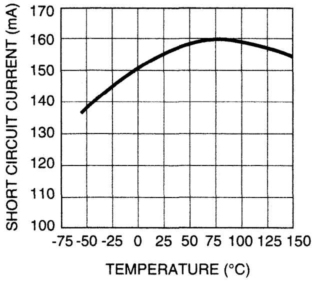
Ground Current



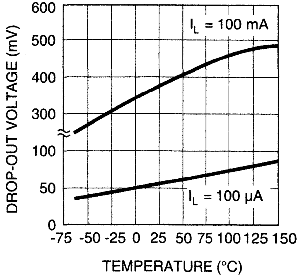
Ground Current



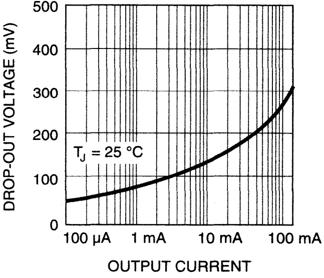
Short Circuit Current



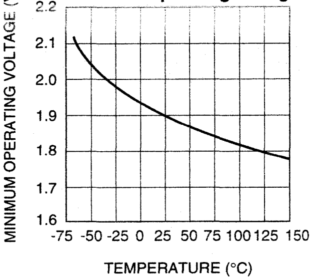
Drop-out Voltage



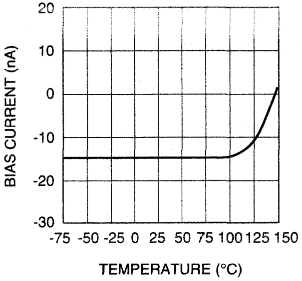
Drop-out Voltage



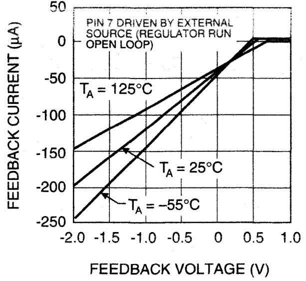
LP2951
Minimum Operating Voltage



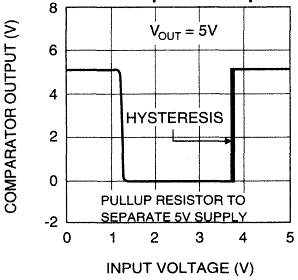
LP2951
Feedback Bias Current



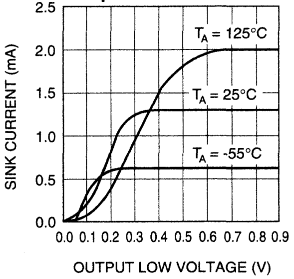
LP2951
Feedback Pin Current



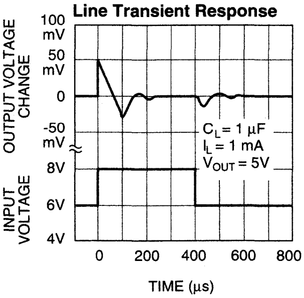
LP2951
Error Comparator Output



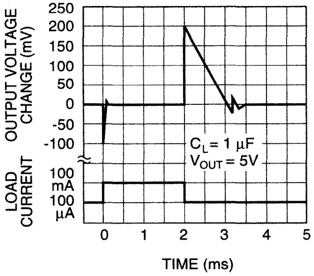
LP2951
Comparator Sink Current



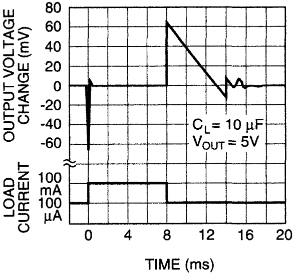
Line Transient Response



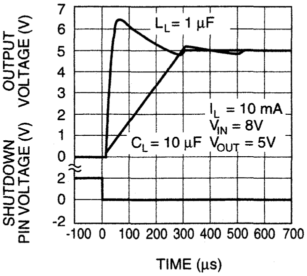
Load Transient Response



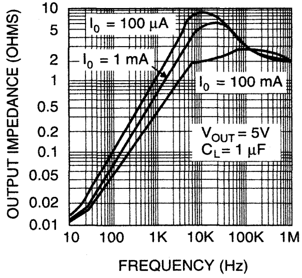
Load Transient Response



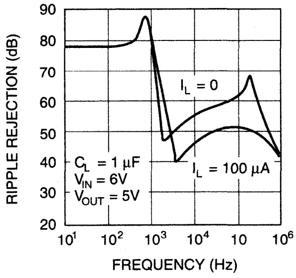
LP2951
Enable Transient



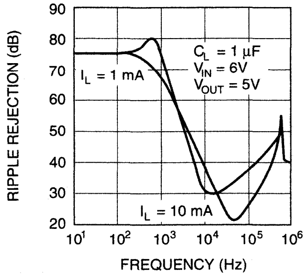
Output Impedance



Ripple Rejection

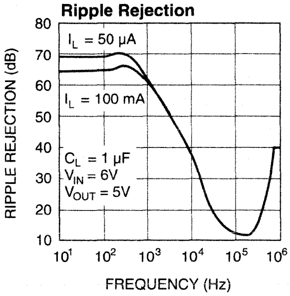


Ripple Rejection

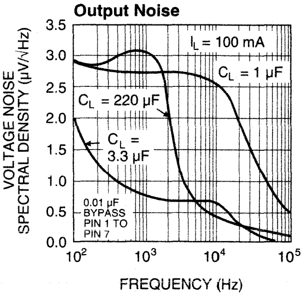


Typical Performance Characteristics (Continued)

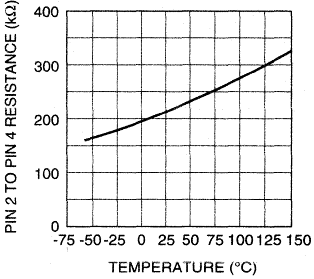
Ripple Rejection



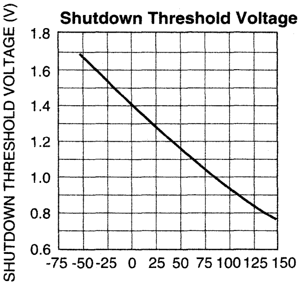
Output Noise



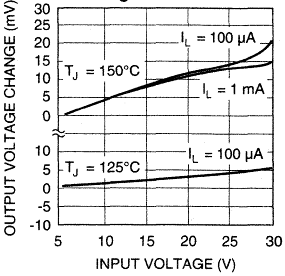
LP2951 Divider Resistance



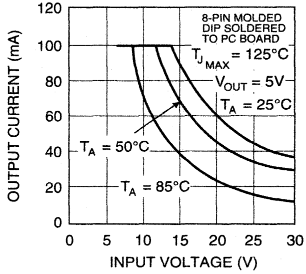
Shutdown Threshold Voltage



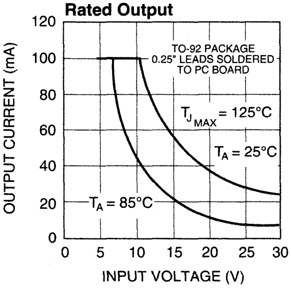
Line Regulation



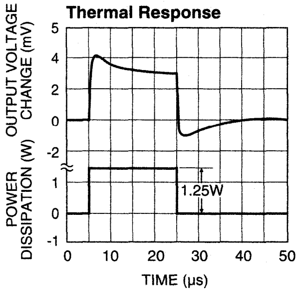
LP2950 Maximum Rated Output Current



LP2950 Maximum Rated Output



Thermal Response



Applications Information

External Capacitors

A 1.0µF (or greater) capacitor is required between the LP2950/LP2951 output and ground to prevent oscillations due to instability. Most types of tantalum or aluminum electrolytics will be adequate; film types will work, but are costly and therefore not recommended. Many aluminum electrolytics have electrolytes that freeze at about −30°C, so solid tantalum capacitors are recommended for operation below −25°C. The important parameters of the capacitor are an effective series resistance of about 5Ω or less and a resonant frequency above 500kHz. The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for output stability. The capacitor can be reduced to 0.33µF for current below 10mA or 0.1µF for currents below 1mA. Using the 8-Pin versions at voltages below 5V runs the error amplifier at lower gains so that more output capacitance is needed. For the worst-case situation of a 100mA load at 1.23V output (Output shorted to Feedback) a 3.3µF (or greater) capacitor should be used.

The LP2950 will remain stable and in regulation with no load in addition to the internal voltage divider, unlike many other voltage regulators. This is especially important in CMOS RAM keep-alive applications. When setting the output voltage of the LP2951 version with external resistors, a minimum load of 1µA is recommended.

A 0.1µF capacitor should be placed from the LP2950/LP2951 input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the input.

Stray capacitance to the LP2951 Feedback terminal (pin 7) can cause instability. This may especially be a problem when using high value external resistors to set the output voltage. Adding a 100pF capacitor between Output and Feedback and increasing the output capacitor to at least 3.3µF will remedy this.

Error Detection Comparator Output

A logic low output will be produced by the comparator whenever the LP2951 output falls out of regulation by more than approximately 5%. This figure is the comparator's built-in offset of about 60mV divided by the 1.235V reference voltage. (Refer to the block diagram on Page 1). This trip level remains "5% below normal" regardless of the programmed output voltage of the LP2951. For example, the error flag trip level is typically 4.75V for a 5V output or 11.4V for a 12V output. The out of regulation condition may be due either to low input voltage, current limiting, or thermal limiting.

Figure 1 is a timing diagram depicting the $\overline{\text{ERROR}}$ signal and the regulated output voltage as the LP2951 input is ramped up and down. The $\overline{\text{ERROR}}$ signal becomes valid (low) at about 1.3V input. It goes high at about 5V input (the input voltage at which $V_{OUT} = 4.75V$). Since the LP2951's dropout voltage is load-dependent (see curve in Typical Performance Characteristics), the input voltage trip point (about 5V) will vary with the load current. The output voltage trip point (approximately 4.75V) does not vary with load.

The error comparator has an open-collector output which requires an external pull-up resistor. Depending on system requirements, this resistor may be returned to the 5V output or some other supply voltage. In determining a value for this resistor, note that while the output is rated to sink 400µA, this sink current adds to battery drain in a low battery condition. Suggested values range from 100k to 1MΩ. The resistor is not required if this output is unused.

Programming the Output Voltage (LP2951)

The LP2951 may be pin-strapped for 5V using its internal voltage divider by tying Pin 1 (output) to Pin 2 (SENSE) and Pin 7 (FEEDBACK) to Pin 6 (5V TAP). Alternatively, it may be programmed for any output voltage between its 1.235V reference and its 30V maximum rating. An external pair of resistors is required, as shown in Figure 2.

The complete equation for the output voltage is

$$V_{OUT} = V_{REF} \times \{ 1 + R_1/R_2 \} + I_{FB} R_2$$

where V_{REF} is the nominal 1.235 reference voltage and I_{FB} is the feedback pin bias current, nominally 20 nA. The minimum recommended load current of 1 µA forces an upper limit of 1.2 MΩ on the value of R_2, if the regulator must work with no load (a condition often found in CMOS in standby), I_{FB} will produce a 2% typical error in V_{OUT} which may be eliminated at room temperature by trimming R_1. For better accuracy, choosing R_2 = 100kΩ reduces this error to 0.17% while increasing the resistor program current to 12µA. Since the LP2951 typically draws 60 µA at no load with Pin 2 open-circuited, this is a small price to pay.

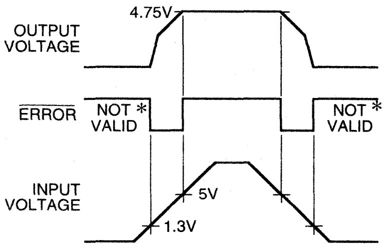
Reducing Output Noise

In reference applications it may be advantageous to reduce the AC noise present at the output. One method is to reduce the regulator bandwidth by increasing the size of the output capacitor. This is the only method by which noise can be reduced on the 3 lead LP2950 and is relatively inefficient, as increasing the capacitor from 1µF to 220µF only decreases the noise from 430µV to 160µV rms for a 100kHz bandwidth at 5V output.

Noise can be reduced fourfold by a bypass capacitor across R_1, since it reduces the high frequency gain from 4 to unity. Pick

$$C_{BYPASS} \cong \frac{1}{2\pi R_1 \bullet 200\text{ Hz}}$$

or about 0.01 µF. When doing this, the output capacitor must be increased to 3.3 µF to maintain stability. These changes reduce the output noise from 430µV to 100µV rms for a 100kHz bandwidth at 5V output. With the bypass capacitor added, noise no longer scales with output voltage so that improvements are more dramatic at higher output voltages.



* SEE APPLICATIONS INFORMATION

Figure 1. ERROR Output Timing

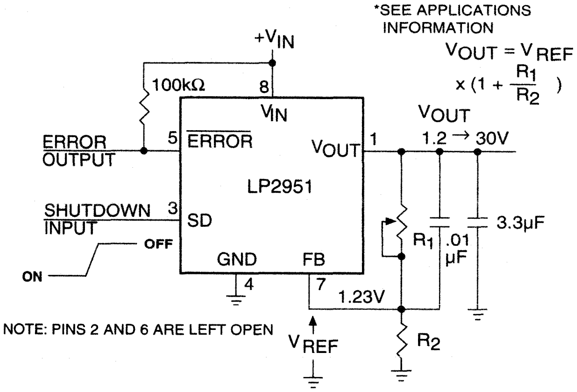
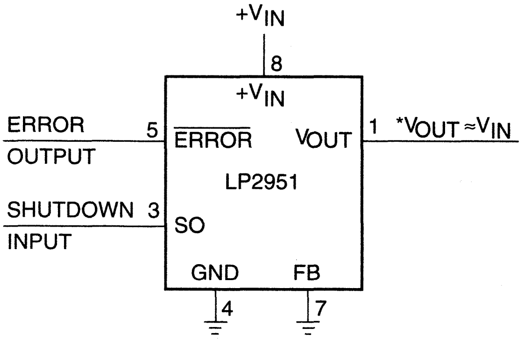


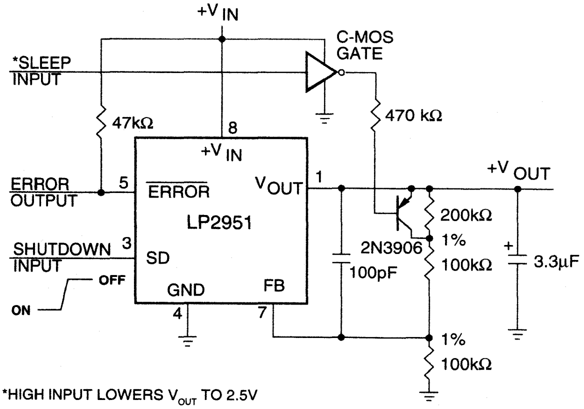
Figure 2. Adjustable Regulator

Typical Applications



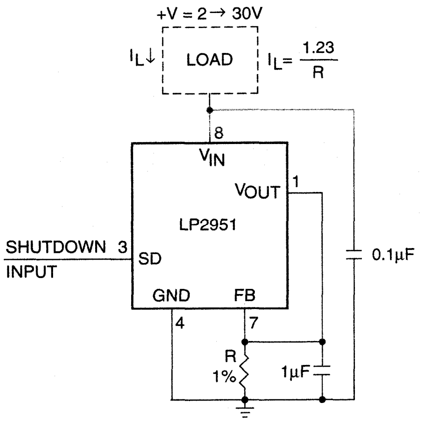
*MINIMUM INPUT-OUTPUT VOLTAGE RANGES FROM 40mV TO 400mV, DEPENDING ON LOAD CURRENT. CURRENT LIMIT IS TYPICALLY 160mA.

Wide Input Voltage Range Current Limiter

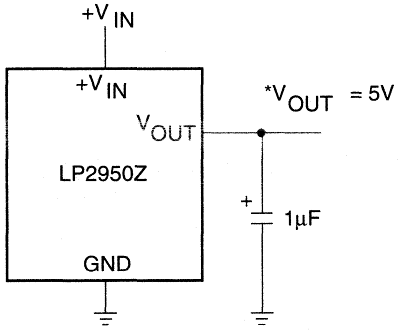


*HIGH INPUT LOWERS V_{OUT} TO 2.5V

5 V Regulator with 2.5 V Sleep Function

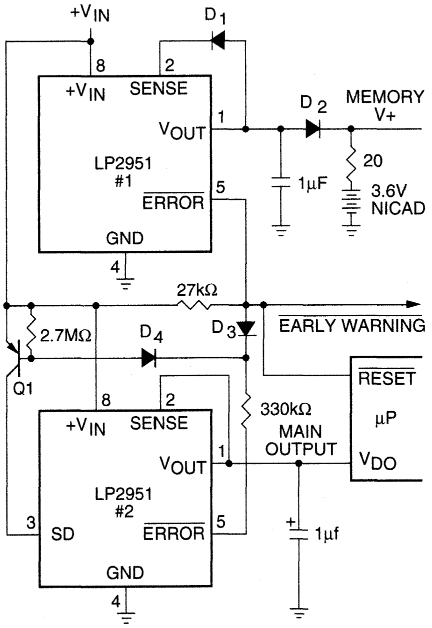


Low Drift Current Source



5 Volt Current Limiter

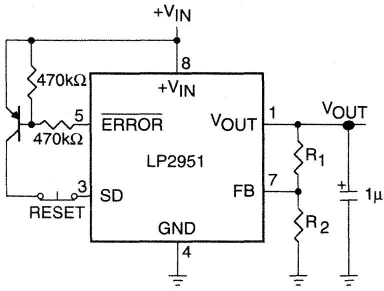
* MINIMUM INPUT-OUTPUT VOLTAGE RANGES FROM 40mV TO 400mV, DEPENDING ON LOAD CURRENT.



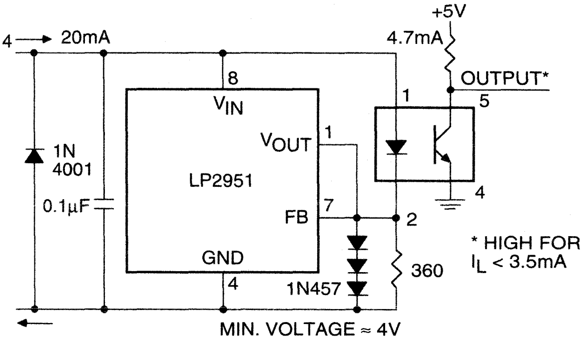
Regulator with Early Warning and Auxiliary Output

- EARLY WARNING FLAG ON LOW INPUT VOLTAGE
- MAIN OUTPUT LATCHES OFF AT LOWER INPUT VOLTAGES
- BATTERY BACKUP ON AUXILIARY OUTPUT

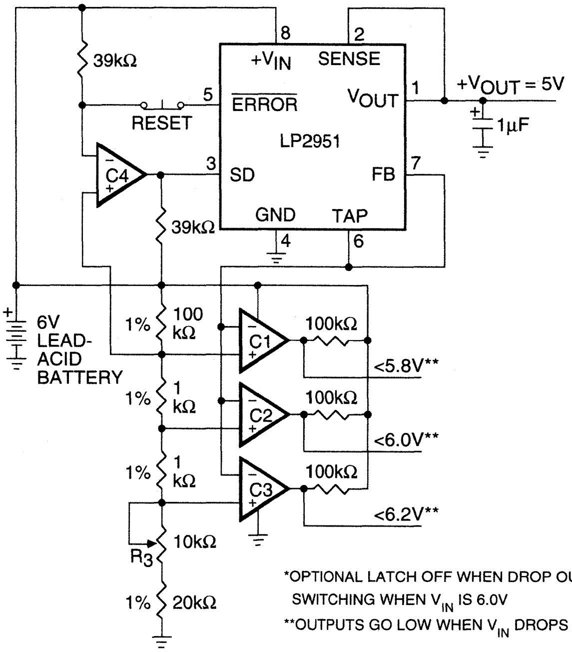
OPERATION: REG. #1'S V_{OUT} IS PROGRAMMED ONE DIODE DROP ABOVE 5 V. ITS ERROR FLAG BECOMES ACTIVE WHEN $V_{IN} \leq 5.7$ V. WHEN V_{IN} DROPS BELOW 5.3 V, THE ERROR FLAG OF REG. #2 BECOMES ACTIVE AND VIA Q1 LATCHES THE MAIN OUTPUT OFF. WHEN V_{IN} AGAIN EXCEEDS 5.7 V REG. #1 IS BACK IN REGULATION AND THE EARLY WARNING SIGNAL RISES, UNLATCHING REG. #2 VIA D3.



Latch Off When Error Flag Occurs



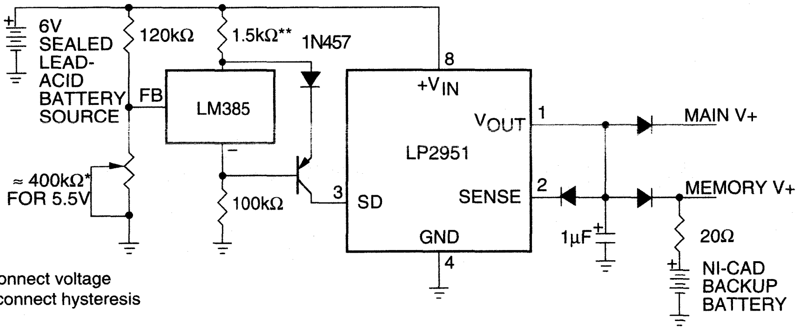
Open Circuit Detector for 4mA to 20mA Current Loop



*OPTIONAL LATCH OFF WHEN DROP OUT OCCURS. ADJUST R3 FOR C2 SWITCHING WHEN V_{IN} IS 6.0V

**OUTPUTS GO LOW WHEN V_{IN} DROPS BELOW DESIGNATED THRESHOLDS.

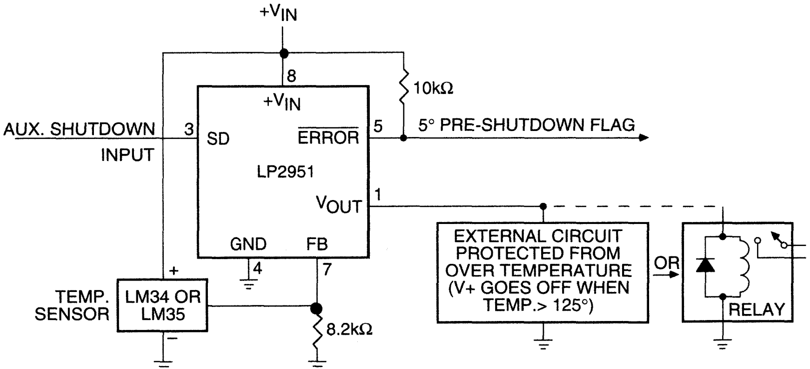
Regulator with State-of-Charge Indicator



* Sets disconnect voltage
** Sets disconnect hysteresis

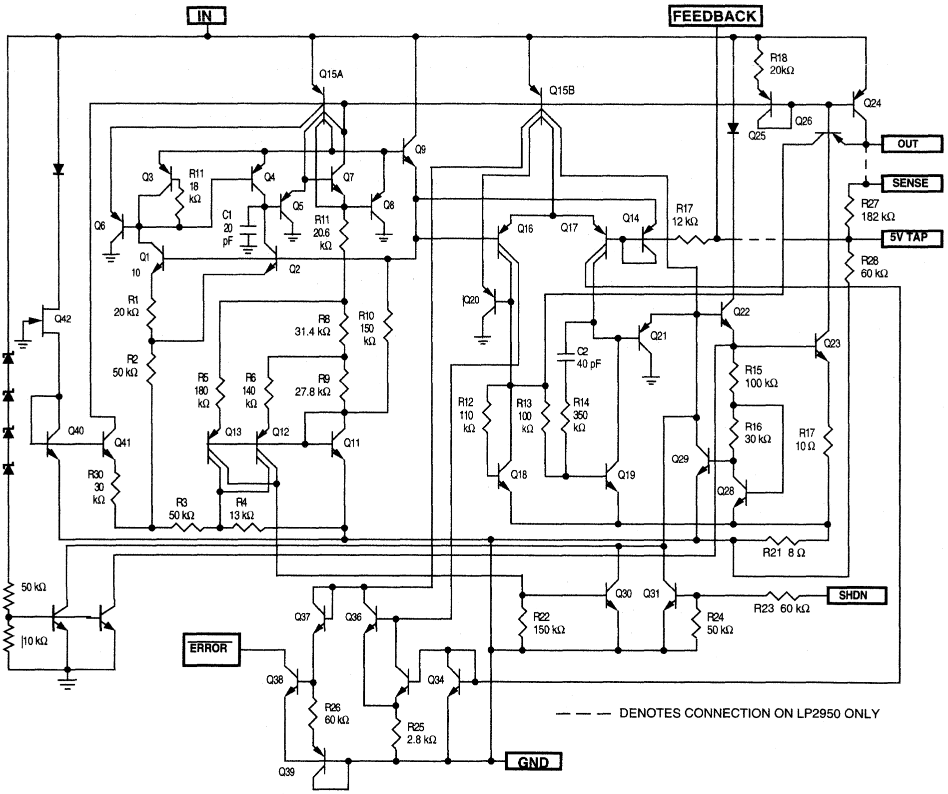
Low Battery Disconnect

For values shown, Regulator shuts down when V_{IN} < 5.5 V and turns on again at 6.0 V. Current drain in disconnected mode is 150µA.



LM34 for 125°F Shutdown
LM35 for 125°C Shutdown

System Over Temperature Protection Circuit


IN
FEEDBACK
Q15A
Q15B
R18
20kΩ
Q24
Q25
Q26
OUT
SENSE
R27
182 kΩ
5V TAP
R28
60 kΩ
Q9
Q3
R11
18
kΩ
Q4
Q7
Q5
Q8
C1
20
pF
R11
20.6
kΩ
Q6
Q1
10
Q2
Q16
Q17
Q14
R17
12 kΩ
Q20
Q42
R1
20 kΩ
R2
50 kΩ
R8
31.4 kΩ
R10
150
kΩ
R5
180
kΩ
R6
140
kΩ
R9
27.8 kΩ
Q22
Q21
C2
40 pF
Q23
R15
100 kΩ
R16
30 kΩ
R17
10 Ω
R12
110
kΩ
R13
100
kΩ
R14
350
kΩ
Q29
Q28
Q40
Q41
Q13
Q12
Q11
Q18
Q19
R30
30
kΩ
R3
50 kΩ
R4
13 kΩ
R21 8 Ω
50 kΩ
10 kΩ
Q37
Q36
R22
150 kΩ
Q30
Q31
R24
50 kΩ
R23 60 kΩ
SHDN
ERROR
Q38
Q34
R26
60 kΩ
R25
2.8 kΩ
Q39
GND
— — — DENOTES CONNECTION ON LP2950 ONLY

MIC2950/2951

150mA Low-Dropout Voltage Regulator

General Description

The MIC2950 and MIC2951 are "bulletproof" micropower voltage regulators with very low dropout voltage (typically 40mV at light loads and 250mV at 100mA), and very low quiescent current. Like their predecessors, the LP2950 and LP2951, the quiescent current of the MIC2950/MIC2951 increases only slightly in dropout, thus prolonging battery life. The MIC2950/MIC2951 are pin for pin compatible with the LP2950/LP2951, but offer lower dropout, lower quiescent current, reverse battery, and automotive load dump protection.

The key additional features and protection offered include higher output current (150mA), positive transient protection for up to 60V (load dump), and the ability to survive an unregulated input voltage transient of –20V below ground (reverse battery).

The plastic DIP and SOIC versions offer additional system functions such as programmable output voltage and logic controlled shutdown. The 3-pin TO-92 MIC2950 is pin-compatible with the older 5V regulators.

Features

- High accuracy 3.3, 4.85, or 5V, guaranteed 150mA output
- Extremely low quiescent current
- Low dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Use as regulator or reference
- Needs only 1.5µF for stability
- Current and thermal limiting
- Unregulated DC input can withstand –20V reverse battery and +60V positive transients

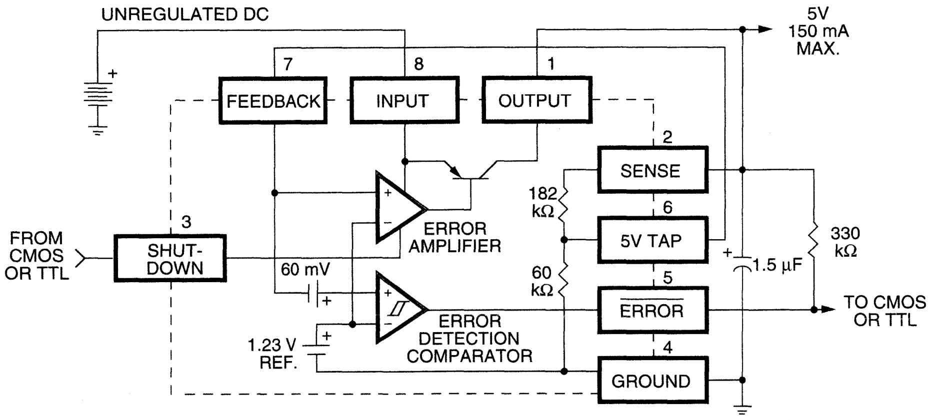
MIC2951 Versions Only

- Error flag warns of output dropout
- Logic-controlled electronic shutdown
- Output programmable from 1.24V to 29V

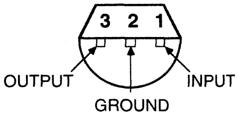
Applications

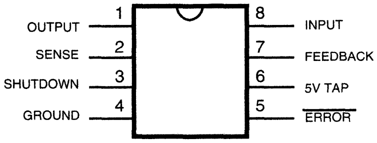
- Automotive Electronics
- Battery Powered Equipment
- Cellular Telephones
- SMPS Post-Regulator
- Voltage Reference
- Avionics
- High Efficiency Linear Power Supplies

Block Diagram and Pin Configuration



MIC2950 and MIC2951 Block Diagram (Pin Numbers Refer to MIC2951)





TO-92 Plastic Package Bottom View (BZ)

DIP and SO Packages (BN and BM)

Refer to the MIC2954 for a 250mA device in the same packages and pinouts.

These system functions also include an error flag output that warns of a low output voltage, which is often due to failing batteries on the input. This may also be used as a power-on reset. A logic-compatible shutdown input is also available which enables the regulator to be switched on and off. This part may also be pin-strapped for a 5 V output, or programmed from 1.24 V to 29 V with the use of two external resistors.

The MIC2950 is available as either an -05 or -06 version. The -05 and -06 versions are guaranteed for junction temperatures from −40°C to +125°C; the -05 version has a tighter output and reference voltage specification range over temperature. The MIC2951 is available as an -01, -02 , or -03 version. The -01 version is guaranteed for junction temperatures from −55°C to +150°C, and has slightly different specifications limits over the full operating temperature range.

The MIC2950 and MIC2951 have a tight initial tolerance (0.5% typical), a very low output voltage temperature coefficient which allows use as a low-power voltage reference, and extremely good load and line regulation (0.04% typical). This greatly reduces the error in the overall circuit, and is the result of careful design techniques and process control.

Ordering Information

Part Number	Voltage	Temperature Range*	Package	Accuracy
MIC2950-05BZ	5.0V	−40°C to +125°C	3-Pin TO-92 plastic	0.5%
MIC2950-06BZ	5.0V	−40°C to +125°C	3-Pin TO-92 plastic	1.0%
MIC2951-02BM	5.0V	−40°C to +125°C	8-Pin SOIC	0.5%
MIC2951-03BM	5.0V	−40°C to +125°C	8-Pin SOIC	1.0%
MIC2951-02BN	5.0V	−40°C to +125°C	8-Pin Plastic DIP	0.5%
MIC2951-03BN	5.0V	−40°C to +125°C	8-Pin Plastic DIP	1.0%
MIC2951-3.3BM	3.3V	−40°C to +125°C	8-Pin SOIC	1.0%
MIC2951-4.8BM	4.85V	−40°C to +125°C	8-Pin SOIC	1.0%

* Junction temperatures

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, contact your local Micrel representative/distributor for availability and specifications.

Power Dissipation (Note 1)	Internally Limited
Lead Temperature (Soldering, 5 seconds)	260°C
Storage Temperature Range	−65°C to +150°C
Operating Junction Temperature Range (Note 1)	
MIC2951-01	−55°C to +150°C
MIC2950-05/MIC2950-06, MIC2951-02/MIC2951-03	−40°C to +125°C
Input Supply Voltage (Note 2)	−20V to +60V
Feedback Input Voltage (Note 3, 4)	−1.5V to +26V
Shutdown Input Voltage (Note 3)	−0.3V to +30V
Error Comparator Output Voltage (Note 3)	−0.3V to +30V
ESD Rating	To be determined.

Electrical Characteristics

Note 5, 6 T_A = 25°C except as noted.

Parameter	Condition	Min	Typ	Max	Units
Output Voltage T_J = 25°C	MIC2951-01 (±0.5%)	4.975	5.000	5.025	V
	MIC295x-02/-05 (±0.5%)	4.975	5.000	5.025	V
	MIC295x-03/-06 (±1%)	4.950	5.000	5.050	V
	MIC2951-3.3 (±1%)	3.267	3.300	3.333	V
	MIC2951-4.8 (±1%)	4.802	4.850	4.899	V
Output Voltage –25°C ≤ T_J ≤ +85°C	MIC295x-02/-05 (±0.5%)	4.950		5.050	V
	MIC295x-03/-06 (±1%)	4.925		5.075	V
	MIC2951-3.3 (±1%)	3.251		3.350	V
	MIC2951-4.8 (±1%)	4.777		4.872	V
Output Voltage Over Full Temperature Range	MIC2951-01 (±0.5%), –55°C to +160°C	**4.940**		**5.060**	V
	MIC295x-02/-05 (±0.5%), –40°C to +125°C	**4.940**		**5.060**	V
	MIC295x-03/-06 (±1%), –40°C to +125°C	**4.900**		**5.100**	V
	MIC2951-3.3 (±1%), –40°C to +125°C	**3.234**		**3.366**	V
	MIC2951-4.8 (±1%), –40°C to +125°C	**4.753**		**4.947**	V
Output Voltage Over Load Variation	MIC2951-01 (±0.5%), 100µA ≤ I_L ≤ 150mA, $T_J \le T_{J(max)}$	**4.925**		**5.075**	V
	MIC295x-02/-05 (±0.5%), 100µA ≤ I_L ≤ 150mA, $T_J \le T_{J(max)}$	**4.930**		**5.070**	V
	MIC295x-03/-06 (±1%), 100µA ≤ I_L ≤ 150mA, $T_J \le T_{J(max)}$	**4.880**		**5.120**	V
	MIC2951-3.3 (±1%), 100µA ≤ I_L ≤ 150mA, $T_J \le T_{J(max)}$	**3.221**		**3.379**	V
	MIC2951-4.8 (±1%), 100µA ≤ I_L ≤ 150mA, $T_J \le T_{J(max)}$	**4.733**		**4.967**	V
Output Voltage Temperature Coefficient	MIC2951-01 (±0.5%), Note 7		**20**	**120**	ppm/°C
	MIC295x-02/-05 (±0.5%), Note 7		**20**	**100**	ppm/°C
	MIC295x-03/-06 (±1%), Note 7		**50**	**150**	ppm/°C
	MIC2951-3.3 (±1%), Note 7		**50**	**150**	ppm/°C
	MIC2951-4.8 (±1%), Note 7		**50**	**150**	ppm/°C
Line Regulation	MIC2951-01 (±0.5%), Note 8, 9		0.03	0.10 **0.50**	% %
	MIC295x-02/-05 (±0.5%), Note 8, 9		0.03	0.10 **0.20**	% %
	MIC295x-03/-06 (±1%), Note 8, 9		0.04	0.20 **0.40**	% %
	MIC2951-3.3 (±1%), Note 8, 9		0.04	0.20 **0.40**	% %
	MIC2951-4.8 (±1%), Note 8, 9		0.04	0.20 **0.40**	% %
Load Regulation	MIC2951-01 (±0.5%), 100µA ≤ I_L ≤ 150mA, Note 8		0.04	0.10 **0.30**	% %
	MIC295x-02/-05 (±0.5%), 100µA ≤ I_L ≤ 150mA, Note 8		0.04	0.10 **0.20**	% %
	MIC295x-03/-06 (±1%), 100µA ≤ I_L ≤ 150mA, Note 8		0.10	0.20 **0.30**	% %
	MIC2951-3.3 (±1%), 100µA ≤ I_L ≤ 150mA, Note 8		0.10	0.20 **0.30**	% %
	MIC2951-4.8 (±1%), 100µA ≤ I_L ≤ 150mA, Note 8		0.10	0.20 **0.30**	% %

Parameter	Condition	Min	Typ	Max	Units
Dropout Voltage	MIC2951-01/-02/-03/-05/-06, I_L = 100μA, Note 10		40	80 **140**	mV mV
	MIC2951-01/-02/-03/-05/-06, I_L = 100mA, Note 10		250	300	mV
	MIC2951-01/-02/-03/-05/-06, I_L = 150mA, Note 10		300	450 **600**	mV mV
	MIC2951-3.3 (±1%), I_L = 100μA, Note 10		40	80 **150**	mV mV
	MIC2951-3.3 (±1%), I_L = 100mA, Note 10		250	350	mV
	MIC2951-3.3 (±1%), I_L = 150mA, Note 10		320	450 **600**	mV mV
	MIC2951-4.8 (±1%), I_L = 100μA, Note 10		40	80 **140**	mV mV
	MIC2951-4.8 (±1%), I_L = 100mA, Note 10		250	300	mV
	MIC2951-4.8 (±1%), I_L = 150mA, Note 10		300	450 **600**	mV mV
Ground Current	MIC2951-01/-02/-03/-05/-06, I_L = 100μA		120	180 **300**	μA μA
	MIC2951-01/-02/-03/-05/-06, I_L = 100mA		1.7	2.5 **3.5**	mA mA
	MIC2951-01/-02/-03/-05/-06, I_L = 150mA		4	6 **8**	mA mA
	MIC2951-3.3 (±1%), I_L = 100μA		100	180 **300**	μA μA
	MIC2951-3.3 (±1%), I_L = 100mA		1.7	2.5	mA
	MIC2951-3.3 (±1%), I_L = 150mA		4	6 **10**	mA mA
	MIC2951-4.8 (±1%), I_L = 100μA		120	180 **300**	μA μA
	MIC2951-4.8 (±1%), I_L = 100mA		1.7	2.5 **3.5**	mA mA
	MIC2951-4.8 (±1%), I_L = 150mA		4	6 **8**	mA mA
Dropout Ground Current	MIC2951-01 (±0.5%), V_{IN} = 4.5V, I_L = 100μA		280	 **400**	μA μA
	MIC295x-02/-03/-05/-06 (±0.5%), V_{IN} = 4.5V, I_L = 100μA		280	350 **400**	μA μA
	MIC2951-3.3 (±1%), V_{IN} = 3.0V, I_L = 100μA		150	350 **400**	μA μA
	MIC295x-4.8 (±1%), V_{IN} = 4.3V, I_L = 100μA		280	350 **400**	μA μA
Current Limit	V_{OUT} = 0V		240	300 **350**	mA mA
Thermal Regulation	Note 11		0.05	0.20	%/W
Output Noise	10Hz to 100kHz, C_L = 1.5μF		430		μV_{RMS}
	10Hz to 100kHz, C_L = 200μF		160		μV_{RMS}
	10Hz to 100kHz, C_L = 3.3μF, 0.01μF bypass Feedback to Output		100		μV_{RMS}

Parameter	Condition	Min	Typ	Max	Units
Reference Voltage	MIC2951-01 (±0.5%)	1.220 **1.200**	1.235	1.250 **1.260**	V V
	MIC295x-02/-05 (±0.5%)	1.220 **1.200**	1.235	1.250 **1.260**	V V
	MIC295x-03/-06 (±1%)	1.210 **1.200**	1.235	1.260 **1.270**	V V
	MIC2951-3.3 (±1%)	1.210 **1.200**	1.235	1.260 **1.270**	V V
	MIC2951-4.8 (±1%)	1.210 **1.200**	1.235	1.260 **1.270**	V V
Reference Voltage	MIC2951-01 (±0.5%), Note 12	**1.190**		**1.270**	V
	MIC295x-02/-05 (±0.5%), Note 12	**1.190**		**1.270**	V
	MIC295x-03/-06 (±1%), Note 12	**1.185**		**1.285**	V
	MIC2951-3.3 (±1%), Note 12	**1.185**		**1.285**	V
	MIC2951-4.8 (±1%), Note 12	**1.185**		**1.285**	V
Feedback Bias Current			20	40 **60**	nA nA
Reference Voltage Temperature Coefficient	MIC2951-01 (±0.5%), Note 7		20		ppm/°C
	MIC295x-02/-05 (±0.5%), Note 7		20		ppm/°C
	MIC295x-03/-06 (±1%), Note 7		50		ppm/°C
	MIC2951-3.3 (±1%), Note 7		50		ppm/°C
	MIC2951-4.8 (±1%), Note 7		50		ppm/°C
Feedback Bias Current Temperature Coefficient			0.1		nA/°C
Error Comparator (Flag) Output Leakage Current	V_{OH} = 30V		0.01	1.00 **2.00**	µA µA
Error Comparator (Flag) Output Low Voltage	V_{IN} = 4.5V, I_{OL} = 200µA		150	250 **400**	mV mV
Error Comparator Upper Threshold Voltage	Note 13	40 **25**	60		mV mV
Error Comparator Lower Threshold Voltage	Note 13		75	95 **140**	mV mV
Error Comparator Hysteresis	Note 13		15		mV
Shutdown Input Logic Voltage	MIC2951-01 (±0.5%) Low High	 **2.0**	1.3	 **0.6**	V V V
	MIC295x-02/-05 (±0.5%) Low High	 **2.0**	1.3	 **0.7**	V V V
	MIC295x-03/-06 (±1%) Low High	 **2.0**	1.3	 **0.7**	V V V
	MIC2951-3.3 (±1%) Low High	 **2.0**	1.3	 **0.7**	V V V
	MIC2951-4.8 (±1%) Low High	 **2.0**	1.3	 **0.7**	V V V

Parameter	**Condition**	**Min**	**Typ**	**Max**	**Units**
Shutdown Input Current	$V_{SHUTDOWN} = 2.4V$		30	50 **100**	μA μA
	$V_{SHUTDOWN} = 30V$		450	600 **750**	μA μA
Regulator Output Current in Shutdown	Note 4		3	10 **20**	μA μA

Note 1: The junction-to-ambient thermal resistance of the TO-92 package is 180°C/W with 0.4" leads and 160°C/W with 0.25" leads to a PC board. The thermal resistance of the 8-pin DIP package is 105°C/W junction-to-ambient when soldered directly to a PC board. Junction-to-ambient thermal resistance for the SOIC (M) package is 160°C/W.

Note 2: May exceed input supply voltage.

Note 3: When used in dual-supply systems where the output terminal sees loads returned to a negative supply, the output voltage should be diode-clamped to ground.

Note 4: $V_{SHUTDOWN} \geq 2V$, $V_{IN} \leq 30$ V, $V_{OUT} = 0$, with Feedback pin tied to 5V Tap.

Note 5: Boldface limits apply at temperature extremes.

Note 6: Unless otherwise specified all limits guaranteed for $T_J = 25°C$, $V_{IN} = 6V$, $I_L = 100\mu A$ and $C_L = 1\mu F$. Additional conditions for the 8-pin versions are Feedback tied to 5V Tap and Output tied to Output Sense ($V_{OUT} = 5V$) and $V_{SHUTDOWN} \leq 0.8V$.

Note 7: Output or reference voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 8: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered in the specification for thermal regulation.

Note 9: Line regulation for the MIC2951 is tested at 150°C for $I_L = 1mA$. For $I_L = 100\mu A$ and $T_J = 125°C$, line regulation is guaranteed by design to 0.2%. See Typical Performance Characteristics for line regulation versus temperature and load current.

Note 10: Dropout voltage is defined as the input to output differential at which the output voltage drops 100mV below its nominal value measured at 1V differential. At very low values of programmed output voltage, the minimum input supply voltage of 2V (2.3V over temperature) must be taken into account.

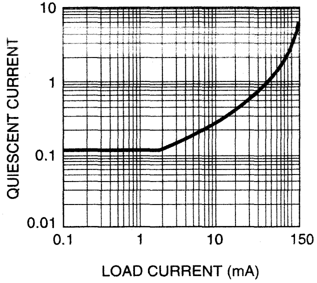
Note 11: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 50mA load pulse at $V_{IN} = 30V$ (1.25W pulse) for t = 10ms.

Note 12: $V_{REF} \leq V_{OUT} \leq (V_{IN} - 1\ V)$, $2.3V \leq V_{IN} \leq 30V$, $100\mu A < I_L \leq 150mA$, $T_J \leq T_{JMAX}$.

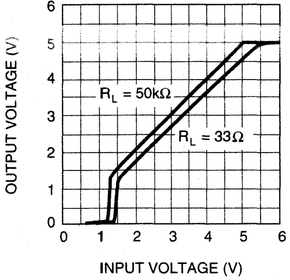
Note 13: Comparator thresholds are expressed in terms of a voltage differential at the Feedback terminal below the nominal reference voltage measured at 6V input. To express these thresholds in terms of output voltage change, multiply by the error amplifier gain = V_{OUT}/V_{REF} = (R1 + R2)/R2. For example, at a programmed output voltage of 5V, the Error output is guaranteed to go low when the output drops by 95mV x 5V/1.235V = 384mV. Thresholds remain constant as a percent of V_{OUT} as V_{OUT} is varied, with the dropout warning occurring at typically 5% below nominal, 7.5% guaranteed.

Typical Characteristics

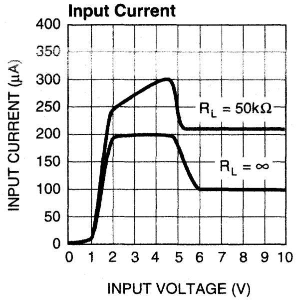
Ground Pin Current



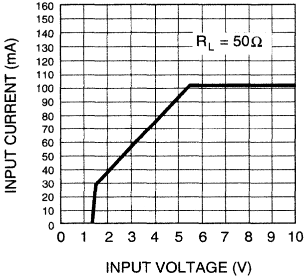
Dropout Characteristics



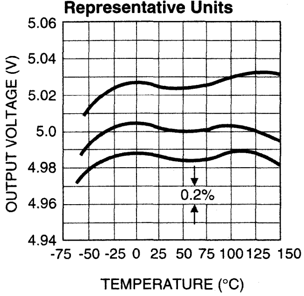
Input Current



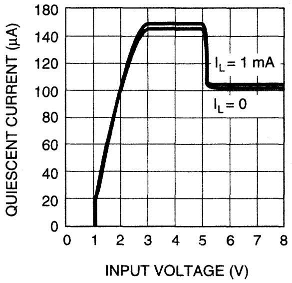
Input Current



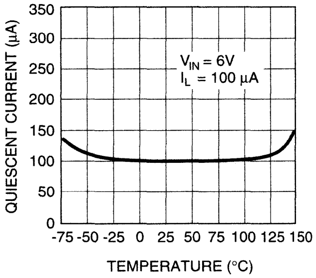
Output Voltage vs. Temperature of 3 Representative Units



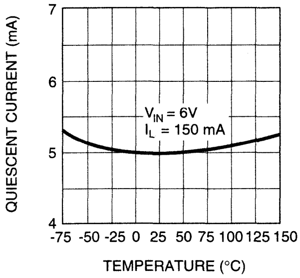
Ground Pin Current



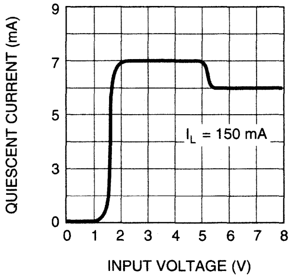
Ground Pin Current



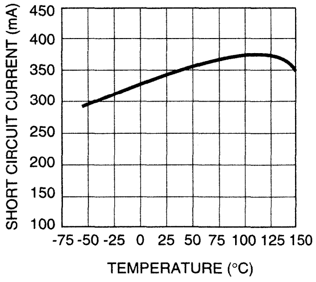
Ground Pin Current



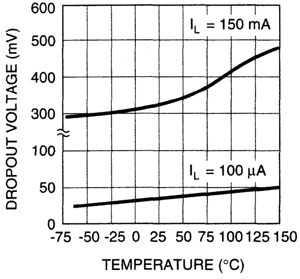
Ground Pin Current



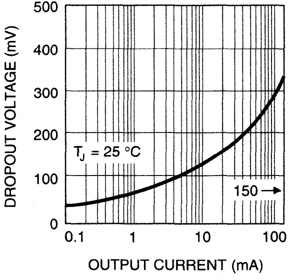
Short Circuit Current



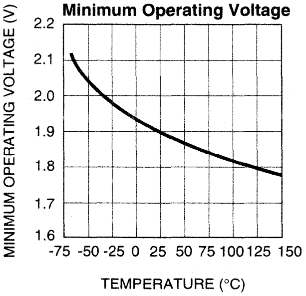
Dropout Voltage



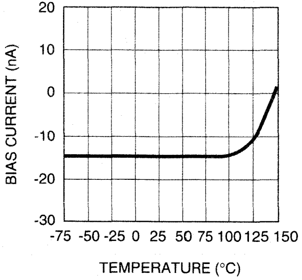
Dropout Voltage



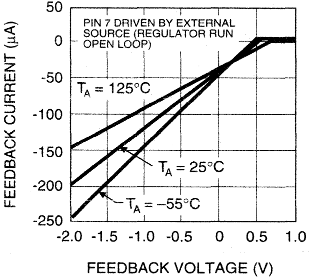
MIC2951
Minimum Operating Voltage



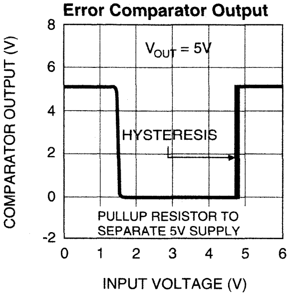
MIC2951
Feedback Bias Current



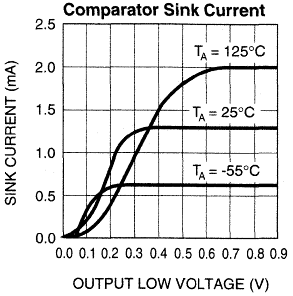
MIC2951
Feedback Pin Current



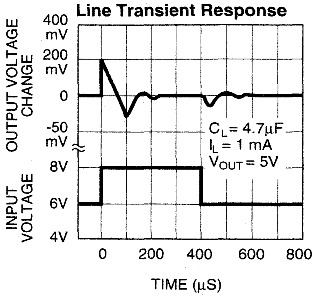
MIC2951
Error Comparator Output



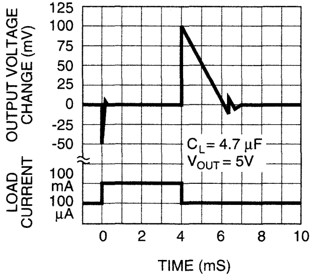
MIC2951
Comparator Sink Current



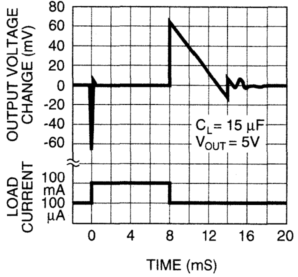
Line Transient Response



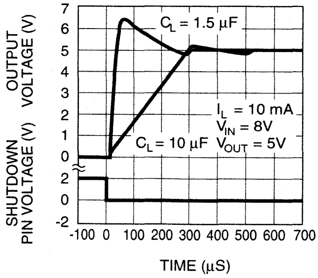
Load Transient Response



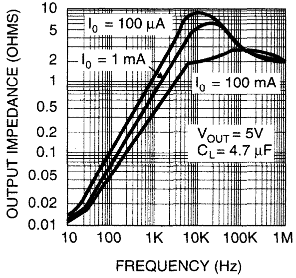
Load Transient Response



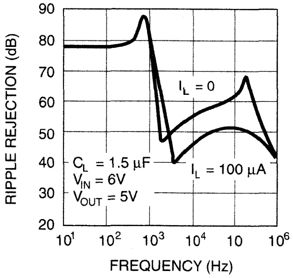
MIC2951
Enable Transient



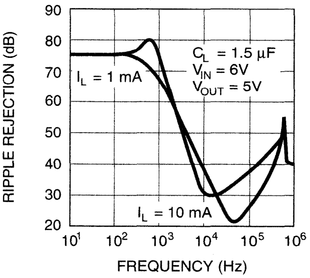
Output Impedance

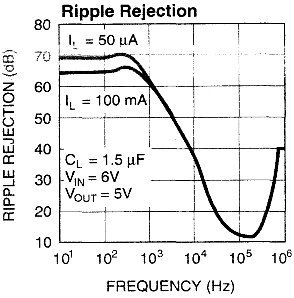


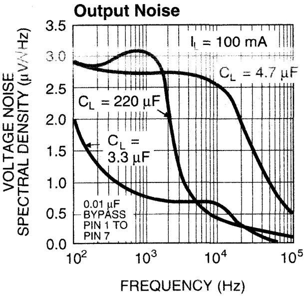
Ripple Rejection

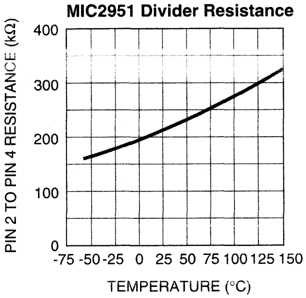


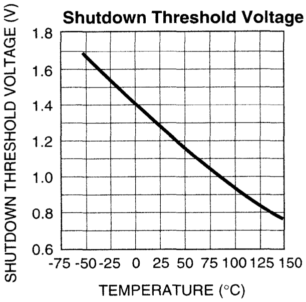
Ripple Rejection

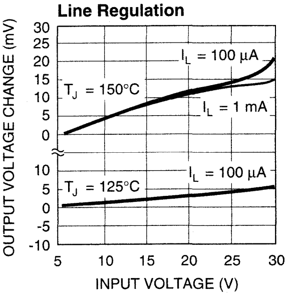


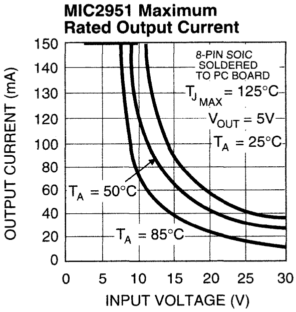

Ripple Rejection

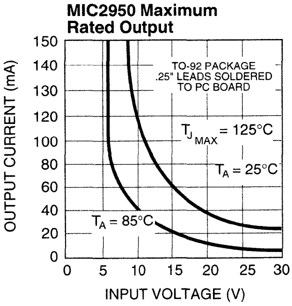

Output Noise

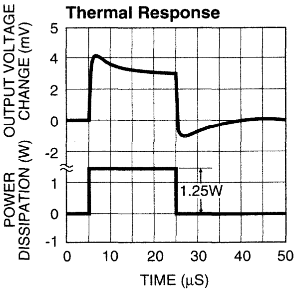

MIC2951 Divider Resistance

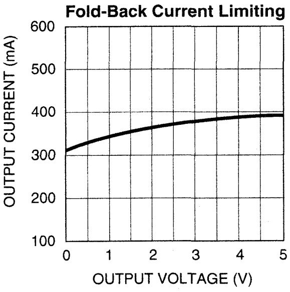

Shutdown Threshold Voltage


Line Regulation


MIC2951 Maximum Rated Output Current


MIC2950 Maximum Rated Output


Thermal Response


Fold-Back Current Limiting

Applications Information

Automotive Applications

The MIC2950/2951 are ideally suited for automotive applications for a variety of reasons. They will operate over a wide range of input voltages, have very low dropout voltages (40mV at light loads), and very low quiescent currents. These features are necessary for use in battery powered systems, such as automobiles. They are also "bulletproof" devices; with the ability to survive both reverse battery (negative transients up to 20V below ground), and load dump (positive transients up to 60V) conditions. A wide operating temperature range with low temperature coefficients is yet another reason to use these versatile regulators in automotive designs.

External Capacitors

A 1.5 µF (or greater) capacitor is required between the MIC2950/MIC2951 output and ground to prevent oscillations due to instability. Most types of tantalum or aluminum electrolytics will be adequate; film types will work, but are costly and therefore not recommended. Many aluminum electrolytics have electrolytes that freeze at about –30°C, so solid tantalums are recommended for operation below –25°C. The important parameters of the capacitor are an effective series resistance of about 5Ω or less and a resonant frequency above 500kHz. The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for output stability. The capacitor can be reduced to 0.5µF for current below 10mA or 0.15µF for currents below 1 mA. Using the 8-pin versions at voltages below 5V runs the error amplifier at lower gains so that more output capacitance is needed. For the worst-case situation of a 150mA load at 1.23V output (Output shorted to Feedback) a 5µF (or greater) capacitor should be used.

The MIC2950 will remain stable and in regulation with no load in addition to the internal voltage divider, unlike many other voltage regulators. This is especially important in CMOS RAM keep-alive applications. When setting the output voltage of the MIC2951 version with external resistors, a minimum load of 1µA is recommended.

A 0.1µF capacitor should be placed from the MIC2950/MIC2951 input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the input.

Stray capacitance to the MIC2951 Feedback terminal (pin 7) can cause instability. This may especially be a problem when using high value external resistors to set the output voltage. Adding a 100pF capacitor between Output and Feedback and increasing the output capacitor to at least 3.3µF will remedy this.

Error Detection Comparator Output

A logic low output will be produced by the comparator whenever the MIC2951 output falls out of regulation by more than approximately 5%. This figure is the comparator's built-in offset of about 60mV divided by the 1.235V reference voltage. (Refer to the block diagram on Page 1). This trip level remains "5% below normal" regardless of the programmed output voltage of the MIC2951. For example, the error flag trip level is typically 4.75V for a 5V output or 11.4V for a 12V output. The out of regulation condition may be due either to low input voltage, current limiting, thermal limiting, or overvoltage on input (over ≅ 40V).

Figure 1 is a timing diagram depicting the $\overline{\text{ERROR}}$ signal and the regulated output voltage as the MIC2951 input is ramped up and down. The $\overline{\text{ERROR}}$ signal becomes valid (low) at about 1.3V input. It goes high at about 5V input (the input voltage at which V_{OUT} = 4.75—for 5.0V applications). Since the MIC2951's dropout voltage is load-dependent (see curve in Typical Performance Characteristics), the input voltage trip point (about 5V) will vary with the load current. The output voltage trip point does not vary with load.

The error comparator has an open-collector output which requires an external pull-up resistor. Depending on system requirements, this resistor may be returned to the output or some other supply voltage. In determining a value for this resistor, note that while the output is rated to sink 200µA, this sink current adds to battery drain in a low battery condition. Suggested values range from 100k to 1MΩ. The resistor is not required if this output is unused.

Programming the Output Voltage (MIC2951)

The MIC2951 may be pin-strapped for 5V (or 3.3V or 4.85V) using its internal voltage divider by tying Pin 1 (output) to Pin 2 (sense) and Pin 7 (feedback) to Pin 6 (5V Tap). Alternatively, it may be programmed for any output voltage between its 1.235V reference and its 30V maximum rating. An external pair of resistors is required, as shown in Figure 2.

The complete equation for the output voltage is

$$V_{OUT} = V_{REF} \times \{ 1 + R_1/R_2 \} + I_{FB} R_1$$

where V_{REF} is the nominal 1.235 reference voltage and I_{FB} is the feedback pin bias current, nominally –20nA. The minimum recommended load current of 1 µA forces an upper limit of 1.2MΩ on the value of R_2, if the regulator must work with no load (a condition often found in CMOS in standby), I_{FB} will produce a 2% typical error in V_{OUT} which may be eliminated at room temperature by trimming R_1. For better accuracy, choosing R_2 = 100k reduces this error to 0.17% while increasing the resistor program current to 12 µA.

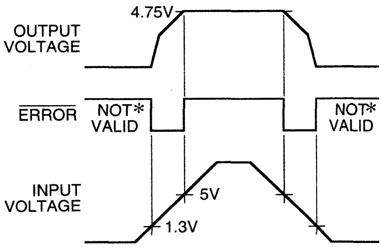
Reducing Output Noise

In some applications it may be advantageous to reduce the AC noise present at the output. One method is to reduce the regulator bandwidth by increasing the size of the output capacitor. This is the only method by which noise can be reduced on the 3 lead MIC2950 and is relatively inefficient, as increasing the capacitor from 1µF to 220µF only decreases the noise from 430µV to 160µV rms for a 100kHz bandwidth at 5V output.

Noise can be reduced fourfold by a bypass capacitor across R_1, since it reduces the high frequency gain from 4 to unity. Pick:

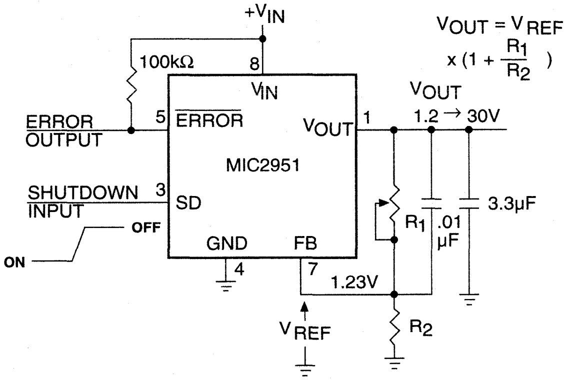
$$C_{BYPASS} \cong \frac{1}{2\pi R_1 \bullet 200\ \text{Hz}}$$

or about 0.01 µF. When doing this, the output capacitor must be increased to 3.3 µF to maintain stability. These changes reduce the output noise from 430 µV to 100 µV rms for a 100 kHz bandwidth at 5V output. With the bypass capacitor added, noise no longer scales with output voltage so that improvements are more dramatic at higher output voltages.



* SEE APPLICATIONS INFORMATION

Figure 1. ERROR Output Timing

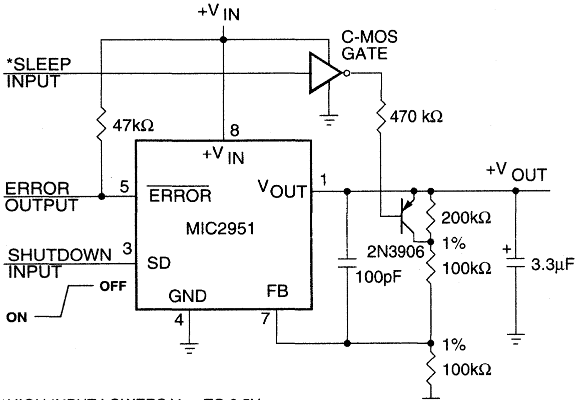


NOTE: PINS 2 AND 6 ARE LEFT OPEN

*SEE APPLICATIONS INFORMATION

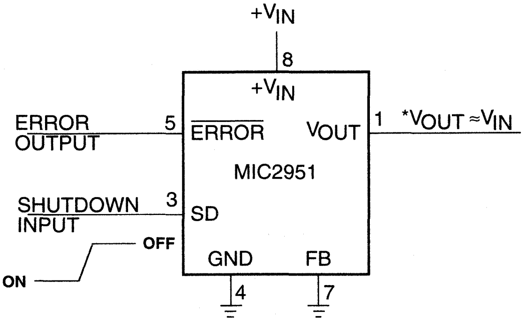
Figure 2. Adjustable Regulator

Typical Applications



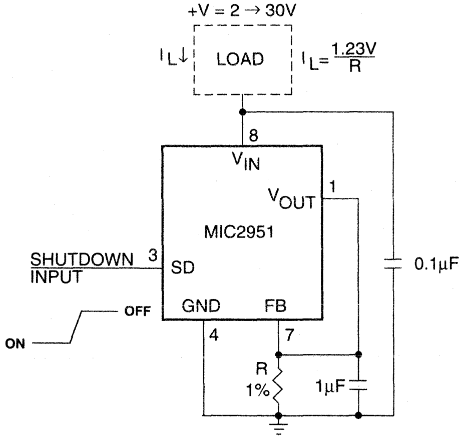
*HIGH INPUT LOWERS V_{OUT} TO 2.5V

5 V Regulator with 2.5 V Sleep Function

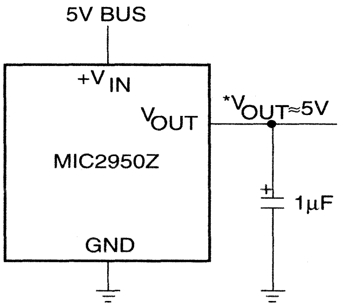


*MINIMUM INPUT-OUTPUT VOLTAGE RANGES FROM 40mV TO 400mV, DEPENDING ON LOAD CURRENT.

Wide Input Voltage Range Current Limiter

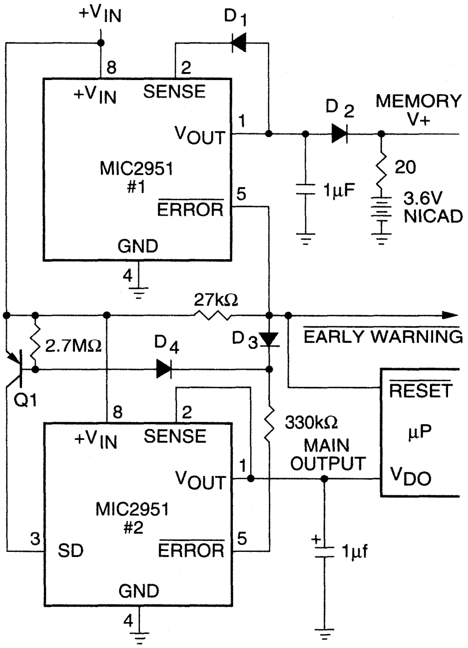


Low Drift Current Source



5 Volt Current Limiter

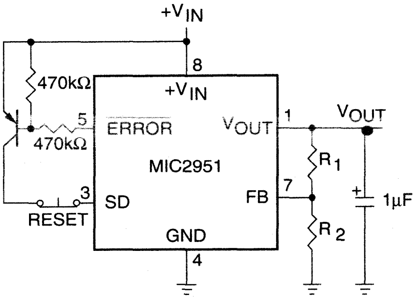
* MINIMUM INPUT-OUTPUT VOLTAGE RANGES FROM 40mV TO 400mV, DEPENDING ON LOAD CURRENT.



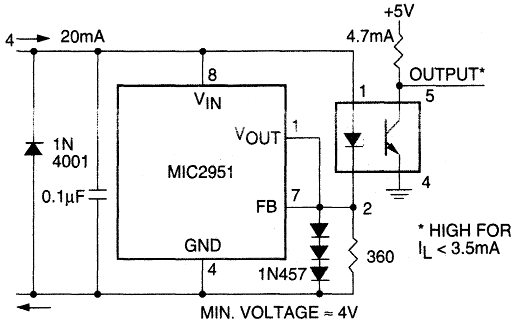
Regulator with Early Warning and Auxiliary Output

- EARLY WARNING FLAG ON LOW INPUT VOLTAGE
- MAIN OUTPUT LATCHES OFF AT LOWER INPUT VOLTAGES
- BATTERY BACKUP ON AUXILIARY OUTPUT

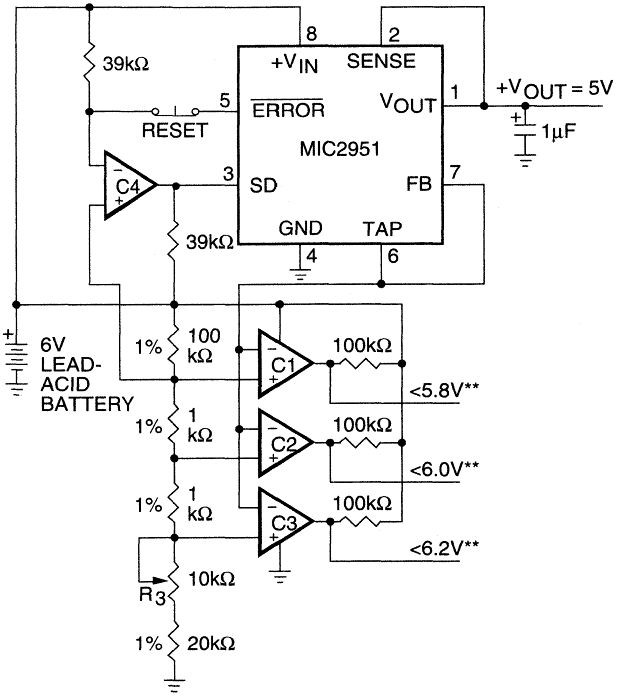
OPERATION: REG. #1'S V_{OUT} IS PROGRAMMED ONE DIODE DROP ABOVE 5 V. ITS ERROR FLAG BECOMES ACTIVE WHEN $V_{IN} \leq 5.7$ V. WHEN V_{IN} DROPS BELOW 5.3 V, THE ERROR FLAG OF REG. #2 BECOMES ACTIVE AND VIA Q1 LATCHES THE MAIN OUTPUT OFF. WHEN V_{IN} AGAIN EXCEEDS 5.7 V REG. #1 IS BACK IN REGULATION AND THE EARLY WARNING SIGNAL RISES, UNLATCHING REG. #2 VIA D3.



Latch Off When Error Flag Occurs

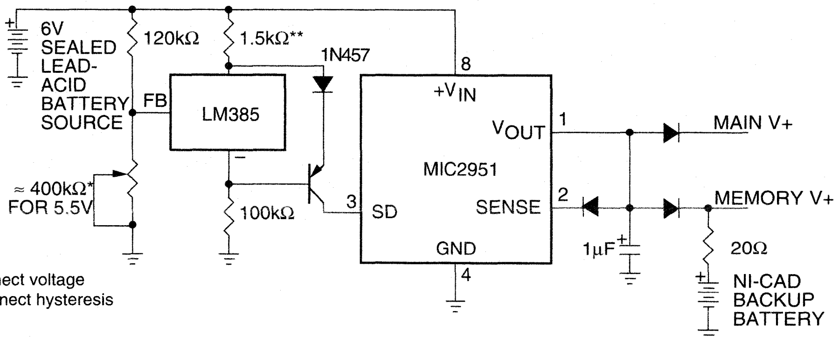


Open Circuit Detector for 4mA to 20mA Current Loop



C1 TO C4 ARE COMPARATORS (LP339 OR EQUIVALENT)
*OPTIONAL LATCH OFF WHEN DROP OUT OCCURS. ADJUST R3 FOR C2 SWITCHING WHEN V_{IN} IS 6.0V
**OUTPUTS GO LOW WHEN V_{IN} DROPS BELOW DESIGNATED THRESHOLDS.

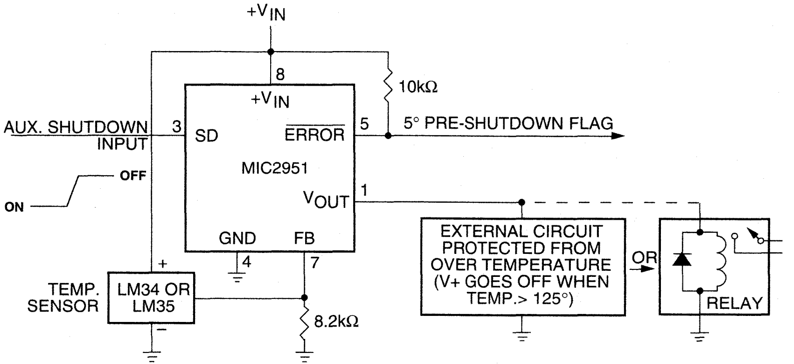
Regulator with State-of-Charge Indicator



* Sets disconnect voltage
** Sets disconnect hysteresis

Low Battery Disconnect

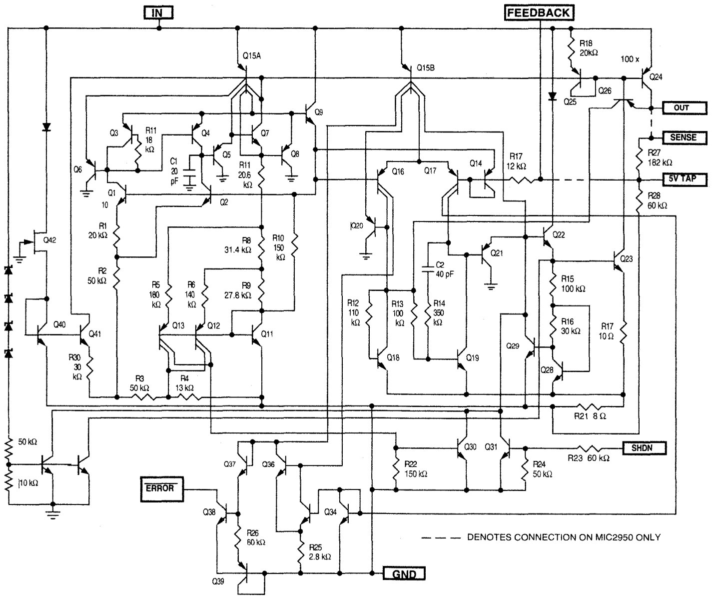
For values shown, Regulator shuts down when V_{IN} < 5.5 V and turns on again at 6.0 V. Current drain in disconnected mode is 150μA.



LM34 for 125°F Shutdown
LM35 for 125°C Shutdown

System Over-Temperature Protection Circuit

Schematic Diagram



MIC2954

250mA Low-Dropout Voltage Regulator

General Description

The MIC2954 is a "bulletproof" efficient voltage regulator with very low dropout voltage (typically 40mV at light loads and 375mV at 250mA), and low quiescent current (120µA typical). The quiescent current of the MIC2954 increases only slightly in dropout, thus prolonging battery life. Key MIC2954 features include protection against reversed battery, fold-back current limiting, and automotive load dump protection (60V positive transient).

The MIC2954-07/08BM is an adjustable version that includes an error flag output that warns of a low output voltage, which is often due to failing batteries on the input. This may also be used as a power-on reset. A logic-compatible shutdown input is provided which enables the regulator to be switched on and off. This part may be pin-strapped for 5V output, or programmed from 1.24 V to 29 V with the use of two external resistors.

The MIC2954 is available in two voltage tolerances, ±0.5% maximum and ±1% maximum. Both are guaranteed for junction temperatures from –40°C to +125°C.

The MIC2954 has a very low output voltage temperature coefficient and extremely good load and line regulation (0.04% typical).

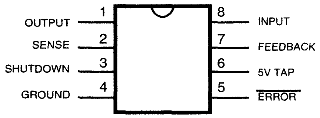
Features

- High accuracy 5V, guaranteed 250mA output
- Low quiescent current
- Low dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Current and thermal limiting
- Input can withstand –20V reverse battery and +60V positive transients
- Error flag warns of output dropout
- Logic-controlled electronic shutdown
- Output programmable from 1.24V to 29V (MIC2954-07/08BM)
- Available in TO-220, TO-92, and Surface Mount SOT-223 and SO-8 packages.

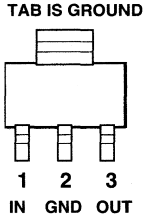
Applications

- Battery Powered Equipment
- Cellular Telephones
- Laptop, Notebook, and Palmtop Computers
- PCMCIA V_{CC} and V_{PP} Regulation/Switching
- Bar Code Scanners
- Automotive Electronics
- SMPS Post-Regulator/ DC to DC Modules
- Voltage Reference
- High Efficiency Linear Power Supplies

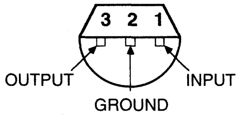
Pin Configuration



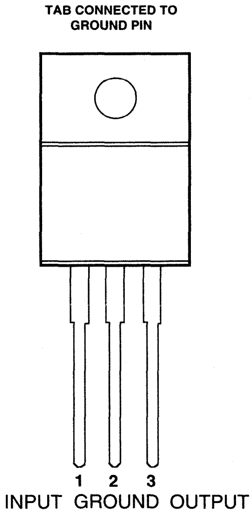
SO Package
(MIC2954-07BM, -08BM)



MIC2954-xxBS



Bottom View
TO-92 Package
(MIC2954-02BZ, -03BZ)



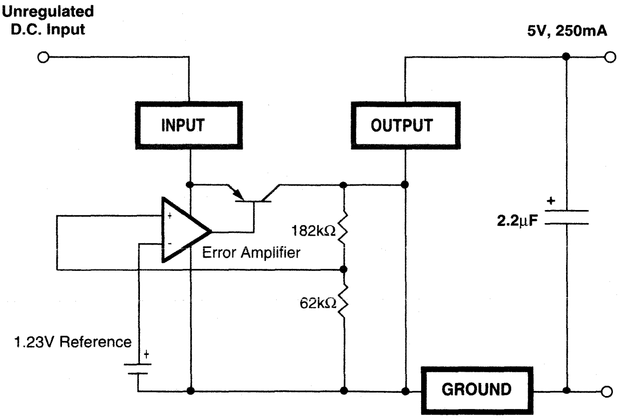
TO-220 Package Front View
(MIC2954-02BT, -03BT)

Ordering Information

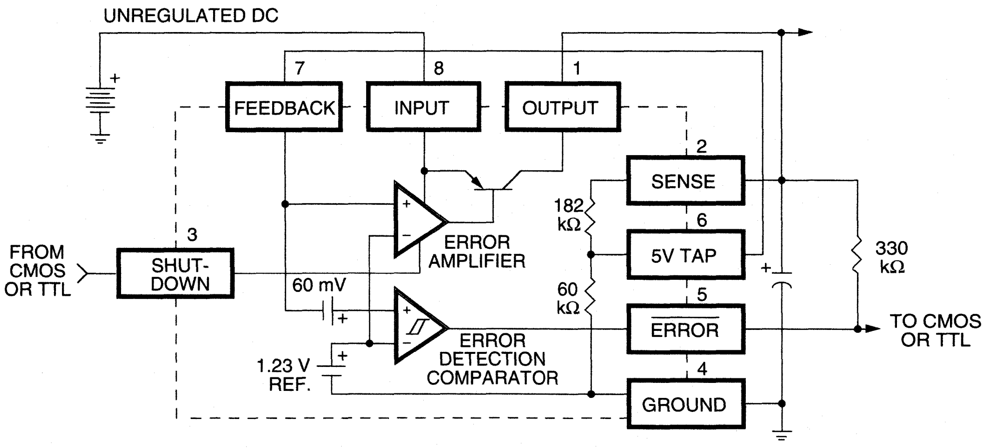
Part Number	Temperature Range*	Package	Accuracy
MIC2954-02BT	–40°C to +125°C	TO-220	0.5%
MIC2954-03BT	–40°C to +125°C	TO-220	1.0%
MIC2954-02BS	–40°C to +125°C	SOT-223	0.5%
MIC2954-03BS	–40°C to +125°C	SOT-223	1.0%
MIC2954-02BZ	–40°C to +125°C	TO-92	0.5%
MIC2954-03BZ	–40°C to +125°C	TO-92	1.0%
MIC2954-07BM	–40°C to +125°C	8-Pin SO-8	0.5%
MIC2954-08BM	–40°C to +125°C	8-Pin SO-8	1.0%

* Junction temperatures

MIC2954-02BT/BZ & 2954-03BT/BZ Block Diagram



MIC2954-07BM & 2954-08BM Block Diagram



Absolute Maximum Ratings

If Military/Aerospace specified devices are required, contact your local Micrel representative/distributor for availability and specifications.

Power Dissipation (Note 1)	Internally Limited	Input Supply Voltage	−20V to +60V
Lead Temperature (Soldering, 5 seconds)	260°C	Feedback Input Voltage (Notes 10 and 11)	−1.5V to +26V
Storage Temperature Range	−65°C to +150°C	Shutdown Input Voltage	−0.3V to +30V
Operating Junction Temperature Range	−40°C to +125°C	Error Comparator Output Voltage	−0.3V to +30V

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C and limits in **boldface** apply over the full operating temperature range. Unless otherwise specified, V_{IN} = 6V, I_L = 1mA, C_L = 2.2μF. The MIC2954-07BM,-08BM Feedback pin is tied to the 5V Tap and Output is tied to Output Sense (V_{OUT} = 5V) and $V_{SHUTDOWN}$ ≤ 0.6V.

				MIC2954-02/-07		MIC2954-03/-08		
Symbol	**Parameter**	**Conditions**	**Typical**	**Min**	**Max**	**Min**	**Max**	**Units**
V_O	Output Voltage		5.0	4.975	5.025	4.950	5.050	V
				4.940	**5.060**	**4.900**	**5.100**	
		1mA ≤ I_L ≤250mA	5.0	**4.930**	**5.070**	**4.880**	**5.120**	
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temperature Coef.	(Note 2)	**20**		**100**		**150**	ppm/°C
$\frac{\Delta V_O}{V_O}$	Line Regulation	V_{IN} = 6V to 26V	0.03		0.10		0.20	%
			(Note 3)		**0.20**		**0.40**	
$\frac{\Delta V_O}{V_O}$	Load Regulation	I_L = 1 to 250mA	0.04		0.16		0.20	%
					0.20		**0.30**	
		(Note 4)						
$V_{IN} - V_O$	Dropout Voltage (Note 5)	I_L = 1mA	60		100		100	mV
					150		**150**	
		I_L = 50mA	220		250		250	
					420		**420**	
		I_L = 100mA	250		300		300	
					450		**450**	
		I_L = 250mA	375		450		450	
					600		**600**	
I_{GND}	Ground Pin Current (Note 6)	I_L = 1mA	140		200		200	μA
					300		**300**	
		I_L = 50mA	0.5		1		1	mA
					2		**2**	
		I_L = 100mA	1.7		2.5		2.5	
					3.5		**3.5**	
		I_L = 250mA	5		9		9	
					12		**12**	
I_{GNDDO}	Ground Pin Current at Dropout (Note 6)	V_{IN} = 4.5V	180		**300**		**300**	μA
I_{LIMIT}	Current Limit	V_{OUT} = 0V			750		750	mA
		(Note 7)			**800**		**800**	
$\frac{\Delta V_O}{\Delta P_D}$	Thermal Regulation	(Note 8)	0.05		0.2		0.2	%/W
e_n	Output Noise Voltage (10Hz to 100kHz) I_L = 100mA	C_L = 2.2μF	400					μV RMS
		C_L = 33μF	260					

Electrical Characteristics, MIC2954-07BM/-08BM,(Continued)

Parameter	Conditions	MIC2954-07BM			MIC2954-08BM			Units
		Typ.	Min	Max	Typ.	Min	Max	
Reference Voltage		1.235	1.220 **1.200**	1.250 **1.260**	1.235	1.210 **1.200**	1.260 **1.270**	V V max
Reference Voltage	(Note 9)		**1.190**	**1.270**		**1.185**	**1.285**	V
Feedback Pin Bias Current		20		40 **60**	20		40 **60**	nA
Reference Voltage Temperature Coefficient	(Note 8)	20			50			ppm/°C
Feedback Pin Bias Current Temperature Coefficient		0.1			0.1			nA/°C
Error Comparator								
Output Leakage Current	$V_{OH} = 30V$	0.01		1.00 **2.00**	0.01		1.00 **2.00**	µA
Output Low Voltage	$V_{IN} = 4.5V$ $I_{OL} = 400\mu A$	150		250 **400**	150		250 **400**	mV
Upper Threshold Voltage	(Note 10)	60	40 **25**		60	40 **25**		mV
Lower Threshold Voltage	(Note 10)	75		95 **140**	75		95 **140**	mV
Hysteresis	(Note 10)	15			15			mV
Shutdown Input								
Input Logic Voltage		1.3			1.3			V
	Low (ON)			**0.7**			**0.7**	
	High (OFF)		**2.0**			**2.0**		
Shutdown Pin Input Current	$V_{SHUTDOWN} = 2.4V$	30		50 **100**	30		50 **100**	µA
	$V_{SHUTDOWN} = 30V$	450		600 **750**	450		600 **750**	µA
Regulator Output Current in Shutdown	(Note 11)	3		10 **20**	3		10 **20**	µA

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions. The maximum allowable power dissipation is a function of the maximum junction temperature, $T_{J\,(MAX)}$, the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using: $P_{(MAX)} = (T_{J(MAX)} - T_A) / \theta_{JA.}$ Exceeding the maximum allowable power dissipation will result in excessive die temperature, and the regulator will go into thermal shutdown. The junction to ambient thermal resistance of the MIC2954BM is 160°C/W mounted on a PC board. (See MIC2954BM Thermal Characteristics section for further information.

Note 2: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 3: Line regulation for the MIC2954 is tested at 150°C for I_L = 1 mA. For I_L = 100 µA and T_J = 125°C, line regulation is guaranteed by design to 0.2%. See Typical Performance Characteristics for line regulation versus temperature and load current.

Note 4: Regulation is measured at constant junction temperature using low duty cycle pulse testing. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

Note 5: Dropout Voltage is defined as the input to output differential at which the output voltage drops 100 mV below its nominal value measured at 1V differential. At very low values of programmed output voltage, the minimum input supply voltage of 2 V (2.3 V over temperature) must be taken into account.

Note 6: Ground pin current is the regulator quiescent current. The total current drawn from the source is the sum of the load current plus the ground pin current.

Note 7: The MIC2954 features fold-back current limiting. The short circuit (V_{OUT} = 0V) current limit is less than the maximum current with normal output voltage.

Note 8: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 200mA load pulse at V_{IN} = 20V (a 4W pulse) for T = 10ms.

Note 9: $V_{REF} \le V_{OUT} \le (V_{IN} - 1\text{ V})$, $2.3\text{V} \le V_{IN} \le 30\text{V}$, $100\ \mu\text{A} < I_L \le 250\text{ mA}$, $T_J \le T_{J\,MAX.}$

Note 10: Comparator thresholds are expressed in terms of a voltage differential at the Feedback terminal below the nominal reference voltage measured at 6V input. To express these thresholds in terms of output voltage change, multiply by the error amplifier gain = V_{OUT}/V_{REF} = (R1 + R2)/R2. For example, at a programmed output voltage of 5V, the Error output is guaranteed to go low when the output drops by 95 mV x 5V/1.235 V = 384 mV. Thresholds remain constant as a percent of VOUT as VOUT is varied, with the dropout warning occurring at typically 5% below nominal, 7.5% guaranteed.

Note 11: $V_{SHUTDOWN} \ge 2$ V, $V_{IN} \le 30$ V, $V_{OUT} = 0$, with Feedback pin tied to 5V Tap.

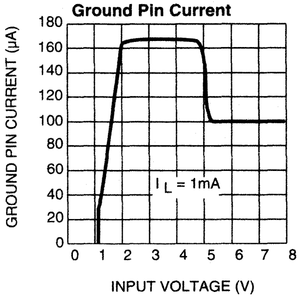
Note 12: When used in dual supply systems where the regulator load is returned to a negative supply, the output voltage must be diode clamped to ground.

Note 13: Maximum positive supply voltage of 60 V must be of limited duration (< 100 ms) and duty cycle (≤ 1%). The maximum continuous supply voltage is 30 V.

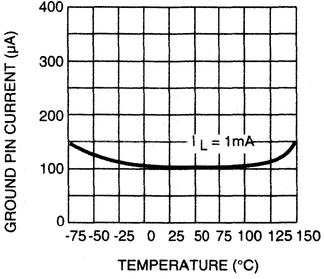
Note 14: Thermal resistance (θ_{JC}) of the TO-220 package is 2.5°C/W, and 15°C/W for the SOT-223. Thermal resistance (θ_{JA}) of the TO-92 package is 180°C/W with 0.4" leads and 160°C/W with 0.25" leads.

Typical Characteristics

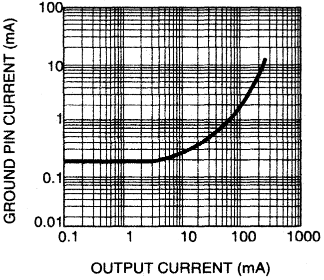
Ground Pin Current



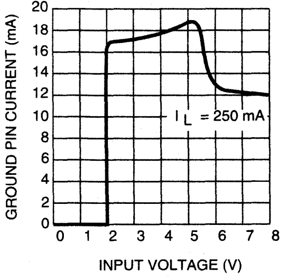
Ground Pin Current



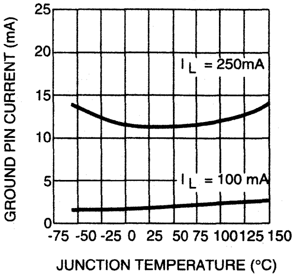
Ground Pin Current vs Load



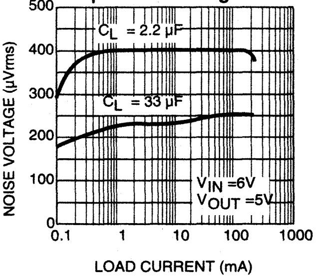
Ground Pin Current



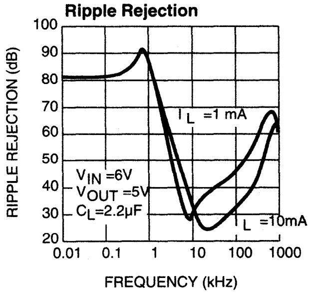
Ground Pin Current



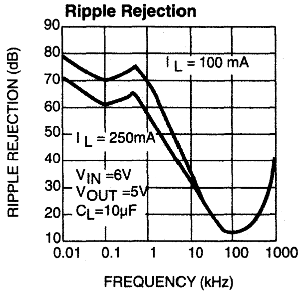
Output Noise Voltage



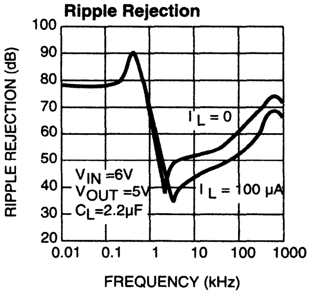
Ripple Rejection



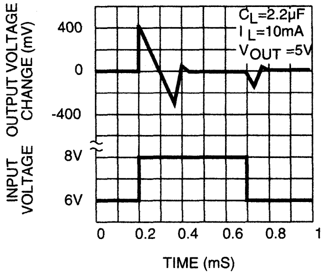
Ripple Rejection



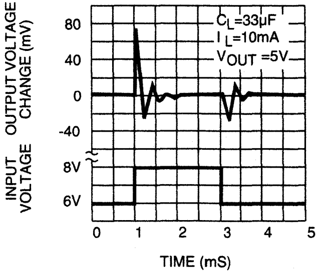
Ripple Rejection



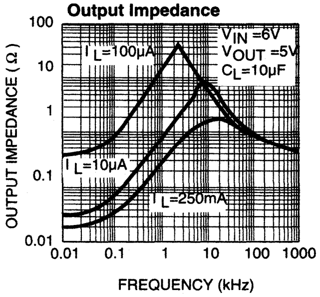
Line Transient Response



Line Transient Response

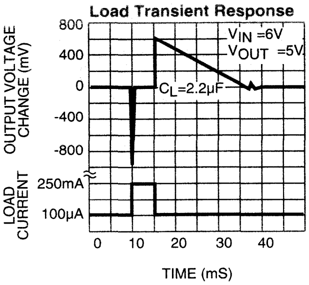


Output Impedance

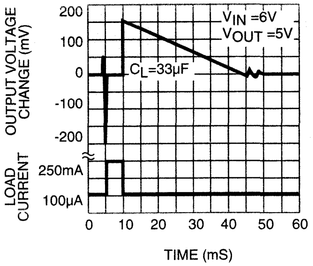


Typical Characteristics, Continued

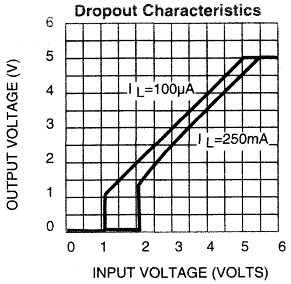
Load Transient Response



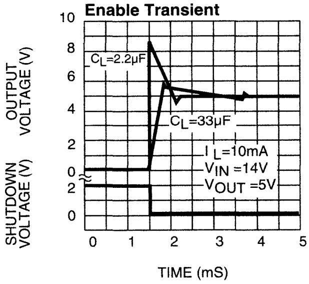
Load Transient Response



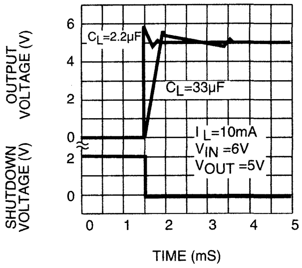
Dropout Characteristics



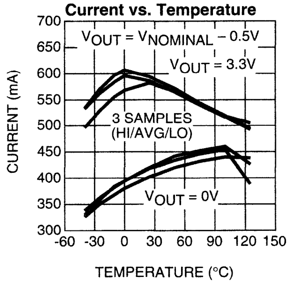
Enable Transient



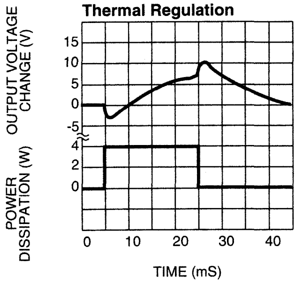
Enable Transient



Short Circuit and Maximum Current vs. Temperature



Thermal Regulation



Applications Information

External Capacitors

A 2.2µF (or greater) capacitor is required between the MIC2954 output and ground to prevent oscillations due to instability. Most types of tantalum or aluminum electrolytics will be adequate; film types will work, but are costly and therefore not recommended. Many aluminum electrolytics have electrolytes that freeze at about –30°C, so solid tantalums are recommended for operation below –25°C. The important parameters of the capacitor are an effective series resistance of about 5Ω or less and a resonant frequency above 500kHz. The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for output stability. The capacitor can be reduced to 0.5µF for current below 10mA or 0.15µF for currents below 1 mA. Adjusting the MIC2954-07BM/-08BM to voltages below 5V runs the error amplifier at lower gains so that more output capacitance is needed. For the worst-case situation of a 250mA load at 1.23V output (Output shorted to Feedback) a 5µF (or greater) capacitor should be used.

The MIC2954 will remain in regulation with a minimum load of 1mA. When setting the output voltage of the MIC2954-07BM/-08BM version with external resistors, the current through these resistors may be included as a portion of the minimum load.

A 0.1µF capacitor should be placed from the MIC2954 input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the input.

Stray capacitance to the MIC2954-07BM/-08BM Feedback terminal (pin 7) can cause instability. This may especially be a problem when using high value external resistors to set the output voltage. Adding a 100pF capacitor between Output and Feedback and increasing the output capacitor to at least 3.3µF will remedy this.

Error Detection Comparator Output (MIC2954-07BM/-08BM)

A logic low output will be produced by the comparator whenever the MIC2954BM output falls out of regulation by more than approximately 5%. This figure is the comparator's built-in offset of about 60mV divided by the 1.235V reference voltage. (Refer to the block diagram on Page 1). This trip level remains "5% below normal" regardless of the programmed output voltage of the MIC2954-07BM/-08BM. For example, the error flag trip level is typically 4.75V for a 5V output or 11.4V for a 12V output. The out of regulation condition may be due either to low input voltage, current limiting, or thermal limiting.

Figure 1 is a timing diagram depicting the $\overline{\text{ERROR}}$ signal and the regulated output voltage as the MIC2954-07BM/-08BM input is ramped up and down. The $\overline{\text{ERROR}}$ signal becomes valid (low) at about 1.3V input. It goes high at about 5V input (the input voltage at which $V_{OUT} = 4.75$). Since the MIC2954-07BM/-08BM's dropout voltage is load-dependent (see curve in Typical Performance Characteristics), the input voltage trip point (about 5V) will vary with the load current. The output voltage trip point (approximately 4.75V) does not vary with load.

The error comparator has an open-collector output which requires an external pull-up resistor. Depending on system requirements, this resistor may be returned to the 5V output or some other supply voltage. In determining a value for this resistor, note that while the output is rated to sink 400µA, this sink current adds to battery drain in a low battery condition. Suggested values range from 100k to 1MΩ. The resistor is not required if this output is unused.

Programming the Output Voltage (MIC2954-07BM/-08BM)

The MIC2954-07BM/-08BM may be pin-strapped for 5V using its internal voltage divider by tying Pin 1 (output) to Pin 2 (sense) and Pin 7 (feedback) to Pin 6 (5V Tap). Alternatively, it may be programmed for any output voltage between its 1.235V reference and its 30V maximum rating. An external pair of resistors is required, as shown in Figure 3.

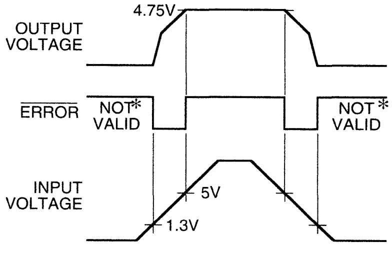
The complete equation for the output voltage is

$$V_{OUT} = V_{REF} \times \{ 1 + R_1/R_2 \} + I_{FB} R_1$$

where V_{REF} is the nominal 1.235 reference voltage and I_{FB} is the feedback pin bias current, nominally -20nA. The minimum recommended load current of 1 µA forces an upper limit of 1.2MΩ on the value of R_2, if the regulator must work with no load (a condition often found in CMOS in standby), I_{FB} will produce a 2% typical error in V_{OUT} which may be eliminated at room temperature by trimming R_1. For better accuracy, choosing R_2 = 100k reduces this error to 0.17% while increasing the resistor program current to 12 µA. Since the MIC2954-07BM/-08BM typically draws 60 µA at no load with Pin 2 open-circuited, this is a negligible addition.

Reducing Output Noise

In reference applications it may be advantageous to reduce the AC noise present at the output. One method is to reduce the regulator bandwidth by increasing the size of the output capacitor. This is relatively inefficient, as increasing the capacitor from 1 µF to 220 µF only decreases the noise from 430µV to 160μV_{RMS} for a 100kHz bandwidth at 5V output.



* SEE APPLICATIONS INFORMATION

Figure 1. $\overline{\text{ERROR}}$ Output Timing

Noise can be reduced fourfold by a bypass capacitor across R_1, since it reduces the high frequency gain from 4 to unity. Pick:

$$C_{BYPASS} \cong \frac{1}{2\pi R_1 \bullet 200\ \text{Hz}}$$

or about 0.01 µF. When doing this, the output capacitor must be increased to 3.3 µF to maintain stability. These changes reduce the output noise from 430 µV to 100 µV rms for a 100 kHz bandwidth at 5V output. With the bypass capacitor added, noise no longer scales with output voltage so that improvements are more dramatic at higher output voltages.

Automotive Applications

The MIC2954 is ideally suited for automotive applications for a variety of reasons. It will operate over a wide range of input voltages with very low dropout voltages (40mV at light loads), and very low quiescent currents (75µA typical). These features are necessary for use in battery powered systems, such as automobiles. It is a "bulletproof" device with the ability to survive both reverse battery (negative transients up to 20V below ground), and load dump (positive transients up to 60V) conditions. A wide operating temperature range with low temperature coefficients is yet another reason to use these versatile regulators in automotive designs.

Typical Applications

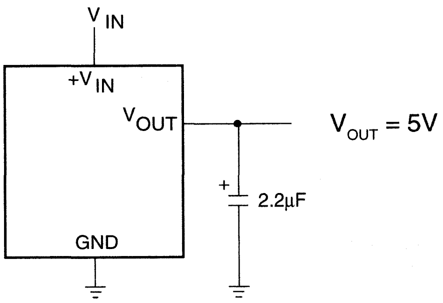
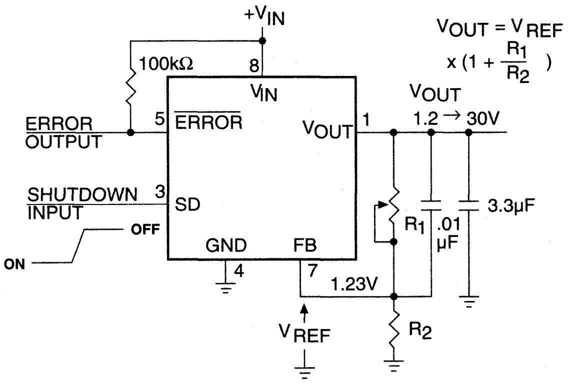


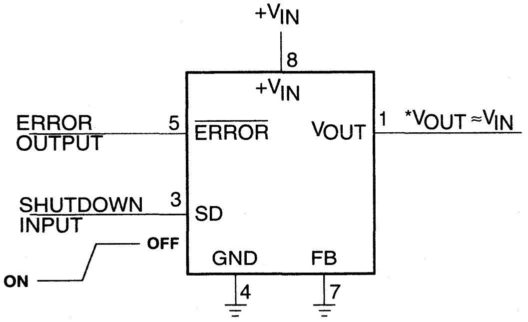
Figure 2. MIC2954 Fixed +5V Regulator



NOTE: PINS 2 AND 6 ARE LEFT OPEN

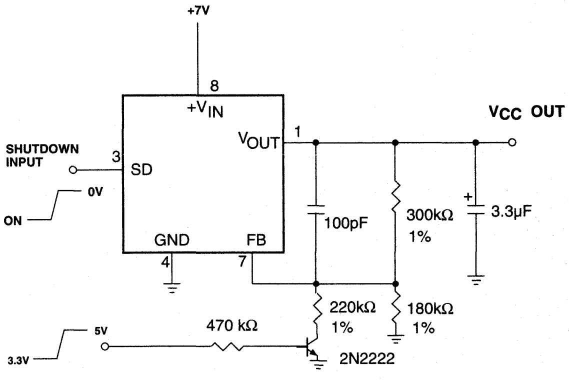
*SEE APPLICATIONS INFORMATION

Figure 3. MIC2954-07BM/-08BM Adjustable Regulator



*MINIMUM INPUT-OUTPUT VOLTAGE RANGES FROM 40mV TO 400mV, DEPENDING ON LOAD CURRENT.

Figure 4. MIC2954-07BM/-08BM Wide Input Voltage Range Current Limiter



PIN 3 LOW= ENABLE OUTPUT. Q1 ON = 3.3V, Q1 OFF = 5.0V.

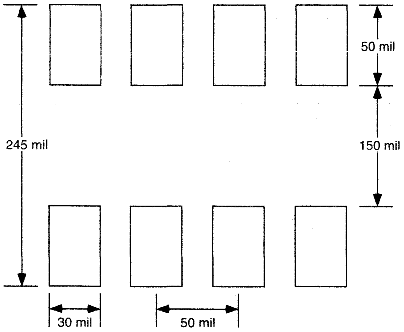
Figure 5. MIC2954-07BM/-08BM 5.0V or 3.3V Selectable Regulator with Shutdown.

MIC2954-07BM/-08BMThermal Calculations

Layout Considerations

The MIC2954-07BM/-08BM (8-Pin Surface Mount Package) has the following thermal characteristics when mounted on a single layer copper-clad printed circuit board.

Pad Layout (minimum recommended geometry)



PC Board Dielectric Material	θ_{JA}
FR4	**160°C/W**
Ceramic	**120°C/W**

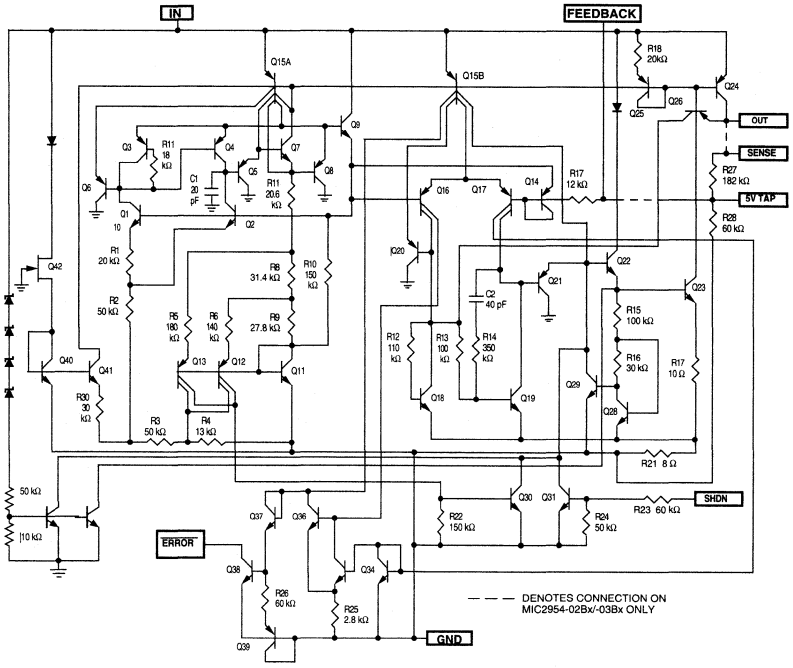
Multi-layer boards having a ground plane, wide traces near the pads, and large supply bus lines provide better thermal conductivity.

Our calculations will use the "worst case" value of 160°C/W, which assumes no ground plane, minimum trace widths, and a FR4 material board.

Nominal Power Dissipation and Die Temperature

The MIC2954-07BM/-08BM at a 55°C ambient temperature will operate reliably at up to 440mW power dissipation when mounted in the "worst case" manner described above. This power level is equivalent to a die temperature of 125°C, the recommended maximum temperature for non-military grade silicon integrated circuits.

Schematic Diagram



MIC29150/29300/29500/29750 Series

High-Current Low-Dropout Regulators

General Description

The MIC29150/29300/29500/29750 are high current, high accuracy, low-dropout voltage regulators. Using Micrel's proprietary Super βeta PNP™ process with a PNP pass element, these regulators feature 300mV to 370mV (full load) dropout voltages and very low ground current. Designed for high current loads, these devices also find applications in lower current, extremely low dropout-critical systems, where their tiny dropout voltage and ground current values are important attributes.

The MIC29150/29300/29500/29750 are fully protected against overcurrent faults, reversed input polarity, reversed lead insertion, overtemperature operation, and positive and negative transient voltage spikes. Five pin fixed voltage versions feature logic level ON/OFF control and an error flag which signals whenever the output falls out of regulation. Flagged states include low input voltage (dropout), output current limit, overtemperature shutdown, and extremely high voltage spikes on the input.

On the MIC29xx1 and MIC29xx2, the ENABLE pin may be tied to V_{IN} if it is not required for ON/OFF control. The MIC29150/29300/29500 are available in 3- and 5-pin TO-220 and surface mount TO-263 packages. The MIC29750 7.5A regulators are available in 3- and 5-pin TO-247 packages.

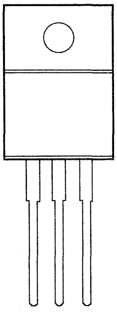
Features

- High Current Capability
  - MIC29150/29151/29152/29153 .... 1.5A
  - MIC29300/29301/29302/29303 .... 3A
  - MIC29500/29501/29502/29503 .... 5A
  - MIC29750/29751/29752/29753 .... 7.5A
- Low-Dropout Voltage .... 350mV at Full Load
- Low Ground Current
- Accurate 1% Guaranteed Tolerance
- Extremely Fast Transient Response
- Reverse-battery and "Load Dump" Protection
- Zero-Current Shutdown Mode (5-Pin versions)
- Error Flag Signals Output Out-of-Regulation (5-Pin versions)
- Also Characterized For Smaller Loads With Industry-Leading Performance Specifications
- Fixed Voltage and Adjustable Versions

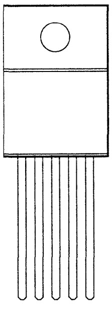
Applications

- Battery Powered Equipment
- High-Efficiency "Green" Computer Systems
- Automotive Electronics
- High-Efficiency Linear Power Supplies
- High-Efficiency Post-Regulator For Switching Supply

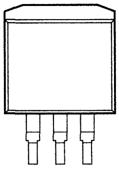
Pin Configuration



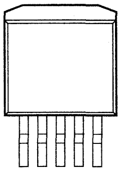
MIC29150/29300/
29500BT and
MIC29750BWT



MIC29151/29152/29153BT
MIC29301/29302/29303BT
MIC29501/29502/29503BT
MIC29751/29752/29753BWT



MIC29150/29300BU



MIC29151/29152/29153BU
MIC29301/29302/29303BU

Pinout **On all devices, the Tab is grounded.**

MIC29150/29300/29500/29750 Three Terminal Devices:

Pin 1 = Input, 2 = Ground, 3 = Output

MIC29151/29301/29501/29751 Five Terminal Fixed Voltage Devices:

Pin 1 = Enable, 2 = Input, 3 = Ground, 4 = Output, 5 = Flag

MIC29152/29302/29502/29752 Adjustable with ON/OFF Control

Pin 1 = Enable, 2 = Input, 3 = Ground, 4 = Output, 5 = Adjust

MIC29153/29303/29503/29753 Adjustable with Flag

Pin 1 = Flag, 2 = Input, 3 = Ground, 4 = Output, 5 = Adjust

Ordering Information

Part Number	Temp. Range*	Volts	Current	Package
MIC29150-3.3BT	–40 to +125°C	3.3	1.5A	TO-220
MIC29150-5.0BT	–40 to +125°C	5.0	1.5A	TO-220
MIC29150-12BT	–40 to +125°C	12	1.5A	TO-220
MIC29150-3.3BU	–40 to +125°C	3.3	1.5A	TO-263
MIC29150-5.0BU	–40 to +125°C	5.0	1.5A	TO-263
MIC29150-12BU	–40 to +125°C	12	1.5A	TO-263
MIC29151-3.3BT	–40 to +125°C	3.3	1.5A	TO-220-5
MIC29151-5.0BT	–40 to +125°C	5.0	1.5A	TO-220-5
MIC29151-12BT	–40 to +125°C	12	1.5A	TO-220-5
MIC29151-3.3BU	–40 to +125°C	3.3	1.5A	TO-263-5
MIC29151-5.0BU	–40 to +125°C	5.0	1.5A	TO-263-5
MIC29151-12BU	–40 to +125°C	12	1.5A	TO-263-5
MIC29152BT	–40 to +125°C	Adj	1.5A	TO-220-5
MIC29152BU	–40 to +125°C	Adj	1.5A	TO-263-5
MIC29153BT	–40 to +125°C	Adj	1.5A	TO-220-5
MIC29153BU	–40 to +125°C	Adj	1.5A	TO-263-5
MIC29300-3.3BT	–40 to +125°C	3.3	3.0A	TO-220
MIC29300-5.0BT	–40 to +125°C	5.0	3.0A	TO-220
MIC29300-12BT	–40 to +125°C	12	3.0A	TO-220
MIC29300-3.3BU	–40 to +125°C	3.3	3.0A	TO-263
MIC29300-5.0BU	–40 to +125°C	5.0	3.0A	TO-263
MIC29300-12BU	–40 to +125°C	12	3.0A	TO-263
MIC29301-3.3BT	–40 to +125°C	3.3	3.0A	TO-220-5
MIC29301-5.0BT	–40 to +125°C	5.0	3.0A	TO-220-5
MIC29301-12BT	–40 to +125°C	12	3.0A	TO-220-5
MIC29301-3.3BU	–40 to +125°C	3.3	3.0A	TO-263-5
MIC29301-5.0BU	–40 to +125°C	5.0	3.0A	TO-263-5
MIC29301-12BU	–40 to +125°C	12	3.0A	TO-263-5
MIC29302BT	–40 to +125°C	Adj	3.0A	TO-220-5
MIC29302BU	–40 to +125°C	Adj	3.0A	TO-263-5
MIC29303BT	–40 to +125°C	Adj	3.0A	TO-220-5
MIC29303BU	–40 to +125°C	Adj	3.0A	TO-263-5

Part Number	Temp. Range*	Volts	Current	Package
MIC29500-3.3BT	–40 to +125°C	3.3	5.0A	TO-220
MIC29500-5.0BT	–40 to +125°C	5.0	5.0A	TO-220
MIC29501-3.3BT	–40 to +125°C	3.3	5.0A	TO-220-5
MIC29501-5.0BT	–40 to +125°C	5.0	5.0A	TO-220-5
MIC29501-3.3BU	–40 to +125°C	3.3	5.0A	TO-263-5
MIC29501-5.0BU	–40 to +125°C	5.0	5.0A	TO-263-5
MIC29502BT	–40 to +125°C	Adj	5.0A	TO-220-5
MIC29502BU	–40 to +125°C	Adj	5.0A	TO-263-5
MIC29503BT	–40 to +125°C	Adj	5.0A	TO-220-5
MIC29503BU	–40 to +125°C	Adj	5.0A	TO-263-5
MIC29750-3.3BWT	–40 to +125°C	3.3	7.5A	TO-247-3
MIC29750-5.0BWT	–40 to +125°C	5.0	7.5A	TO-247-3
MIC29751-3.3BWT	–40 to +125°C	3.3	7.5A	TO-247-5
MIC29751-5.0BWT	–40 to +125°C	5.0	7.5A	TO-247-5
MIC29752BWT	–40 to +125°C	Adj	7.5A	TO-247-5

* Junction Temperature

MIC29xx0 versions are 3-terminal fixed voltage devices. MIC29xx1 are fixed voltage devices with ENABLE and ERROR flag. MIC29xx2 are adjustable regulators with ENABLE control. MIC29xx3 are adjustables with an ERROR flag.

Absolute Maximum Ratings

Power Dissipation	Internally Limited
Lead Temperature (Soldering, 5 seconds)	260°C
Storage Temperature Range	–65°C to +150°C
Input Supply Voltage (Note 1)	–20V to +60V

Operating Ratings

Operating Junction Temperature	–40°C to +125°C
Maximum Operating Input Voltage	26V
TO-220 θ_{JC}	2°C/W
TO-263 θ_{JC}	2°C/W
TO-247 θ_{JC}	1.5°C/W

Electrical Characteristics

All measurements at T_J = 25°C unless otherwise noted. **Bold** values are guaranteed across the operating temperature range. Adjustable versions aree programmed to 5.0V.

Parameter	Condition	Min	Typ	Max	Units
Output Voltage	I_O = 10mA	–1		1	%
	10mA ≤ I_O ≤ I_{FL}, (V_{OUT} + 1V) ≤ V_{IN} ≤ 26V (Note 2)	**–2**		**2**	%
Line Regulation	I_O = 10mA, (V_{OUT} + 1V) ≤ V_{IN} ≤ 26V		0.06	0.5	%
Load Regulation	V_{IN} = V_{OUT} + 5V, 10mA ≤ I_{OUT} ≤ $I_{FULL\ LOAD}$ (Note 2, 6)		0.2	1	%
$\frac{\Delta V_O}{\Delta T}$	Output Voltage (Note 6) Temperature Coef.		**20**	**100**	ppm/°C
Dropout Voltage	ΔV_{OUT} = – 1%, (Note 3)				
	MIC29150 I_O = 100mA		80	**200**	mV
	I_O = 750mA		220		
	I_O = 1.5A		350	**600**	
	MIC29300 I_O = 100mA		80	**175**	
	I_O = 1.5A		250		
	I_O = 3A		370	**600**	
	MIC29500 I_O = 250mA		125	**250**	
	I_O = 2.5A		250		
	I_O = 5A		370	**600**	
	MIC29750 I_O = 250mA		80	**200**	
	I_O = 4A		270		
	I_O = 7.5A		425	**600**	
Ground Current	MIC29150 I_O = 750mA, V_{IN} = V_{OUT} + 1V		8	**20**	mA
	I_O = 1.5A		22		
	MIC29300 I_O = 1.5A, V_{IN} = V_{OUT} + 1V		10	**35**	mA
	I_O = 3A		37		
	MIC29500 I_O = 2.5A, V_{IN} = V_{OUT} + 1V		15	**50**	mA
	I_O = 5A		70		
	MIC29750 I_O = 4A, V_{IN} = V_{OUT} + 1V		35	**75**	mA
	I_O = 7.5A		120		
I_{GNDDO}Ground Pin Current at Dropout	V_{IN} = 0.5V less than specified V_{OUT}. I_{OUT} = 10mA				
	MIC29150		0.9		mA
	MIC29300		1.7		mA
	MIC29500		2.1		mA
	MIC29750		3.1		mA
Current Limit	MIC29150 V_{OUT} = 0V (Note 4)		2.1	**3.5**	A
	MIC29300 V_{OUT} = 0V (Note 4)		4.5	**5.0**	A
	MIC29500 V_{OUT} = 0V (Note 4)		7.5	**10.0**	A
	MIC29750 V_{OUT} = 0V (Note 4)		9.5	**15**	A
e_n, Output Noise Voltage (10Hz to 100kHz) I_L = 100mA	C_L = 10µF		400		µV RMS
	C_L = 33µF		260		

Electrical Characteristics (Continued)

Reference **MIC29xx2/MIC29xx3**

Parameter	Conditions	Min	Typical	Max	Units
Reference Voltage		1.228 **1.215**	1.240	1.252 **1.265**	V V max
Reference Voltage	(Note 8)	**1.203**		**1.277**	V
Adjust Pin Bias Current			40	80 **120**	nA
Reference Voltage Temperature Coefficient	(Note 7)		20		ppm/°C
Adjust Pin Bias Current Temperature Coefficient			0.1		nA/°C

Flag Output (Error Comparator) MIC29xx1/29xx3

Output Leakage Current	V_{OH} = 26V		0.01	1.00 **2.00**	μA
Output Low Voltage	Device set for 5V. V_{IN} = 4.5V I_{OL} = 250μA		220	300 **400**	mV
Upper Threshold Voltage	Device set for 5V (Note 9)	40 **25**	60		mV
Lower Threshold Voltage	Device set for 5V (Note 9)		75	95 **140**	mV
Hysteresis	Device set for 5V (Note 9)		15		mV

ENABLE Input **MIC29xx1/MIC29xx2**

Input Logic Voltage					V
Low (OFF)				**0.8**	
High (ON)		**2.4**			
Enable Pin Input Current	V_{EN} = 26V		100	600 **750**	μA
	V_{EN} =0.8V			1 **2**	μA
Regulator Output Current in Shutdown	(Note 10)		10	**500**	μA

Notes

Note 1: Maximum positive supply voltage of 60V must be of limited duration (<100msec) and duty cycle (≤1%). The maximum continuous supply voltage is 26V.

Note 2: Full Load current (I_{FL}) is defined as 1.5A for the MIC29150, 3A for the MIC29300, 5A for the MIC29500, and 7.5A for the MIC29750 families.

Note 3: Dropout voltage is defined as the input-to-output differential when the output voltage drops to 99% of its nominal value with V_{OUT} + 1V applied to V_{IN}

Note 4: $V_{IN} = V_{OUT\,(nominal)} + 1V$. For example, use V_{IN} = 4.3V for a 3.3V regulator or use 6V for a 5V regulator. Employ pulse-testing procedures to minimize temperature rise.

Note 5: Ground pin current is the regulator quiescent current. The total current drawn from the source is the sum of the load current plus the ground pin current.

Note 6: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 7: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 200mA load pulse at V_{IN} = 20V (a 4W pulse) for T = 10ms.

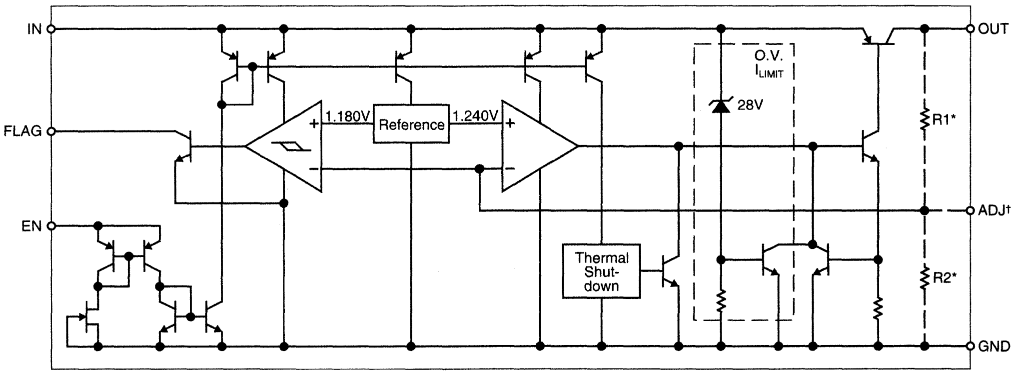
Note 8: $V_{REF} \leq V_{OUT} \leq (V_{IN} - 1\ V)$, $2.3V \leq V_{IN} \leq 26V$, $10mA < I_L \leq I_{FL}$, $T_J \leq T_{J\ MAX}$.

Note 9: Comparator thresholds are expressed in terms of a voltage differential at the Adjust terminal below the nominal reference voltage measured at 6V input. To express these thresholds in terms of output voltage change, multiply by the error amplifier gain = V_{OUT}/V_{REF} = (R1 + R2)/R2. For example, at a programmed output voltage of 5V, the Error output is guaranteed to go low when the output drops by 95 mV x 5V/1.240 V = 384 mV. Thresholds remain constant as a percent of V_{OUT} as V_{OUT} is varied, with the dropout warning occurring at typically 5% below nominal, 7.7% guaranteed.

Note 10: $V_{EN} \leq 0.8V$ and $V_{IN} \leq 26V$, $V_{OUT} = 0$.

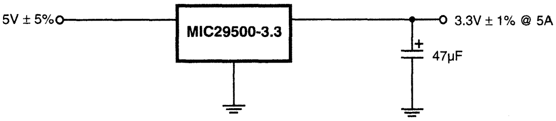
Note 11: When used in dual supply systems where the regulator load is returned to a negative supply, the output voltage must be diode clamped to ground.

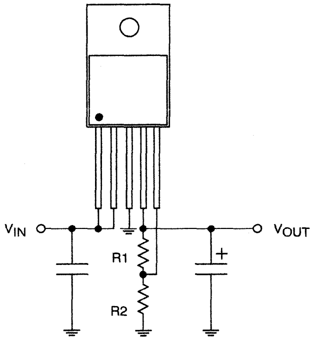
Block Diagram



* Feedback network in fixed versions only
† Adjustable version only

Typical Applications





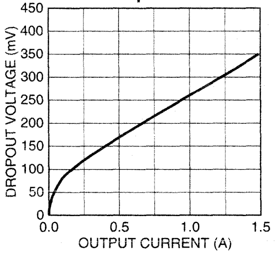
V_{OUT} = 1.240V × [1 + (R1 / R2)]

Figure 1. Fixed output voltage.

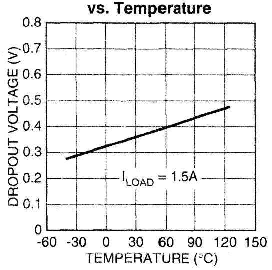
Figure 2. Adjustable output voltage configuration. For best results, the total series resistance should be small enough to pass the minimum regulator load current.

Typical Characteristics MIC2915x

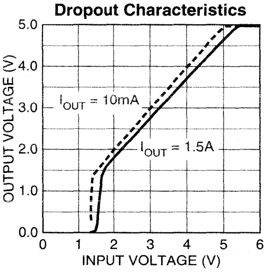
MIC2915x Dropout Voltage vs. Output Current



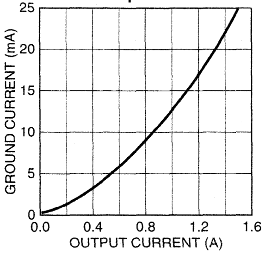
MIC2915x Dropout Voltage vs. Temperature



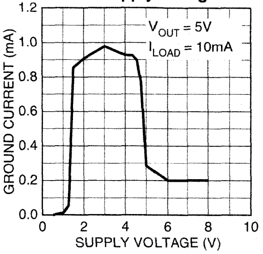
MIC29150-3.3 Dropout Characteristics



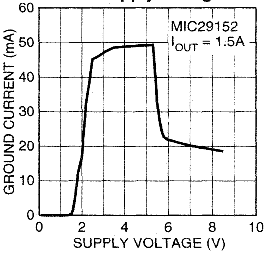
MIC2915x Ground Current vs. Output Current



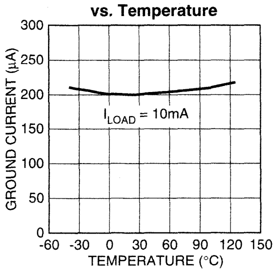
MIC2915x Ground Current vs. Supply Voltage



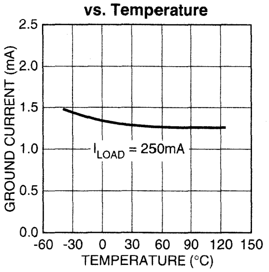
MIC2915x Ground Current vs. Supply Voltage



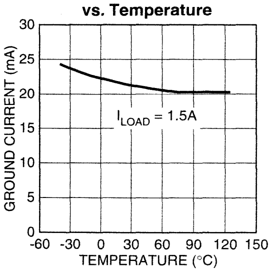
MIC2915x Ground Current vs. Temperature



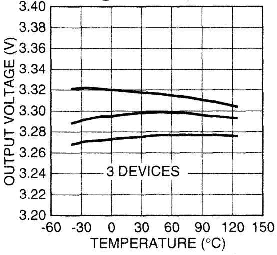
MIC2915x Ground Current vs. Temperature



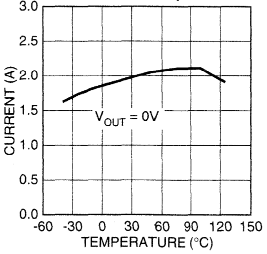
MIC2915x Ground Current vs. Temperature



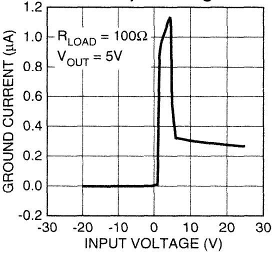
MIC29150-3.3 Output Voltage vs. Temperature

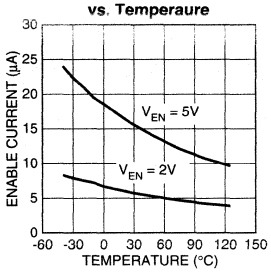


MIC29150-3.3 Short Circuit Current vs. Temperature

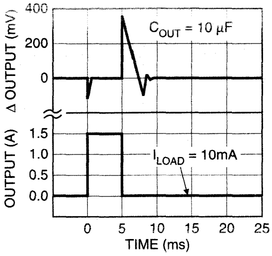


MIC2915x Ground Current vs. Input Voltage

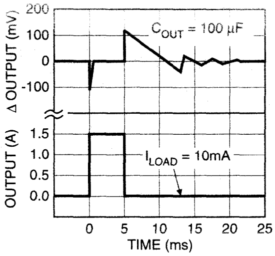




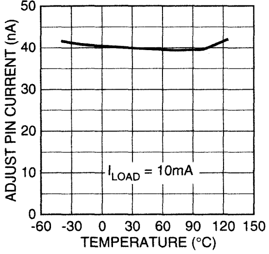
MIC29151-xx/2 Enable Current vs. Temperaure



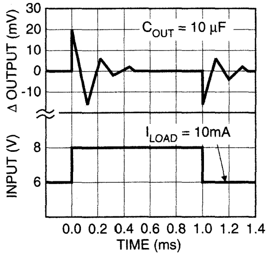
MIC2915x Load Transient



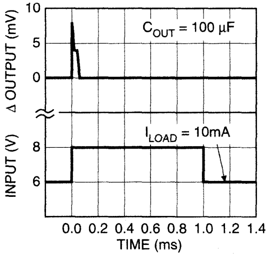
MIC2915x Load Transient



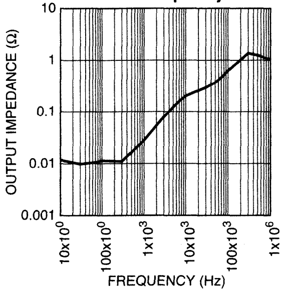
MIC29152/3 Adjust Pin Current vs. Temperature



MIC2915x Line Transient



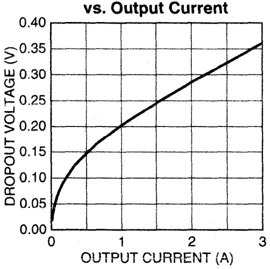
MIC2915x Line Transient



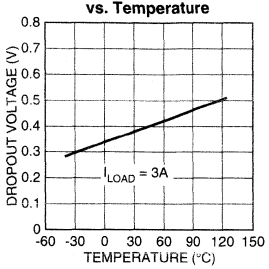
MIC2915x Output Impedance vs. Frequency

Typical Characteristics MIC2930x

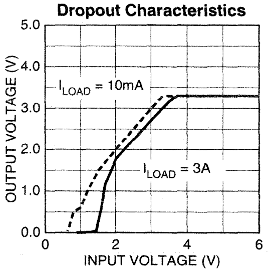
MIC2930x Dropout Voltage vs. Output Current



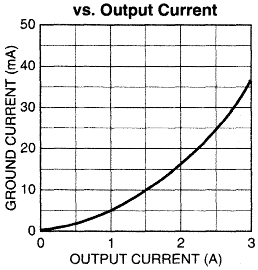
MIC2930x Dropout Voltage vs. Temperature



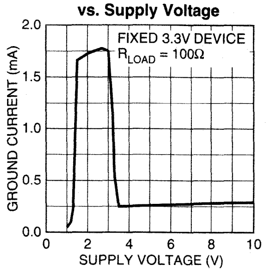
MIC29300-3.3 Dropout Characteristics



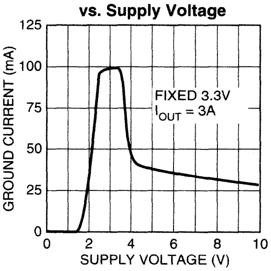
MIC2930x Ground Current vs. Output Current



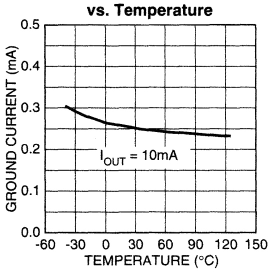
MIC2930x Ground Current vs. Supply Voltage



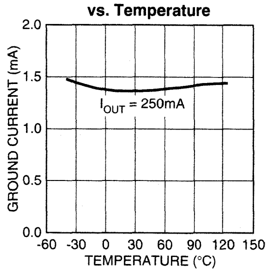
MIC2930x Ground Current vs. Supply Voltage



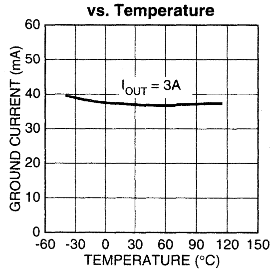
MIC2930x Ground Current vs. Temperature



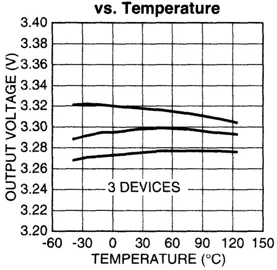
MIC2930x Ground Current vs. Temperature



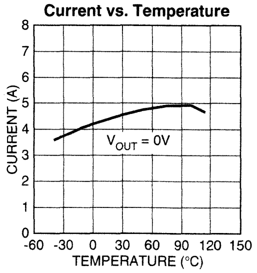
MIC2930x Ground Current vs. Temperature



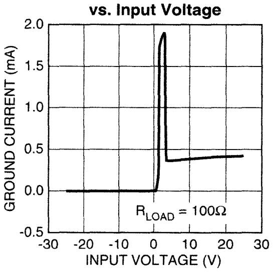
MIC29300-3.3 Output Voltage vs. Temperature

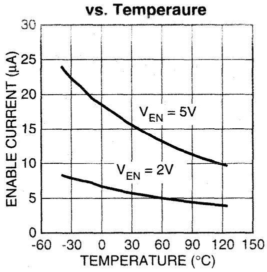


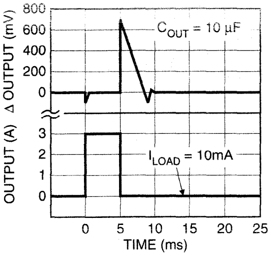
MIC29300-5.0 Short Circuit Current vs. Temperature

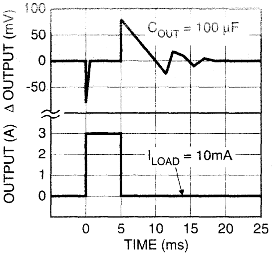


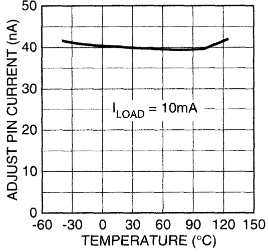
MIC2930x Ground Current vs. Input Voltage

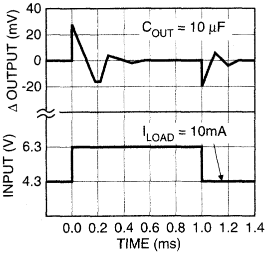


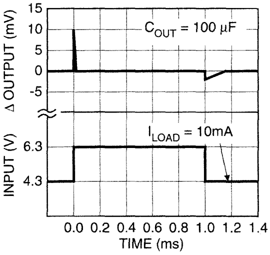

MIC29301-x/2 Enable Current vs. Temperaure

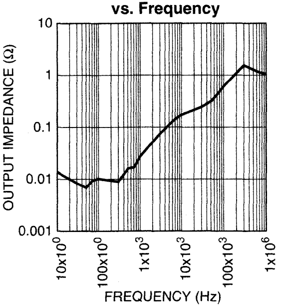

MIC2930x Load Transient


MIC2930x Load Transient

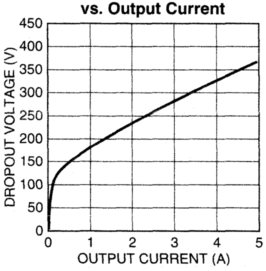

MIC29302/3 Adjust Pin Current vs. Temperature


MIC2930x Line Transient

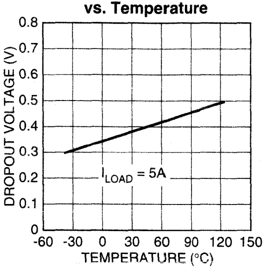

MIC2930x Line Transient


MIC2930x Output Impedance vs. Frequency

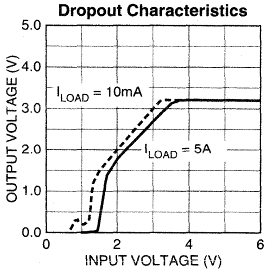
Typical Characteristics MIC2950x



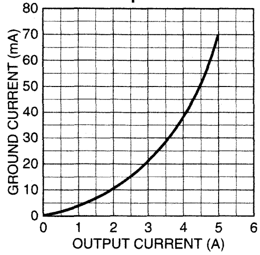
MIC2950x Dropout Voltage vs. Output Current



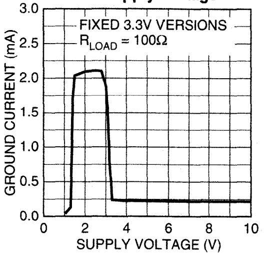
MIC2950x Dropout Voltage vs. Temperature



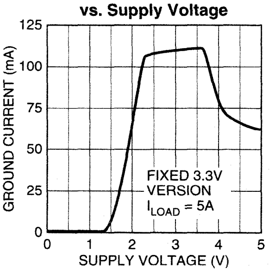
MIC29500-3.3 Dropout Characteristics



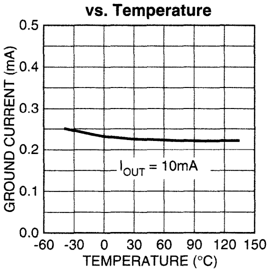
MIC2950x Ground Current vs. Output Current



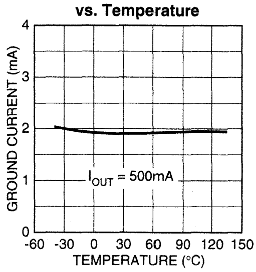
MIC2950x Ground Current vs. Supply Voltage



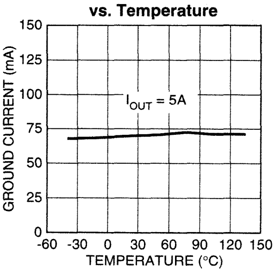
MIC2950x Ground Current vs. Supply Voltage



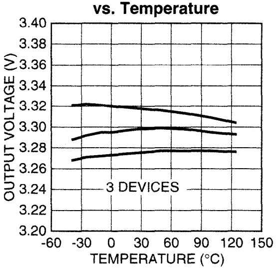
MIC2950x Ground Current vs. Temperature



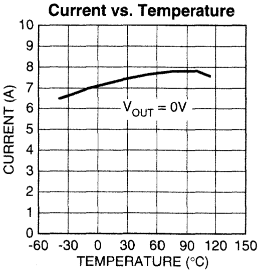
MIC2950x Ground Current vs. Temperature



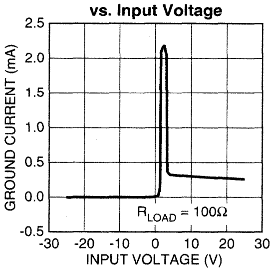
MIC2950x Ground Current vs. Temperature



MIC29500-3.3 Output Voltage vs. Temperature

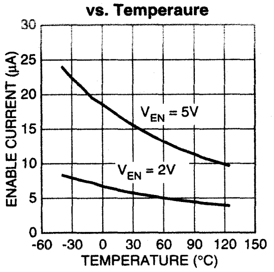


MIC2950x-5.0 Short Circuit Current vs. Temperature

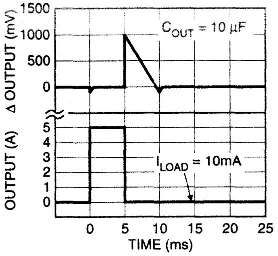


MIC2950x Ground Current vs. Input Voltage

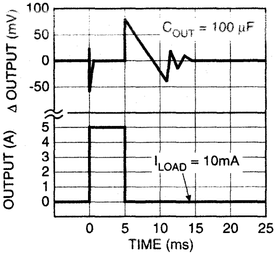
MIC29501-xx/2 Enable Current vs. Temperaure



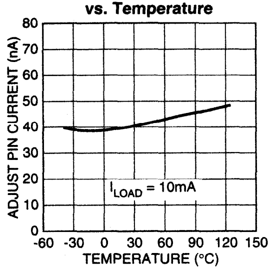
MIC2950x Load Transient



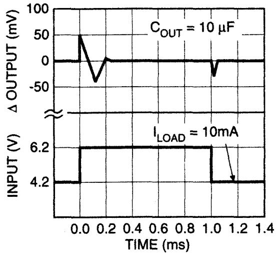
MIC2950x Load Transient



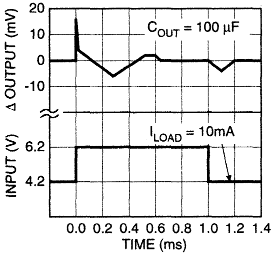
MIC29502/3 Adjust Pin Current vs. Temperature



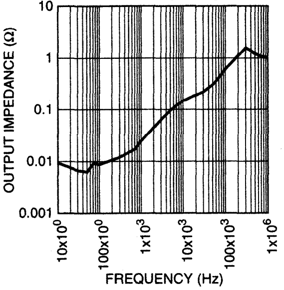
MIC2950x Line Transient



MIC2950x Line Transient

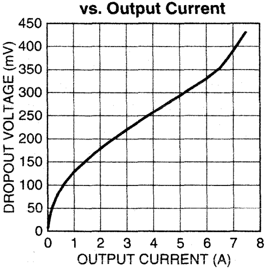


MIC2950x Output Impedance vs. Frequency

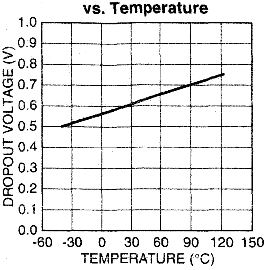


Typical Characteristics MIC2975x

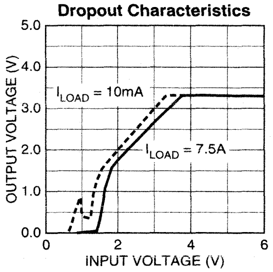
MIC2975x Dropout Voltage vs. Output Current



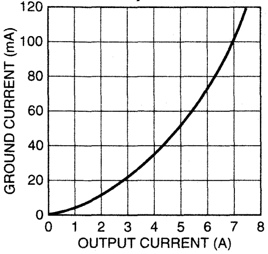
MIC2975x Dropout Voltage vs. Temperature



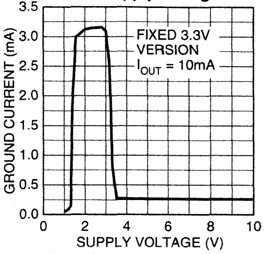
MIC29750-3.3 Dropout Characteristics



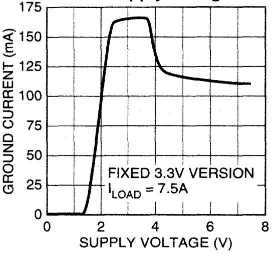
MIC2975x Ground Current vs. Output Current



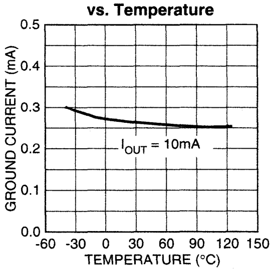
MIC2975x Ground Current vs. Supply Voltage



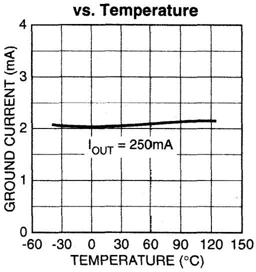
MIC2975x Ground Current vs. Supply Voltage



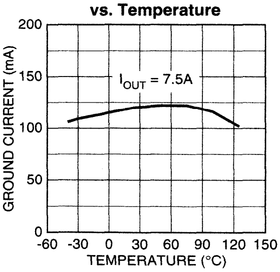
MIC2975x Ground Current vs. Temperature



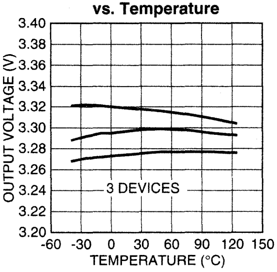
MIC2975x Ground Current vs. Temperature



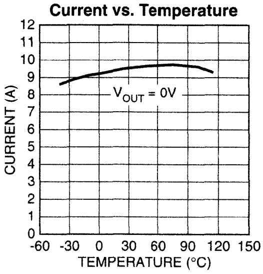
MIC2975x Ground Current vs. Temperature



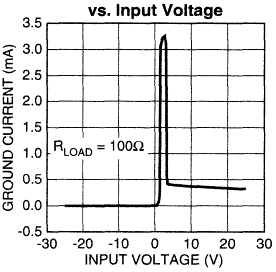
MIC29750-3.3 Output Voltage vs. Temperature



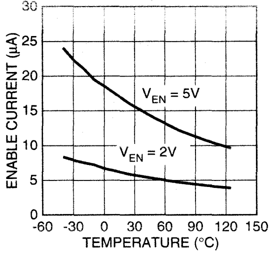
MIC29750-5.0 Short Circuit Current vs. Temperature



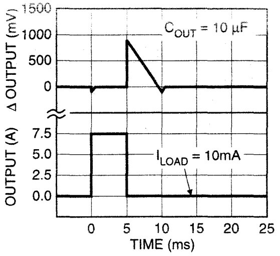
MIC2975x Ground Current vs. Input Voltage



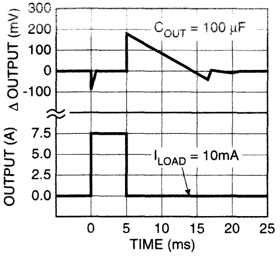
MIC29751-xx/2 Enable Current vs. Temperaure



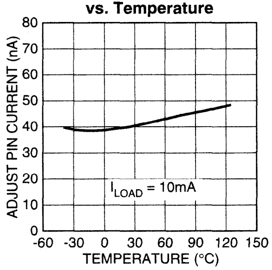
MIC2975x Load Transient



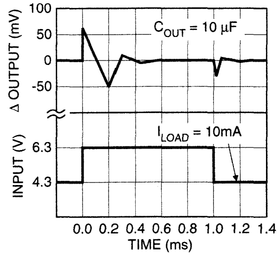
MIC2975x Load Transient



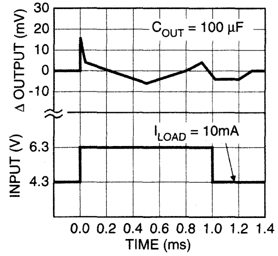
MIC29752/3 Adjust Pin Current vs. Temperature



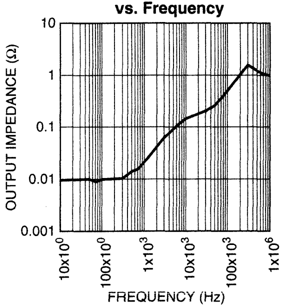
MIC2975x Line Transient



MIC2975x Line Transient



MIC2975x Output Impedance vs. Frequency



Applications Information

The MIC29150/29300/29500/29750 are high performance low-dropout voltage regulators suitable for all moderate to high-current voltage regulator applications. Their 300mV to 400mV dropout voltage at full load make them especially valuable in battery powered systems and as high efficiency noise filters in "post-regulator" applications. Unlike older NPN-pass transistor designs, where the minimum dropout voltage is limited by the base-emitter voltage drop and collector-emitter saturation voltage, dropout performance of the PNP output of these devices is limited merely by the low V_{CE} saturation voltage.

A trade-off for the low dropout voltage is a varying base drive requirement. But Micrel's Super ßeta PNP™ process reduces this drive requirement to merely 1% of the load current.

The MIC29150–29750 family of regulators is fully protected from damage due to fault conditions. Current limiting is provided. This limiting is linear; output current under overload conditions is constant. Thermal shutdown disables the device when the die temperature exceeds the 125°C maximum safe operating temperature. Transient protection allows device (and load) survival even when the input voltage spikes between –20V and +60V. When the input voltage exceeds about 35V to 40V, the overvoltage sensor temporarily disables the regulator. The output structure of these regulators allows voltages in excess of the desired output voltage to be applied without reverse current flow. MIC29xx1 and MIC29xx2 versions offer a logic level ON/OFF control: when disabled, the devices draw nearly zero current.

An additional feature of this regulator family is a common pinout: a design's current requirement may change up or down yet use the same board layout, as all of these regulators have identical pinouts.

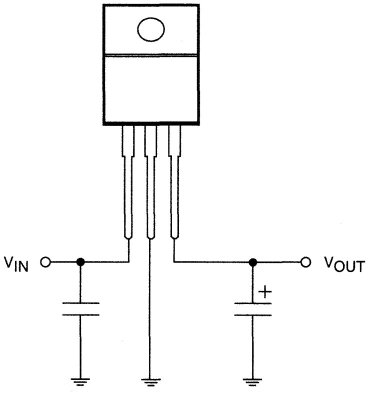


Figure 3. Linear regulators require only two capacitors for operation.

Thermal Design

Linear regulators are simple to use. The most complicated design parameters to consider are thermal characteristics. Thermal design requires the following application-specific parameters:

- Maximum ambient temperature, T_A
- Output Current, I_{OUT}
- Output Voltage, V_{OUT}
- Input Voltage, V_{IN}

First, we calculate the power dissipation of the regulator from these numbers and the device parameters from this datasheet.

$$P_D = I_{OUT} \times (1.01V_{IN} - V_{OUT})$$

Where the ground current is approximated by 1% of I_{OUT}. Then the heat sink thermal resistance is determined with this formula:

$$\theta_{SA} = \frac{T_{J\,MAX} - T_A}{P_D} - (\theta_{JC} + \theta_{CS})$$

Where $T_{J\,MAX} \leq 125°C$ and θ_{CS} is between 0 and 2°C/W.

The heat sink may be significantly reduced in applications where the minimum input voltage is known and is large compared with the dropout voltage. Use a series input resistor to drop excessive voltage and distribute the heat between this resistor and the regulator. The low dropout properties of Micrel Super ßeta PNP regulators allow very significant reductions in regulator power dissipation and the associated heat sink without compromising performance. When this technique is employed, a capacitor of at least 0.1µF is needed directly between the input and regulator ground.

Please refer to Application Note 9 and Application Hint 17 for further details and examples on thermal design and heat sink specification.

Capacitor Requirements

For stability and minimum output noise, a capacitor on the regulator output is necessary. The value of this capacitor is dependent upon the output current; lower currents allow smaller capacitors. MIC29150—29750 regulators are stable with the following minimum capacitor values at full load:

Device	Full Load Capacitor
MIC29150	10µF
MIC29300	10µF
MIC29500	10µF
MIC29750	22µF

This capacitor need not be an expensive low ESR type: aluminum electrolytics are adequate. In fact, extremely low ESR capacitors may contribute to instability. Tantalum capacitors are recommended for systems where fast load transient response is important.

Where the regulator is powered from a source with a high AC impedance, a 0.1µF capacitor connected between Input and GND is recommended. This capacitor should have good characteristics to above 250kHz.

Minimum Load Current

The MIC29150–29750 regulators are specified between finite loads. If the output current is too small, leakage currents dominate and the output voltage rises. The following minimum load current swamps any expected leakage current across the operating temperature range:

Device	**Minimum Load**
MIC29150	5mA
MIC29300	7mA
MIC29500	10mA
MIC29750	10mA

Adjustable Regulator Design

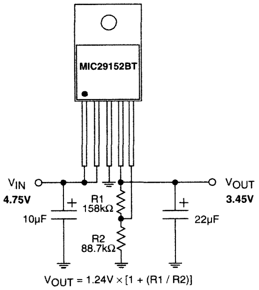


Figure 4. Adjustable Regulator with Resistors

The adjustable regulator versions, MIC29xx2 and MIC29xx3, allow programming the output voltage anywhere between 1.25V and the 26V maximum operating rating of the family. Two resistors are used. Resistors can be quite large, up to 1MΩ, because of the very high input impedance and low bias current of the sense comparator: The resistor values are calculated by:

$$R_1 = R_2 \times \left(\frac{V_{OUT}}{1.240} - 1 \right)$$

Where V_O is the desired output voltage. Figure 4 shows component definition. Applications with widely varying load currents may scale the resistors to draw the minimum load current required for proper operation (see above).

Error Flag

MIC29xx1 and MIC29xx3 versions feature an Error Flag, which looks at the output voltage and signals an error condition when this voltage drops 5% below its expected value. The error flag is an open-collector output that pulls low under fault conditions. It may sink 10mA. Low output voltage signifies a number of possible problems, including an over-current fault (the device is in current limit) and low input voltage. The flag output is inoperative during overtemperature shutdown conditions.

Enable Input

MIC29xx1 and MIC29xx2 versions feature an enable (EN) input that allows ON/OFF control of the device. Special design allows "zero" current drain when the device is disabled—only microamperes of leakage current flows. The EN input has TTL/CMOS compatible thresholds for simple interfacing with logic, or may be directly tied to ≤ 30V. Enabling the regulator requires approximately 20µA of current.

MIC29310/29312

3A Fast-Response LDO Regulator

Preliminary Information

General Description

The MIC29310 and MIC29312 are high-current, high-accuracy, low-dropout voltage regulators featuring fast transient recovery from input voltage surges and output load current changes. These regulators use a PNP pass element that features Micrel's proprietary Super ßeta PNP™ process.

The MIC29310/2 is available in two versions: the three-pin fixed output MIC29310 and the five pin adjustable output voltage MIC29312. All versions are fully protected against overcurrent faults, reversed input polarity, reversed lead insertion, overtemperature operation, and positive and negative transient voltage spikes.

A TTL compatible enable (EN) control pin supports external on/off control. If on/off control is not required, the device may be continuously enabled by connecting EN to IN.

The MIC29310/2 is available in the standard three and five pin TO-220 package with an operating junction temperature range of 0°C to +125°C.

For applications requiring even lower dropout voltage, input voltage greater than 16V, or an error flag, see the MIC29300/29301/29302/29303.

Features

- Fast transient response
- 3A current over full temperature range
- 600mV dropout voltage at full load
- Low ground current
- Accurate 1% guaranteed tolerance
- "Zero" current shutdown mode (MIC29312)
- Fixed voltage and adjustable versions

Applications

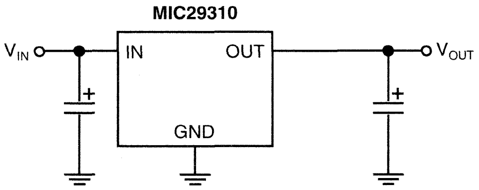
- Pentium™ and Power PC™ processor supplies
- High-efficiency "green" computer systems
- High-efficiency linear power supplies
- High-efficiency switching supply post regulator
- Battery-powered equipment

Ordering Information

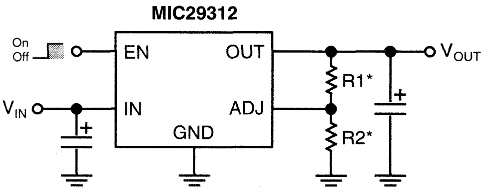
Part Number	Temp. Range*	Voltage	Current	Package
MIC29310-3.3BT	0°C to +125°C	3.3V	3.0A	TO-220-3
MIC29310-5.0BT	0°C to +125°C	5.0V	3.0A	TO-220-3
MIC29312BT	0°C to +125°C	Adj.	3.0A	TO-220-5

* Junction Temperature

Typical Application



Fixed Regulator Configuration

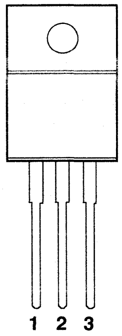


$$V_{OUT} = 1.240\left(\frac{R1}{R2} + 1\right)$$

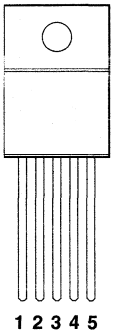
* For best performance, total series resistance (R1 + R2) should be small enough to pass the minimum regulator load current of 10mA.

Adjustable Regulator Configuration

Pin Configuration



MIC29310BT



MIC29312BT

On all devices, the Tab is grounded.

Pin Description

3-Pin TO-220 (MIC29310)

Pin Number	Pin Name	Pin Function
1	IN	Unregulated Input: +16V maximum supply.
2	GND	Ground: Internally connected to tab (ground).
3	OUT	Regulated Output

5-Pin TO-220 (MIC29312)

Pin Number	Pin Name	Pin Function
1	EN	Enable (Input): Logic-level ON/OFF control.
2	IN	Unregulated Input: +16V maximum supply.
3	GND	Ground: Internally connected to tab (ground).
4	OUT	Regulated Output
5	ADJ	Output Voltage Adjust: 1.240V feedback from external resistive divider.

Absolute Maximum Ratings

Input Supply Voltage (Note 1)	–20V to +20V
Power Dissipation	Internally Limited
Storage Temperature Range	–65°C to +150°C
Lead Temperature (Soldering, 5 sec.)	260°C

Operating Ratings

Operating Junction Temperature	0°C to +125°C
θ_{JC} (TO-220)	2°C/W
θ_{JA} (TO-220)	55°C/W

Electrical Characteristics

All measurements at $T_J = 25°C$ unless otherwise noted. **Bold** values are guaranteed across the operating temperature range.

Parameter	Condition	Min	Typ	Max	Units
Output Voltage	$10mA \le I_O \le I_{FL}$, $(V_{OUT} + 1V) \le V_{IN} \le 8V$ (Note 2)	**–2**		**2**	%
Line Regulation	$I_O = 10mA$, $(V_{OUT} + 1V) \le V_{IN} \le 16V$		0.06	0.5	%
Load Regulation	$V_{IN} = V_{OUT} + 1V$, $10mA \le I_{OUT} \le I_{FULL\ LOAD}$ (Notes 2, 6)		0.2	1	%
$\Delta V_O / \Delta T$	Output Voltage Temperature Coefficient (Note 6)		**20**	**100**	ppm/°C
Dropout Voltage	$\Delta V_{OUT} = -1\%$, (Note 3)				
	MIC29310/29312 $I_O = 100mA$		80	**200**	mV
	$I_O = 750mA$		220		mV
	$I_O = 1.5A$		330		mV
	$I_O = 3A$		600	**1000**	mV
Ground Current	MIC29310/29312 $I_O = 750mA$, $V_{IN} = V_{OUT} + 1V$		5	**20**	mA
	$I_O = 1.5A$		15		mA
	$I_O = 3A$		60	**150**	mA
I_{GNDDO} Ground Pin Current at Dropout	$V_{IN} = 0.5V$ less than specified V_{OUT}. $I_{OUT} = 10mA$		2	3	mA
Current Limit	MIC29310/29312 $V_{OUT} = 0V$ (Note 4)	3.0	3.8		A
Minimum Load Current			7	10	mA
e_n, Output Noise Voltage (10Hz to 100kHz) $I_L = 100mA$	$C_L = 10\mu F$		400		μV_{RMS}
	$C_L = 33\mu F$		260		μV_{RMS}

Reference (MIC29312 only)

Reference Voltage	$10mA \le I_O \le I_{FL}$, $V_{OUT} + 1V \le V_{IN} \le 8V$ (Note 2)	**1.215**		**1.265**	V_{MAX}
Adjust Pin Bias Current			40	80 **120**	nA nA
Reference Voltage Temperature Coefficient	(Note 7)		20		ppm/°C
Adjust Pin Bias Current Temperature Coefficient			0.1		nA/°C

Parameter	Conditions	Min	Typical	Max	Units
Enable Input (MIC29312 only)					
Input Logic Voltage	Low (Off)			**0.8**	V
	High (On)	**2.4**			V
Enable (EN) Pin Input Current	$V_{EN} = V_{IN}$		15	30	µA
				75	µA
	$V_{EN} = 0.8V$		–	2	µA
				4	µA
Regulator Output Current in Shutdown	(Note 8)		10		µA
				20	µA

General Note: Devices are ESD sensitive. Handling precautions recommended.

Note 1: The maximum continuous supply voltage is 16V.

Note 2: Full Load current is defined as 3A for the MIC29310/29312. For testing, V_{OUT} is programmed to 5V.

Note 3: Dropout voltage is defined as the input-to-output differential when the output voltage drops to 99% of its nominal value with V_{OUT} + 1V applied to V_{IN}.

Note 4: For this test, V_{IN} is the larger of 8V or V_{OUT} + 3V.

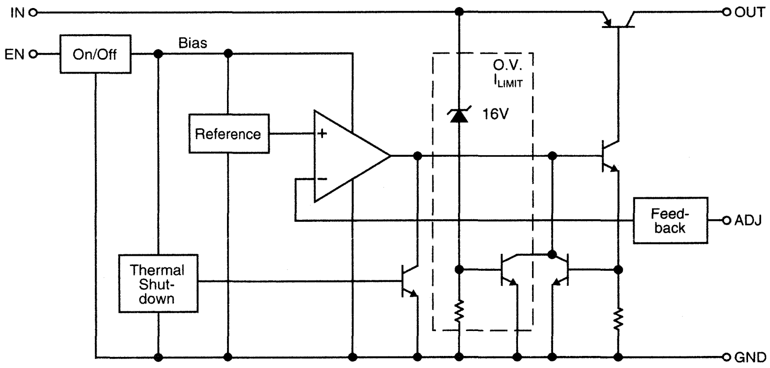
Note 5: Ground pin current is the regulator quiescent current. The total current drawn from the source is the sum of the load current plus the ground pin current.

Note 6: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

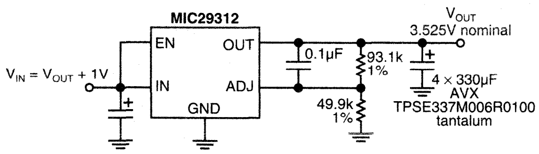
Note 7: $V_{REF} \leq V_{OUT} \leq (V_{IN} - 1\text{ V})$, $2.4V \leq V_{IN} \leq 16V$, $10mA < I_L \leq I_{FL}$, $T_J \leq T_{J\,MAX}$.

Note 8: $V_{EN} \leq 0.8V$ and $V_{IN} \leq 8V$, $V_{OUT} = 0$.

Block Diagram



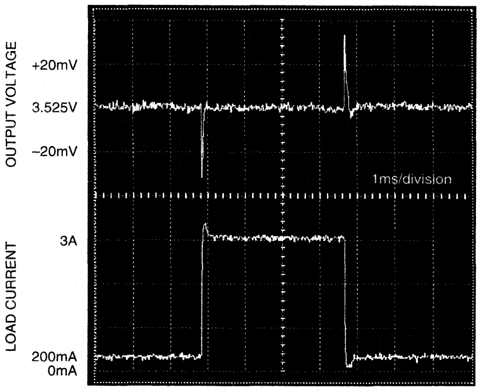
Typical Characteristics



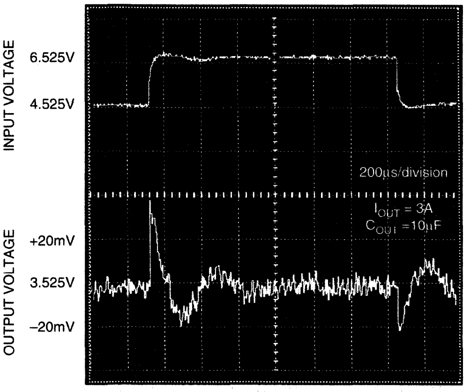
V_{OUT} load (not shown): *Intel® Power Validator*

MIC29312 Load Transient Response Test Circuit

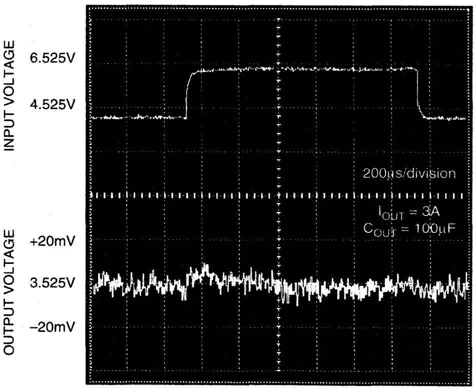
MIC29312 Load Transient Response (See Test Circuit Schematic)



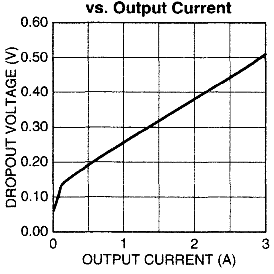
MIC29312 Line Transient Response with 3A Load, 10µF Output Capacitance



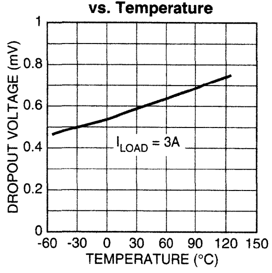
MIC29312 Line Transient Response with 3A Load, 100µF Output Capacitance



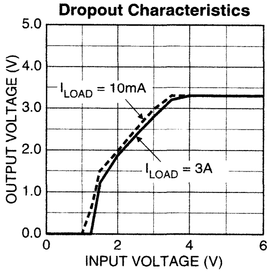
MIC2931x Dropout Voltage vs. Output Current



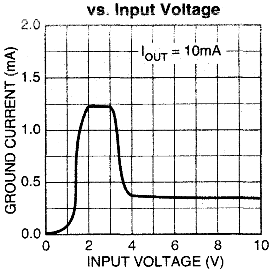
MIC2931x Dropout Voltage vs. Temperature



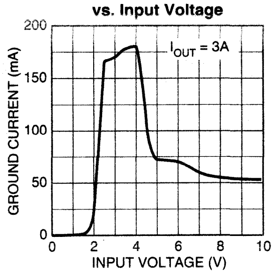
MIC29310-3.3 Dropout Characteristics



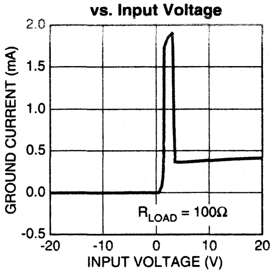
MIC2931x Ground Current vs. Input Voltage



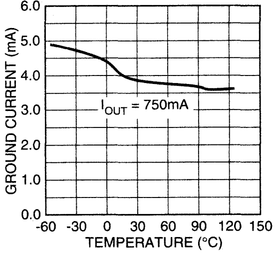
MIC2931x Ground Current vs. Input Voltage



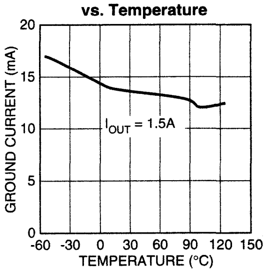
MIC29310 Ground Current vs. Input Voltage



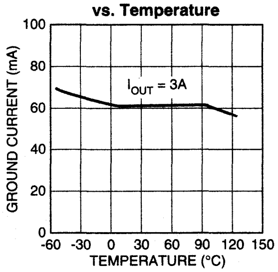
MIC2931x Ground Current vs. Temperature



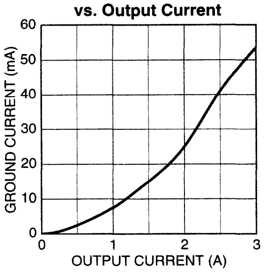
MIC2931x Ground Current vs. Temperature



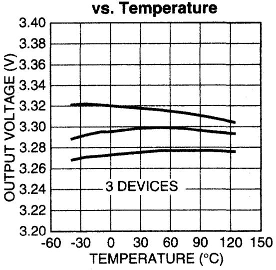
MIC2931x Ground Current vs. Temperature



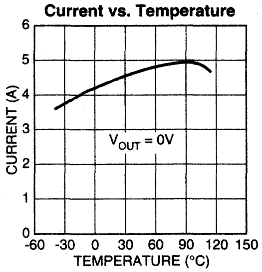
MIC2931x Ground Current vs. Output Current



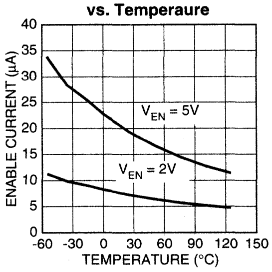
MIC29310-3.3 Output Voltage vs. Temperature



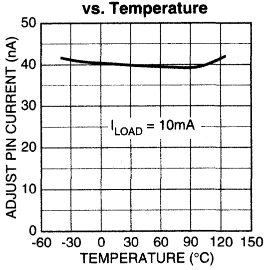
MIC2931x Short Circuit Current vs. Temperature



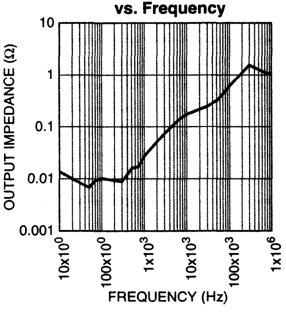
MIC29312 Enable Current vs. Temperaure



MIC29312 Adjust Pin Current vs. Temperature



MIC2931x Output Impedance vs. Frequency



Applications Information

The MIC29310 and MIC29312 are high performance low-dropout voltage regulators suitable for all moderate to high-current voltage regulator applications. Their 600mV of dropout voltage at full load make them especially valuable in battery powered systems and as high efficiency noise filters in "post-regulator" applications. Unlike older NPN-pass transistor designs, where the minimum dropout voltage is limited by the base-emitter voltage drop and collector-emitter saturation voltage, dropout performance of the PNP output of these devices is limited merely by the low V_{CE} saturation voltage.

A trade-off for the low dropout voltage is a varying base drive requirement. But Micrel's Super ßeta PNP™ process reduces this drive requirement to merely 2% to 5% of the load current.

MIC29310/312 regulators are fully protected from damage due to fault conditions. Current limiting is provided. This limiting is linear; output current under overload conditions is constant. Thermal shutdown disables the device when the die temperature exceeds the maximum safe operating temperature. Transient protection allows device (and load) survival even when the input voltage spike above and below nominal. The output structure of these regulators allows voltages in excess of the desired output voltage to be applied without reverse current flow. The MIC29312 version offers a logic level ON/OFF control: when disabled, the devices draw nearly zero current.

An additional feature of this regulator family is a common pinout: a design's current requirement may change up or down yet use the same board layout, as all of Micrel's high-current Super ßeta PNP™ regulators have identical pinouts.

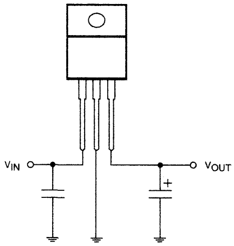


Figure 3. The MIC29310 regulator requires only two capacitors for operation.

Thermal Design

Linear regulators are simple to use. The most complicated design parameters to consider are thermal characteristics. Thermal design requires the following application-specific parameters:

- Maximum ambient temperature, T_A
- Output Current, I_{OUT}
- Output Voltage, V_{OUT}
- Input Voltage, V_{IN}

First, we calculate the power dissipation of the regulator from these numbers and the device parameters from this datasheet.

$$P_D = I_{OUT} \times (1.02V_{IN} - V_{OUT})$$

Where the ground current is approximated by 2% of I_{OUT}. Then the heat sink thermal resistance is determined with this formula:

$$\theta_{SA} = \frac{T_{J\,MAX} - T_A}{P_D} - (\theta_{JC} + \theta_{CS})$$

Where $T_{J\,MAX} \leq 125°C$ and θ_{CS} is between 0 and 2°C/W.

The heat sink may be significantly reduced in applications where the minimum input voltage is known and is large compared with the dropout voltage. Use a series input resistor to drop excessive voltage and distribute the heat between this resistor and the regulator. The low dropout properties of Micrel Super ßeta PNP regulators allow very significant reductions in regulator power dissipation and the associated heat sink without compromising performance. When this technique is employed, a capacitor of at least 0.1µF is needed directly between the input and regulator ground.

Please refer to Application Note 9 for further details and examples on thermal design and heat sink specification.

Capacitor Requirements

For stability and minimum output noise, a capacitor on the regulator output is necessary. The value of this capacitor is dependent upon the output current; lower currents allow smaller capacitors. MIC29310/2 regulators are stable with a minimum capacitor value of 10µF at full load.

This capacitor need not be an expensive low ESR type: aluminum electrolytics are adequate. In fact, extremely low ESR capacitors may contribute to instability. Tantalum capacitors are recommended for systems where fast load transient response is important.

Where the regulator is powered from a source with a high AC impedance, a 0.1µF capacitor connected between Input and GND is recommended. This capacitor should have good characteristics to above 250kHz.

Transient Response and 5V to 3.3V Conversion

The MIC29310/2 have excellent response to variations in input voltage and load current. By virtue of their low dropout voltage, these devices do not saturate into dropout as readily as similar NPN-based designs. A 3.3V output Micrel LDO will maintain full speed and performance with an input supply as low as 4.2V, and will still provide some regulation with supplies down to 3.8V, unlike NPN devices that require 5.1V or more for good performance and become nothing more than a resistor under 4.6V of input. Micrel's PNP regulators provide superior performance in "5V to 3.3V" conversion applications than NPN regulators, especially when all tolerances are considered.

Minimum Load Current

The MIC29310/2 regulators are specified between finite loads. If the output current is too small, leakage currents dominate and the output voltage rises. A 10mA minimum load current is necessary for proper regulation.

Adjustable Regulator Design

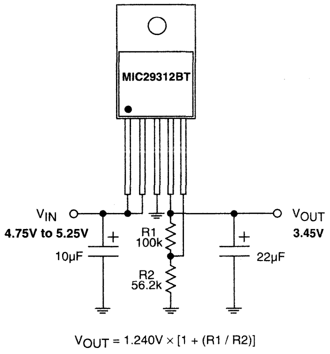


Figure 4. Adjustable Regulator with Resistors

The adjustable regulator version, MIC29312, allows programming the output voltage anywhere between 1.25V and the 15V maximum operating rating of the family. Two resistors are used. Resistors can be quite large, up to 1MΩ, because of the very high input impedance and low bias current of the sense comparator. The resistor values are calculated by:

$$R1 = R2 \times \left(\frac{V_{OUT}}{1.240} - 1 \right)$$

Where V_O is the desired output voltage. Figure 4 shows component definition. Applications with widely varying load currents may scale the resistors to draw the minimum load current required for proper operation (see the table below).

Enable Input

The MIC29312 version features an enable (EN) input that allows ON/OFF control of the device. Special design allows "zero" current drain when the device is disabled—only microamperes of leakage current flows. The EN input has TTL/CMOS compatible thresholds for simple interfacing with logic, or may be directly tied to V_{IN}. Enabling the regulator requires approximately 20µA of current into the EN pin.

Resistor Value Table for the MIC29312 Adjustable Regulator

Voltage	Standard (Ω)		Min. Load (Ω)	
	R1	R2	R1	R2
2.85	100k	76.8k	162	124
2.9	100k	75.0k	165	124
3.0	100k	69.8k	174	124
3.1	100k	66.5k	187	124
3.15	100k	64.9k	191	124
3.3	100k	60.4k	205	124
3.45	100k	56.2k	221	124
3.6	100k	52.3k	237	124
3.8	100k	48.7k	255	124
4.0	100k	45.3k	274	124
4.1	100k	43.2k	287	124

Note: This regulator has a minimum load requirement. "Standard" values assume the load meets this requirement. "Minimum Load" values are calculated to draw 10mA and allow regulation with an open load (the minimum current drawn from the load may be zero).

MIC29510/29512

5A Fast-Response LDO Regulator

Preliminary Information

General Description

The MIC29510 and MIC29512 are high-current, high-accuracy, low-dropout voltage regulators featuring fast transient recovery from input voltage surges and output load current changes. These regulators use a PNP pass element that features Micrel's proprietary Super ßeta PNP™ process.

The MIC29510/2 is available in two versions: the three pin fixed output MIC29510 and the five pin adjustable output voltage MIC29512. All versions are fully protected against overcurrent faults, reversed input polarity, reversed lead insertion, overtemperature operation, and positive and negative transient voltage spikes.

A TTL compatible enable (EN) control pin supports external on/off control. If on/off control is not required, the device may be continuously enabled by connecting EN to IN.

The MIC29510/2 is available in the standard three and five pin TO-220 package with an operating junction temperature range of 0°C to +125°C.

For applications requiring even lower dropout voltage, input voltage greater than 16V, or an error flag, see the MIC29500/29501/29502/29503.

Features

- Fast transient response
- 5A current capability
- 700mV dropout voltage at full load
- Low ground current
- Accurate 1% guaranteed tolerance
- "Zero" current shutdown mode (MIC29512)
- Fixed voltage and adjustable versions

Applications

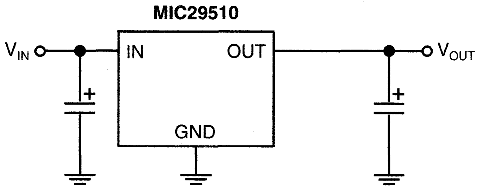
- Pentium™ and Power PC™ processor supplies
- High-efficiency "green" computer systems
- High-efficiency linear power supplies
- High-efficiency switching supply post regulator
- Battery-powered equipment

Ordering Information

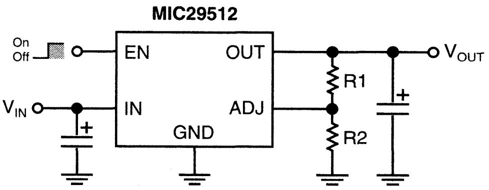
Part Number	Temp. Range*	Voltage	Current	Package
MIC29510-3.3BT	0°C to +125°C	3.3V	5.0A	TO-220-3
MIC29510-5.0BT	0°C to +125°C	5.0V	5.0A	TO-220-3
MIC29512BT	0°C to +125°C	Adj.	5.0A	TO-220-5

* Junction Temperature

Typical Application



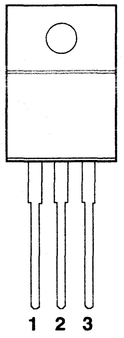
Fixed Regulator Configuration



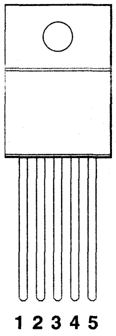
$$V_{OUT} = 1.240\left(\frac{R1}{R2} + 1\right)$$

Adjustable Regulator Configuration

Pin Configuration



MIC29510BT



MIC29512BT

On all devices, the Tab is grounded.

Pin Description

3-Pin TO-220 (MIC29510)

Pin Number	Pin Name	Pin Function
1	IN	Unregulated Input: +16V maximum supply.
2	GND	Ground: Internally connected to tab (ground).
3	OUT	Regulated Output

5-Pin TO-220 (MIC29512)

Pin Number	Pin Name	Pin Function
1	EN	Enable (Input): Logic-level ON/OFF control.
2	IN	Unregulated Input: +16V maximum supply.
3	GND	Ground: Internally connected to tab (ground).
4	OUT	Regulated Output
5	ADJ	Output Voltage Adjust: 1.240V feedback from external resistive divider.

Absolute Maximum Ratings

Input Supply Voltage (Note 1)	–20V to +20V
Power Dissipation	Internally Limited
Storage Temperature Range	–65°C to +150°C
Lead Temperature (Soldering, 5 sec.)	260°C

Operating Ratings

Operating Junction Temperature	0°C to +125°C
θ_{JC} (TO-220)	2°C/W
θ_{JA} (TO-220)	55°C/W

Electrical Characteristics

All measurements at T_J = 25°C unless otherwise noted. **Bold** values are guaranteed across the operating temperature range.

Parameter	Condition	Min	Typ	Max	Units
Output Voltage	10mA ≤ I_O ≤ I_{FL}, (V_{OUT} + 1V) ≤ V_{IN} ≤ 8V (Note 2)	**–2**		**2**	%
Line Regulation	I_O = 10mA, (V_{OUT} + 1V) ≤ V_{IN} ≤ 8V		0.06	0.5	%
Load Regulation	V_{IN} = V_{OUT} + 1V, 10mA ≤ I_{OUT} ≤ $I_{FULL\ LOAD}$ (Notes 2, 6)		0.2	1	%
$\Delta V_O / \Delta T$	Output Voltage Temperature Coefficient (Note 6)		**20**	**100**	ppm/°C
Dropout Voltage	ΔV_{OUT} = – 1%, (Note 3)				
	MIC29510/29512 I_O = 100mA		80	**200**	mV
	I_O = 750mA		200		mV
	I_O = 1.5A		320		mV
	I_O = 3A		500		mV
	I_O = 5A		700	**1000**	mV
Ground Current	MIC29510/29512 I_O = 750mA, V_{IN} = V_{OUT} + 1V		3	**20**	mA
	I_O = 1.5A		10		mA
	I_O = 3A		36		mA
	I_O = 5A		100	**150**	mA
I_{GNDDO} Ground Pin Current at Dropout	V_{IN} = 0.5V less than specified V_{OUT}. I_{OUT} = 10mA		2	3	mA
Current Limit	MIC29510/29512 V_{OUT} = 0V (Note 4)	5.0	6.5		A
e_n, Output Noise Voltage (10Hz to 100kHz) I_L = 100mA	C_L = 47µF		260		μV_{RMS}

Reference (MIC29512 only)

Reference Voltage	10mA ≤ I_O ≤ I_{FL}, V_{OUT} + 1V ≤ V_{IN} ≤ 8V (Note 2)	**1.215**		**1.265**	V_{MAX}
Adjust Pin Bias Current			40	80	nA
				120	nA
Reference Voltage Temperature Coefficient	(Note 7)		20		ppm/°C
Adjust Pin Bias Current Temperature Coefficient			0.1		nA/°C

Parameter	Conditions	Min	Typical	Max	Units
Enable Input (MIC29512 only)					
Input Logic Voltage	Low (Off) High (On)	 **2.4**		**0.8**	V V
Enable (EN) Pin Input Current	$V_{EN} = V_{IN}$		15	30 **75**	µA µA
	$V_{EN} = 0.8V$		–	2 **4**	µA µA
Regulator Output Current in Shutdown	(Note 8)		10	 **20**	µA µA

General Note: Devices are ESD sensitive. Handling precautions recommended.

Note 1: The maximum continuous supply voltage is 16V.

Note 2: Full Load current is defined as 5A for the MIC29510/29512. For testing, V_{OUT} is programmed to 5V.

Note 3: Dropout voltage is defined as the input-to-output differential when the output voltage drops to 99% of its nominal value with V_{OUT} + 1V applied to V_{IN}.

Note 4: For this test, V_{IN} is the larger of 8V or V_{OUT} + 3V.

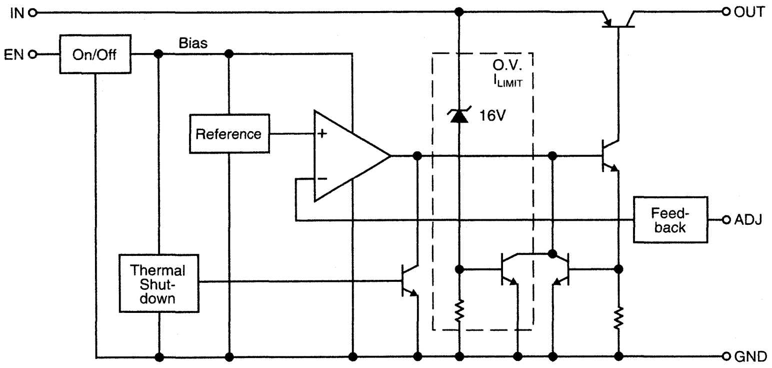
Note 5: Ground pin current is the regulator quiescent current. The total current drawn from the source is the sum of the load current plus the ground pin current.

Note 6: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

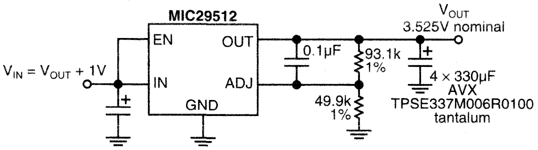
Note 7: $V_{REF} \le V_{OUT} \le (V_{IN} - 1\ V)$, $2.4V \le V_{IN} \le 16V$, $10mA < I_L \le I_{FL}$, $T_J \le T_{J\ MAX}$.

Note 8: $V_{EN} \le 0.8V$ and $V_{IN} \le 8V$, $V_{OUT} = 0$.

Block Diagram



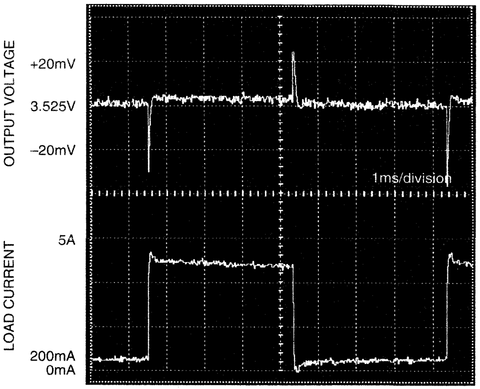
Typical Characteristics



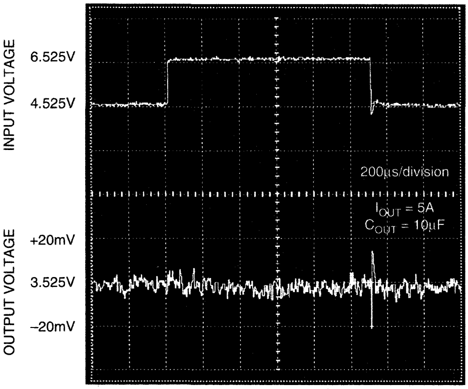
VOUT load (not shown):
Intel® Power Validator

MIC29512 Load Transient Response Test Circuit

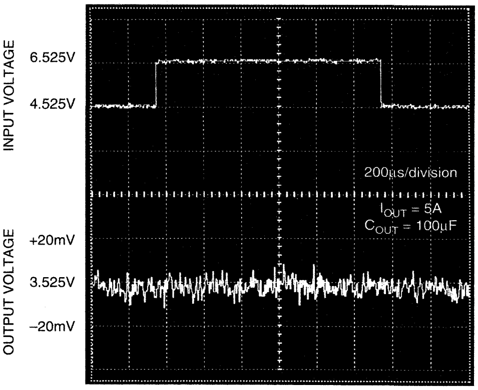
MIC29512 Load Transient Response (See Test Circuit Schematic)



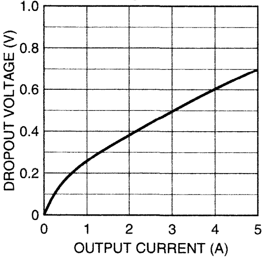
MIC29512 Line Transient Response with 5A Load, 10µF Output Capacitance



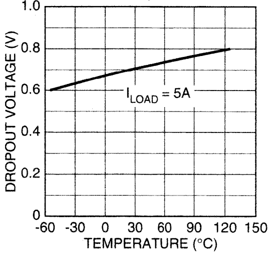
MIC29512 Line Transient Response with 5A Load, 100µF Output Capacitance



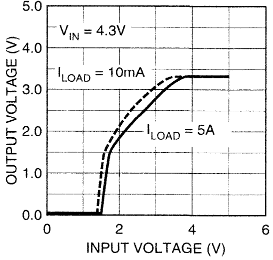
MIC2951x Dropout Voltage vs. Output Current



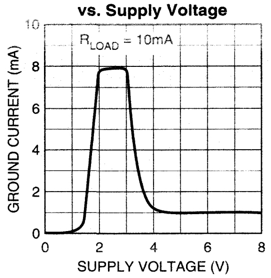
MIC2951x Dropout Voltage vs. Temperature



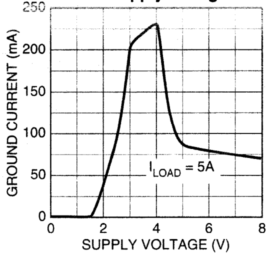
MIC29510-3.3 Dropout Characteristics



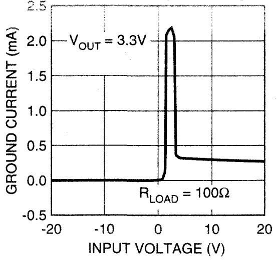
MIC2951x-3.3 Ground Current vs. Supply Voltage



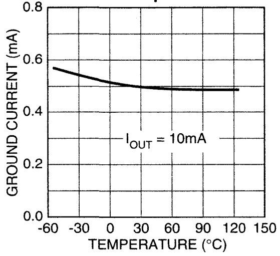
MIC2951x-3.3 Ground Current vs. Supply Voltage



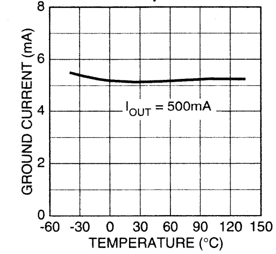
MIC2951x Ground Current vs. Input Voltage



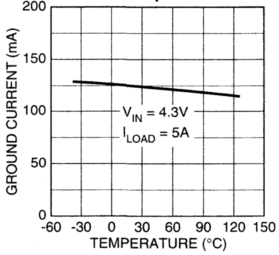
MIC2951x Ground Current vs. Temperature



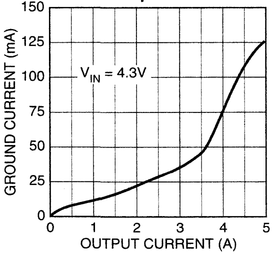
MIC2951x Ground Current vs. Temperature



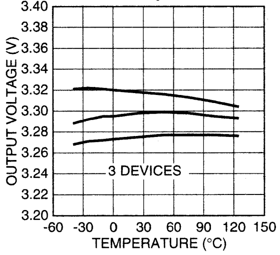
MIC2951x-3.3 Ground Current vs. Temperature



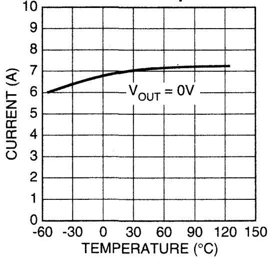
MIC2951x-3.3 Ground Current vs. Output Current



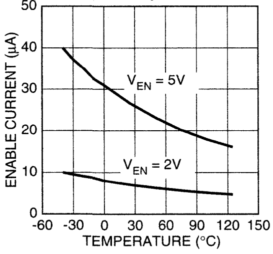
MIC29510-3.3 Output Voltage vs. Temperature



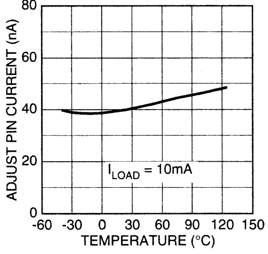
MIC2951x Short Circuit Current vs. Temperature



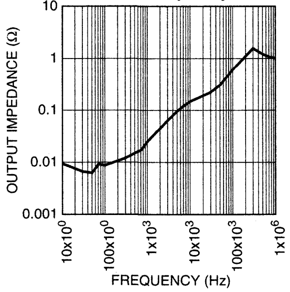
MIC29512 Enable Current vs. Temperaure



MIC29512 Adjust Pin Current vs. Temperature



MIC2951x Output Impedance vs. Frequency



Applications Information

The MIC29510 and MIC29512 are high performance low-dropout voltage regulators suitable for all moderate to high-current voltage regulator applications. Their 600mV of dropout voltage at full load make them especially valuable in battery powered systems and as high efficiency noise filters in “post-regulator” applications. Unlike older NPN-pass transistor designs, where the minimum dropout voltage is limited by the base-emitter voltage drop and collector-emitter saturation voltage, dropout performance of the PNP output of these devices is limited merely by the low V_{CE} saturation voltage.

A trade-off for the low dropout voltage is a varying base drive requirement. But Micrel’s Super ßeta PNP™ process reduces this drive requirement to merely 2 to 5% of the load current.

MIC29510/512 regulators are fully protected from damage due to fault conditions. Current limiting is provided. This limiting is linear; output current under overload conditions is constant. Thermal shutdown disables the device when the die temperature exceeds the maximum safe operating temperature. Transient protection allows device (and load) survival even when the input voltage spike above and below nominal. The output structure of these regulators allows voltages in excess of the desired output voltage to be applied without reverse current flow. The MIC29512 version offers a logic level ON/OFF control: when disabled, the devices draw nearly zero current.

An additional feature of this regulator family is a common pinout: a design’s current requirement may change up or down yet use the same board layout, as all of Micrel’s high-current Super ßeta PNP™ regulators have identical pinouts.

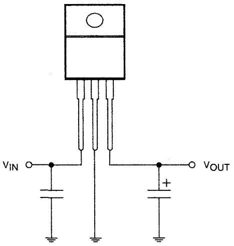


Figure 3. The MIC29510 LDO regulator requires only two capacitors for operation.

Thermal Design

Linear regulators are simple to use. The most complicated design parameters to consider are thermal characteristics. Thermal design requires the following application-specific parameters:

- Maximum ambient temperature, T_A
- Output Current, I_{OUT}
- Output Voltage, V_{OUT}
- Input Voltage, V_{IN}

First, we calculate the power dissipation of the regulator from these numbers and the device parameters from this datasheet.

$$P_D = I_{OUT} \times (1.02V_{IN} - V_{OUT})$$

Where the ground current is approximated by 2% of I_{OUT}. Then the heat sink thermal resistance is determined with this formula:

$$\theta_{SA} = \frac{T_{J\,MAX} - T_A}{P_D} - (\theta_{JC} + \theta_{CS})$$

Where $T_{J\,MAX} \leq 125°C$ and θ_{CS} is between 0 and 2°C/W.

The heat sink may be significantly reduced in applications where the minimum input voltage is known and is large compared with the dropout voltage. Use a series input resistor to drop excessive voltage and distribute the heat between this resistor and the regulator. The low dropout properties of Micrel Super ßeta PNP regulators allow very significant reductions in regulator power dissipation and the associated heat sink without compromising performance. When this technique is employed, a capacitor of at least 0.1µF is needed directly between the input and regulator ground.

Please refer to Application Note 9 for further details and examples on thermal design and heat sink specification.

Capacitor Requirements

For stability and minimum output noise, a capacitor on the regulator output is necessary. The value of this capacitor is dependent upon the output current; lower currents allow smaller capacitors. MIC29510/2 regulators are stable with a minimum capacitor value of 47µF at full load.

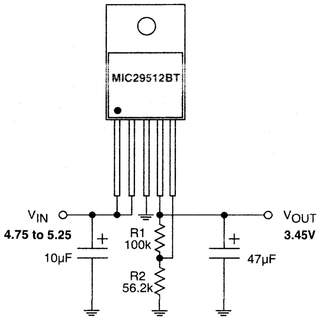
This capacitor need not be an expensive low ESR type: aluminum electrolytics are adequate. In fact, extremely low ESR capacitors may contribute to instability. Tantalum capacitors are recommended for systems where fast load transient response is important.

Where the regulator is powered from a source with a high AC impedance, a 0.1µF capacitor connected between Input and GND is recommended. This capacitor should have good characteristics to above 250kHz.

Transient Response and 5V to 3.3V Conversion

The MIC29510/2 have excellent response to variations in input voltage and load current. By virtue of their low dropout voltage, these devices do not saturate into dropout as readily as similar NPN-based designs. A 3.3V output Micrel LDO will maintain full speed and performance with an input supply as low as 4.2V, and will still provide some regulation with supplies down to 3.8V, unlike NPN devices that require 5.1V or more for good performance and become nothing more than a resistor under 4.6V of input. Micrel’s PNP regulators provide superior performance in “5V to 3.3V” conversion applications than NPN regulators, especially when all tolerances are considered.

Adjustable Regulator Design



$V_{OUT} = 1.240V \times [1 + (R1 / R2)]$

Figure 4. Adjustable Regulator with Resistors

The adjustable regulator version, MIC29512, allows programming the output voltage anywhere between 1.25V and the 16V maximum operating rating of the family. Two resistors are used. Resistors can be quite large, up to 100kΩ, because of the very high input impedance and low bias current of the sense comparator. The resistor values are calculated by:

$$R1 = R2 \times \left(\frac{V_{OUT}}{1.240} - 1 \right)$$

Where V_O is the desired output voltage. Figure 4 shows component definition.

Enable Input

The MIC29512 versions features an enable (EN) input that allows ON/OFF control of the device. Special design allows "zero" current drain when the device is disabled—only microamperes of leakage current flows. The EN input has TTL/CMOS compatible thresholds for simple interfacing with logic, or may be directly tied to V_{IN}. Enabling the regulator requires approximately 20µA of current into the EN pin.

Resistor Value Table for the MIC29512 Adjustable Regulator

Voltage	Standard (Ω)	
	R1	R2
2.85	100k	76.8k
2.9	100k	75.0k
3.0	100k	69.8k
3.1	100k	66.5k
3.15	100k	64.9k
3.3	100k	60.4k
3.45	100k	56.2k
3.6	100k	52.3k
3.8	100k	48.7k
4.0	100k	45.3k
4.1	100k	43.2k

MIC29710/29712

7.5A Fast-Response LDO Regulator

Preliminary Information

General Description

The MIC29710 and MIC29712 are high-current, high-accuracy, low-dropout voltage regulators featuring fast transient recovery from input voltage surges and output load current changes. These regulators use a PNP pass element that features Micrel's proprietary Super ßeta PNP™ process.

The MIC29710/2 is available in two versions: the three pin fixed output MIC29710 and the five pin adjustable output voltage MIC29712. All versions are fully protected against overcurrent faults, reversed lead insertion, overtemperature operation, and positive and negative transient voltage spikes.

A TTL compatible enable (EN) control pin supports external on/off control. If on-off control is not required, the device may be continuously enabled by connecting EN to IN.

The MIC29710/2 is available in the standard three and five pin TO-220 package with an operating junction temperature range of 0°C to +125°C.

For applications requiring even lower dropout voltage or input voltage greater than 16V, see the MIC29750/29752.

Features

- Fast transient response
- 7.5A current capability
- 700mV dropout voltage at full load
- Low ground current
- Accurate 1% guaranteed tolerance
- "Zero" current shutdown mode (MIC29712)
- No minimum load current
- Fixed voltage and adjustable versions

Applications

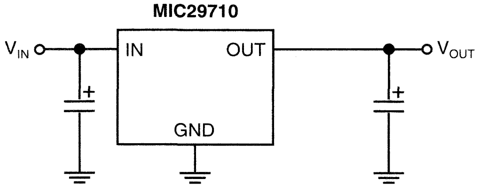
- Pentium™, Pentium Plus™, and Power PC™ processor supplies
- High-efficiency "green" computer systems
- High-efficiency linear power supplies
- High-efficiency switching supply post regulator
- Battery-powered equipment

Ordering Information

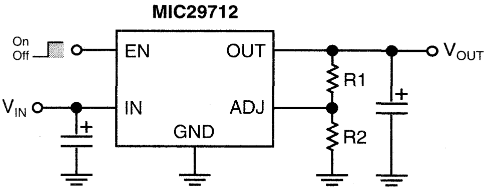
Part Number	Temp. Range*	Voltage	Current	Package
MIC29710-3.3BT	0°C to +125°C	3.3V	7.5A	TO-220-3
MIC29710-5.0BT	0°C to +125°C	5.0V	7.5A	TO-220-3
MIC29712BT	0°C to +125°C	Adj.	7.5A	TO-220-5

* Junction Temperature

Typical Application



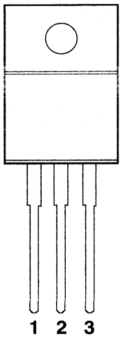
Fixed Regulator Configuration



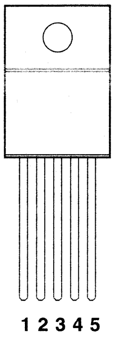
$$V_{OUT} = 1.240 \left(\frac{R1}{R2} + 1 \right)$$

Adjustable Regulator Configuration

Pin Configuration



MIC29710BT



MIC29712BT

On all devices, the Tab is grounded.

Pin Description

3-Pin TO-220 (MIC29710)

Pin Number	Pin Name	Pin Function
1	IN	Unregulated Input: +16V maximum supply.
2	GND	Ground: Internally connected to tab (ground).
3	OUT	Regulated Output

5-Pin TO-220 (MIC29712)

Pin Number	Pin Name	Pin Function
1	EN	Enable (Input): Logic-level ON/OFF control.
2	IN	Unregulated Input: +16V maximum supply.
3	GND	Ground: Internally connected to tab (ground).
4	OUT	Regulated Output
5	ADJ	Output Voltage Adjust: 1.240V feedback from external resistive divider.

Absolute Maximum Ratings

Input Supply Voltage (Note 1)	–0.7 V to +20V
Power Dissipation	Internally Limited
Storage Temperature Range	–65°C to +150°C
Lead Temperature (Soldering, 5 sec.)	260°C

Operating Ratings

Operating Junction Temperature	0°C to +125°C
θ_{JC} (TO-220)	2°C/W
θ_{JA} (TO-220)	55°C/W

Electrical Characteristics

All measurements at T_J = 25°C unless otherwise noted. **Bold** values are guaranteed across the operating temperature range.

Parameter	Condition	Min	Typ	Max	Units
Output Voltage	10mA ≤ I_O ≤ 7.5A, (V_{OUT} + 1V) ≤ V_{IN} ≤ 8V (Note 2)	**–2**		**2**	%
Line Regulation	I_O = 10mA, (V_{OUT} + 1V) ≤ V_{IN} ≤ 8V		0.06	**0.5**	%
Load Regulation	V_{IN} = V_{OUT} + 1V, 10mA ≤ I_{OUT} ≤ 7.5A (Notes 2, 6)		0.2	**1**	%
$\Delta V_O / \Delta T$	Output Voltage Temperature Coefficient (Note 6)		**20**	**100**	ppm/°C
Dropout Voltage	ΔV_{OUT} = – 1%, (Note 3)				
	MIC29710/29712 I_O = 100mA		80	**200**	mV
	I_O = 750mA		180		mV
	I_O = 1.5A		220		mV
	I_O = 3A		300		mV
	I_O = 5A		450		mV
	I_O = 7.5A		700	**1000**	mV
Ground Current	MIC29710/29712 I_O = 750mA, V_{IN} = V_{OUT} + 1V		6	**20**	mA
	I_O = 1.5A		20		mA
	I_O = 3A		36		mA
	I_O = 5A		100		mA
	I_O = 7.5A		250	**375**	mA
I_{GNDDO} Ground Pin Current at Dropout	V_{IN} = 0.5V less than specified V_{OUT}. I_{OUT} = 10mA		1	2	mA
Current Limit	MIC29710/29712 V_{OUT} = 0V (Note 4)		11	15	A
e_n, Output Noise Voltage (10Hz to 100kHz) V_{OUT} = 5.0V	C_L = 47µF I_o = 100mA		260		µV_{RMS}

Reference (MIC29712 only)

Reference Voltage	10mA ≤ I_O ≤ 7.5A, V_{OUT} + 1V ≤ V_{IN} ≤ 8V (Note 2)	**1.215**	1.240	**1.265**	V_{MAX}
Adjust Pin Bias Current			40	80 **120**	nA nA
Reference Voltage Temperature Coefficient	(Note 7)		20		ppm/°C
Adjust Pin Bias Current Temperature Coefficient			0.1		nA/°C

Parameter	Conditions	Min	Typical	Max	Units
Enable Input (MIC29712 only)					
Input Logic Voltage	Low (Off)			**0.8**	V
	High (On)	**2.4**			V
Enable (EN) Pin Input Current	$V_{EN} = V_{IN}$		15	30	µA
				75	µV
	V_{EN} = 0.8V		–	2	µA
				4	µA
Regulator Output Current in Shutdown	(Note 8)		10		µA
				20	µA

General Note: Devices are ESD sensitive. Handling precautions are recommended.

Note 1: The maximum continuous supply voltage is 16V.

Note 2: For testing, MIC29712 V_{OUT} is programmed to 5V.

Note 3: Dropout voltage is defined as the input-to-output differential when the output voltage drops to 99% of its nominal value with V_{OUT} + 1V applied to V_{IN}.

Note 4: For this test, V_{IN} is the larger of 8V or V_{OUT} + 3V.

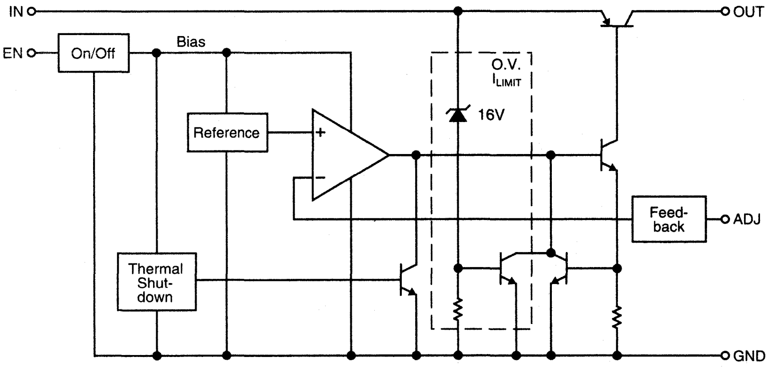
Note 5: Ground pin current is the regulator quiescent current. The total current drawn from the source is the sum of the load current plus the ground pin current.

Note 6: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

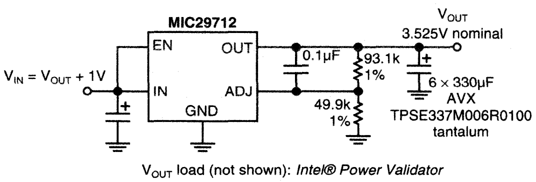
Note 7: $V_{REF} \leq V_{OUT} \leq (V_{IN} - 1\text{ V})$, $2.4V \leq V_{IN} \leq 8V$, $10mA < I_L \leq 7.5A$, $T_J \leq T_{J\,MAX}$.

Note 8: $V_{EN} \leq 0.8V$ and $V_{IN} \leq 16V$, $V_{OUT} = 0$.

Block Diagram

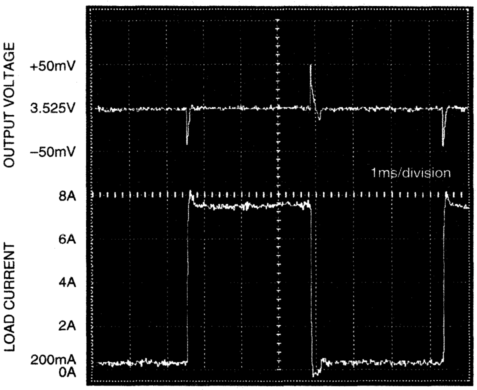


Typical Characteristics

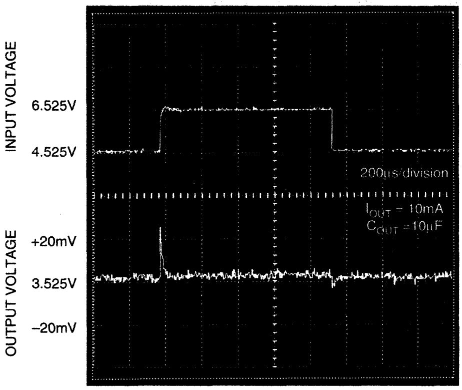


MIC29712 Load Transient Response Test Circuit

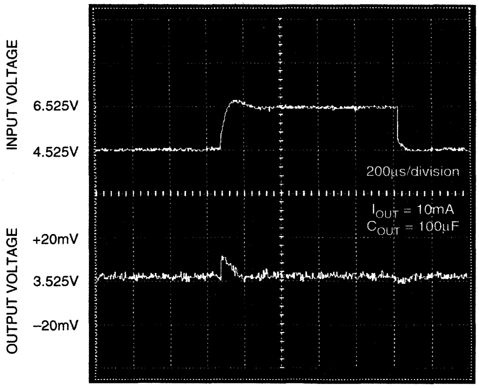
MIC29712 Load Transient Response (See Test Circuit Schematic)



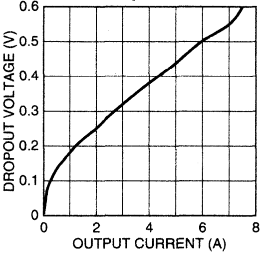
MIC29712 Line Transient Response with 10mA Load, 10µF Output Capacitance



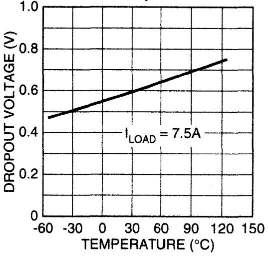
MIC29712 Line Transient Response with 10mA Load, 100µF Output Capacitance



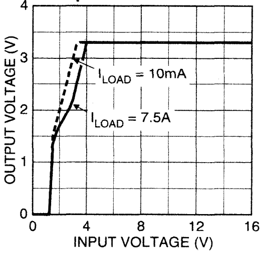
MIC29710/2 Dropout Voltage vs. Output Current



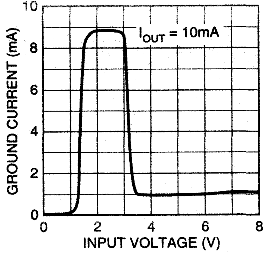
MIC29710/2 Dropout Voltage vs. Temperature



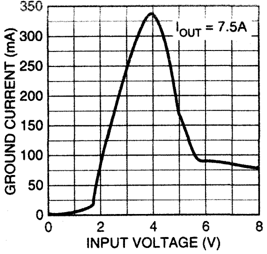
MIC29710-3.3 Dropout Characteristics



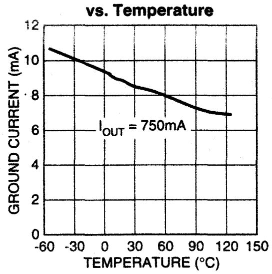
MIC29710/2 Ground Current vs. Input Voltage



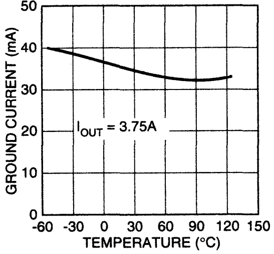
MIC29710/2 Ground Current vs. Input Voltage



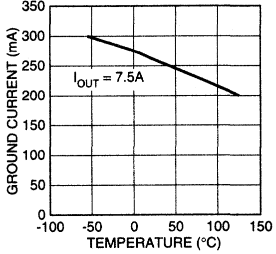
MIC29710/2 Ground Current vs. Temperature



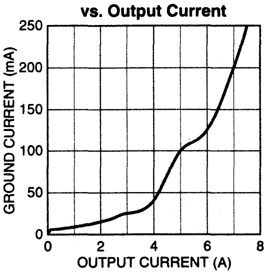
MIC29710/2 Ground Current vs. Temperature



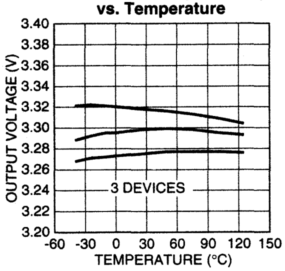
MIC29710/2 Ground Current vs. Temperature



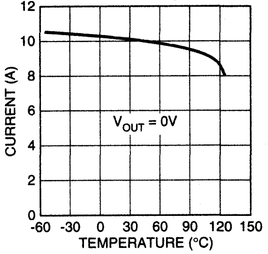
MIC29710/2 Ground Current vs. Output Current



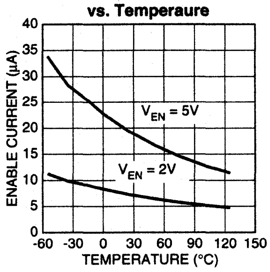
MIC29710-3.3 Output Voltage vs. Temperature



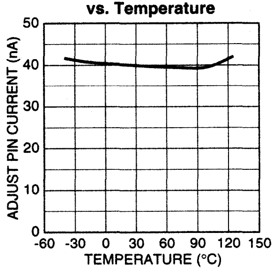
MIC29710/2 Short Circuit Current vs. Temperature



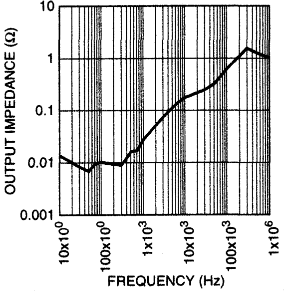
MIC29712 Enable Current vs. Temperaure



MIC29712 Adjust Pin Current vs. Temperature



MIC29710/2 Output Impedance vs. Frequency



Applications Information

The MIC29710 and MIC29712 are high performance low-dropout voltage regulators suitable for all moderate to high-current voltage regulator applications. Their 700mV of dropout voltage at full load make them especially valuable in battery powered systems and as high efficiency noise filters in "post-regulator" applications. Unlike older NPN-pass transistor designs, where the minimum dropout voltage is limited by the base-emitter voltage drop and collector-emitter saturation voltage, dropout performance of the PNP output of these devices is limited merely by the low V_{CE} saturation voltage.

A trade-off for the low dropout voltage is a varying base drive requirement. But Micrel's Super ßeta PNP™ process reduces this drive requirement to merely 2 to 5% of the load current.

MIC29710/712 regulators are fully protected from damage due to fault conditions. Current limiting is provided. The output current under overload conditions is limited to a constant value. Thermal shutdown disables the device when the die temperature exceeds the maximum safe operating temperature. Transient protection allows device (and load) survival even when the input voltage spike above and below nominal. The output structure of these regulators allows voltages in excess of the desired output voltage to be applied without reverse current flow. The MIC29712 version offers a logic level ON/OFF control: when disabled, the devices draw nearly zero current.

An additional feature of this regulator family is a common pinout: a design's current requirement may change up or down yet use the same board layout, as all of Micrel's high-current Super ßeta PNP™ regulators have identical pinouts.

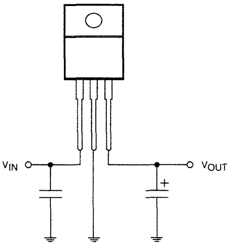


Figure 3. The MIC29710 requires only two capacitors for operation.

Thermal Design

Linear regulators are simple to use. The most complicated design parameters to consider are thermal characteristics. Thermal design requires the following application-specific parameters:

- Maximum ambient temperature, T_A
- Output Current, I_{OUT}
- Output Voltage, V_{OUT}
- Input Voltage, V_{IN}

First, we calculate the power dissipation of the regulator from these numbers and the device parameters from this datasheet.

$$P_D = I_{OUT} \times (1.01V_{IN} - V_{OUT})$$

Where the ground current is approximated by 2% of I_{OUT}. Then the heat sink thermal resistance is determined with this formula:

$$\theta_{SA} = \frac{T_{J\,MAX} - T_A}{P_D} - (\theta_{JC} + \theta_{CS})$$

Where $T_{J\,MAX} \leq 125°C$ and θ_{CS} is between 0 and 2°C/W.

The heat sink may be significantly reduced in applications where the minimum input voltage is known and is large compared with the dropout voltage. Use a series input resistor to drop excessive voltage and distribute the heat between this resistor and the regulator. The low dropout properties of Micrel Super ßeta PNP regulators allow very significant reductions in regulator power dissipation and the associated heat sink without compromising performance. When this technique is employed, a capacitor of at least 0.1µF is needed directly between the input and regulator ground.

Please refer to Application Note 9 for further details and examples on thermal design and heat sink specification.

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For stability and minimum output noise, a capacitor on the regulator output is necessary. The value of this capacitor is dependent upon the output current; lower currents allow smaller capacitors. MIC29710/2 regulators are stable with a minimum capacitor value of 47µF at full load.

This capacitor need not be an expensive low ESR type: aluminum electrolytics are adequate. In fact, extremely low ESR capacitors may contribute to instability. Tantalum capacitors are recommended for systems where fast load transient response is important.

Where the regulator is powered from a source with a high AC impedance, a 0.1µF capacitor connected between Input and GND is recommended. This capacitor should have good characteristics to above 250kHz.

Transient Response and 5V to 3.3V Conversion

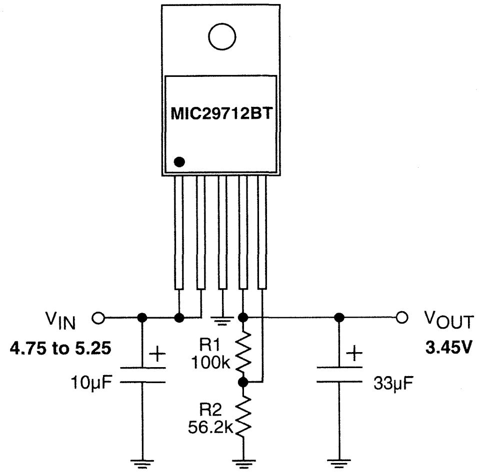
The MIC29710/2 have excellent response to variations in input voltage and load current. By virtue of their low dropout voltage, these devices do not saturate into dropout as readily as similar NPN-based designs. A 3.3V output Micrel LDO will maintain full speed and performance with an input supply as low as 4.2V, and will still provide some regulation with supplies down to 3.8V, unlike NPN devices that require 5.1V or more for good performance and become nothing more than a resistor under 4.6V of input. Micrel's PNP regulators provide superior performance in "5V to 3.3V" conversion applications, especially when all tolerances are considered.

Adjustable Regulator Design

The adjustable regulator version, MIC29712, allows programming the output voltage anywhere between 1.25V and the 16V maximum operating rating of the family. Two resistors are used. Resistors can be quite large, up to 100kΩ, because of the very high input impedance and low bias current of the sense comparator. The resistor values are calculated by:

$$R1 = R2 \times \left(\frac{V_{OUT}}{1.240} - 1 \right)$$

Where V_O is the desired output voltage. Figure 4 shows component definition.



$V_{OUT} = 1.240V \times [1 + (R1 / R2)]$

Figure 4. Adjustable Regulator with Resistors

Enable Input

The MIC29712 versions features an enable (EN) input that allows ON/OFF control of the device. Special design allows "zero" current drain when the device is disabled—only microamperes of leakage current flows. The EN input has TTL/CMOS compatible thresholds for simple interfacing with logic, or may be directly tied to V_{IN}. Enabling the regulator requires approximately 20µA of current into the EN pin.

Voltage	Standard (Ω)	
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3.1	100k	66.5k
3.15	100k	64.9k
3.3	100k	60.4k
3.45	100k	56.2k
3.525	93.1k	51.1k
3.6	100k	52.3k
3.8	100k	48.7k
4.0	100k	45.3k
4.1	100k	43.2k

Figure 5. MIC29712 Resistor Table

MIC5156/5157/5158

Super LDO™ Regulator Controller

General Description

The MIC5156, MIC5157, and MIC5158 Super Low-Dropout (LDO) Regulator Controllers are single IC solutions for high-current low-dropout linear voltage regulation. Super LDO™ Regulators have the advantages of an external N-channel power MOSFET as the linear pass element.

The MIC5156/7/8 family features a dropout voltage as low as the $R_{DS(ON)}$ of the external power MOSFET multiplied by the output current. The output current can be as high as the largest MOSFETs can provide.

The MIC5156/7/8 family operates from 3V to 36V. The MIC5156 requires an external gate drive supply to provide the higher voltage needed to drive the gate of the external MOSFET. The MIC5157 and MIC5158 each have an internal charge pump tripler to produce the gate drive voltage. The tripler is capable of providing enough voltage to drive a logic-level MOSFET to 3.3V output from a 3.5V supply and is clamped to 17.5V above the supply voltage. The tripler requires three external capacitors.

The regulator output is constant-current limited when the controller detects 35mV across an optional external sense resistor. An active-low open-collector flag indicates a low voltage of 8% or more below nominal output. A shutdown (low) signal to the TTL-compatible enable control reduces controller supply current to less than 1µA while forcing the output voltage to ground.

The MIC5156-3.3 and MIC5156-5.0 controllers have internally fixed output voltages. The MIC5156 [adjustable] output is configured using two external resistors. The MIC5157 is a fixed output controller which is externally configured to select either 3.3V, 5.0V, or 12V. The MIC5158 can be configured as a fixed 5V controller or programmed to any voltage from 1.3V to 36V using two external resistors.

The MIC5156 is available in an 8-pin plastic DIP, ceramic DIP, or SOIC package. The MIC5157 and MIC5158 are available in a 14-pin plastic DIP, ceramic DIP, or SOIC. The plastic DIP and SOIC versions operate from –40°C to +85°C. The ceramic DIP versions cover the –55°C to +125°C military temperature range.

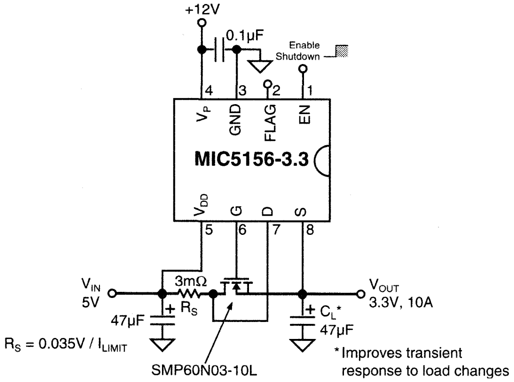
Features

- 4.5mA typical operating current
- <1µA typical standby current
- Low external parts count
- Optional current limit (35mV typical threshold)
- 1% initial output voltage tolerance in most configurations
- 2% output voltage tolerance over temperature
- Fixed output voltages of 3.3V, 5.0V (MIC5156)
- Fixed output voltages of 3.3V, 5.0V, 12V (MIC5157)
- Programmable (1.3 to 36V) with 2 resistors (MIC5156/8)
- Internal charge pump voltage tripler (MIC5157/8)
- Enable pin to activate or shutdown the regulator
- Internal gate-to-source protective clamp
- All versions available in DIP and SOIC

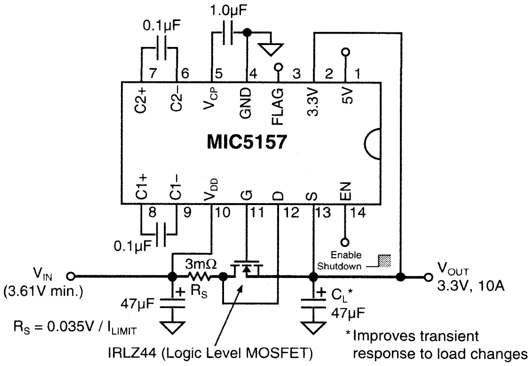
Applications

- Ultra-high current ultra-low dropout voltage regulator
- Constant high-current source
- Low parts count 5.0V to 3.3V computer supply
- Low noise/low-dropout SMPS post regulator
- High-current, current-limited switch

Typical Applications



10A 5V to 3.3V Desktop Computer Regulator



10A Low-Dropout Voltage Regulator

Super LDO is a trademark of Micrel, Inc.

Ordering Information MIC5156

Part Number	Temperature Range	Voltage	Package
MIC5156-3.3BN	–40°C to +85°C	3.3V	8-pin P-DIP
MIC5156-5.0BN	–40°C to +85°C	5.0V	8-pin P-DIP
MIC5156BN	–40°C to +85°C	Adjustable	8-pin P-DIP
MIC5156-3.3BM	–40°C to +85°C	3.3V	8-pin SOIC
MIC5156-5.0BM	–40°C to +85°C	5.0V	8-pin SOIC
MIC5156BM	–40°C to +85°C	Adjustable	8-pin SOIC
MIC5156-3.3AJ	–55°C to +125°C	3.3V	8-pin CerDIP
MIC5156-5.0AJ	–55°C to +125°C	5.0V	8-pin CerDIP
MIC5156AJ	–55°C to +125°C	Adjustable	8-pin CerDIP

Ordering Information MIC5157

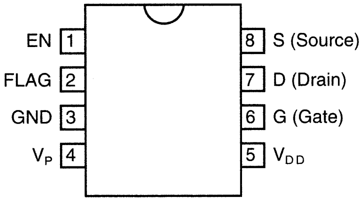
Part Number	Temperature Range	Voltage	Package
MIC5157BN	–40°C to +85°C	Selectable	14-pin P-DIP
MIC5157BM	–40°C to +85°C	Selectable	14-pin SOIC
MIC5157AJ	–55°C to +125°C	Selectable	14-pin CerDIP

Ordering Information MIC5158

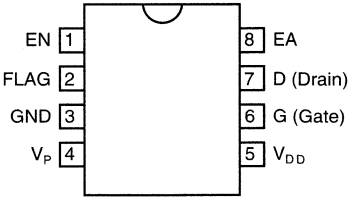
Part Number	Temperature Range	Voltage	Package
MIC5158BN	–40°C to +85°C	5.0V/Adj.	14-pin P-DIP
MIC5158BM	–40°C to +85°C	5.0V/Adj.	14-pin SOIC
MIC5158AJ	–55°C to +125°C	5.0V/Adj.	14-pin CerDIP

Pin Configuration

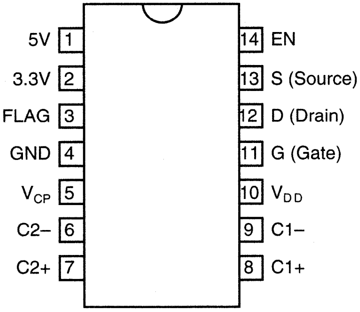
MIC5156-x.x



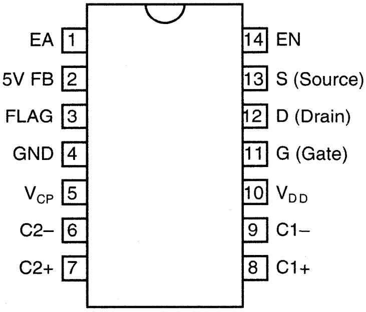
MIC5156



MIC5157



MIC5158



Pin Description MIC5156

Pin Number	Pin Name	Pin Function
1	EN	Enable (Input): TTL high enables regulator; TTL low shuts down regulator.
2	FLAG	Output Flag (Output): Open collector output is active (low) when V_{OUT} is more than 8% below nominal output. Circuit has 3% hysteresis.
3	GND	Circuit ground.
4	V_P	N-channel Gate Drive Supply Voltage: User supplied voltage for driving the gate of the external MOSFET.
5	V_{DD}	Supply Voltage (Input): Supply voltage connection. Connect sense resistor (R_S) to V_{DD} if current limiting used. Connect supply bypass capacitor to ground near device.
6	G	Gate (Output): Drives the gate of the external MOSFET.
7	D	Drain and Current Limit (Input): Connect to external MOSFET drain and external sense resistor (current limit), or connect to V_{DD} and external MOSFET drain (no current limit).
8 (3.3V, 5V)	S	Source (Input): Top of internal resistive divider chain. Connect directly to the load for best load regulation.
8 (adjustable)	EA	Error Amplifier (Input): Connect to external resistive divider.

Pin Description MIC5157, MIC5158

Pin Number	Pin Name	Pin Function
1 (MIC5157)	5V	5V Configuration (Input): Connect to S (source) pin for 5V output.
1 (MIC5158)	EA	Error Amplifier (Input): Connect to external resistive divider to obtain adjustable output.
2 (MIC5157)	3.3V	3.3V Configuration (Input): Connect to S (source) pin for 3.3V output.
2 (MIC5158)	5V FB	5V Feedback (Input): Connect to EA for fixed 5V output.
3	FLAG	Output Voltage Flag (Output): Open collector is active (low) when V_{OUT} is 8% or more below its nominal value.
4	GND	Circuit ground.
5	V_{CP}	Voltage Tripler Output [Filter Capacitor]. Connect a 1 to 10µF capacitor to ground.
6	C2–	Charge Pump Capacitor 2: Second stage of internal voltage tripler. Connect a 0.1µF capacitor from C2+ to C2–.
7	C2+	Charge Pump Capacitor 2: See C2– pin 6.
8	C1+	Charge Pump Capacitor 1: First stage of internal voltage tripler. Connect a 0.1µF capacitor from C1+ to C1–.
9	C1–	Charge Pump Capacitor 1: See C1+ pin 8.
10	V_{DD}	Supply Voltage (Input): Supply voltage connection. Connect sense resistor (R_S) to V_{DD} if current limiting used. Connect supply bypass capacitor to ground near device.
11	G	Gate (Output): Connect to External MOSFET gate.
12	D	Drain and Current Limit (Input): Connect to external MOSFET drain and external sense resistor (current limit), or connect to V_{DD} and external MOSFET drain (no current limit).
13 (MIC5157)	S	Source and 3.3V/5V Configuration: Top of internal resistor chain. Connect to source of external MOSFET for 3.3V, 5V, and 12V operation. Also see 3.3V and 5V pin descriptions.
13 (MIC5158)	S	Source (Input): Top of internal resistor chain. Connect to top of external resistive divider and source of external MOSFET.
14	EN	Enable (Input): TTL high enables regulator; TTL low shuts down regulator.

Absolute Maximum Ratings

V_{DD}	38V
EN	–0.3V to 36V
V_G (MIC5156)	55V
V_{CP} (MIC5157/8)	55V
V_{SOURCE}	1.3 to 36V
FLAG	–0.3 to 40V
Operating Junction Temperature	
T_J	150°C

Ambient Temperature Range	
T_A (MIC515xBM/BN)	–40°C to +85°C
T_A (MIC515xAJ)	–55°C to +125°C
Storage Temperature	–65°C to +150°C
Lead Temperature (soldering 10s)	300°C

Package θ_{JA}	*MIC5156*	*MIC5157/8*
Plastic DIP	100°C/W	90°C/W
Ceramic DIP	125°C/W	110°C/W
SOIC	160°C/W	120°C/W

Electrical Characteristics

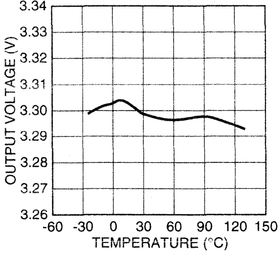
Symbol	Parameter	Condition (Note 1)	Min	Typ	Max	Units
V_{DD}	Supply Voltage		3		36	V
$I_{DD(ON)}$	Supply Current MIC5156	Operating, $V_{EN} = 5V$		2.7	10	mA
$I_{DD(OFF)}$		Shutdown, $V_{EN} = 0V$		0.1	5	µA
$I_{DD(ON)}$	Supply Current MIC5157/8	Operating, $V_{EN} = 5V$		4.5	10	mA
$I_{DD(OFF)}$		Shutdown, $V_{EN} = 0V$		0.1	5	µA
V_{IH}	Enable Input Threshold	High	2.4	1.3		V
V_{IL}		Low		1.3	0.8	V
EN I_B	Enable Input Bias Current	$V_{EN} = 2.4V$		20	25	µA
V_{CP}	Max. Charge Pump Voltage	$V_{CP} - V_{DD}$, $V_{DD} > 10V$		17.5	18.5	V
f_{CP}	Charge Pump Frequency			160		kHz
$V_{OUT\ MAX}$	Maximum Gate Drive Voltage (MIC5157/8)	$V_{SOURCE} = 0V$				
		$V_{DD} = 3.5V$	5	7.0	9	V
		$V_{DD} = 5V$	9	11.3	15	V
		$V_{DD} = 12V$	24	28	30	V
$V_{OUT\ MIN}$	Minimum Gate Drive Voltage	$V_{SOURCE} > V_{OUT(NOM)}$		1.0		V
V_{LIM}	Current Limit Threshold	$V_{DD} - V_D$ @ I_{LIM}	28	35	42	mV
V_S	Source Voltage	Short G (gate) to (S) source, **Note 2**				
		MIC5156-3.3	3.267	3.3	3.333	V
		MIC5156-5.0	4.950	5.0	5.050	V
		MIC5157, 3.3V pin to S pin (3.3V config.)	3.250	3.3	3.350	V
		MIC5157, 5V pin to S pin (5V config.)	4.950	5.0	5.050	V
		MIC5157, $V_{DD} = 7V$, (12V config.)	11.70	12	12.30	V
		MIC5158, 5V FB pin to EA pin (5V config.)	4.925	5.0	5.075	V
V_{BG}	Bandgap Reference Voltage	MIC5156 [adjustable] and MIC5158	1.222	1.235	1.248	V
V_{LR}	Output Voltage Line Regulation	$5V < V_{DD} < 15V$, $V_{OUT} = 3.3V$		2	7	mV
$V_{GS\ MAX}$	Gate to Source Clamp		14	16.6	20	V
V_{FT}	Flag Comparator Threshold	% of nominal V_{SOURCE}		92		%
V_{FH}	Flag Comparator Hysteresis	% of nominal V_{SOURCE}		3		%
V_{SAT}	Flag Comparator Sat. Voltage	$I_{FLAG} = 1mA$		0.09	0.2	V

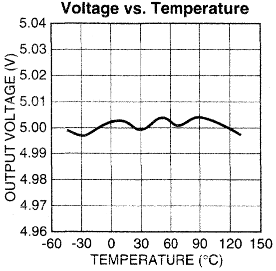
General Note: Devices are ESD sensitive. Handling precautions recommended.

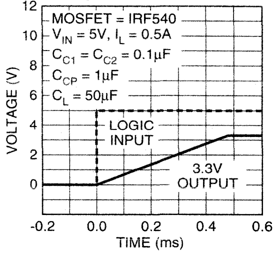
Note 1: $T_A = 25°C$, $V_{DD} = 5V$, $V_{EN} = 5V$, unless noted.

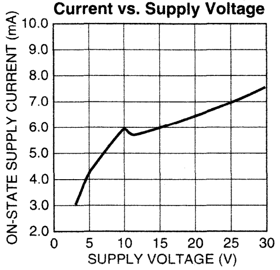
Note 2: Test configuration. External MOSFET not used.

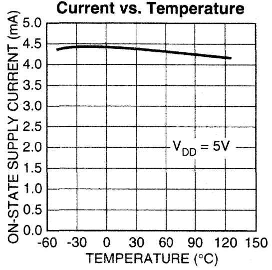
Typical Characteristics

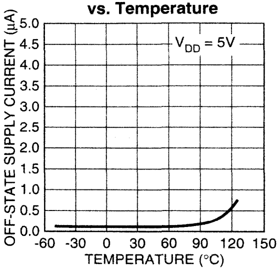

3.3V Regulator Output Voltage vs. Temperature

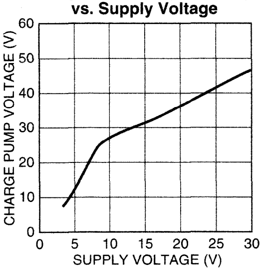

5.0V Regulator Output Voltage vs. Temperature

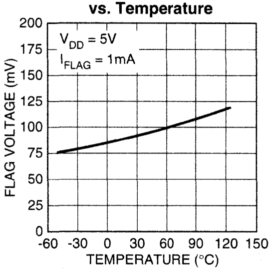

MIC5157/8 Turn-On Response Time for 3.3V

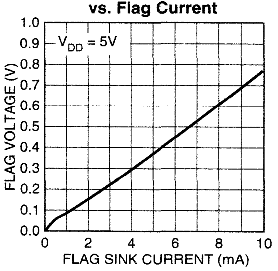

MIC5157/8 On-State Supply Current vs. Supply Voltage

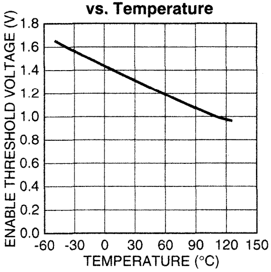

MIC5157/8 On-State Supply Current vs. Temperature

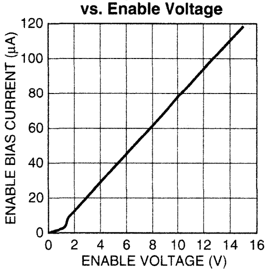

Off-State Supply Current vs. Temperature

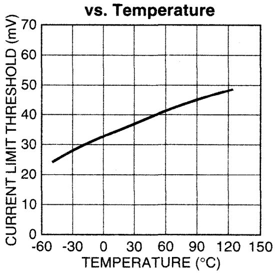

Charge-Pump Output Voltage vs. Supply Voltage


Flag Output Voltage vs. Temperature

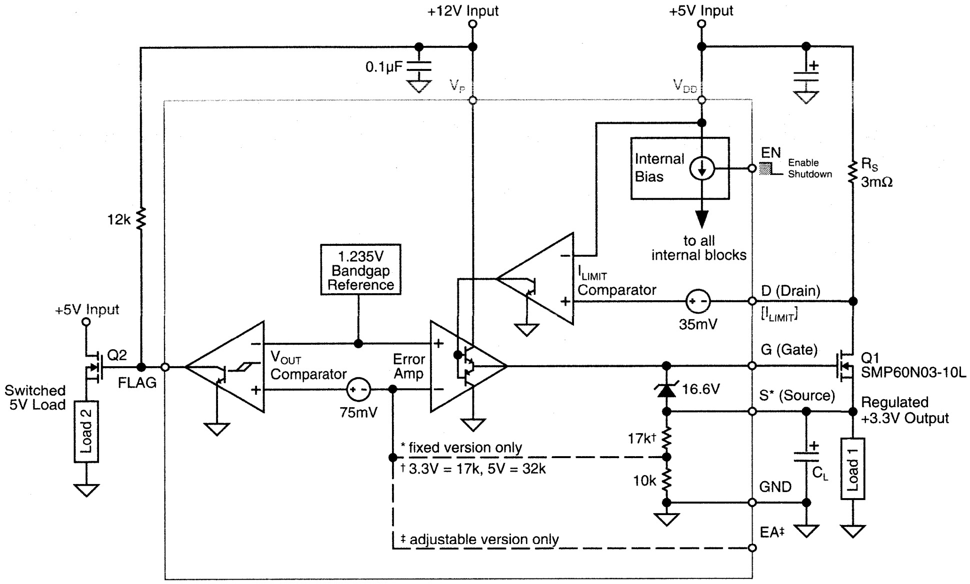

Flag Output Voltage vs. Flag Current


Enable Threshold Voltage vs. Temperature


Enable Input Bias Current vs. Enable Voltage

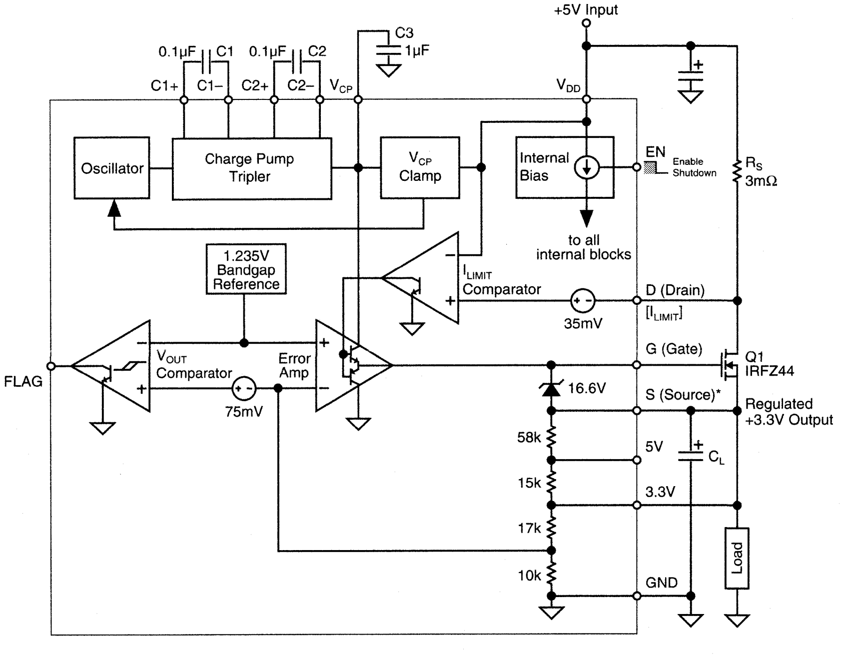

Current Limit Threshold vs. Temperature

Block Diagram MIC5156



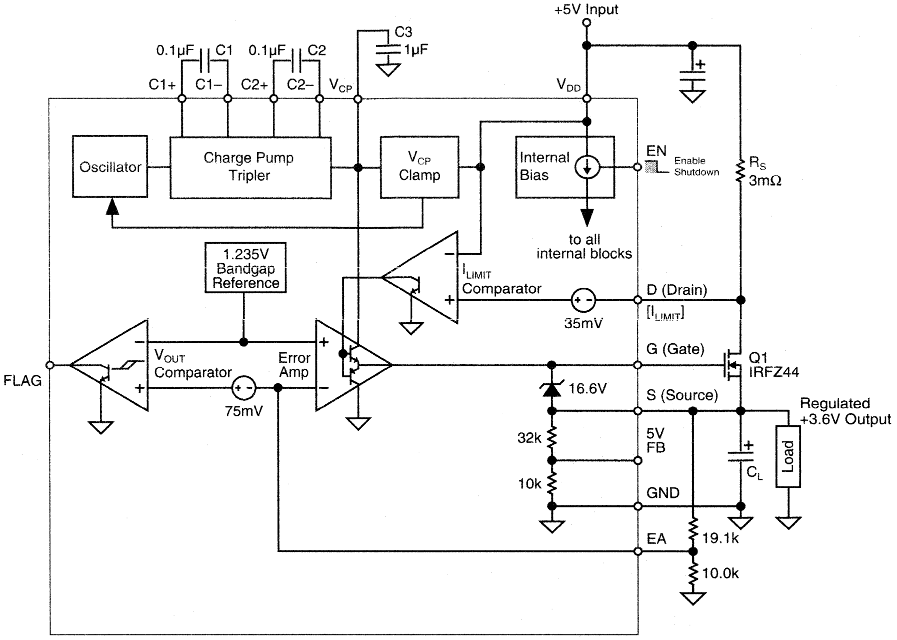
Block Diagram with External Components
Fixed 3.3V Power Supply with 5.0V Load Switch

Block Diagram MIC5157



Block Diagram with External Components
Fixed 3.3V 10A Power Supply

Block Diagram MIC5158



Block Diagram with External Components
Adjustable Power Supply, 3.6V Configuration

Functional Description

A *Super LDO Regulator* is a complete regulator built around Micrel's *Super LDO Regulator Controller.*

Refer to Block Diagrams MIC5156, MIC5157, and MIC5158.

Version Differences

The MIC5156 requires an external voltage for MOSFET gate drive and is available in 3.3V fixed output, 5V fixed output, or adjustable output versions. With 8-pins, the MIC5156 is the smallest of the Super LDO Regulator Controllers.

The MIC5157 and MIC5158 each have an internal charge pump which provides MOSFET gate drive voltage. The MIC5157 has a selectable fixed output of 3.3V, 5V, or 12V. The MIC5158 may be configured for a fixed 5V or adjustable output.

Enable (EN)

With at least 3.0V on V_{DD}, applying a TTL low to EN places the controller in shutdown mode. A TTL high on EN enables the internal bias circuit which powers all internal circuitry. EN must be pulled high if unused. The voltage applied to EN may be as high as 36V.

The controller draws less than 1µA in shutdown mode.

Gate Enhancement

The Super LDO Regulator Controller manages the gate-to-source enhancement voltage for an external N-channel MOSFET (regulator pass element) placed between the supply and the load. The gate-to-source voltage may vary from 1V to 16V depending upon the supply and load conditions.

Because the source voltage (output) approaches the drain voltage (input) when the regulator is in dropout and the MOSFET is fully enhanced, an additional higher supply voltage is required to produce the necessary gate-to-source enhancement. This higher gate drive voltage is provided by an external gate drive supply (MIC5156) or by an internal charge pump (MIC5157 and MIC5158).

Gate Drive Supply Voltage (MIC5156 only)

The gate drive supply voltage must not be more than 14V above the supply voltage ($V_P - V_{DD} < 14V$). The minimum necessary gate drive supply voltage is:

$$V_P = V_{OUT} + V_{GS} + 1$$

where:

V_P = gate drive supply voltage
V_{OUT} = regulator output voltage
V_{GS} = gate-to-source voltage for full MOSFET gate enhancement

The error amplifier uses the gate drive supply voltage to drive the gate of the external MOSFET. The error amplifier output can swing to within 1V of V_P.

Charge Pump (MIC5157/5158 only)

The charge pump tripler creates a dc voltage across reservoir capacitor C3. External capacitors C1 and C2 provide the necessary storage for the stages of the charge pump tripler.

The tripler's approximate dc output voltage is:

$$V_{CP} \approx 3\,(V_{DD} - 1)$$

where:

V_{CP} = charge pump output voltage
V_{DD} = supply voltage

The V_{CP} clamp circuit limits the charge pump voltage to 16V above V_{DD} by gating the charge pump oscillator ON or OFF as required. The charge pump oscillator operates at 160kHz.

The error amplifier uses the charge pump voltage to drive the gate of the external MOSFET. It provides a constant load of about 1mA to the charge pump. The error amplifier output can swing to within 1V of V_{CP}.

Although the MIC5157/8 is designed to provide gate drive using its internal charge pump, an external gate drive supply voltage can be applied to V_{CP} . When using an external gate drive supply, V_{CP} must not be forced more than 14V higher than V_{DD}.

When constant loads are driven, the ON/OFF switching of the charge pump may be evident on the output waveform. This is caused by the charge pump switching ON and rapidly increasing the supply voltage to the error amplifier. The period of this small charge pump excitation is determined by a number of factors: the input voltage, the 1mA op-amp load, any dc leakage associated with the MOSFET gate circuit, the size of the charge pump capacitors, the size of the charge pump reservoir capacitor, and the characteristics of the input voltage and load. The period is lengthened by increasing the charge pump reservoir capacitor (C3). The amplitude is reduced by weakening the charge pump—this is accomplished by reducing the size of the pump capacitors (C1 and C2). If this small burst is a problem in the application, use a 10µF reservoir capacitor at C3 and 0.01µF pump capacitors at C1 and C2. Note that the recovery time to repetitive load transients may be affected with small pump capacitors.

Gate-to-Source Clamp

A gate-to-source protective voltage clamp of 16.6V protects the MOSFET in the event that the output voltage is suddenly forced to zero volts. This prevents damage to the external MOSFET during shorted load conditions. Refer to "Charge Pump" for normal clamp circuit operation.

The source connection required by the gate-to-source clamp is not available on the adjustable version of the MIC5156.

Output Regulation

At start-up, the error amplifier feedback voltage (EA), or internal feedback on fixed versions, is below nominal when compared to the internal 1.235V bandgap reference. This forces the error amplifier output high which turns on external MOSFET Q1. Once the output reaches regulation, the controller maintains constant output voltage under changing input and load conditions by adjusting the error amplifier output voltage (gate enhancement voltage) according to the feedback voltage.

Out-of-Regulation Detection

When the output voltage is 8% or more below nominal, the open-collector FLAG output (normally high) is forced low to signal a fault condition. The FLAG output can be used to signal or control external circuitry. The FLAG output can also be used to shut down the regulator using the EN control.

Current Limiting

Super LDO Regulators perform constant-current limiting (not foldback). To implement current limiting, a sense resistor (R_S) must be placed in the "power" path between V_{DD} and D (drain).

If the voltage drop across the sense resistor reaches 35mV, the current limit comparator reduces the error amplifier output. The error amplifier output is decreased only enough to reduce the output current, keeping the voltage across the sense resistor from exceeding 35mV.

Application Information

MOSFET Selection

Standard N-channel enhancement-mode MOSFETs are acceptable for most Super LDO regulator applications.

Logic-level N-channel enhancement-mode MOSFETs may be necessary if the external gate drive voltage is too low (MIC5156), or the input voltage is too low, to provide adequate charge pump voltage (MIC5157/8) to enhance a standard MOSFET.

Circuit Layout

For the best voltage regulation, place the source, ground, and error amplifier connections as close as possible to the load. See figures (1a) and (1b).

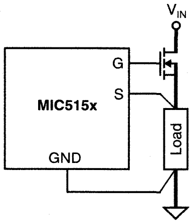


Figure 1a. Connections for Fixed Output

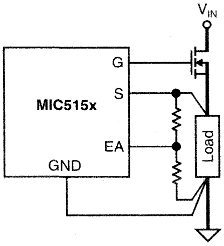
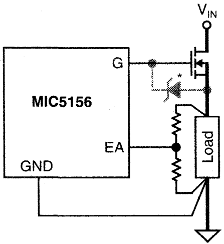


Figure 1b. Connections for Adjustable Output



* Optional 16V zener diode recommended in applications where V_G is greater than 18V

Figure 1c. MIC5156 Connections for Adjustable Output

MOSFET Gate-to-Source Protection

When using the adjustable version of the MIC5156, an external 16V zener diode placed from gate-to-source is recommended for MOSFET protection. All other versions of the Super LDO regulator controller use the internal gate-to-source clamp.

Output Voltage Configuration

Fixed Configurations

The MIC5156-3.3 and MIC5156-5.0 are preset for 3.3V and 5.0V respectively.

The MIC5157 operates at 3.3V when the 3.3V pin is connected to the S (source) pin; 5.0V when the 5.0V pin is connected to the S pin; or 12V if the 3.3V and 5.0V pins are open.

The MIC5158 operates at a fixed 5V (without an external resistive divider) if the 5V FB pin is connected to EA.

Adjustable Configurations

Micrel's MIC5156 [adjustable] and MIC5158 require an external resistive divider to set the output voltage from 1.235V to 36V. For best results, use a 10kΩ resistor for R2. See equation (1) and figure (2).

$$1)\quad R_1 = 1\times10^4\left(\frac{V_{OUT}}{1.235} - 1\right)$$

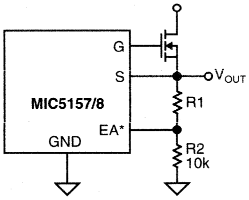


Figure 2. Typical Resistive Divider

Input Filter Capacitor

The Super LDO requires an input bypass capacitor for accommodating wide changes in load current and for decoupling the error amplifier and charge pump. A medium to large value low-ESR (equivalent series resistance) capacitor is best, mounted close to the device.

Output Filter Capacitor

An output filter capacitor may be used to reduce ripple and improve load regulation. Stable operation does not require a large capacitor, but for transient load regulation the size of the output capacitor may become a consideration. Common aluminum electrolytic capacitors perform nicely; very low-ESR capacitors are not necessary. Increased capacitance (rather than reduced ESR) is preferred. The capacitor value should be large enough to provide sufficient I = C × dV/dt current consistent with the required transient load regulation quality. For a given step increase in load current, the output voltage will drop by about dV = I × dt/C, where I represents the increase in load current over time t. This relationship assumes that all output current was being supplied via the MOSFET pass device prior to the load increase. Small (0.01µF to 10µF) film capacitors parallel to the load will further improve response to transient loads.

Some linear regulators specify a minimum required output filter capacitance because the capacitor determines the dominant pole of the system, and thereby stabilizes the system. This is not the situation for the MIC5156/7/8; its dominant pole is determined within its error amplifier.

Current Limiting

Current sensing requires a low-value series resistance (R_S) between V_{DD} and D (drain). Refer to the typical applications. The internal current-limiting circuit limits the voltage drop across the sense resistor to 35mV. Equation (2) provides the sense resistor value required for a given maximum current.

$$2)\quad R_S = \frac{35\text{mV}}{I_{LIM}}$$

where:

R_S = sense resistor value
I_{LIM} = maximum output current

Most current-limited applications require low-value resistors. See *Application Hints 21 and 25* for construction hints.

Non-Current Limited Applications

For circuits not requiring current limiting, do not use a sense resistor between V_{DD} and D (drain). See figure (3). The controller will not limit current when it does not detect a 35mV drop from V_{DD} to D.

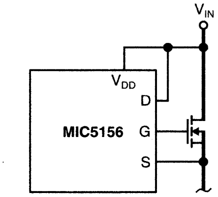


Figure 3. No Current Limit

3.3V Microprocessor Applications

For computer designs that use 3.3V microprocessors with 5V logic, the FLAG output can be used to suppress the 5V supply until the 3.3V output is in regulation. Refer to the external components shown with the MIC5156 Block Diagram.

SMPS Post Regulator Application

A Super LDO regulator can be used as a post regulator for a switch-mode power supply. The Super LDO regulator can provide a significant reduction in peak-to-peak ripple voltage.

High-Current Switch Application

All versions of the MIC5156/7/8 may be used for current-limited, high-current, high-side switching with or without voltage regulation. See figure (4a). Simply leave the "S" terminal open. A 16V zener diode from the gate to the source of the MOSFET protects the MOSFET from overdrive during fault conditions.

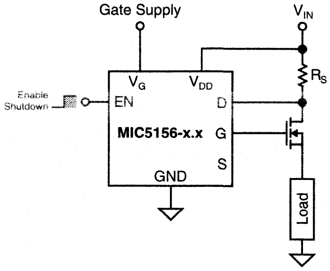


Figure 4a. High-Side Switch

If a MIC5157 or MIC5158 is used and is shutdown for a given time, the charge pump reservoir V_{CP} will bleed off. If recharging the reservoir causes an unacceptable delay in the load reaching its operating voltage, do not use the EN pin for on/off control. Instead, use the MIC5158, hold EN high to keep the charge pump in continuous operation, and switch the MOSFET on or off by overriding the error amplifier input as shown in figure (4b).

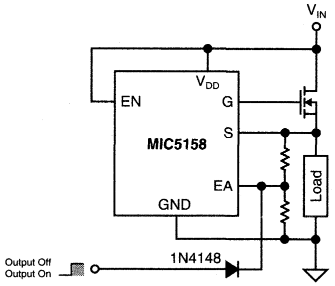


Figure 4b. Fast High-Side Switch

Battery Charger Application

The MIC5158 may be used in constant-current applications such as battery chargers. See figure (5). The regulator supplies a constant-current (35mV ÷ R3) until the battery approaches the float voltage:

$$V_{FL} = 1.235\left(1 + \frac{R1}{R2}\right)$$

where:

V_{FL} = float voltage

At float voltage, the MOSFET is shut off. A trickle charge is supplied by R4.

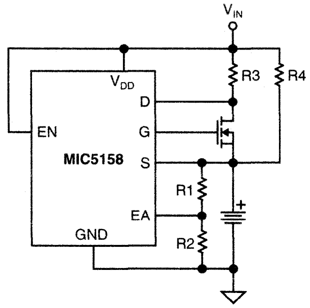


Figure 5. Battery Charger Concept

Uninterruptible Power Supply

The MIC5157 and two N-channel MOSFETs provide battery switching for uninterruptible power as shown in figure (6). Two MOSFETs are placed source-to-source to prevent current flow through their body diodes when switched off. The Super LDO regulator is continuously enabled to achieve fast battery switch-in. Careful attention must be paid to the ac-line monitoring circuitry to ensure that the output voltage does not fall below design limits while the battery is being switched in.

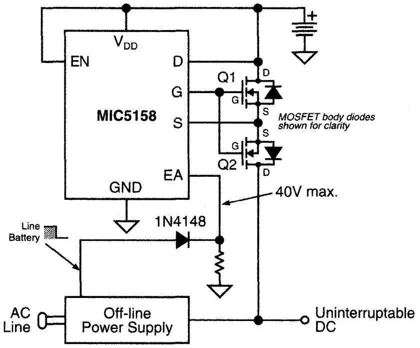


Figure 6. UPS Power Supply Concept

MIC5200

100mA Low-Dropout Voltage Regulator

Preliminary Information

General Description

The MIC5200 is an efficient linear voltage regulator with very low dropout voltage (typically 17mV at light loads and 200mV at 100mA), and very low ground current (1mA at 100mA output), offering better than 1% initial accuracy with a logic compatible ON/OFF switching input. Designed especially for hand-held battery powered devices, the MIC5200 is switched by a CMOS or TTL compatible logic signal. The ENABLE control may be tied directly to V_{IN} if unneeded. When disabled, power consumption drops nearly to zero. The ground current of the MIC5200 increases only slightly in dropout, further prolonging battery life. Key MIC5200 features include protection against reversed battery, current limiting, and over-temperature shutdown.

The MIC5200 is available in several fixed voltages and accuracy configurations. Other options are available; contact Micrel for details.

Features

- High output voltage accuracy
- Variety of output voltages
- Guaranteed 100mA output
- Low quiescent current
- Low dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Current and thermal limiting
- Zero OFF mode current
- Logic-controlled electronic shutdown
- Available in SO-8 and SOT-223 packages

Applications

- Cellular Telephones
- Laptop, Notebook, and Palmtop Computers
- Battery Powered Equipment
- PCMCIA V_{CC} and V_{PP} Regulation/Switching
- Bar Code Scanners
- SMPS Post-Regulator/ DC to DC Modules
- High Efficiency Linear Power Supplies

Ordering Information

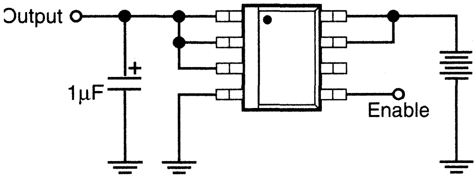
Part Number	Volts	Accuracy	Temperature Range*	Package
MIC5200-3.0BM	3.0	1%	–40°C to +125°C	SO-8
MIC5200-3.3BM	3.3	1%	–40°C to +125°C	SO-8
MIC5200-4.8BM	4.85	1%	–40°C to +125°C	SO-8
MIC5200-5.0BM	5.0	1%	–40°C to +125°C	SO-8
MIC5200-3.0BS	3.0	1%	–40°C to +125°C	SOT-223
MIC5200-3.3BS	3.3	1%	–40°C to +125°C	SOT-223
MIC5200-4.8BS	4.85	1%	–40°C to +125°C	SOT-223
MIC5200-5.0BS	5.0	1%	–40°C to +125°C	SOT-223

* *Junction Temperature*

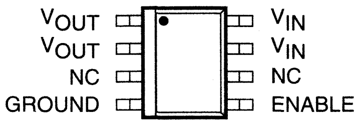
Other voltages are available; contact Micrel for details.

Typical Application

MIC5200-3.3

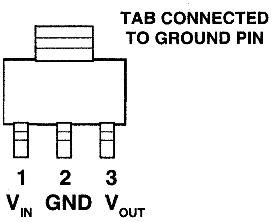


Pin Configuration



MIC5200-xxBM

Both V_{IN} and both V_{OUT} pins must be tied together. ENABLE must be pulled high for operation.



MIC5200-xxBS

ENABLE may be tied directly to V_{IN}

Absolute Maximum Ratings

Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its specified **Operating Ratings.**

Power Dissipation	Internally Limited
Lead Temperature (Soldering, 5 seconds)	260°C
Operating Junction Temperature Range	–40°C to +125°C
Input Supply Voltage	–20V to +60V
ENABLE Input Voltage	–20V to +60V
ESD Rating	> 2000V

Thermal Characteristics

SOT-223 θ_{JC}	15°C/W
SO-8 θ_{JA}	See Note 1

Recommended Operating Conditions

Input Voltage	2.5V to 26V
Operating Junction Temperature Range	–40°C to +125°C
ENABLE Input Voltage	–20V to V_{IN}

Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$ and limits in **boldface** apply over the junction temperature range of –40°C to +125°C. Unless otherwise specified, $V_{IN} = V_{OUT} + 1V$, $I_L = 1mA$, $C_L = 3.3\mu F$, and $V_{ENABLE} \geq 2.0V$

Symbol	Parameter	Conditions	Min	Typical	Max	Units
V_O	Output Voltage Accuracy	Variation from specified V_{OUT}	–1 **–2**		1 **2**	%
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temperature Coef.	(Note 2)		**40**	**150**	ppm/°C
$\frac{\Delta V_O}{V_{IN}}$	Line Regulation	$V_{IN} = V_{OUT} + 1$ V to 26V		0.004	0.10 **0.40**	%
$\frac{\Delta V_O}{I_L}$	Load Regulation	$I_L = 0.1mA$ to 100mA (Note 3)		0.04	0.16 **0.30**	%
$V_{IN} - V_O$	Dropout Voltage (Note 4)	$I_L = 100\mu A$		17		mV
		$I_L = 20mA$		130		
		$I_L = 30mA$		150		
		$I_L = 50mA$		190		
		$I_L = 100mA$		230	**350**	
I_{GND}	Quiescent Current	$V_{ENABLE} \leq 0.7V$ (Shutdown)		0.01	10	µA
I_{GND}	Ground Pin Current	$V_{ENABLE} \geq 2.0V$, $I_L = 100\mu A$		130		µA
		$I_L = 20mA$		270	350	
		$I_L = 30mA$		330		
		$I_L = 50mA$		500		
		$I_L = 100mA$		1000	**1500**	
PSRR	Ripple Rejection			70		dB
I_{GNDDO}	Ground Pin Current at Dropout	$V_{IN} = 0.5V$ less than specified V_{OUT} $I_L = 100\mu A$ (Note 5)		270	**330**	µA
I_{LIMIT}	Current Limit	$V_{OUT} = 0V$	100	**250**		mA
$\frac{\Delta V_O}{\Delta P_D}$	Thermal Regulation	(Note 6)		0.05		%/W
e_n	Output Noise			100		µV

ENABLE Input

	Input Voltage Level					
V_{IL}	Logic Low	OFF			**0.7**	V
	Logic High	ON	**2.0**			
I_{IL}	ENABLE Input Current	$V_{IL} \leq 0.7V$		0.01	1	µA
I_{IH}		$V_{IH} \geq 2.0V$		15	**50**	

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions. The maximum allowable power dissipation is a function of the maximum junction temperature, $T_{J\,(MAX)}$, the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using: $P_{(MAX)} = (T_{J(MAX)} - T_A) \div \theta_{JA}$. Exceeding the maximum allowable power dissipation will result in excessive die temperature, and the regulator will go into thermal shutdown. The θ_{JC} of the MIC5200-xxBS is 15°C/W and θ_{JA} for the MIC5200BM is 160°C/W mounted on a PC board (see "Thermal Considerations" section for further details).

Note 2: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

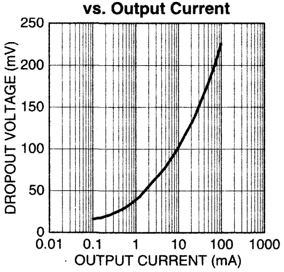
Note 3: Regulation is measured at constant junction temperature using low duty cycle pulse testing. Parts are tested for load regulation in the load range from 0.1mA to 100mA. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

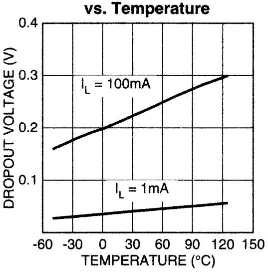
Note 4: Dropout Voltage is defined as the input to output differential at which the output voltage drops 2% below its nominal value measured at 1V differential.

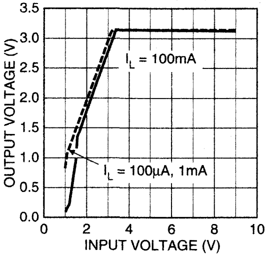
Note 5: Ground pin current is the regulator quiescent current plus pass transistor base current. The total current drawn from the supply is the sum of the load current plus the ground pin current.

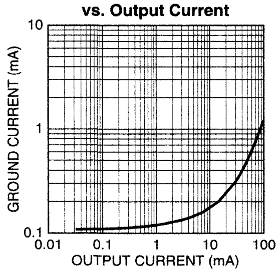
Note 6: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 100mA load pulse at V_{IN} = 26V for T = 10ms.

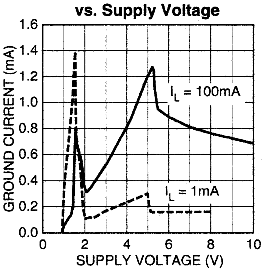
Typical Characteristics

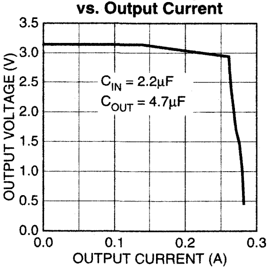

Dropout Voltage vs. Output Current


Dropout Voltage vs. Temperature


Dropout Characteristics

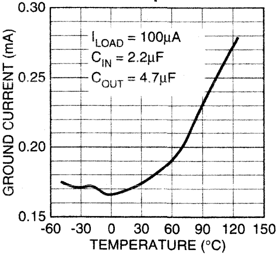

Ground Current vs. Output Current


Ground Current vs. Supply Voltage

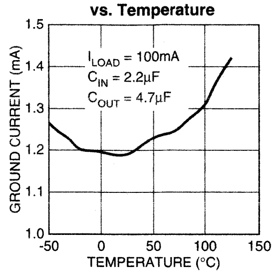

Output Voltage vs. Output Current

Typical Characteristics

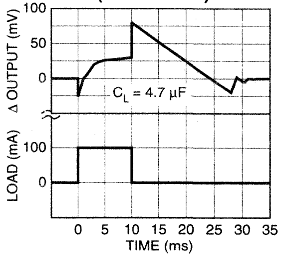
Ground Current vs. Temperature



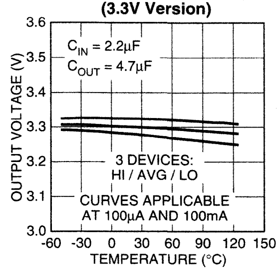
Ground Current vs. Temperature



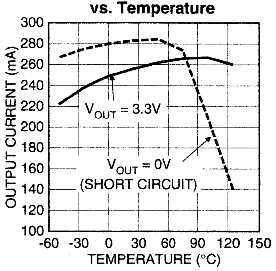
Thermal Regulation (3.3V Version)



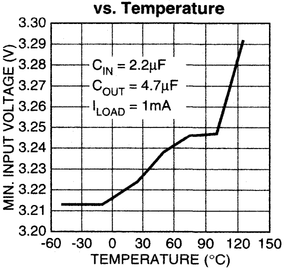
Output Voltage vs. Temp. (3.3V Version)



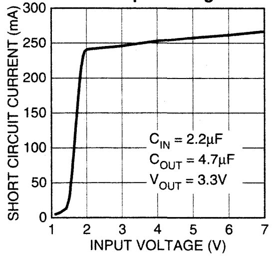
Output Current vs. Temperature



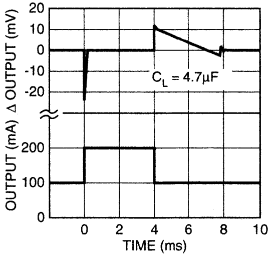
Minimum Input Voltage vs. Temperature



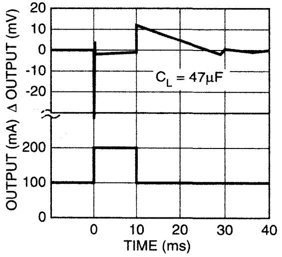
Short Circuit Current vs. Input Voltage



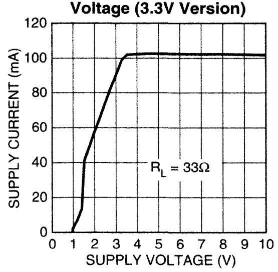
Load Transient



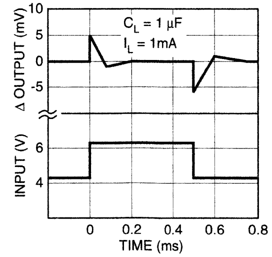
Load Transient



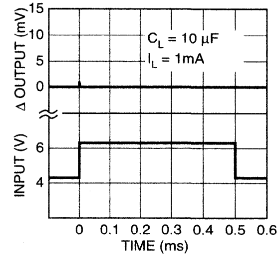
Supply Current vs. Supply Voltage (3.3V Version)

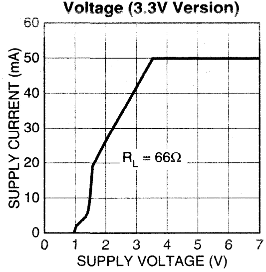


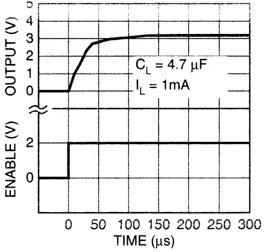
Line Transient

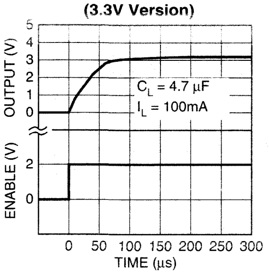


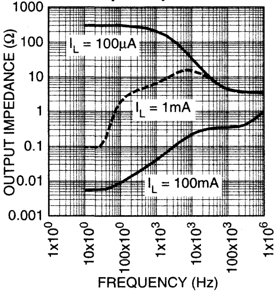
Line Transient

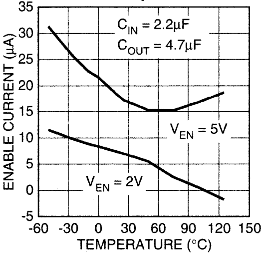


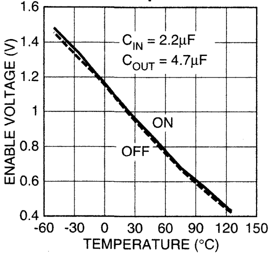

Supply Current vs. Supply Voltage (3.3V Version)

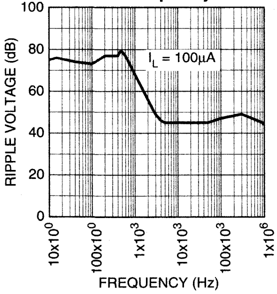

Enable Transient (3.3V Version)

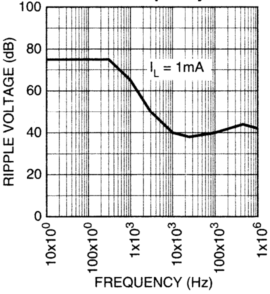

Enable Transient (3.3V Version)

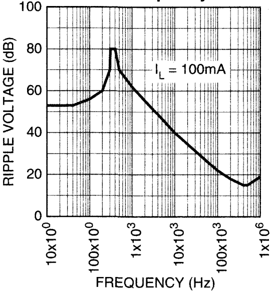

Output Impedance


Enable Current Threshold vs. Temperature


Enable Voltage Threshold vs. Temperature


Ripple vs. Frequency


Ripple vs. Frequency


Ripple vs. Frequency

Applications Information

External Capacitors

A 1µF capacitor is recommended between the MIC5200 output and ground to prevent oscillations due to instability. Larger values serve to improve the regulator's transient response. Most types of tantalum or aluminum electrolytics will be adequate; film types will work, but are costly and therefore not recommended. Many aluminum electrolytics have electrolytes that freeze at about –30°C, so solid tantalum capacitors are recommended for operation below –25°C. The important parameters of the capacitor are an effective series resistance of about 5Ω or less and a resonant frequency above 500kHz. The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for output stability. The capacitor can be reduced to 0.47µF for current below 10mA or 0.33µF for currents below 1 mA. A 1µF capacitor should be placed from the MIC5200 input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the input.

The MIC5200 will remain stable and in regulation with no load in addition to the internal voltage divider, unlike many other voltage regulators. This is especially important in CMOS RAM keep-alive applications.

When used in dual supply systems where the regulator load is returned to a negative supply, the output voltage must be diode clamped to ground.

ENABLE Input

The MIC5200 features nearly zero OFF mode current. When the ENABLE input is held below 0.7V, all internal circuitry is powered off. Pulling this pin high (over 2.0V) re-enables the device and allows operation. The ENABLE pin requires a small amount of current, typically 15µA. While the logic threshold is TTL/CMOS compatible, ENABLE may be pulled as high as 30V, independent of the voltage on V_{IN}.

Thermal Considerations

Part I. Layout

The MIC5200-xxBM (8-pin surface mount package) has the following thermal characteristics when mounted on a single layer copper-clad printed circuit board.

PC Board Dielectric	θ_{JA}
FR4	160°C/W
Ceramic	120°C/W

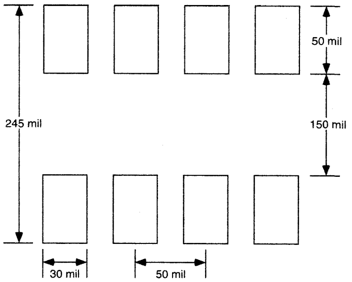
Multi-layer boards having a ground plane, wide traces near the pads, and large supply bus lines provide better thermal conductivity.

The "worst case" value of 160°C/W assumes no ground plane, minimum trace widths, and a FR4 material board.

Part II. Nominal Power Dissipation and Die Temperature

The MIC5200-xxBM at a 25°C ambient temperature will operate reliably at up to 625mW power dissipation when mounted in the "worst case" manner described above. At an ambient temperature of 55°C, the device may safely dissipate 440mW. These power levels are equivalent to a die temperature of 125°C, the recommended maximum temperature for non-military grade silicon integrated circuits.

For MIC5200-xxBS (SOT-223 package) heat sink characteristics, please refer to Micrel Application Hint 17, “Calculating P.C. Board Heat Sink Area for Surface Mount Packages”.



Minimum recommended board pad size, SO-8.

MIC5201

200mA Low-Dropout Voltage Regulator

Preliminary Information

General Description

The MIC5201 is an efficient linear voltage regulator with very low dropout voltage (typically 17mV at light loads and 200mV at 100mA), and very low ground current (1mA at 100mA output), offering better than 1% initial accuracy with a logic compatible ON/OFF switching input. Designed especially for hand-held battery powered devices, the MIC5201 is switched by a CMOS or TTL compatible logic signal. This ENABLE control may be tied directly to V_{IN} if unneeded. When disabled, power consumption drops nearly to zero. The ground current of the MIC5201 increases only slightly in dropout, further prolonging battery life. Key MIC5201 features include protection against reversed battery, current limiting, and over-temperature shutdown.

The MIC5201 is available in several fixed voltages and accuracy configurations. It features the same pinout as the LT1121 with better performance. Other options are available; contact Micrel for details.

Features

- High output voltage accuracy
- Variety of output voltages
- Guaranteed 200mA output
- Low quiescent current
- Low dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Current and thermal limiting
- Reverse-battery protection
- Zero OFF mode current
- Logic-controlled electronic enable
- Available in SO-8 and SOT-223 packages

Applications

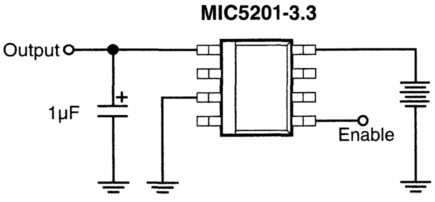
- Cellular Telephones
- Laptop, Notebook, and Palmtop Computers
- Battery Powered Equipment
- PCMCIA V_{CC} and V_{PP} Regulation/Switching
- Bar Code Scanners
- SMPS Post-Regulator/ DC to DC Modules
- High Efficiency Linear Power Supplies

Ordering Information

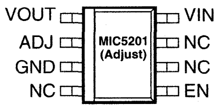
Part Number	Volts	Accuracy	Temperature Range*	Package
MIC5201BM	Adj	1%	–40°C to +125°C	SO-8
MIC5201-3.0BM	3.0	1%	–40°C to +125°C	SO-8
MIC5201-3.3BM	3.3	1%	–40°C to +125°C	SO-8
MIC5201-5.0BM	5.0	1%	–40°C to +125°C	SO-8
MIC5201-3.0BS	3.0	1%	–40°C to +125°C	SOT-223
MIC5201-3.3BS	3.3	1%	–40°C to +125°C	SOT-223
MIC5201-4.8BS	4.85	1%	–40°C to +125°C	SOT-223
MIC5201-5.0BS	5.0	1%	–40°C to +125°C	SOT-223

** Junction Temperature*
Other voltages are available; contact Micrel for details.

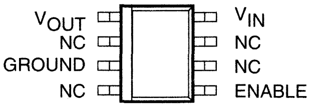
Typical Application



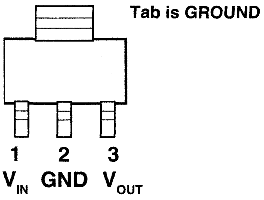
Pin Configuration



MIC5201BM Adjustable regulator



MIC5201-xxBM



MIC5201-xxBS

ENABLE may be tied directly to V_{IN}

Absolute Maximum Ratings

Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its specified **Operating Ratings.**

Power Dissipation	Internally Limited
Lead Temperature (Soldering, 5 seconds)	260°C
Operating Junction Temperature Range	–40°C to +125°C
Input Supply Voltage	–20V to +60V
ENABLE Input Voltage	–20V to +60V
ESD Rating	> 2000V

Recommended Operating Conditions

Input Voltage	2.5V to 26V
Operating Junction Temperature Range	–40°C to +125°C
ENABLE Input Voltage	0V to V_{IN}

Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$ and limits in **boldface** apply over the junction temperature range of –40°C to +125°C. Unless otherwise specified, $V_{IN} = V_{OUT} + 1V$, $I_L = 100\mu A$, $C_L = 3.3\mu F$, and $V_{ENABLE} \geq 2.0V$

Symbol	Parameter	Conditions	Min	Typical	Max	Units
V_O	Output Voltage Accuracy	Variation from specified V_{OUT}	–1		1	%
			–2		**2**	
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temperature Coef.	(Note 2)		**40**	**150**	ppm/°C
$\frac{\Delta V_O}{V_O}$	Line Regulation	$V_{IN} = V_{OUT} + 1$ V to 26V		0.004	0.20	%
					0.40	
$\frac{\Delta V_O}{V_O}$	Load Regulation	$I_L = 0.1mA$ to 200mA (Note 3)		0.04	0.16	%
					0.30	
$V_{IN} - V_O$	Dropout Voltage (Note 4)	$I_L = 100\mu A$		17		mV
		$I_L = 20mA$		130		
		$I_L = 50mA$		180		
		$I_L = 100mA$		225		
		$I_L = 200mA$		270	**400**	
I_{GND}	Quiescent Current	$V_{ENABLE} \leq 0.7V$ (Shutdown)		0.01		µA
I_{GND}	Ground Pin Current	$V_{ENABLE} \geq 2.0V$, $I_L = 100\mu A$		130		µA
		$I_L = 20mA$		270	400	
		$I_L = 50mA$		500		
		$I_L = 100mA$		1000	**2000**	
		$I_L = 200mA$		3.0		mA
PSRR	Ripple Rejection			75		dB
I_{GNDDO}	Ground Pin Current at Dropout	$V_{IN} = 0.5V$ less than specified V_{OUT} $I_L = 100\mu A$ (Note 5)		270	**330**	µA
I_{LIMIT}	Current Limit	$V_{OUT} = 0V$		**280**	500	mA
$\frac{\Delta V_O}{\Delta P_D}$	Thermal Regulation	(Note 6)		0.05		%/W
e_n	Output Noise			100		µV

ENABLE Input

V_{IL}	Input Voltage Level					
	Logic Low	OFF			**0.7**	V
	Logic High	ON	**2.0**			
I_{IL}	ENABLE Input Current	$V_{IL} \leq 0.7V$		0.01	**1**	µA
I_{IH}		$V_{IH} \geq 2.0V$		15	**50**	

Symbol	Parameter	Conditions	Min	Typical	Max	Units
Reference (MIC5201BM adjustable version only)						
V_{REF}	Reference Voltage		1.223 **1.217**	1.242	1.255 **1.267**	V
I_{IL}	Reference Voltage Temperature Coefficient			20		ppm/°C

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions. The maximum allowable power dissipation is a function of the maximum junction temperature, $T_{J\ (MAX)}$, the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using: $P_{(MAX)} = (T_{J(MAX)} - T_A) \div \theta_{JA}$. Exceeding the maximum allowable power dissipation will result in excessive die temperature, and the regulator will go into thermal shutdown. The θ_{JC} of the MIC5201-xxBS is 15°C/W and θ_{JA} for the MIC5201BM is 160°C/W mounted on a PC board (see "Thermal Considerations" section for further details).

Note 2: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 3: Regulation is measured at constant junction temperature using low duty cycle pulse testing. Parts are tested for load regulation in the load range from 0.1mA to 200mA. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

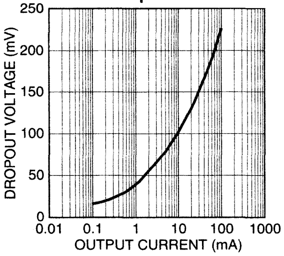
Note 4: Dropout Voltage is defined as the input to output differential at which the output voltage drops 2% below its nominal value measured at 1V differential.

Note 5: Ground pin current is the regulator quiescent current plus pass transistor base current. The total current drawn from the supply is the sum of the load current plus the ground pin current.

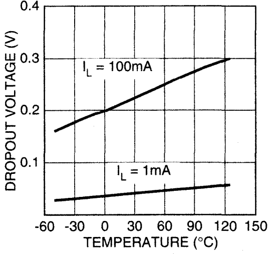
Note 6: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 200mA load pulse at V_{IN} = 26V for T = 10ms.

Typical Characteristics

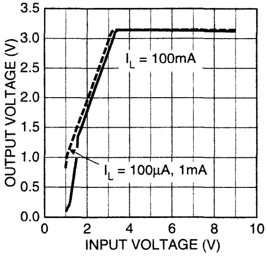
Dropout Voltage vs. Output Current



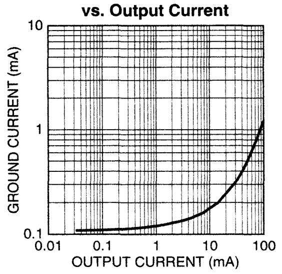
Dropout Voltage vs. Temperature



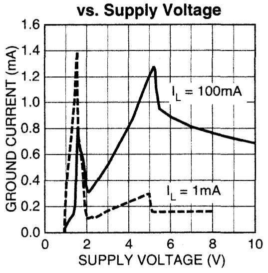
Dropout Characteristics



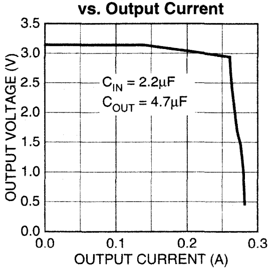
Ground Current vs. Output Current



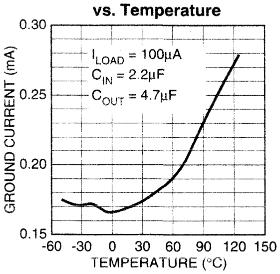
Ground Current vs. Supply Voltage



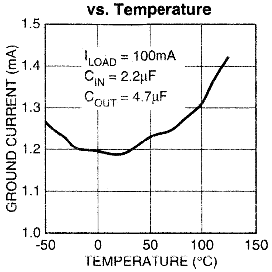
Output Voltage vs. Output Current



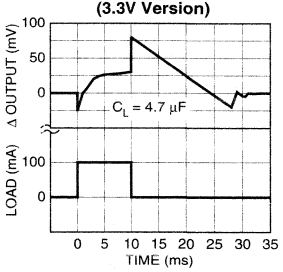
Ground Current vs. Temperature



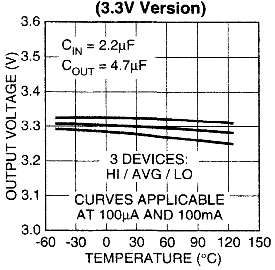
Ground Current vs. Temperature



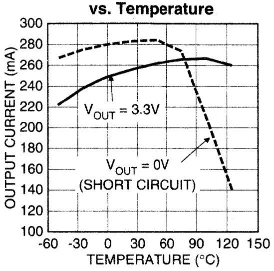
Thermal Regulation (3.3V Version)



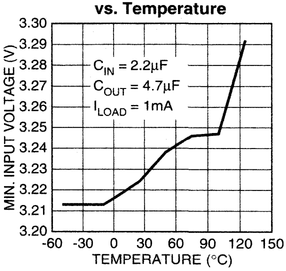
Output Voltage vs. Temp. (3.3V Version)



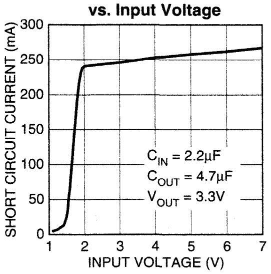
Output Current vs. Temperature



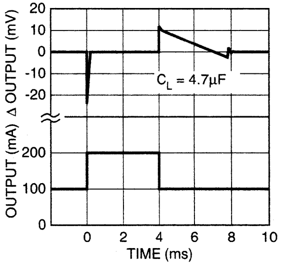
Minimum Input Voltage vs. Temperature



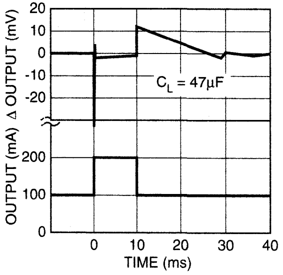
Short Circuit Current vs. Input Voltage



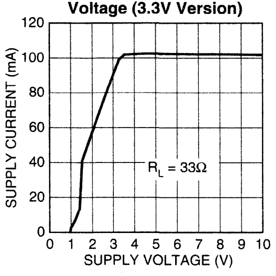
Load Transient



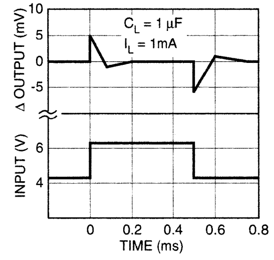
Load Transient



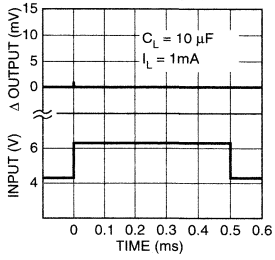
Supply Current vs. Supply Voltage (3.3V Version)

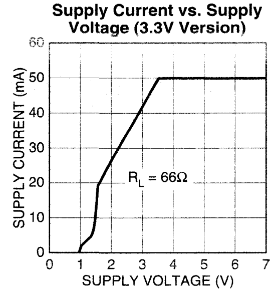


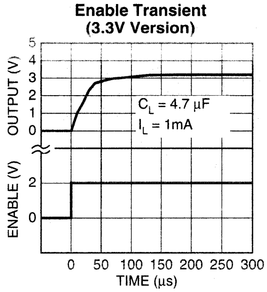
Line Transient

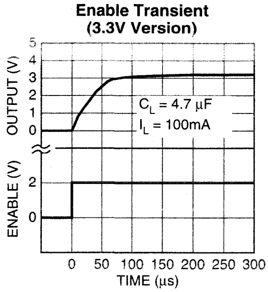


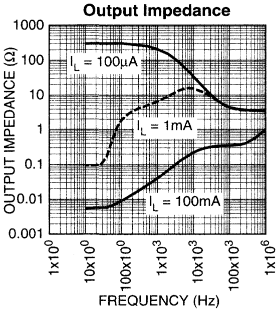
Line Transient

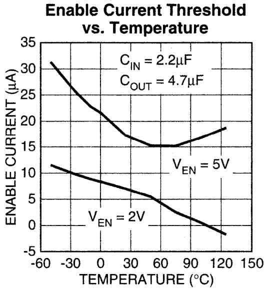


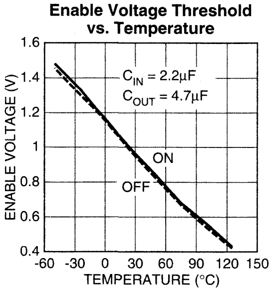

Supply Current vs. Supply Voltage (3.3V Version)

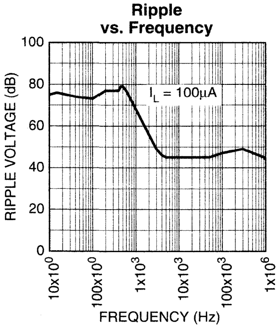

Enable Transient (3.3V Version)

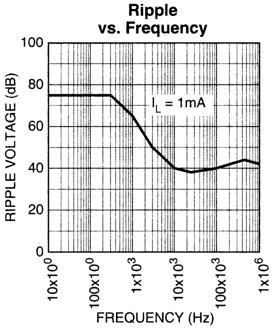

Enable Transient (3.3V Version)

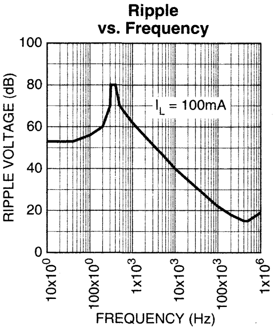

Output Impedance


Enable Current Threshold vs. Temperature


Enable Voltage Threshold vs. Temperature


Ripple vs. Frequency


Ripple vs. Frequency


Ripple vs. Frequency

Applications Information

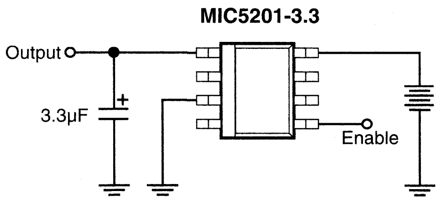
External Capacitors

A 1µF capacitor is recommended between the MIC5201 output and ground to prevent oscillations due to instability. Larger values serve to improve the regulator's transient response. Most types of tantalum or aluminum electrolytics will be adequate; film types will work, but are costly and therefore not recommended. Many aluminum electrolytics have electrolytes that freeze at about –30°C, so solid tantalums are recommended for operation below –25°C. The important parameters of the capacitor are an effective series resistance of about 5Ω or less and a resonant frequency above 500kHz. The value of this capacitor may be increased without limit.

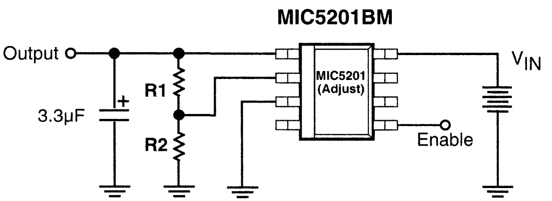
At lower values of output current, less output capacitance is required for output stability. The capacitor can be reduced to 0.47µF for current below 10mA or 0.33µF for currents below 1 mA. A 1µF capacitor should be placed from the MIC5201 input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the input.

The MIC5201 will remain stable and in regulation with no load in addition to the internal voltage divider, unlike many other voltage regulators. This is especially important in CMOS RAM keep-alive applications.

When used in dual supply systems where the regulator load is returned to a negative supply, the output voltage must be diode clamped to ground.



MIC5201 Fixed voltage application.



$$V_{OUT} = 1.242V \times \left(1 + \frac{R2}{R1}\right)$$

MIC5201 Adjustable application. A capacitor from the adjust pin (pin 2) to ground will decrease high frequency noise on the output.

Thermal Considerations

Part I. Layout

The MIC5201-xxBM (8-pin surface mount package) has the following thermal characteristics when mounted on a single layer copper-clad printed circuit board.

PC Board Dielectric	θ_{JA}
FR4	160°C/W
Ceramic	120°C/W

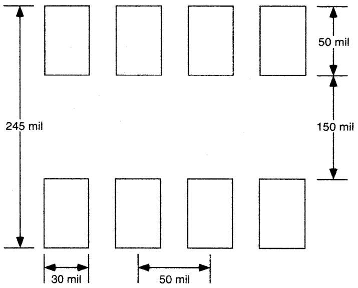
Multi-layer boards having a ground plane, wide traces near the pads, and large supply bus lines provide better thermal conductivity.

The "worst case" value of 160°C/W assumes no ground plane, minimum trace widths, and a FR4 material board.

Part II. Nominal Power Dissipation and Die Temperature

The MIC5201-xxBM at a 25°C ambient temperature will operate reliably at up to 625mW power dissipation when mounted in the "worst case" manner described above. At an ambient temperature of 55°C, the device may safely dissipate 440mW. These power levels are equivalent to a die temperature of 125°C, the recommended maximum temperature for non-military grade silicon integrated circuits.

For MIC5201-xxBS (SOT-223 package) heat sink characteristics, please refer to Micrel Application Hint 17, "P.C. Board Heat Sinking".



Minimum recommended board pad size, SO-8.

MIC5202

Dual 100mA Low-Dropout Voltage Regulator

Preliminary Information

General Description

The MIC5202 is a family of dual linear voltage regulators with very low dropout voltage (typically 17mV at light loads and 210mV at 100mA), and very low ground current (1mA at 100mA output–each section), offering better than 1% initial accuracy with a logic compatible ON/OFF switching input. Designed especially for hand-held battery powered devices, the MIC5202 is switched by a CMOS or TTL compatible logic signal. This ENABLE control my be tied directly to V_{IN} if unneeded. When disabled, power consumption drops nearly to zero. The ground current of the MIC5202 increases only slightly in dropout, further prolonging battery life. Key MIC5202 features include protection against reversed battery, current limiting, and over-temperature shutdown.

The MIC5202 is available in several fixed voltages. Other options are available; contact Micrel for details.

Features

- High output voltage accuracy
- Variety of output voltages
- Guaranteed 100mA output
- Low quiescent current
- Low dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Current and thermal limiting
- Reverse-battery protection
- Zero OFF mode current
- Logic-controlled electronic shutdown
- Available in SO-8 package

Applications

- Cellular Telephones
- Laptop, Notebook, and Palmtop Computers
- Battery Powered Equipment
- PCMCIA V_{CC} and V_{PP} Regulation/Switching
- Bar Code Scanners
- SMPS Post-Regulator/ DC to DC Modules
- High Efficiency Linear Power Supplies

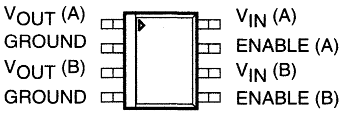
Ordering Information

Part Number	Volts	Accuracy	Temperature Range*	Package
MIC5202-3.0BM	3.0	1%	–40°C to +125°C	SO-8
MIC5202-3.3BM	3.3	1%	–40°C to +125°C	SO-8
MIC5202-4.8BM	4.85	1%	–40°C to +125°C	SO-8
MIC5202-5.0BM	5.0	1%	–40°C to +125°C	SO-8

* Junction Temperature

Other voltages are available; contact Micrel for details.

Pin Configuration

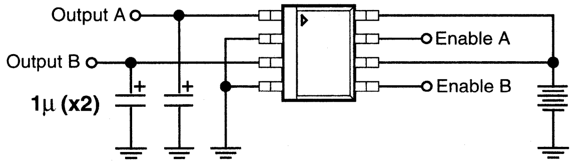


MIC5202-xxBM

Both GROUND pins must be tied to the same potential. V_{IN} (A) and V_{IN} (B) may run from separate supplies.

Typical Application

MIC5202-3.3



ENABLE pins may be tied directly to V_{IN}

Absolute Maximum Ratings

Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its specified **Operating Ratings.**

Power Dissipation	Internally Limited
Lead Temperature (Soldering, 5 seconds)	260°C
Operating Junction Temperature Range	–40°C to +125°C
Input Supply Voltage	–20V to +60V
ENABLE Input Voltage	–20V to +60V
ESD Rating	> 2000V
SO-8 θ_{JA}	See Note 1

Recommended Operating Conditions

Input Voltage	2.5V to 26V
Operating Junction Temperature Range	–40°C to +125°C
ENABLE Input Voltage	0V to V_{IN}

Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$ and limits in **boldface** apply over the junction temperature range of –40°C to +125°C. Specifications are for each half of the (dual) MIC5202. Unless otherwise specified, $V_{IN} = V_{OUT} + 1V$, $I_L = 1mA$, $C_L = 10\mu F$, and $V_{CONTROL} \geq 2.0V$.

Symbol	Parameter	Condition	Min	Typ	Max	Units
V_O	Output Voltage	Variation from specified V_{OUT} Accuracy	–1 **–2**		1 **2**	%
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temperature Coef.	(Note 2)		**40**	**150**	ppm/°C
$\frac{\Delta V_O}{V_O}$	Line Regulation	$V_{IN} = V_{OUT} + 1$ V to 26V		0.004	0.10 **0.40**	%
$\frac{\Delta V_O}{V_O}$	Load Regulation	$I_L = 0.1mA$ to 100mA (Note 3)		0.04	0.16 **0.30**	%
$V_{IN} - V_O$	Dropout Voltage (Note 4)	$I_L = 100\mu A$ $I_L = 20mA$ $I_L = 30mA$ $I_L = 50mA$ $I_L = 100mA$		17 130 150 180 225	 **350**	mV
I_Q	Quiescent Current	$V_{CONTROL} \leq 0.7V$ (Shutdown)		0.01		µA
I_{GND}	Ground Pin Current	$V_{CONTROL} \geq 2.0V$, $I_L = 100\mu A$ $I_L = 20mA$ $I_L = 30mA$ $I_L = 50mA$ $I_L = 100mA$		170 270 330 500 1200	 **1500**	µA
PSRR	Ripple Rejection			75		dB
I_{GNDDO}	Ground Pin Current at Dropout	$V_{IN} = 0.5V$ less specified V_{OUT}, $I_L = 100\mu A$ (Note 5)		270	**330**	µA
I_{LIMIT}	Current Limit	$V_{OUT} = 0V$		**280**		mA
$\frac{\Delta V_O}{\Delta P_D}$	Thermal Regulation	(Note 6)		0.05		%/W
e_n	Output Noise			100		µV

Control Input

V_{IL}	Input Voltage Level Logic Low Logic High	 OFF ON	 **2.0**		 **0.7** 	V
I_{IL} IH	Control Input Current	$V_{IL} \leq 0.7V$ $V_{IH} \geq 2.0V$		0.01 8	 **50**	µA

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions. The maximum allowable power dissipation is a function of the maximum junction temperature, $T_{J(MAX)}$ the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using: $P_{(MAX)} = (T_{J(MAX)} - T_A) / \theta_{JA}$. Exceeding the maximum allowable power dissipation will result in excessive die temperature, and the regulator will go into thermal shutdown. The junction to ambient thermal resistance of the MIC5202BM is 160°C/W mounted on a PC board.

Note 2: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 3: Regulation is measured at constant junction temperature using low duty cycle pulse testing. Parts are tested for load regulation in the load range from 0.1mA to 100mA. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

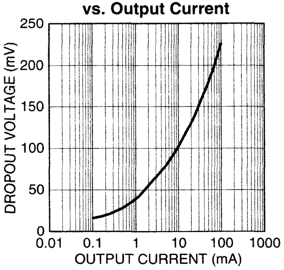
Note 4: Dropout Voltage is defined as the input to output differential at which the output voltage drops 2% below its nominal value measured at 1V differential.

Note 5: Ground pin current is the regulator quiescent current plus pass transistor base current. The total current drawn from the supply is the sum of the load current plus the ground pin current.

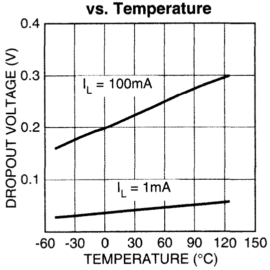
Note 6: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 100mA load pulse at V_{IN} = 26V for T = 10ms, and is measured separately for each section.

Typical Characteristics *(Each Regulator—2 Regulators/Package)*

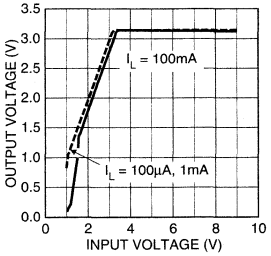
Dropout Voltage vs. Output Current



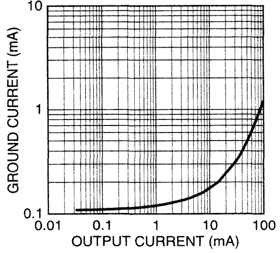
Dropout Voltage vs. Temperature



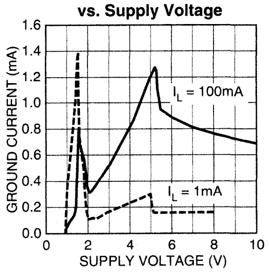
Dropout Characteristics



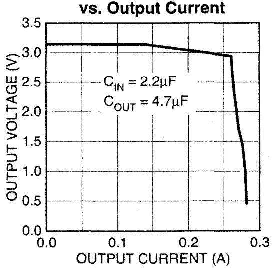
Ground Current vs. Output Current



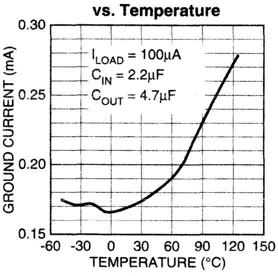
Ground Current vs. Supply Voltage



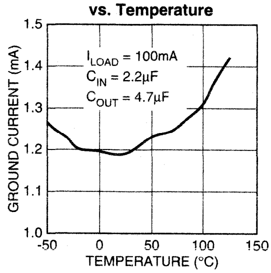
Output Voltage vs. Output Current



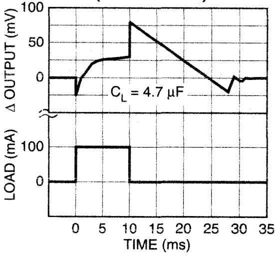
Ground Current vs. Temperature



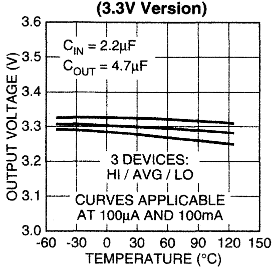
Ground Current vs. Temperature



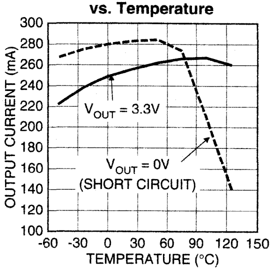
Thermal Regulation (3.3V Version)



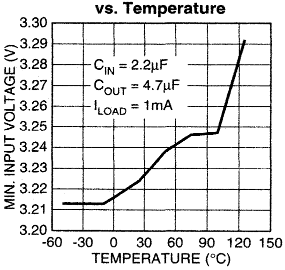
Output Voltage vs. Temp. (3.3V Version)



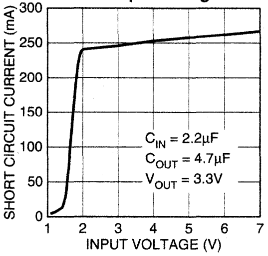
Output Current vs. Temperature



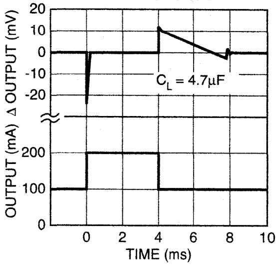
Minimum Input Voltage vs. Temperature



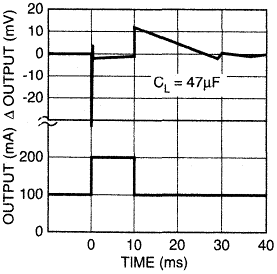
Short Circuit Current vs. Input Voltage



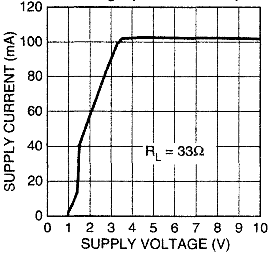
Load Transient



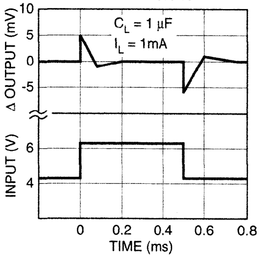
Load Transient



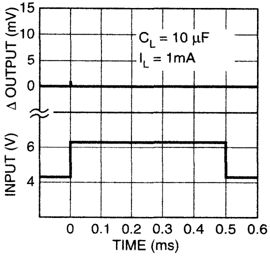
Supply Current vs. Supply Voltage (3.3V Version)

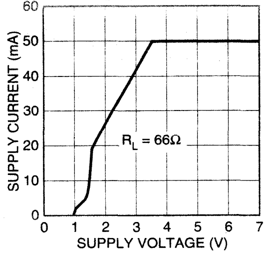


Line Transient

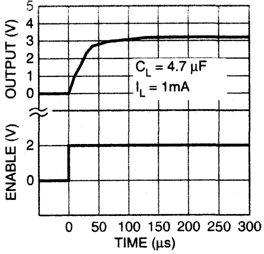


Line Transient

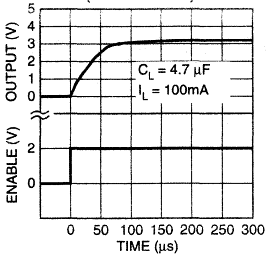




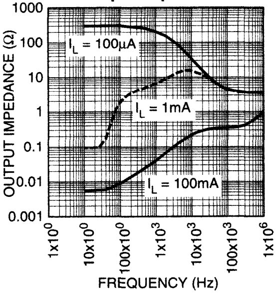
Supply Current vs. Supply Voltage (3.3V Version)



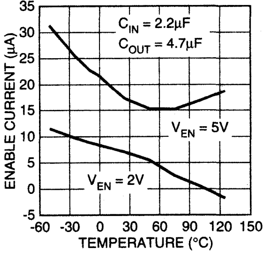
Enable Transient (3.3V Version)



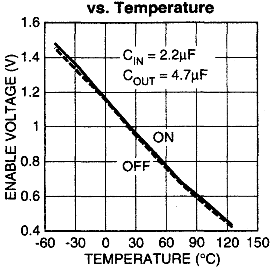
Enable Transient (3.3V Version)



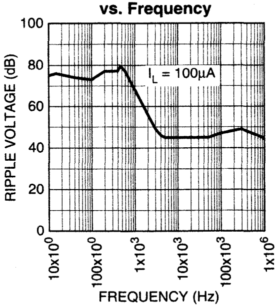
Output Impedance



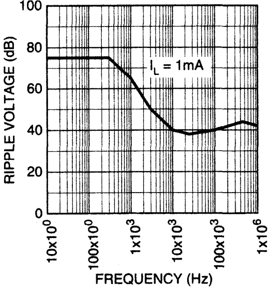
Enable Current Threshold vs. Temperature



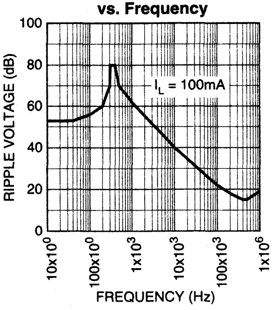
Enable Voltage Threshold vs. Temperature



Ripple vs. Frequency



Ripple vs. Frequency



Ripple vs. Frequency

Applications Information

External Capacitors

A 1µF capacitor is recommended between the MIC5202 output and ground to prevent oscillations due to instability. Larger values serve to improve the regulator's transient response. Most types of tantalum or aluminum electrolytics will be adequate; film types will work, but are costly and therefore not recommended. Many aluminum electrolytics have electrolytes that freeze at about –30°C, so solid tantalums are recommended for operation below –25°C. The important parameters of the capacitor are an effective series resistance of about 5Ω or less and a resonant frequency above 500kHz. The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for output stability. The capacitor can be reduced to 0.47µF for current below 10mA or 0.33µF for currents below 1 mA. A 1µF capacitor should be placed from the MIC5202 input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the supply.

ENABLE Input

The MIC5202 features nearly zero OFF mode current. When the ENABLE input is held below 0.7V, all internal circuitry is powered off. Pulling this pin high (over 2.0V) re-enables the device and allows operation. The ENABLE pin requires a small amount of current, typically 15µA. While the logic threshold is TTL/CMOS compatible, ENABLE may be pulled as high as 30V, independent of the voltage on V_{IN}. The two portions of the MIC5202 may be enabled separately.

General Notes

The MIC5202 will remain stable and in regulation with no load in addition to the internal voltage divider, unlike many other voltage regulators. This is especially important in CMOS RAM keep-alive applications. Thermal shutdown is independant on both halfs of the dual MIC5202, however an over-temperature condition on one half might affect the other because of proximity. When used in dual supply systems where the regulator load is returned to a negative supply, the output voltage must be diode clamped to ground.

Both MIC5202 GROUND pins must be tied to the same ground potential. Isolation between the two halfs allows connecting the two V_{IN} pins to different supplies.

Thermal Considerations

Part I. Layout

The MIC5202-xxBM (8-pin surface mount package) has the following thermal characteristics when mounted on a single layer copper-clad printed circuit board.

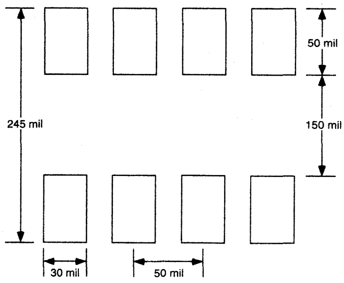
PC Board Dielectric	θ_{JA}
FR4	160°C/W
Ceramic	120°C/W

Multi-layer boards having a ground plane, wide traces near the pads, and large supply bus lines provide better thermal conductivity.

The "worst case" value of 160°C/W assumes no ground plane, minimum trace widths, and a FR4 material board.

Part II. Nominal Power Dissipation and Die Temperature

The MIC5202-xxBM at a 25°C ambient temperature will operate reliably at up to 625mW power dissipation when mounted in the "worst case" manner described above. At an ambient temperature of 55°C, the device may safely dissipate 440mW. These power levels are equivalent to a die temperature of 125°C, the recommended maximum temperature for non-military grade silicon integrated circuits.



Minimum recommended board pad size, SO-8.

MIC5203

80mA Low-Dropout Voltage Regulator

Preliminary Information

General Description

The MIC5203 is a family of efficient linear voltage regulators with very low dropout voltage (typically 20mV at light loads and 300mV at 80mA), and very low ground current (225µA at 10mA output), offering better than 3% initial accuracy with a logic compatible ON/OFF switching input. Designed especially for hand-held battery powered devices, the MIC5203 is switched by a CMOS or TTL compatible logic signal and when disabled, power consumption drops nearly to zero. If logic control is not required, the Enable pin may be tied to the Input for 3-terminal operation. The ground current of the MIC5203 increases only slightly in dropout, further prolonging battery life. Key MIC5203 features include protection against reversed battery, current limiting, and overtemperature shutdown.

The MIC5203 is available in 3.0V, 3.3V, 3.6V, 3.8V, 4.0V, 4.75V, and 5.0V fixed voltage configurations. Other voltages are available; contact Micrel for details.

Features

- Tiny four lead surface mount package
- Wide Selection of output voltages
- Guaranteed 80mA output
- Low quiescent current
- Low dropout voltage
- Tight load and line regulation
- Low temperature coefficient
- Current and thermal limiting
- Reversed input polarity protection
- Zero OFF mode current
- Logic-controlled electronic shutdown

Applications

- Cellular Telephones
- Laptop, Notebook, and Palmtop Computers
- Battery Powered Equipment
- Bar Code Scanners
- SMPS Post-Regulator/ DC to DC Modules
- High Efficiency Linear Power Supplies

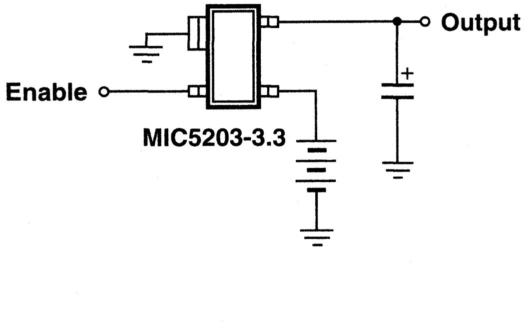
Ordering Information

Part Number	Marking	Volts	Junction Temperature Range	Package
MIC5203-3.0BM4	LA30	3.0	–40°C to +125°C	SOT-143
MIC5203-3.3BM4	LA33	3.3	–40°C to +125°C	SOT-143
MIC5203-3.6BM4	LA36	3.6	–40°C to +125°C	SOT-143
MIC5203-3.8BM4	LA38	3.8	–40°C to +125°C	SOT-143
MIC5203-4.0BM4	LA40	4.0	–40°C to +125°C	SOT-143
MIC5203-4.7BM4	LA47	4.75	–40°C to +125°C	SOT-143
MIC5203-5.0BM4	LA50	5.0	–40°C to +125°C	SOT-143

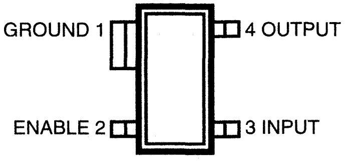
Other voltages are available; contact Micrel for details.

The –40°C to +125°C rated MIC5203-xxBM4 replaces the 0°C to +125°C MIC5203CM4.

Typical Application



Pin Configuration



Absolute Maximum Ratings

Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its specified **Recommended Operating Conditions.**

Power Dissipation .... Internally Limited
Lead Temperature (Soldering, 5 seconds) .... 260°C
Storage Temperature Range .... –60°C to +150°C
Input Supply Voltage .... –20V to +20V
ENABLE Input Voltage .... –20V to +20V

Recommended Operating Conditions

Input Voltage .... 2.5V to 16V
Operating Junction Temperature Range .... –40°C to +125°C
ENABLE Input Voltage .... 0V to V_{CC}
SOT-143 θ_{JA} .... See Note 1

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C and limits in **boldface** apply over the junction temperature range of –40°C to +125°C. Unless otherwise specified, $V_{IN} = V_{OUT} + 1V$, I_L = 1mA, C_L = 1μF, and $V_{CONTROL} \geq 2.0V$.

Symbol	Parameter	Conditions	Min	Typical	Max	Units
V_O	Output Voltage Accuracy		–3 **–4**		3 **4**	%
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temperature Coef.	(Note 2)		**50**	**200**	ppm/°C
$\frac{\Delta V_O}{V_O}$	Line Regulation	$V_{IN} = V_{OUT}$+1 V to 16V		0.008	0.3 **0.5**	%
$\frac{\Delta V_O}{V_O}$	Load Regulation	I_L = 0.1mA to 80mA (Note 3)		0.08	0.3 **0.5**	%
$V_{IN} - V_O$	Dropout Voltage (Note 4)	I_L = 100μA I_L = 20mA I_L = 50mA I_L = 80mA		20 200 250 300	 **350** **600**	mV
I_Q	Quiescent Current	$V_{CONTROL} \leq 0.4V$ (Shutdown)		0.01	10	μA
I_{GND}	Ground Pin Current (Note 5)	$V_{CONTROL} \geq 2.0V$ (Active), I_L = 100μA I_L = 20mA I_L = 50mA I_L = 80mA		180 225 850 1800	 **750** **3000**	μA
I_{GNDDO}	Ground Pin Current at Dropout	V_{IN} = 0.5V less than designed V_{OUT} (Note 5)		200	**300**	μA
I_{LIMIT}	Current Limit	V_{OUT} = 0V		180	**250**	mA
$\frac{\Delta V_O}{\Delta P_D}$	Thermal Regulation	(Note 6)		0.05		%/W
Control Input						
	Input Voltage Level					V
V_{IL}	Logic Low	OFF			**0.6**	
V_{IH}	Logic High	ON	**2.0**			
I_{IL}	Control Input Current	$V_{IL} \leq 0.6V$		0.01	1	μA
I_{IH}		$V_{IH} \geq 2.0V$		15	**50**	

Notes:

General Note: Devices are ESD protected, however, handling precautions are recommended.

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions. The maximum allowable power dissipation is a function of the maximum junction temperature, $T_{J\,MAX}$, the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using: $P_{MAX} = (T_{JMAX} - T_A) / \theta_{JA}$. Exceeding the maximum allowable power dissipation will result in excessive die temperature, and the regulator will go into thermal shutdown. θ_{JA} of the SOT-143 is 250°C/W, mounted on a PC board.

Note 2: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

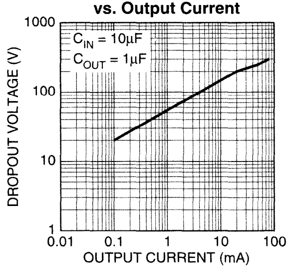
Note 3: Regulation is measured at constant junction temperature using low duty cycle pulse testing. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

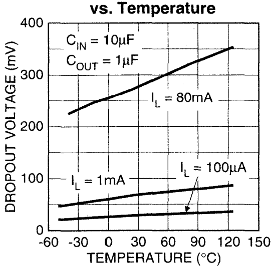
Note 4: Dropout voltage is defined as the input to output differential at which the output voltage drops 2% below its nominal value measured at 1V differential.

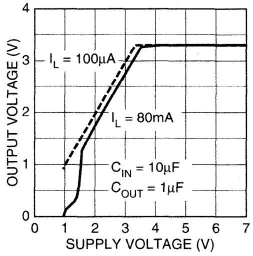
Note 5: Ground pin current is the regulator quiescent current plus pass transistor base current. The total current drawn from the supply is the sum of the load current plus the ground pin current.

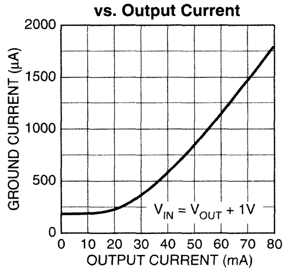
Note 6: Thermal regulation is defined as the change in output voltage at a time "t" after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 80mA load pulse at V_{IN} = 16V for t = 10ms.

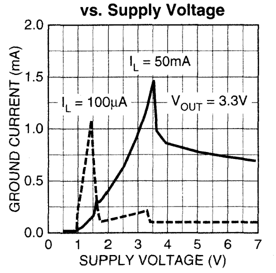
Typical Characteristics

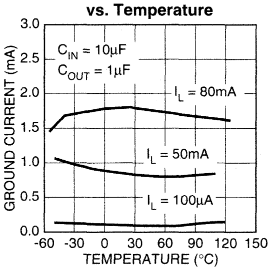

Dropout Voltage vs. Output Current


Dropout Voltage vs. Temperature

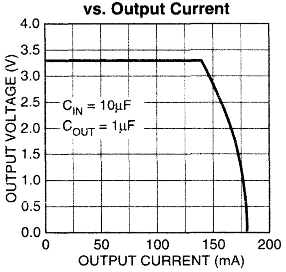

Dropout Characteristics

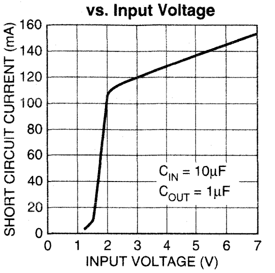

Ground Current vs. Output Current

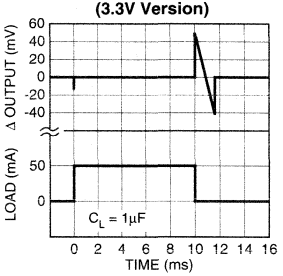

Ground Current vs. Supply Voltage

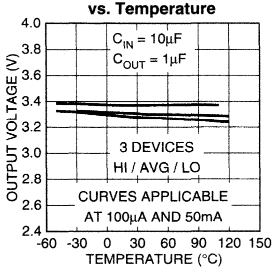

Ground Current vs. Temperature

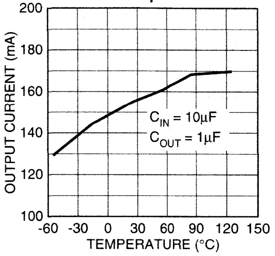
Typical Characteristics

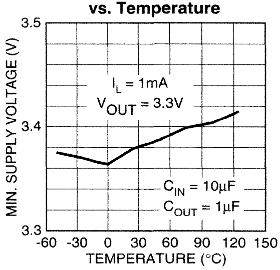

Output Voltage vs. Output Current

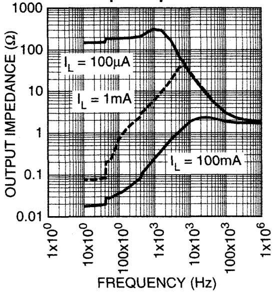

Short Circuit Current vs. Input Voltage


Thermal Regulation (3.3V Version)


Output Voltage vs. Temperature


Short Circuit Current vs. Temperature


Minimum Supply Voltage vs. Temperature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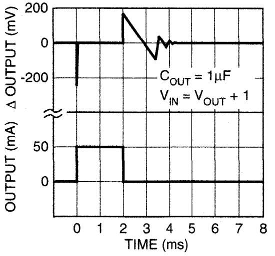
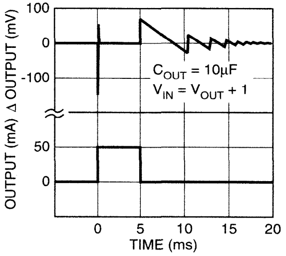

Load Transient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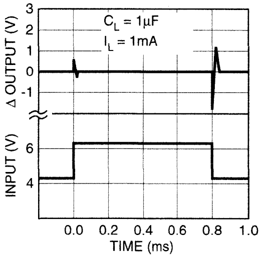
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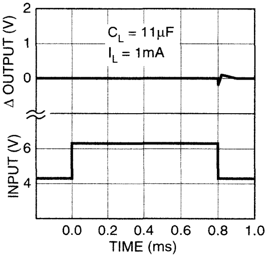
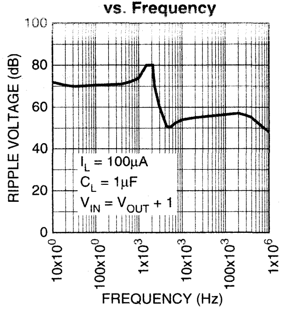
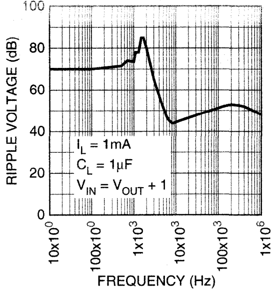

Line Transient


Ripple Voltage vs. Frequency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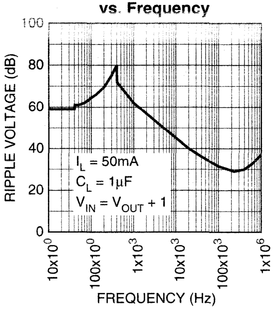
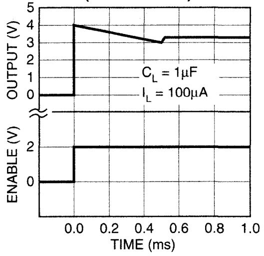

Ripple Voltage vs. Frequency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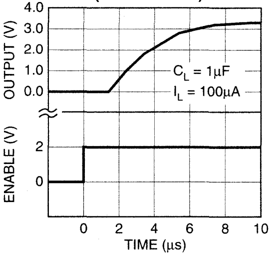
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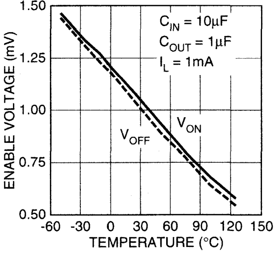
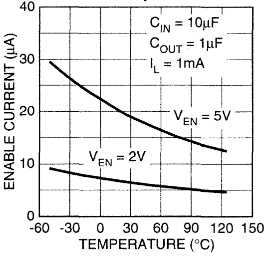

Enable Voltage vs. Temperature


Enable Current vs. Temperature

Applications Information

External Capacitors

A 1µF capacitor is recommended between the MIC5203 output and ground to prevent oscillations due to instability. Larger values serve to improve the regulator's transient response. Most types of tantalum or aluminum electrolytics will be adequate; film types will work, but are costly and therefore not recommended. Many aluminum electrolytics have electrolytes that freeze at about –30°C, so solid tantalums are recommended for operation below –25°C. The important parameters of the capacitor are an effective series resistance of about 5Ω or less and a self-resonant frequency above 500kHz. The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for output stability. The capacitor can be reduced to 0.22µF for current below 10mA or 0.1µF for currents below 1 mA.

The MIC5203 will remain stable and in regulation with no load other than the internal voltage divider, unlike many other voltage regulators. This is especially important in CMOS RAM keep-alive applications.

A 0.1µF (or larger) capacitor should be placed from the MIC5203 input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the input.

ENABLE Input

The MIC5203 features nearly zero OFF mode current. When the ENABLE input is held below 0.6V, all internal circuitry is powered off. Pulling this pin high (over 2.0V) re-enables the device and allows operation. The ENABLE pin requires a small amount of current, typically 15µA. While the logic threshold is TTL/CMOS compatible, ENABLE may be pulled as high as 20V, independent of the voltage on V_{IN}.

MIC5205

150mA Low-Noise LDO Voltage Regulator

Advance Information

General Description

The MIC5205 is an efficient linear voltage regulator with ultra-low noise output and very low dropout voltage (typically 17mV at light loads and 200mV at 150mA), and very low ground current (800µA at 100mA output), offering better than 1% initial accuracy with a logic compatible ON/OFF switching input. Designed especially for hand-held battery powered devices, the MIC5205 is switched by a CMOS or TTL compatible logic signal. When disabled, power consumption drops nearly to zero. The ground current of the MIC5205 increases only slightly in dropout, further prolonging battery life. Key MIC5205 features include a reference bypass pin for excellent low-noise performance, protection against reversed battery, current limiting, and overtemperature shutdown.

The MIC5205 is available in several fixed voltages and an adjustable output voltage version in a small SOT-23-5 package. It features a similar pinout to the LP2980 with significantly better performance.

Features

- Ultra-low noise output
- High output voltage accuracy
- Guaranteed 150mA output
- Low quiescent current
- Low dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Current and thermal limiting
- Reverse-battery protection
- "Zero" OFF-mode current
- Logic-controlled electronic enable

Applications

- Cellular Telephones
- Laptop, Notebook, and Palmtop Computers
- Battery Powered Equipment
- PCMCIA V_{CC} and V_{PP} Regulation/Switching
- Consumer/Personal Electronics
- SMPS Post-Regulator/ DC to DC Modules
- High Efficiency Linear Power Supplies

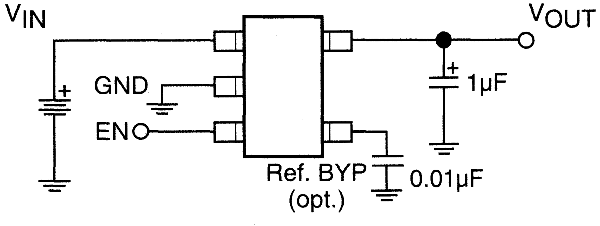
Ordering Information

Part Number	Marking	Volts	Accuracy	Temperature Range*	Package
MIC5205BM5	LBAA	Adj	1%	–40°C to +125°C	SOT-23-5
MIC5205-3.0BM5	LB30	3.0	1%	–40°C to +125°C	SOT-23-5
MIC5205-3.3BM5	LB33	3.3	1%	–40°C to +125°C	SOT-23-5
MIC5205-3.6BM5	LB36	3.6	1%	–40°C to +125°C	SOT-23-5
MIC5205-3.8BM5	LB38	3.8	1%	–40°C to +125°C	SOT-23-5
MIC5205-4.0BM5	LB40	4.0	1%	–40°C to +125°C	SOT-23-5
MIC5205-5.0BM5	LB50	5.0	1%	–40°C to +125°C	SOT-23-5

* *Junction Temperature*

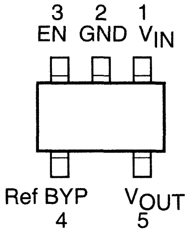
Other voltages are available; contact Micrel for details.

Typical Application

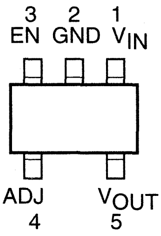


ENABLE may be tied directly to V_{IN}

Pin Configuration



MIC5205-xxBM5



MIC5205BM5 (Adjustable)

Absolute Maximum Ratings

Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its specified **Operating Ratings.**

Power Dissipation	Internally Limited
Lead Temperature (Soldering, 5 seconds)	260°C
Operating Junction Temperature Range	–40°C to +125°C
Input Supply Voltage	–20V to +20V
ENABLE Input Voltage	–20V to +20V

Recommended Operating Conditions

Input Voltage	2.5V to 16V
Operating Junction Temperature Range	–40°C to +125°C
ENABLE Input Voltage	0V to V_{IN}
SOT-23-5 θ_{JA}	See Note 1

Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$ and limits in **boldface** apply over the junction temperature range of –40°C to +125°C. Unless otherwise specified, $V_{IN} = V_{OUT} + 1V$, $I_L = 100\mu A$, $C_L = 3.3\mu F$, and $V_{ENABLE} \geq 2.0V$

Symbol	Parameter	Conditions	Min	Typical	Max	Units
V_O	Output Voltage Accuracy	Variation from specified V_{OUT}	–1 **–2**		1 **2**	%
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temperature Coef.	(Note 2)		**40**		ppm/°C
$\frac{\Delta V_O}{V_O}$	Line Regulation	$V_{IN} = V_{OUT} + 1V$ to 16V		0.004		%
$\frac{\Delta V_O}{V_O}$	Load Regulation	$I_L = 0.1mA$ to 150mA (Note 3)		0.04		%
$V_{IN} - V_O$	Dropout Voltage (Note 4)	$I_L = 100\mu A$		17		mV
		$I_L = 20mA$		80		
		$I_L = 50mA$		115		
		$I_L = 100mA$		140		
		$I_L = 150mA$		165		
I_{GND}	Quiescent Current	$V_{ENABLE} \leq 0.7V$ (Shutdown)		< 1		µA
I_{GND}	Ground Pin Current (Note 5)	$V_{ENABLE} \geq 2.0V$, $I_L = 100\mu A$		80		µA
		$I_L = 20mA$		160		
		$I_L = 50mA$		350		
		$I_L = 100mA$		720		
		$I_L = 150mA$		1300		
PSRR	Ripple Rejection			75		dB
I_{LIMIT}	Current Limit	$V_{OUT} = 0V$		**320**		mA
$\frac{\Delta V_O}{\Delta P_D}$	Thermal Regulation	(Note 6)		0.05		%/W
e_{no}	Output Noise	$I_L = 50mA$, $C_L = 4.7\mu F$, 0.01µF from Ref BYP to ground		260		nV/√Hz

ENABLE Input

V_{IL}	Input Voltage Level					
	Logic Low	OFF		0.4		V
	Logic High	ON	**2.0**			
I_{IL}	ENABLE Input Current	$V_{IL} \leq 0.18V$		0.01		µA
I_{IH}		$V_{IH} \geq 2.0V$		2		

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions. The maximum allowable power dissipation is a function of the maximum junction temperature, $T_{J\ (MAX)}$, the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using: $P_{(MAX)} = (T_{J(MAX)} - T_A)\ \theta_{JA}$. Exceeding the maximum allowable power dissipation will result in excessive die temperature, and the regulator will go into thermal shutdown. The θ_{JA} of the MIC5205–xxBM5 (all versions) is 250°C/W mounted on a PC board (see "Thermal Considerations" section for further details).

Note 2: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 3: Regulation is measured at constant junction temperature using low duty cycle pulse testing. Parts are tested for load regulation in the load range from 0.1mA to 150mA. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

Note 4: Dropout Voltage is defined as the input to output differential at which the output voltage drops 2% below its nominal value measured at 1V differential.

Note 5: Ground pin current is the regulator quiescent current plus pass transistor base current. The total current drawn from the supply is the sum of the load current plus the ground pin current.

Note 6: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 150mA load pulse at V_{IN} = 16V for T = 10ms.

Applications Information

Typical Applications Circuits

Figure 1 shows the MIC5205-xxBM5 standard application circuit. The EN (enable) pin is pulled high (> 2V) to enable the regulator. CMOS logic gates may be used. If ON/OFF functionality is not required, pull EN to the input supply.

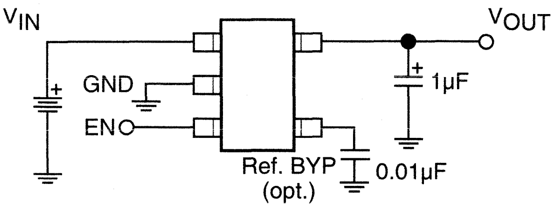


Figure 1. Fixed Voltage MIC5205 Application

Figure 2 shows the MIC5205BM5 adjustable output voltage configuration. Two resistors set the output voltage. The formula for output voltage is:

$$V_{OUT} = 1.242V \times \left(\frac{R2}{R1} + 1 \right)$$

Resistor values are not critical as the ADJ pin has high input impedance, but for best results use resistors of 470kΩ or less. A capacitor from ADJ to ground will provide greatly improved noise performance.

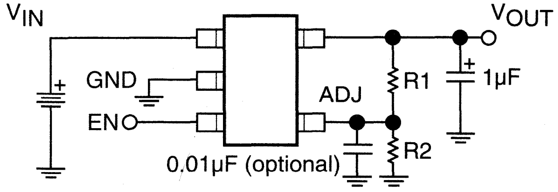


Figure 2. Adjustable output voltage MIC5205 Application. A optional 0.01µF noise bypass capacitor from the ADJ pin to ground serves to reduce output noise.

Output Capacitor

A 1µF capacitor is recommended between the MIC5205 output and ground to prevent oscillations due to instability. Larger values serve to improve the regulator's transient response. Most types of tantalum or aluminum electrolytics will be adequate; film types will work, but are costly and therefore not recommended. Many aluminum electrolytics have electrolytes that freeze at about –30°C, so solid tantalums are recommended for operation below –25°C. The important parameters of the capacitor are an effective series resistance of about 5Ω or less and a resonant frequency above 1MHz. The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for output stability. The capacitor can be reduced to 0.47µF for current below 10mA or 0.33µF for currents below 1 mA. A 1µF capacitor should be placed from the MIC5205 input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the input.

The MIC5205 will remain stable and in regulation with no load in addition to the internal voltage divider, unlike many other voltage regulators. This is especially important in CMOS RAM keep-alive applications.

When used in dual supply systems where the regulator load is returned to a negative supply, the output voltage must be diode clamped to ground.

Reference Bypass Capacitor

The MIC5205 provides access to the internal reference. A 0.01µF capacitor on the Ref. BYP pin quiets this reference and provides a significant reduction in output noise. If output noise is not a major concern, this pin may be left unconnected.

The start-up speed of the MIC5205 is inversely proportional to the size of this capacitor. Applications requiring a slow ramp-up of output voltage should consider larger values of C_{BYP}. Likewise, if rapid turn-ON is necessary, use 470pF or less.

Thermal Considerations

Layout

The MIC5205-xxBM5 (5-pin surface mount SOT-23 package) has the following thermal characteristics when mounted on a single layer copper-clad printed circuit board.

PC Board Dielectric	θ_{JA}
FR4	220°C/W
Ceramic	200°C/W

Multilayer boards having a ground plane, wide traces near the pads, and large supply bus lines provide better thermal conductivity.

The "worst case" value of 220°C/W assumes no ground plane, minimum trace widths, and a FR4 material board.

Nominal Power Dissipation and Die Temperature

The MIC5205-xxBM5 at a 25°C ambient temperature will operate reliably at over 450mW power dissipation when mounted in the "worst case" manner described above. At an ambient temperature of 40°C, the device may safely dissipate over 380mW. These power levels are equivalent to a die temperature of 125°C, the maximum operating junction temperature for the MIC5205.

For additional heat sink characteristics, please refer to Micrel Application Hint 17, "Calculating P.C. Board Heat Sink Area For Surface Mount Packages".

Application Note 9

Design Considerations for 5V to 3.3V Pass Regulators

By Bob Wolbert

General Description

The rise of 3.3V logic and memory components in personal computer systems has created demand for 3.3V power supplies. Several options exist for the computer system designer. One of these options is to provide both 3.3V and 5.0V from the main system power supply and use a switch matrix for voltage selection (see Application Hint 15 for representative circuitry). Two drawbacks to this technique exist: (1) the extra 3.3V output costs money; and (2), at current levels above about 1A, the MOSFETs used in the 3.3V portion of the matrix require exceptionally low ON resistance to maintain output tolerance and are quite expensive. Another option uses the existing high current 5V supply and employs a low drop-out (LDO) linear regulator to provide 3.3V. This is a low cost option, requiring only short design work and little motherboard space. Linear regulators provide clean, accurate output and do not radiate RFI, so government certification is not jeopardized. They are fast starting, and may provide ON/OFF control and an error flag that indicates power system trouble. At low current levels, thermal considerations are not difficult; however, at currents of 3.5 to 5 amperes, the resulting heat may be troublesome. This note discusses the LDO option, including choosing between simple three terminal regulators and full-featured five terminal regulators, and provides formulas, calculations, and a selection of commercial heat sinks for powering 3.3V logic circuitry requiring up to 5 amps from a standard +5V supply. Additionally, a "trick" for reducing heat sink requirements by distributing power dissipation with a series resistor is discussed.

Why Choose Five Terminal Regulators?

What do the extra pins of the five pin linear regulators provide? After all, three terminal regulators give Input, Output, and Ground; what else is necessary? Five terminal devices allow the system designer to monitor power quality to the load and digitally switch the supply ON and OFF. Power quality is monitored by a flag output. When the output voltage is within a few percent of its desired value, the flag is high, indicating "Good". If the output drops, because of either low input voltage to the regulator or an over-current condition, the flag drops to signal a fault condition. A controller can monitor this output and make decisions regarding the system's readiness. For example, at initial power-up, the flag will instantaneously read high (if pulled up to an external supply), but as soon as the input supply to the regulator reaches about 2V, the flag pulls low. It stays low until the regulator output nears its desired value. With the MIC29150 family of low drop-out linear regulators, the flag rises when the output voltage reaches about 97% of the desired value. In a 3.3V system, the flag indicates "power good" with $V_{OUT} = 3.2V$.

Digital power control allows "sleep" mode operation and results in better energy efficiency. The ENABLE input of the MIC29150 family is TTL and 5V or 3.3V CMOS compatible. When this input is pulled above approximately 1.4V, the regulator is activated. A special feature of this regulator family is *zero power consumption* when inactive. Whenever the digital control input is low, all internal circuitry is biased OFF. (A tiny leakage current, measured in nanoamperes, may flow).

Three terminal regulators are used whenever ON/OFF control is not necessary and processing power is not available to use the flag output information. Three terminal regulators need only a single output filter capacitor so design effort is minimal.

Five terminal regulators provide all the functionality of three pin devices PLUS allow power supply quality monitoring and ON/OFF switching for "sleep" mode applications.

Thermal Design Considerations

Micrel low drop-out (LDO) regulators are very easy to use. Only one external filter capacitor is necessary for operation so electrical design effort is minimal. In many cases, thermal design is also quite simple, due to the low drop-out characteristic of Micrel's LDOs. Unlike other linear regulators, Micrel's LDOs operate with drop-out voltages of 300mV–often less. The resulting Voltage x Current power loss can be quite small with low to moderate output current. At higher currents, however, selecting the correct heat sink is an important chore. Power dissipation in a linear regulator is:

$$P_D = [(V_{IN} - V_{OUT})\, I_{OUT}] + (V_{IN} \bullet I_{GND})$$

Where: P_D = Power dissipation

V_{IN} = Input voltage applied to the regulator

V_{OUT} = Regulator output voltage

I_{OUT} = Regulator output current

I_{GND} = Regulator biasing currents

Proper design dictates use of worst case values for all parameters. Worst case V_{IN} is high supply; in this case, 5V + 5%, or 5.25V. Worst case V_{OUT} for thermal considerations is minimum, or 3.3V – 2% = 3.234V.[1] I_{OUT} is taken at its highest steady-state value. The ground current value comes from the device's datasheet, from the graph of I_{GND} vs. I_{OUT}. Armed with this information, we calculate the thermal resistance (θ_{SA}) required of the heat sink using the following formula:

$$\theta_{SA} = \frac{T_J - T_A}{P_D} - (\theta_{JC} + \theta_{CS})$$

Assuming a Micrel LDO with a maximum die temperature of 125°C in a TO-220 package with a θ_{JC} of 2°C/W and a mounting resistance (θ_{CS}) of 1°C/W^2, operating at an ambient temperature of 50°C, we get

$$\theta_{SA} = \frac{125 - 50°C}{10.5W} - (2 + 1°C/W) = \mathbf{4.1\ °C/W}$$

Performing similar calculations for 1.25A, 1.5A, 2.0A, 2.5A, 3.0A, 4.0A, and 5.0A gives the results shown in Table 1.

Regulator	I_{OUT}	P_D (W)	θ_{SA}(°C/W)
MIC29150	1.25A	2.6	25
MIC29150	1.5A	3.2	21
MIC29300	2.0A	4.2	15
MIC29300	2.5A	5.2	11
MIC29300	3.0A	6.3	8.8
MIC29500	4.0A	8.4	5.9
MIC29500	5.0A	10.5	4.1

Table 1. Micrel LDO power dissipation and heat sink requirements for various 3.3V current levels.

Table 2 shows the effect maximum ambient temperature has on heat sink thermal properties. Lower thermal resistances require physically larger heat sinks. The table clearly shows cooler running systems need smaller heat sinks, as common sense suggests.

Heat Sink Selection

With this information we may specify a heat sink. The worst case is still air (natural convection). The heat sink should be mounted so that at least 0.25 inches (about 6mm) of separation exists between the sides and top of the sink and other components or the system case. Thermal properties are maximized when the heat sink is mounted so that natural vertical motion of warm air is directed along the long axis of the sink fins.

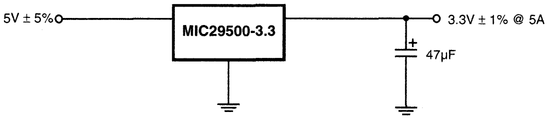


Figure 2. Using a Micrel LDO is very simple. Only an output filter capacitor is necessary. Here, 3.3V at 5A is produced from a nominal 5V input.

If we are fortunate enough to have some forced airflow, reductions in heat sink cost and space are possible by characterizing air speed–even a slow airstream significantly assists cooling. As with natural convection, a small gap allowing the airstream to pass is necessary. Fins should be located to maximize airflow along them. Orientation with respect to vertical is not important, as the airflow dominates.

Output	Ambient Temperature		
	40°C	50°C	60°C
1.5A	24°C/W	21°C/W	17°C/W
5A	5.1°C/W	4.1°C/W	3.2°C/W

Table 2. Ambient temperature affects heat sink requirements

As an example, we will select heat sinks for 1.5A and 5A outputs. We consider four airflow cases: natural convection, 200 feet/minute (1m/sec), 300 feet/minute (1.5m/sec), and 400 feet/minute (2m/sec). Table 3 shows heat sinks for these air velocities; note the rapid reduction in size and weight (fin thickness) when forced air is available. Consulting manufacturer's charts,[3,4] we see a variety of sinks are made that are suitable for our application. At 5A (10.5W worst case package dissipation) and natural convection, sinks are sizable, but at 1.5A (3.2W worst case package dissipation) and 400 feet/minute airflow, modest heat sinks are adequate.

The heat sink required for 5A applications in still air is massive and expensive. There is a better way to manage heat problems: we take advantage of the very low drop out voltage characteristic of Micrel's Super ßeta PNP™ regulators and dissipate some power externally in a series resistance.[5] By distributing the voltage drop between this low cost resistor and the regulator, we distribute the heating, and reduce the size of the regulator heat sink. Knowing the worst case voltages in the system and the peak current requirements, we select a resistor that drops a portion of the excess voltage without sacrificing performance. The maximum value of the resistor is calculated from:

$$R_{MAX} = \frac{V_{IN\ MIN} - (V_{OUT\ MAX} + V_{DO})}{I_{OUT\ PEAK} + I_{GND}}$$

Where: $V_{IN\ MIN}$ is low supply (5V – 5% = 4.75V)

$V_{OUT\ MAX}$ is the maximum output voltage across the full temperature range (3.3V + 2% = 3.366V)

V_{DO} is the worst case dropout voltage across the full temperature range (600mV)

$I_{OUT\ PEAK}$ is the maximum 3.3V load current

I_{GND} is the regulator ground current.

For our 5A output example:

$$R_{MAX} = \frac{4.75 - (3.366 + 0.6)\ V}{5 + 0.08\ A} = \frac{0.784V}{5.08A} = 0.154\Omega$$

The power drop across this resistor is

$$P_{D\ RES} = (I_{OUT\ PEAK} + I_{GND})^2 \bullet R$$

or 4.0W. This subtracts directly from the 10.5W of regulator power dissipation that occurs without the resistor, reducing regulator heat generation to 6.5W.

$$P_{D(Regulator)} = P_{D(R\,=\,0\Omega)} - P_{D\ RES}$$

Considering 5% resistor tolerances and standard values leads us to a 0.15Ω ± 5% resistor. This produces a nominal power savings of 3.9W. With worst-case tolerances, the regulator power dissipation drops to 6.8W maximum. This heat drop reduces our heat sinking requirements for the MIC29500 significantly. We can use a smaller heat sink with a larger thermal resistance. Now, a heat sink with 8.3°C/W thermal characteristics is suitable–nearly a factor of 2 better than without the resistor. Table 4 lists representative heat sinks meeting these conditions.

	Output Current	
Airflow	**1.5A**	**5A**
400 ft./min. (2m/sec)	Thermalloy 6049PB	Thermalloy 6232 Thermalloy 6034 Thermalloy 6391B
300 ft./min. (1.5m/sec)		AAVID 504222B AAVID 563202B AAVID 593202B AAVID 534302B Thermalloy 7021B Thermalloy 6032 Thermalloy 6234B
200 ft./min. (1m/sec)	AAVID 577002 Thermalloy 6043PB Thermalloy 6045B	AAVID 508122 AAVID 552022 AAVID 533302 Thermalloy 7025B Thermalloy 7024B Thermalloy 7022B Thermalloy 6101B
Natural Convection (no forced airflow)	AAVID 576000 AAVID 574802 592502 579302 Thermalloy 6238B Thermalloy 6038 Thermalloy 7038	AAVID 533602B (vertical) AAVID 519922B (horizontal) AAVID 532802B (vertical) Thermalloy 6299B (vertical) Thermalloy 7023 (horizontal)

Table 3. Commercial heat sinks for 1.5A and 5.0A applications

Airflow	**Heat Sink Model**
400 ft./min. (2m/sec)	AAVID 530700 AAVID 574802 Thermalloy 6110 Thermalloy 7137, 7140 Thermalloy 7128
300 ft./min. (1.5m/sec)	AAVID 57302 AAVID 530600 AAVID 577202 AAVID 576802 Thermalloy 6025 Thermalloy 6109 Thermalloy 6022
200 ft./min. (1m/sec)	AAVID 575102 AAVID 574902 AAVID 523002 AAVID 504102 Thermalloy 6225 Thermalloy 6070 Thermalloy 6030 Thermalloy 6230 Thermalloy 6021, 6221 Thermalloy 7136, 7138
Natural Convection (no forced airflow)	AAVID 563202 AAVID 593202 AAVID 534302 Thermalloy 6232 Thermalloy 6032 Thermalloy 6034 Thermalloy 6234

Table 4. Representative commercial heat sinks for the 5.0A output example using a series dropping resistor. Assumptions: $T_A = 50°C$, $R = 0.15\Omega \pm 5\%$, $I_{OUT\ MAX} = 5.0A$, θ_{JC} = 2°C/W, θ_{CS} = 1°C/W, resulting in a required θ_{SA} = 8.0°C/W.

For the 1.5A output application using the MIC29150, we calculate a maximum R of 0.512Ω. Using R = 0.51Ω, savings of at least 1.1W are achieved, dropping power dissipation to only 2.0W–a heat sink probably is not required. This circuit is shown in Figure 4.

Another option exists for designers of lower current systems. The MIC29150 and MIC29300 regulators are available in the surface mount derivative of the TO-220 package, the TO-263, which is soldered directly to the PC board. No separate heat sink is necessary, as copper area on the board acts as the heat exchanger. For further information, refer to Micrel's Application Hint 17, "P.C. Board Heat Sinking".

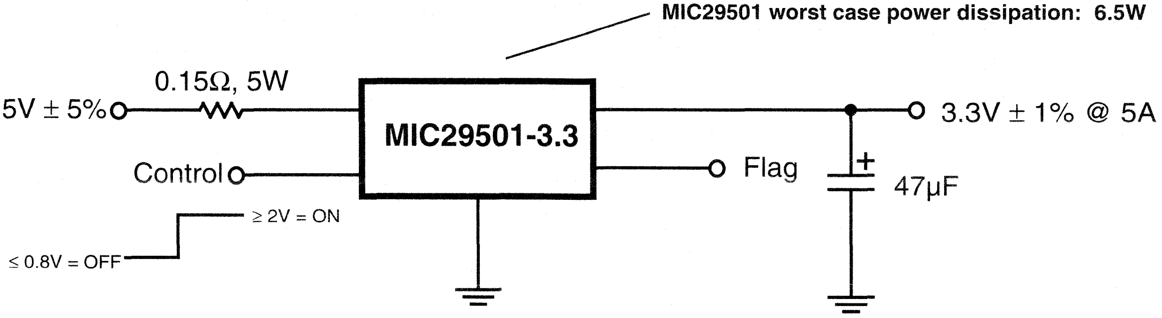


Figure 3. Producing 3.3V at 5A with minimal heat sink requirements. A 0.15Ω resistor dissipates excess power, reducing regulator heat generation. The resistor needs no heat sink.

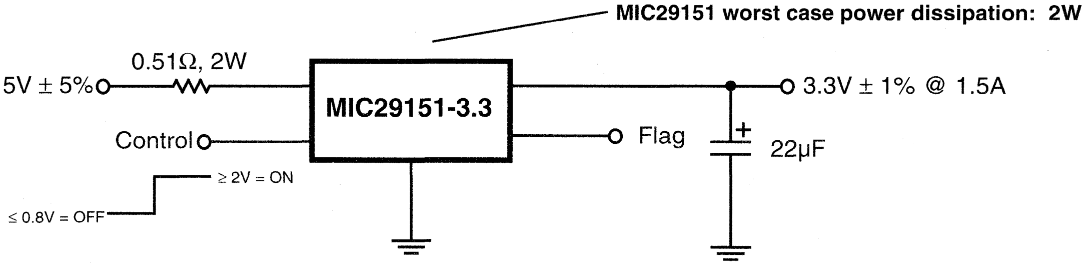


Figure 4. The MIC29151-3.3 produces 1.5A at 3.3V. No heat sink is necessary in most situations when the external power sharing resistor is employed.

Notes

NOTE 1: The MIC29150, MIC29300, MIC29500, and MIC29750 LDO regulator family feature trimmed outputs guaranteed to ±1% under standard conditions. Across the full temperature range, with load and input voltage variations, the device output voltage varies less than 2% worst case.

NOTE 2: The mounting tab of the MIC29150 family regulators is grounded. The estimated value of θ_{CS} assumes no electrical insulation between mounting tab and heat sink.

NOTE 3: AAVID Engineering, Inc., One Kool Path, Laconia, NH 03247. (603) 528-3400.

NOTE 4: Thermalloy Inc., P.O. Box 810839, Dallas, TX 75381. (214) 243-4321.

NOTE 5: Super ßeta PNP™ is a registered trademark of Micrel, Inc.

Application Note 16

Improving Adjustable Regulator Accuracy

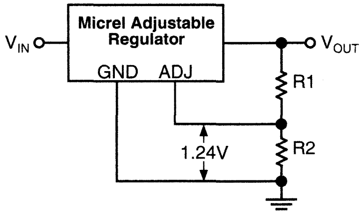
by Bob Wolbert

Introduction

Micrel LDO Regulators are high accuracy devices with output voltages factory-trimmed to much better than 1% accuracy. Across the operating temperature, input voltage, and load current ranges, their worst-case accuracies are still better than ±2%. For adjustable regulators, the output also depends upon the accuracy of two programming resistors. Common systems, such as high performance, low-voltage microprocessors, require supply voltage accuracies better than ±2.5%—including noise and transients. While noise is generally not a major contributor to output inaccuracy, load transients caused by high-speed microprocessors are significant, even when using fast transient-response LDO regulators and high-quality filter capacitors.

This note will demonstrate that the most cost-effective way to achieve better than ±2.5% accuracy is by employing a precision reference in the feedback loop. While the MIC29512 is the "featured" regulator, the same techniques are directly applicable for the MIC29152/3, MIC29302/3, MIC29312, MIC29502/3, MIC29712, and MIC29752. Other Micrel adjustable regulators achieve similar performance enhancement.

"Adjustable Regulator Sensitivity" describes the accuracy of the standard adjustable regulator with the usual resistor feedback configuration. "Improving Accuracy" describes how the output performance may be improved using the Micrel LM4041-ADJ voltage reference.



$$V_{OUT} = 1.240 \times (1 + \frac{R1}{R2})$$

Figure 1. Basic Adjustable Regulator Circuit.

Adjustable Regulator Sensitivity

Achieving a worst-case error of ±2.5%, including all D/C and A/C error terms, is possible by increasing the basic accuracy of the regulator itself, but this is expensive since high current regulators have significant self-heating. Its internal reference must maintain accuracy across a wide temperature range. Testing for this level of performance is time consuming and raises the cost of the regulator, which is unacceptable for extremely price-sensitive marketplaces.

Resistor Tolerance Effects on Adjustable Regulator Accuracy

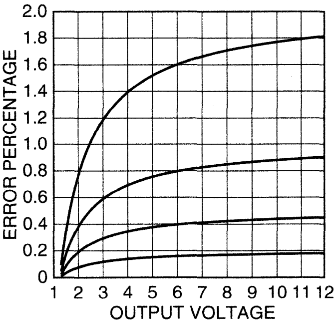


Figure 2.

Adjustable regulators use the ratio of two resistors to multiply the reference voltage as required to produce the desired output voltage (see Figure 1). The formula for output voltage from two resistors is presented as Equation 1.

$$V_{OUT} = V_{REF} \times \left(1 + \frac{R1}{R2}\right)$$

The basic MIC29512 has a production-trimmed reference (V_{REF}) with better than ±1% accuracy at a fixed temperature of 25°C. It is guaranteed better than ±2% over the full operating temperature range, input voltage variations, and load current changes. Since practical circuits experience large temperature swings we should use the ±2% specification as our theoretical worst-case. This value assumes no error contribution from the programming resistors.

Referring to Figure 1 and Equation 1, we see that resistor tolerance (tol) must be added to the reference tolerance to determine the total regulator inaccuracy. A sensitivity analysis of this equation shows that the error contribution of the adjust resistors is:

$$\text{Error Contribution (\%)} = \left(\frac{2 \times \text{tol\%}}{1 - (\text{tol\%}/100)}\right) \times \left(1 - \frac{V_{REF}}{V_{OUT}}\right)$$

Since the output voltage is proportional to the product of the reference voltage and the ratio of the programming resistors, at high output voltage, the error contribution of the programming resistors is the sum of each resistor's tolerance. Two standard ±1% resistors contribute as much as 2% to output voltage error. At lower voltages, the error is less significant. Figure 2 shows the effects of resistor tolerance on regulator accuracy from the minimum output voltage (V_{REF}) to 12V. At the minimum V_{OUT}, theoretical resistor tolerance has no effect on output accuracy. Resistor error increases proportionally with output voltage: at an output of 2.5V, the sensitivity factor is 0.5; at 5V it is about 0.75; and at 12V it is over 0.9. This means that with 5V of output, the error contribution of 1% resistors is 0.75 times the sum of the tolerances, or 0.75 × 2% = 1.5%. As expected, more precise resistors offer more accurate performance.

The output voltage error of the entire regulator system is the sum of reference tolerance and the resistor error contribution. Figure 3 shows this worst-case tolerance for the MIC29512 as the output voltage varies from minimum to 12V using ±1%, ±0.5%, ±0.25%, and ±0.1% resistors. The more expensive, tighter accuracy resistors provide improved tolerance, but it is still limited by the adjustable regulator's ±2% internal reference.

A better method is possible: increase the overall accuracy of the regulator by employing a precision reference in the feedback loop.

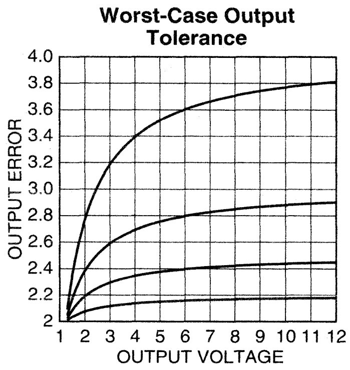


Figure 3.

Improving Accuracy

Some systems require better than ±2% accuracy. This high degree of accuracy is possible using Micrel's LM4041 voltage reference instead of one of the programming resistors (refer to Figure 4). The regulator output voltage is the sum of the internal reference and the LM4041's programmed voltage (Equation 3).

$$V_{OUT} = V_{REF\ Regulator} + V_{LM404} = 1.240 + V_{LM4041}$$

The benefit of this circuit is the increased accuracy possible by eliminating the multiplicative effect of the MIC29512's internal reference. In normal configurations, the reference

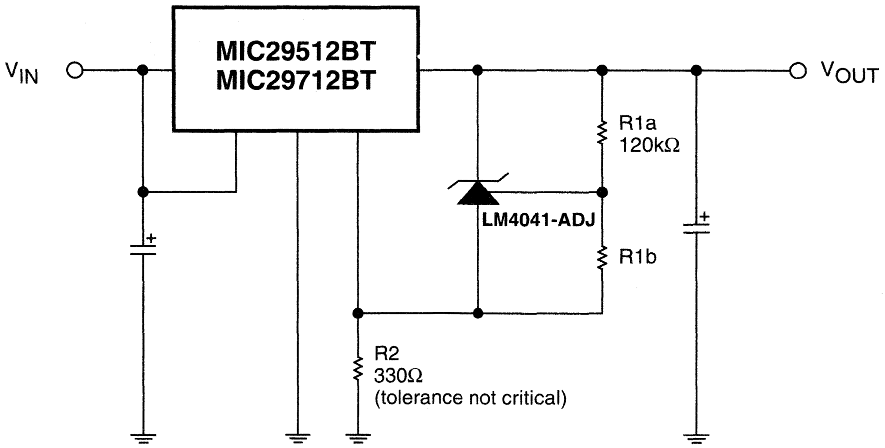


Figure 4. Improved Accuracy Composite Regulator Circuit

error is multiplied up by the resistor ratio, keeping the error percentage constant. With this circuit, the error voltage is within 25mV, absolute. Another benefit of this arrangement is that the LM4041 is not a dissipative device: there is only a small internal temperature rise to degrade accuracy. Additionally, both references are operating in their low-sensitivity range so we get less error contribution from the resistors. A drawback of this configuration is that the minimum output voltage is now the sum of both references, or about 2.5V. The adjustable LM4041 is available in accuracies of ±0.5% and ±1%, which allows better overall system output voltage accuracy.

Equation 4 presents the formula for the LM4041-ADJ output voltage. Note the output voltage has a slight effect on the reference. Refer to the LM4040 data sheet for full details regarding this second-order coefficient.

$$V_{LM4041} = \left[V_{OUT} \times \frac{\Delta V_{REF}}{\Delta V_{OUT}} + 1.233\right] \times \left[\frac{R1b}{R1a} + 1\right]$$

Actually, the voltage drop across R1b is slightly higher than that calculated from Equation 4. Approximately 60nA of current flows out of the LM4041 FB terminal. With large values of R1b, this current creates millivolts of higher output voltage; for best accuracy, compensate R1b by reducing its size accordingly. This error is +1mV with R1b = 16.5kΩ.

Equation 5 shows the nominal output voltage for the composite regulator of Figure 4.

$$V_{OUT} = \frac{1.233 \times \left(\frac{R1b}{R1a} + 1\right)}{1.013 + \left(\frac{0.0013R1b}{R1a}\right)} + (60nA \times R1b) + 1.40V$$

Note that the tolerance of R2 has no effect on output voltage accuracy. It sets the diode reverse (operating) current and also allows the divider current from R1a and R1b to pass. With R2 = 1.2kΩ, 1mA of bias flows. If R2 is too small (less than about 105Ω, the maximum reverse current of the LM4041-ADJ is exceeded. If it is too large with respect to R1a and R1b then the circuit will not regulate. The recommended range for R2 is from 121Ω to $^{R1a}/_{10}$.

With this circuit we achieve much improved accuracies. Our error terms are:

25mV	(constant) from the MIC29512
0.5%	from the LM4041C
+ 0 to 2%	from R1a and R1b
0.5% + 25mV to 2.5% + 25mV	Total Error budget

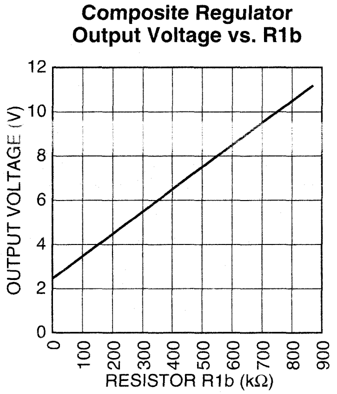


Figure 5.

Figure 6 shows the resistor error contribution to the LM4041C reference output voltage tolerance. Figure 7 shows the worst-case output voltage error of the composite regulator circuit using various resistor tolerances and a 0.5% LM4041C reference is employed. The top four traces reflect use of 1%, 0.5%, 0.25%, and 0.1% resistors. Table 1 lists the production accuracy obtained with the low-cost LM4041C and standard 1% resistors as well as the improvement possible with 0.1% resistors.

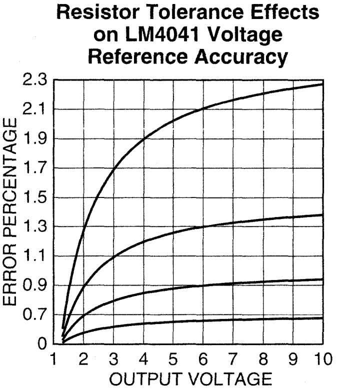


Figure 6.

What does the extra complexity of the composite regulator circuit of Figure 4 buy us in terms of extra accuracy? With precision components, we may achieve tolerances better than ±1% with the composite regulator, as compared to a theoretical best case of worse than 2% with the standard regulator and resistor configuration. Figure 8 and Table 2 show the accuracy difference between the circuits as the output voltage changes. The accuracy difference is the

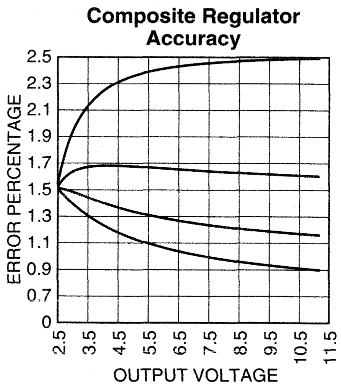

Composite Regulator Accuracy

Figure 7.

tolerance of the two-resistor circuit minus the tolerance of the composite circuit. Both tolerances are the calculated worst-case value, using 1% resistors. This figure shows the composite circuit is always at least 1% better than the standard configuration. Both the figure and the table assume standard ±1% resistors and the LM4041C-ADJ (0.5%) reference.

V_{OUT}	1% Resistors	0.1% Resistors
2.50V	±1.54%	±1.50%
2.90V	±1.88%	±1.41%
3.00V	±1.94%	±1.39%
3.30V	±2.07%	±1.34%
3.45V	±2.12%	±1.31%
3.525V	±2.14%	±1.30%
3.60V	±2.16%	±1.29%
5.00V	±2.36%	±1.13%
6.00V	±2.41%	±1.07%
8.00V	±2.46%	±0.98%
10.00V	±2.49%	±0.92%
11.00V	±2.49%	±0.90%

Table 1. Worst-case output voltage error for typical operating voltages

Conclusion

Adjustable regulator applications requiring high-accuracy output voltages may be satisfied by replacing the normal resistive divider circuit with a precision reference. The resulting high accuracy is achieved by a combination of reduced reference tolerances and lower sensitivity to resistor tolerances. The accuracy improvement afforded by the reference circuit is greater than 1% and absolute accuracy of less than ±1% is attainable.

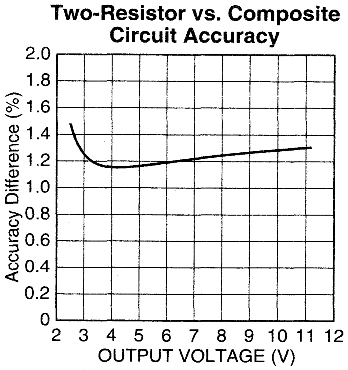

Two-Resistor vs. Composite Circuit Accuracy

Figure 8.

V_{OUT}	Composite Circuit	Standard Circuit
2.50V	±1.6%	±3.0%
3.00V	±1.9%	±3.2%
3.30V	±2.1%	±3.3%
3.50V	±2.1%	±3.2%
5.00V	±2.4%	±3.5%
6.00V	±2.4%	±3.6%
8.00V	±2.5%	±3.7%
10.00V	±2.5%	±3.8%
11.00V	±2.5%	±3.8%

Table 2. Comparing the worst-case output voltage error for the two topologies with typical output voltages.

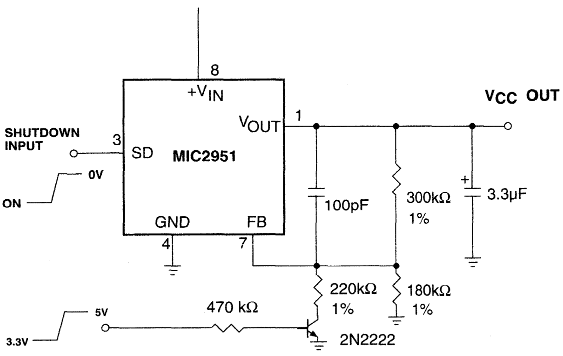
Application Hint 7

Using Low Current LDO Regulators

by Bob Wolbert

General Description

The MIC2951 brings the benefits of linear regulation to surface mountable packaging. High accuracy, high efficiency, very low ripple, and excellent protective features are combined into a useful device for laptop/notebook computers, communications equipment, and battery operated instrumentation.



MIC2951 Configured as a selectable 3.3V or 5.0V output regulator.

Features

- High accuracy +5V or adjustable output voltage
- Extremely small size; up to 150mA output current
- Low dropout voltage and quiescent curent
- Thermal and over-current protection
- Error flag warns of output dropout
- Logic-controlled electronic shutdown

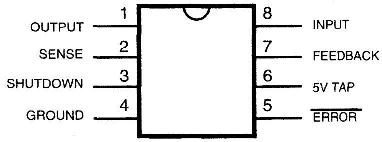
MIC Versus LP Benefits

- Lower dropout voltage
- 150mA output current vs. 100mA
- One-sixth the ground current
- Reverse battery protection for load
- Survives automotive "Load Dump" transient (60V)

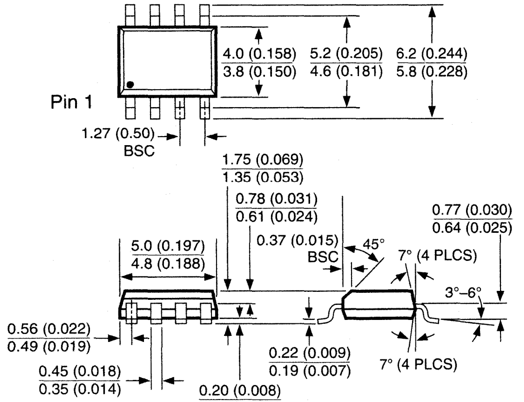
Ordering Information

Part Number	Temperature Range	Package	Accuracy
LP2951-02BM	–40°C to + 85°C	8-Pin SOIC	0.5%
LP2951-03BM	–40°C to + 85°C	8-Pin SOIC	1.0%
MIC2951-02BM	–40°C to + 85°C	8-Pin SOIC	0.5%
MIC2951-03BM	–40°C to + 85°C	8-Pin SOIC	1.0%

Pin Configuration



Package Dimensions



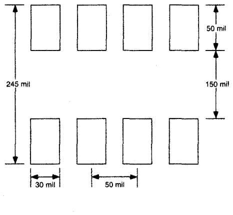
Dimensions in mm (inch)

Thermal Considerations

Part I. Layout

The MIC2951-02/03BM (8-pin surface mount package) has the following thermal characteristics when mounted on a single layer copper-clad printed circuit board.

PC Board Dielectric	θ_{JA}
FR4	160°C/W
Ceramic	120°C/W



Minimum recommended board pad size

Multi-layer boards having a ground plane, wide traces near the pads, and large supply bus lines provide better thermal conductivity.

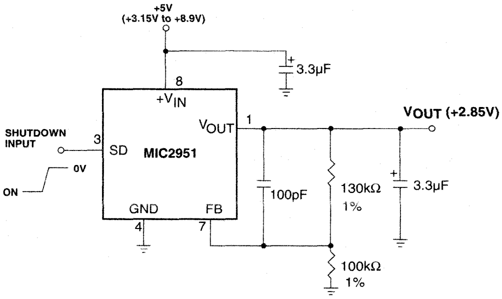
The "worst case" value of 160°C/W assumes no ground plane, minimum trace widths, and a FR4 material board.

Part II. Nominal Power Dissipation and Die Temperature

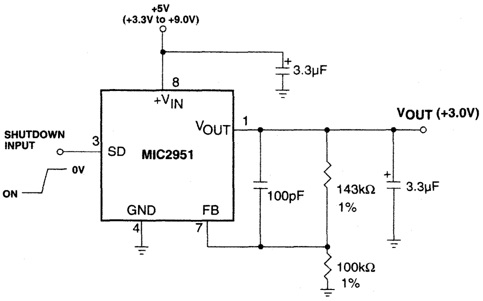
The MIC2951-02/-03BM at a 25°C ambient temperature will operate reliably at up to 625mW power dissipation when mounted in the "worst case" manner described above. At an ambient temperature of 55°C, the device may safely dissipate 440mW. These power levels are equivalent to a die temperature of 125°C, the recommended maximum temperature for non-military grade silicon integrated circuits.

Typical Applications

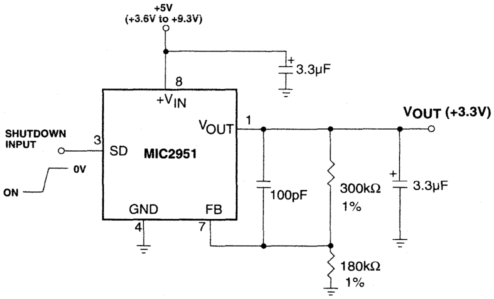
MIC2951-02/-03BM common voltage applications. Calculations assume 100mA of output current, 25°C ambient temperature, 100% duty cycle, and 160°C/W mounting. The Shutdown Input may be left floating if it is not used.



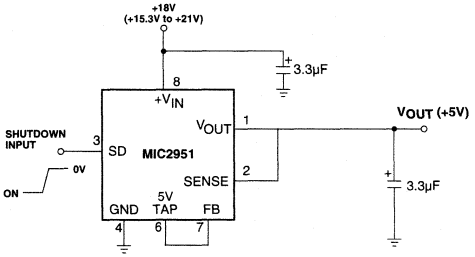
MIC2951 +2.85V Regulator



MIC2951 +3.0V Regulator

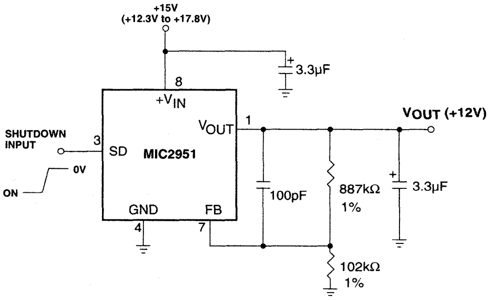


MIC2951 +3.3V Regulator

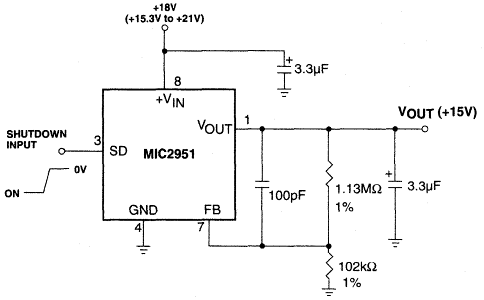


(Note: no external resistors are necessary)

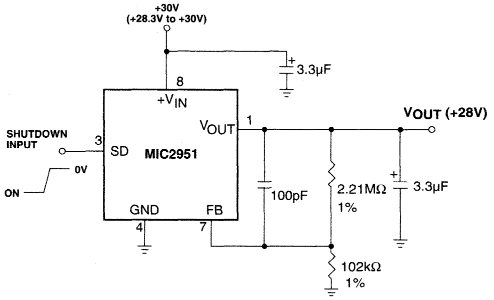
MIC2951 +5.0V Regulator



MIC2951 +12.0V Regulator



MIC2951 +15.0V



MIC2951 +28.0V Regulator

Application Hint 17

Designing P.C. Board Heat Sinks

By Bob Wolbert

General Description

System designers increasingly face the restriction of using all surface-mounted components in their new designs; even including the power components. Through-hole components can dissipate excess heat with clip-on or bolt-on heat sinks keeping things cool. Surface mounted components do not have this flexibility and rely on the conductive traces or pads on the printed circuit board for heat transfer. This hint addresses the question "How much PC board pad area does my design require?"

We will determine if a Micrel surface mount low dropout linear regulator may operate using only a PC board pad as its heat sink. We start with the circuit requirements.

System Requirements:

$V_{OUT} = 5.0V$
$V_{IN\ (MAX)} = 9.0V$
$V_{IN\ (MIN)} = 5.6V$
$I_{OUT} = 700mA$
Duty cycle = 100%
$T_A = 50°C$

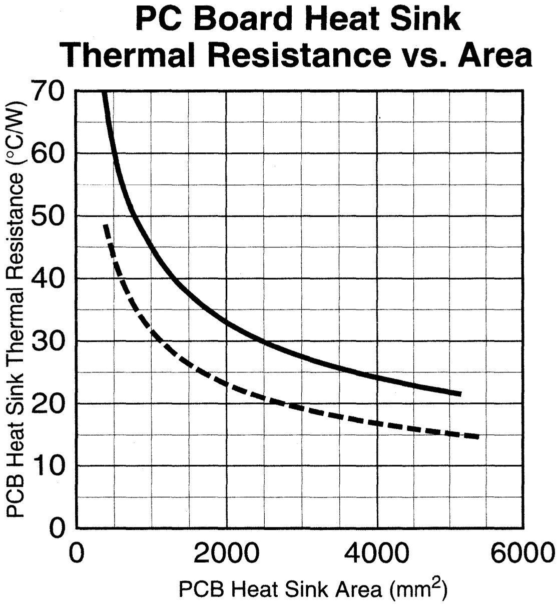


Figure 1. Graph to determine PC board area for a given thermal resistance. See text for discussion of the two curves.

This leads us to choose the 750mA MIC2937A-5.0BU voltage regulator, which has these characteristics:

$V_{OUT} = 5V \pm 2\%$ (worst case over temperature)
$T_{J\ MAX} = 125°C$
θ_{JC} of the TO-263 = 3°C/W
$\theta_{CS} \approx 0°C/W$ (soldered directly to board)

Preliminary Calculations

$V_{OUT\ (MIN)} = 5V - 2\% = 4.9V$

$P_D = (V_{IN\ (MAX)} - V_{OUT\ (MIN)}) \times I_{OUT} + (V_{IN\ (MAX)} \times I_{GND})$
$= [9V - 4.9V] \times 700mA + (9V \times 15mA) = 3W$

Maximum temperature rise, $\Delta T = T_{J(MAX)} - T_A$
$= 125°C - 50°C = 75°C$

Thermal resistance requirement, θ_{JA} (worst case):

$$\frac{\Delta T}{P_D} = \frac{75°C}{3.0W} = 25°C/W$$

Heat sink thermal resistance, $\theta_{SA} = \theta_{JA} - (\theta_{JC} + \theta_{CS})$

$\theta_{SA} = 25 - (3 + 0) =$ **22°C/W (max)**

Heat sink physical size determination

Figure 1 shows the total area of a round or square pad, centered on the device. The solid trace represents the area of a square, single sided, horizontal, solder masked, copper PC board trace heat sink, measured in square millimeters. No airflow is assumed. The dashed line shows a heat sink covered in black oil-based paint and with 1.3m/sec (250 feet per minute) airflow. This approaches a "best case" pad heat sink.

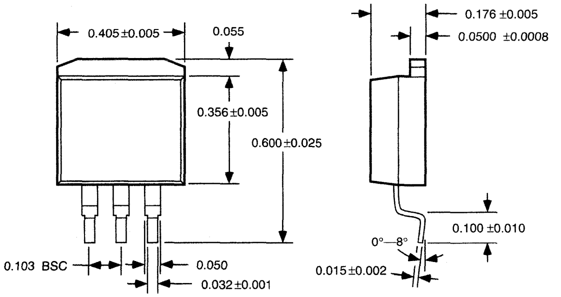


Figure 2. The TO-263 "U" Package. Derived from the popular TO-220 power package, the TO-263 has excellent thermal properties for a surface mount package.

Conservative design dictates using the solid trace data, which indicates a pad size of 5000 mm^2 is needed. This is a pad 71mm by 71mm (2.8 inches per side).

Example 2, SO-8 and SOT-223 package.

Given the following requirements, determine the safe heat sink pad area.

$V_{OUT} = 5.0V$

$V_{IN\ (MAX)} = 14V$

$V_{IN\ (MIN)} = 5.6V$

$I_{OUT} = 150mA$

Duty cycle = 100%

$T_A = 50°C$

Your board production facility prefers handling the dual-in-line SO-8 packages whenever possible. Is the SO-8 up to this task? Choosing the MIC2951-03BM, we get these characteristics:

$T_{J\ MAX} = 125°C$

θ_{JC} of the SO-8 ≈ 100°C/W

SO-8 Calculations:

$P_D = [14V - 5V] \times 150mA + (14V \times 8mA) = \mathbf{1.46W}$

Temperature rise = 125°C – 50°C = **75°C**

Thermal resistance requirement, θ_{JA} (worst case):

$$\frac{\Delta T}{P_D} = \frac{75°C}{1.46W} = \mathbf{51.3°C/W}$$

Heat sink $\theta_{SA} = 51 - 100 = \underline{\mathbf{-49\ °C/W}}\ \mathbf{(max)}$

Which obviously presents a problem: without refrigeration, the SO-8 is not suitable for this application. Consider the MIC5201-5.0BS in a SOT-223 package. This package is smaller than the SO-8, but its three terminals are designed for much better thermal flow. Choosing the MIC5201-3.3BS, we get these characteristics:

$T_{J\ MAX} = 125°C$

θ_{JC} of the SOT-223 = 15°C/W

θ_{CS} = 0 °C/W (soldered directly to board)

SOT-223 Calculations:

$P_D = [14V - 4.9V] \times 150mA + (14V \times 1.5mA) = \mathbf{1.4W}$

Temperature rise = 125°C – 50°C = **75°C**

Thermal resistance requirement, θ_{JA} (worst case):

$$\frac{\Delta T}{P_D} = \frac{75°C}{1.4W} = \mathbf{54°C/W}$$

Heat sink $\theta_{SA} = 54 - 15 = \mathbf{39°C/W\ (max)}$

Board Area

Referring to Figure 1, a pad of 1400mm^2 (a square pad 1.5 inches per side) provides the required thermal characteristics.

Conclusion:

These formulae are provided as a general guide to thermal characteristics for surface mounted power components. Many estimations and generalizations were made; your system will vary. Please use this information as a rough approximation of board area required and fully evaluate the thermal properties of each board you design to confirm the validity of the equations.

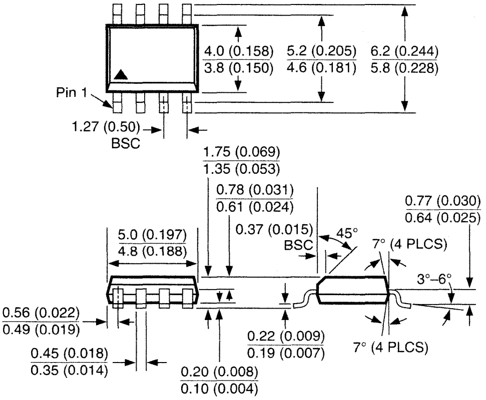


Figure 2. SO-8 Package. The SO-8 is small and very popular, but is far from ideal thermally.

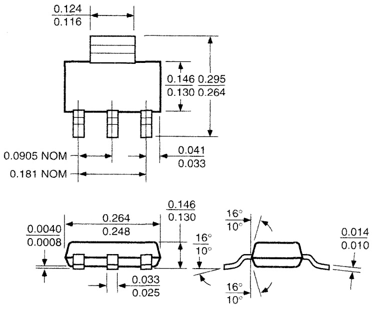


Figure 3. SOT-223 Package. Smaller than the popular SO-8, the SOT-223 has significantly better thermal characteristics.

Application Hint 18

Powering the IntelDX4™ Processor

By Bob Wolbert

General Description

The IntelDX4™ Processor and IntelDX4 Processor "OverDrive™" microprocessors are upgrades to the popular 486 microprocessor and share the same basic pinout.[1] A computer motherboard may be designed that accepts either processor, allowing the end user to initially use the lower cost 486 and later upgrade to the IntelDX4 Processor by simply replacing ICs. There is a catch: the IntelDX4 Processor operates from a 3.3V supply[2,3]. Pin S4 on the IntelDX4 Processor, VOLDET (voltage detect), is grounded to indicate the 3.3V processor is installed. This pin is either not connected or pulled high on 486 processors. Using this indicator, we can design a power control system that insures the proper voltage is applied to the processor.

This note describes a circuit that reads VOLDET from a IntelDX4 Processor-series processor and automatically determines whether to supply 5V or 3.3V. It operates from a single +5V ± 5% power supply and produces 3.3V output with a low drop-out linear regulator.

Circuit Discussion

Our goal is to provide the proper supply voltage to the microprocessor. We begin by determining what is the proper voltage. Intel has assigned IntelDX4 Processor pin S4 to "VOLDET". This pin position, unassigned on the 486, is internally bonded to ground on the IntelDX4 Processor. A pull-up resistor connected from VOLDET to a system supply will allow differentiation between the grounded IntelDX4 Processor and the open-circuited or logic high 486.

Our next consideration is to provide switched +5V from the main supply when a 486 is used. A low ON resistance switch will work. Micrel's MIC5014 high side MOSFET driver and a medium sized N-channel power MOSFET is ideal.

Now, we must produce a clean 3.3V source. The Intel IntelDX4 Processor requires up to 1.25A at 3.3V. The Intel IntelDX4 Processor OverDrive™ needs up to 3A. The 1.5A Micrel MIC29150-3.3 easily supplies the IntelDX4 Processor, and the MIC29300 is perfect for suppling the IntelDX4 Processor OverDrive™.

Finally, we put the blocks together and iron out interfacing. Figure 1 shows the power system block diagram.

Details

The schematic diagram for the power control block appears as Figure 2. With a 486 processor installed, the pull-up resistor, R1, pulls the MIC5014 input pin high, enabling the MOSFET driver. An internal charge pump voltage multiplier charges the power MOSFET (Q1) gate and supplies +5V V_{CC} to the processor. Voltage to the processor is V_{CC} minus a voltage drop determined by processor supply current times MOSFET ON resistance. The MOSFET size is determined by the maximum allowable voltage drop:

$$R_{MOSFET\ ON} = (V_{CC\ (S)\ MIN} - V_{CC\ (P)\ MIN}) / I_{CC}$$

Where: $V_{CC\ (S)\ MIN}$ is the minimum supply voltage from the power source

$V_{CC\ (P)\ MIN}$ is the minimum operating voltage for the processor

I_{CC} is the peak processor operating current

Assuming a 5V ±5% supply and a 486 rated for ±10% supply tolerance, the MOSFET ON resistance is:

$$R_{MOSFET} = (4.75 - 4.50) / I_{CC} = 0.25V / I_{CC}$$

Or 250 milliohms for a 1A load. A MOSFET with 0.25Ω or lower ON resistance will work.

Providing 3.3V from a nominal 5V supply is an easy matter using Micrel's low drop out linear regulators. These regulators need only one external component for operation, an

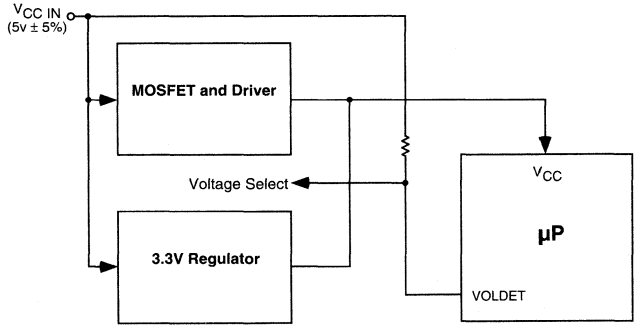


Figure 1. Block diagram for an auto-select voltage block for powering a computer motherboard that uses either 486 or IntelDX4 Processor microprocessors. VOLDET signals the MOSFET and Driver block and the 3.3V Regulator block whether the 5V 486 or the 3.3V IntelDX4 Processor is installed. The end user can upgrade his microprocessor without worrying about supply voltage jumpers.

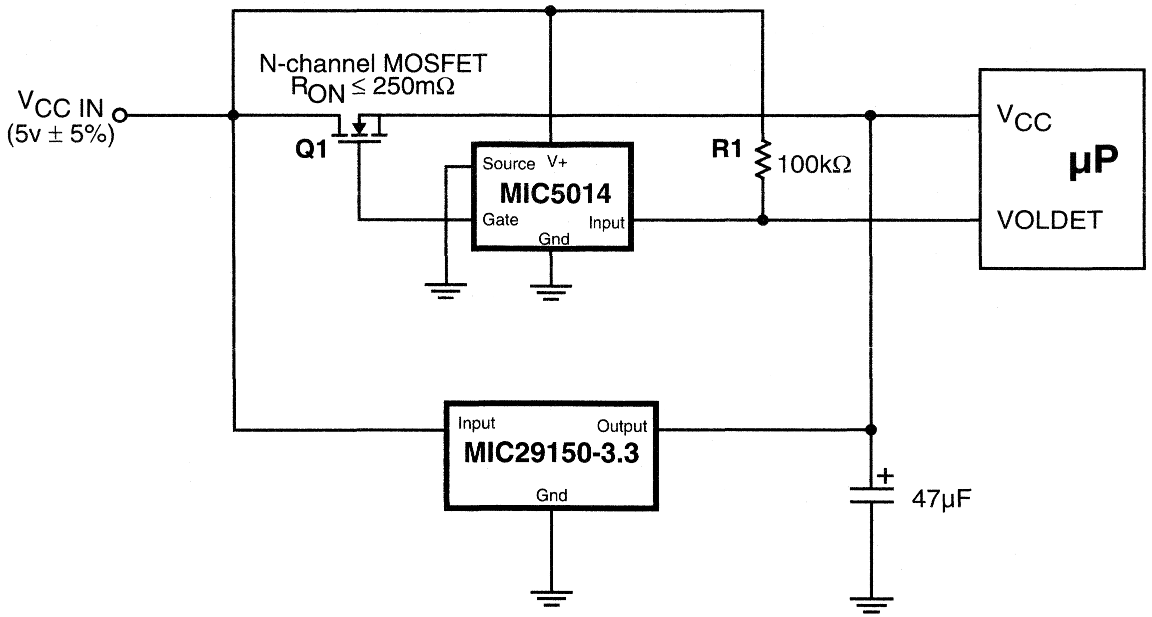


Figure 2. Complete schematic for an automatic voltage selection switch using the IntelDX4 Processor VOLDET pin.

output filter capacitor. Micrel's Super ßeta PNP™ LDOs are ideal for this application for other reasons as well. Unlike other regulators, Micrel's LDOs operate with drop-out voltages of 300mV–often less. This is important when we consider worst case tolerances: The "5V" supply can be as low as 4.75V and still be within its specification. The MIC29150-3.3 output may be as high as 3.366V under worst case conditions. This gives us a worst case available drop out voltage of only 1.384V (4.75V – 3.366V) . This is well within the 300mV typical performance of Micrel's LDOs as well as comfortably within the 600mV guaranteed maximum (over the full operating temperature range) specification. No NPN-pass element linear regulator can approach this performance. Additionally, Micrel LDOs feature "reverse battery" protection. This is like an ideal diode in series with the regulator that prevents reverse current flow caused either by a negative input voltage *or a higher voltage present on the regulator output.* This feature lets us connect the 3.3V LDO directly in parallel with the 5V switch to the microprocessor V_{CC}. If the 5V supply is disabled, the LDO will source 3.3V. When the 5V supply is enabled, it will reverse bias the "diode" in the LDO output and effectively shut off the regulator. This means a simple three terminal LDO can be employed.

"Green" systems conserve power when full performance is not needed. The IntelDX4 Processor implements "green" features, powering down to only a few hundred milliamperes in sleep mode. It reawakens in less than a microsecond and draws full power. Proper operation under these conditions requires a low inductance, low effective series resistance (ESR) capacitor. Generally, this is best implemented by paralleling the regulator filter capacitor with a small (0.1µF to 2.2µF) capacitor.

If other output voltages are required, Micrel's adjustable MIC29152 and MIC29302 are available and allow the designer to select any output voltage from 1.24V to the maximum rating of the device. Please refer to Application Hint 19 for further discussion of adjustable regulator applications.

At the 1.25A IntelDX4 Processor level, thermal considerations are not difficult; however at the 3A level of the IntelDX4 Processor OverDrive, proper heat sinking is essential. For full details on heat sinking Micrel LDOs in this application, refer to Micrel Application Note 9, "Design Considerations for 5V to 3.3V Pass Regulators".

Notes

NOTE 1: Intel™, IntelDX4™, and OverDrive™ are trademarks of Intel Corp.

NOTE 2: The IntelDX4 Processor accepts logic inputs as high as 5.3V when operating in a mixed-V_{CC} environment.

NOTE 3: The IntelDX4 Processor uses a nominal 3.3V supply. However, Intel has reserved the right to supply devices that run on other voltages (for example, one batch might require 3.6V, the next, 3.45V). Micrel recommends using an adjustable regulator (MIC29152 or MIC29302) until this situation is resolved. Refer to Application Hint 19 for further details.

Application Hint 19

Powering IBM Blue Lightning™ Microprocessors

By Bob Wolbert

General Description

The IBM Blue Lightning™ microprocessor is a 486-type processor built on a proprietary IBM process and uses a nominal 3.60V power supply.[1] Some versions operate at 3.3V, while higher performance devices require 3.6V, 3.8V, and even 4.1V. With its internal clock tripling circuitry, they dissipate up to a maximum of 3.6W, drawing about 1A. This power supply voltage creates a problem with PC motherboard manufacturers because a 3.3V to 4.1V variable supply is not available from standard computer power supplies. Micrel's MIC29152BU, in a surface mount TO-263 package, will power any version of the Blue Lightning from a standard 5V supply. This hint provides the circuit and thermal design for this application.

Circuit and Thermal Calculations

If the Blue Lightning version you use employs either a 3.3V or 3.6V power supply, Micrel offers a three terminal MIC29150 regulator that will simplify your design. Figure 1 shows the schematic diagram of the 3.3V or 3.6V power supply: only one external component is necessary for operation, an output filter capacitor. If the higher performance Blue Lightning processor is contemplated, or rapid production changes between versions using the same motherboard design is expected, the MIC29152 adjustable regulator is preferred. Figure 2 shows the schematic diagram of this flexible supply. Two resistors determine the output voltage. Since the layout remains the same, the production line can rapidly accommodate processor changes (and the required supply voltage changes) by simply changing one of the two resistors. Table 1 shows resistor values for the common processor supply voltages. For voltage requirements not listed, the formula for resistor ratio is:

$$\frac{V_O}{1.240} - 1 = \frac{R1}{R2}$$

The pinout of the three terminal MIC29150 and the center three pins of the MIC29152 is the same, with slightly different lead spacing. This means a single motherboard layout is possible that allows *both* the 3-pin fixed and 5-pin adjustable versions. Micrel's Super ßeta PNP™ LDOs are ideal for this application for other reasons as well.[2] Unlike other regulators, Micrel's LDOs operate with drop-out voltages of 300mV–often less. This is important when we consider worst case tolerances: The "5V" supply can be as low as 4.75V and still be in-specification. The MIC29150-3.3 output may be as high as 3.672V under worst case conditions. This gives us a worst case available drop out voltage of only 1.078V (4.75V – 3.672V). This is well within the 300mV typical performance of Micrel's LDOs as well as comfortably within the 600mV guaranteed maximum (over the full operating temperature range) specification. No NPN-pass element linear regulator can approach this performance. Additionally, Micrel LDOs feature "reverse battery" protection.

Our thermal calculations are conservative and assume a worst case current of 1.0A at 3.67V (3.6V + 2%). Worst case drop out available is 1.08V (4.75V – 3.67V), which is well above the 0.60V guaranteed level of the MIC29150-3.6, so we have a fine match. Using the formula for power dissipation:

$$P_D = (V_{IN\,MAX} - V_{OUT\,MIN}) \times I_{OUT\,MAX} + V_{IN\,MAX} \times I_{GND}$$

the worst case power dissipation operating from a 5V ± 5% supply is:

$$P_D = (5.25V - 3.53V) \times 1.0A + (5.25V \times 10mA)$$

$$= \mathbf{1.77W}$$

What size of heat sink, if any, is necessary? The thermal resistance of a heat sink is:

$$\theta_{SA} = \frac{T_J - T_A}{P_D} - (\theta_{JC} + \theta_{CS})$$

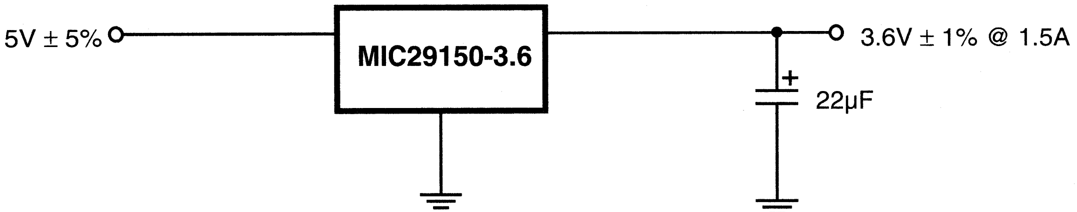
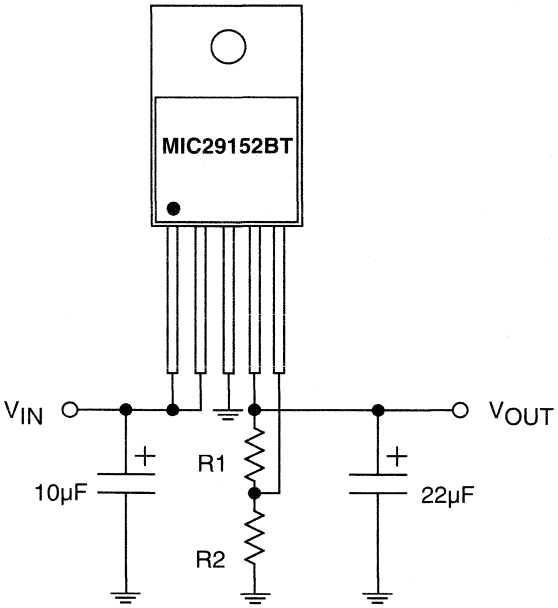


Figure 1. The MIC29150-3.6BU powers the IBM Blue Lightning from a nominal 5V supply without requiring any heat sinking other than the P.C. board mounting pad itself.



$$V_{OUT} = 1.240V \times [1 + (R1 / R2)]$$

Figure 2. MIC29152 Adjustable regulator circuit for use with Blue Lightning. Refer to Table 1 for resistor values.

Voltage Required	R1	R2
3.3V*	158k	95.3k
3.6V†	158k	82.5k
3.8V	158k	76.1k
4.1V	158k	68.1k

* The MIC29150-3.3 is a three terminal replacement if production-time voltage selection is not necessary.

† The MIC29150-3.6 is a three terminal replacement if production-time voltage selection is not necessary.

Table 1. Resistor values for Figure 1 calculated for common Blue Lightning operating voltages.

Assuming a θ_{JC} of 2°C/W, a θ_{CS} of 0.5°C/W, (the surface mount TO-263 is soldered directly to the PC board heat sink) and an ambient temperature, T_A, of 50°C, the maximum allowable heat sink thermal resistance is:

$$\theta_{SA} = \frac{125°C - 50°C}{1.8W} - (2°C/W + 0.5°C/W) = \mathbf{39°C/W}$$

Referring to Application Hint 17, we see that a square P.C. board pad of 40mm by 40mm (1.6 inches per side) is adequate. No external series dropping resistor is necessary for power sharing as this design is conservative. This pad is shown in Figure 3.

The through-hole MIC29150-3.6BT in a TO-220 package does not require a heat sink.

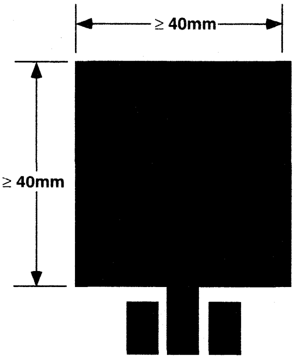


Figure 3. Suitable P.C. board heat sink for the MIC29150 powering "Blue Lightning".

Conclusion

The IBM Blue Lightning microprocessor operates from a nominal 3.6V supply[3], which can be obtained from a surface mount MIC29150-3.6BU without any heat sink other than the P.C. board itself. The entire schematic consists of only two components, the regulator and a filter capacitor, and is shown in Figure 1. At the 1A Blue Lightning current level, thermal considerations are not difficult and a P.C. board heat sink pad will serve. For full details on heat sinking Micrel LDOs in this application, refer to Micrel Application Hint 17, "P.C. Board Heat Sinking", or for more stringent requirements refer to Micrel Application Note 9, "Design Considerations for 5V to 3.3V Pass Regulators".

Notes

NOTE 1: IBM and Blue Lightning are trademarks of IBM Corp.

NOTE 2: Super ßeta PNP is a trademark of Micrel, Inc.

NOTE 3: At press time, the Blue Lightning supply currents and voltages have not been finalized. If other than 3.3V or 3.6V are needed, the Micrel MIC29152 adjustable 1.5A regulator is available which can provide any output voltage from about 1.2V to 25V, programmed using two external resistors. See the MIC29150 datasheet for full details.

Application Hint 20

Introduction to the Super LDO™ Regulator

by Randy Cook and George Hall

A brief review of the significant changes in IC linear regulators leads to the Micrel Super LDO™ Regulator and highlights its important advantages.

Basic NPN Regulators

Economical high-current regulators continue to employ the original space-efficient NPN transistor for the pass element (see figure 1a). The NPN regulator allows high device output currents, but the large input to output voltage drop that results from operating the NPN as an emitter follower often requires a substantial heat sink.

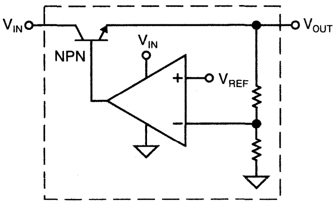


Figure 1a. NPN Monolithic Regulator

PNP Low Dropout Regulators

Demand for a large reduction in dropout voltage resulted in the introduction of the LDO (low dropout) regulator. The LDO's reduction of the input to output voltage drop was achieved by using a PNP transistor as the pass element (see figure 1b). Because a PNP requires substantially more die area than an electrically similar NPN, early LDO regulators were offered with relatively low output current capabilities. These LDO regulators also required large ground (or quiescent) currents to drive the PNP transistor which resulted in low efficiency.

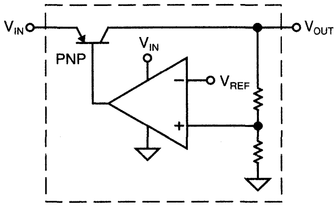


Figure 1b. PNP Monolithic Regulator

Advances in silicon fabrication, such as Micrel's Super βeta PNP™ technology, made higher current, with reduced ground current, LDO regulators technically and economically feasible . LDO regulators are now available with output currents rivaling those using the NPN as the pass element.

P-Channel Improved Efficiency Regulators

The need for higher efficiency regulators for battery powered equipment has led to monolithic regulators which use a P-channel enhancement-mode MOSFET as the pass element (see figure 1c). The P-channel MOSFET dramatically reduces ground current, but even more than with the PNP, requires a large die area for even low output current regulators. P-channel MOSFET are typically 2.5 times the size of an equivalent N-channel MOSFET. Another drawback when using this regulator is the dramatic increase of MOSFET on resistance at low input voltages, further limiting its maximum output current capability.

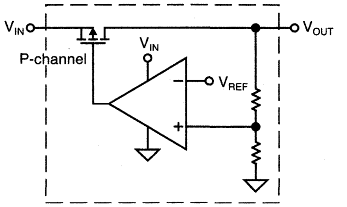


Figure 1c. P-Channel Monolithic Regulator

High-Output Low Dropout Regulators

Managing moderate to high output currents can be accomplished using a dedicated control IC to drive an external pass element.

The external pass element offers the designer two advantages unattainable with the monolithic approach: First, because the control circuitry is separate, the pass element's die area in a given package can be increased. This results in lower dropout voltages at higher output currents. Second, the junction-to-case thermal resistance is much less allowing higher output currents before a heat sink is required. As with the monolithic approach, for equal die areas, a PNP transistor offers the lowest dropout voltage, a P-channel MOSFET the lowest ground current, and the NPN transistor the lowest cost.

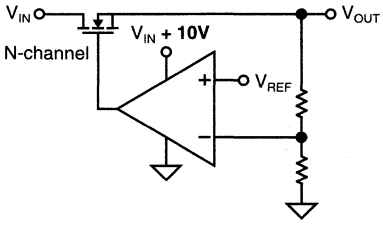


Figure 2. N-Channel Regulator

The most attractive device for the external pass element is the N-channel power MOSFET (see figure 2). Discrete N-channel MOSFET prices continue to decrease (due to high volume usage), and the race for lower and lower on resistance works in the customer's favor. The N-channel MOSFET, like the P-channel MOSFET, reduces ground current.

With device on resistance now below 10mΩ, dropout voltages below 100mV are possible with output currents in excess of 10A. Even lower dropouts are possible by using two or more pass elements in parallel.

Unfortunately, full gate-to-source enhancement of the N-channel MOSFET requires an additional 10V to 15V above the required output voltage. Controlling the MOSFET's gate using a second higher voltage supply requires additional circuitry and is clumsy at best.

Micrel's New Super LDO Family

Micrel's Super LDO Regulator family consists of three regulators which control an external N-channel MOSFET for low dropout at high current. Two members of the family internally generate the required higher MOSFET enhancement voltage, while the other relies on an existing external supply voltage.

All members of the Super LDO Regulator family have a 35mV current limit threshold, ±2% nominal output voltage setting, and a guaranteed 3V to 36V operating voltage range. All family members also include a TTL compatible enable/shutdown input (EN) and an open collector fault output (FLAG). When shutdown (TTL low), the device draws less than 1µA. The FLAG output is low whenever the output voltage is 6% or more below its nominal value.

The MIC5156

The MIC5156 Super LDO Regulator occupies the least printed circuit board space in applications where a suitable voltage is available for MOSFET gate enhancement. To minimize external parts, the MIC5156 is available in fixed output versions of 3.3V or 5V. An adjustable version is also available which uses two external resistors to set the output voltage from 1.3V to 36V.

The MIC5157 and MIC5158

For stand-alone applications the MIC5157 and MIC5158 incorporate an internal charge-pump voltage tripler to supply the necessary gate enhancement for an external N-channel MOSFET. Both devices can fully enhance a logic-level N-channel MOSFET from a supply voltage as low as 3.0V. Three inexpensive small value capacitors are required by the charge pump.

The MIC5157 output voltage is externally selected for a fixed output voltage of 3.3V, 5V or 12V.

The MIC5158 output voltage is externally selectable for either a fixed 5V output or an adjustable output. Two external resistors are required to set the output voltage for adjustable operation.

Computer Power Supply Application

Figure 3 shows a typical 3.3V and 5V computer power supply application. The MIC5156 provides regulated 3.3V using Q1 as the pass element and also controls a MOSFET switch for the 5V supply.

When the 3.3V output has reached regulation, the FLAG output goes high, enhancing Q2, which switches 5V to Load 2. This circuit complies with the requirements of new microprocessors that require the 5V supply input to remain below 3.0V until the 3.3V supply input is greater than 3.0V.

An optional current limiting sense resistor (R_S) limits the load current to 12A maximum. For less costly designs, the sense resistor's value and function can be duplicated using one of two techniques: A solid piece of copper wire with appropriate length and diameter (gauge) makes a reasonably accurate low-value resistor. Another method uses a printed circuit trace to create the sense resistor. The resistance value is a function of the trace thickness, width, and length.

3.3V, 10A Regulator Application

Figure 4 shows the MIC5157's ability to supply the additional MOSFET gate enhancement in a low dropout 3.3V, 10A supply application. Capacitors C1 and C2 perform the voltage tripling required by the N-channel logic-level MOSFETs. As with any linear regulator, improved response to load transients is accomplished by using output capacitors with low ESR characteristics. The exact capacitance value required for a given design depends on the maximum output voltage disturbance that can be tolerated during a worse case load change. Adding low value (0.01µF to 0.1µF) film capacitors (such as Wima MKS2 series) near the load will also improve the regulator's transient response.

Super LDO is a trademark of Micrel, Inc.

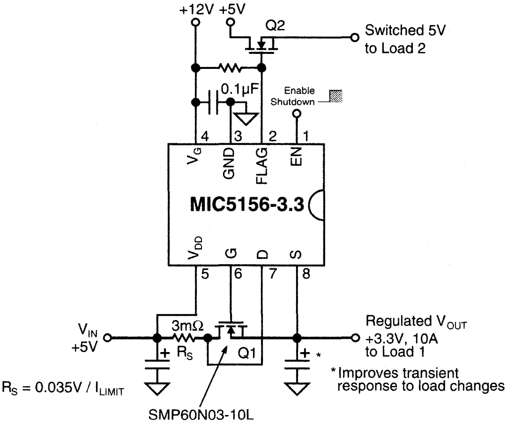


Figure 3. Microprocessor Supply

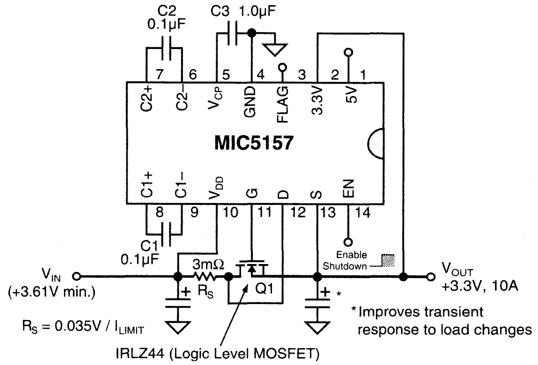


Figure 4. N-Channel Regulator

Application Hint 21

Sense Resistors for the Super LDO™ Regulator

by Daryl Sugasawara

Power Dissipation

The power dissipation of sense resistors used in Super LDO regulator circuits is small and generally does not require the power dissipation capability found in most low-value resistors.

Alternate Resistors

A low-value resistor can be made from a length of copper magnet wire or from a printed circuit board trace. Tables are provided for wire and printed circuit traces.

Copper has a positive temperature coefficient of resistivity of +0.39%/°C. This can be significant when higher accuracy current limiting is required.

A Kelvin connection between the sense element and the Super LDO Regulator Controller improve the accuracy of the current limit setpoint.

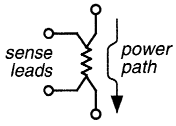
Printed Circuit Copper Resistance

Conductor Thickness	Conductor Width in	Resistance mΩ / in
½oz/ft^2 (18μm)	0.025 0.050 0.100 0.200 0.500	39.3 19.7 9.83 4.91 1.97
1 oz/ft^2 (35μm)	0.025 0.050 0.100 0.200 0.500	19.7 9.83 4.91 2.46 0.98
2oz/ft^2 (70μm)	0.025 0.050 0.100 0.200 0.500	9.83 4.91 2.46 1.23 0.49
3oz/ft^2 (106μm)	0.025 0.050 0.100 0.200 0.500	6.5 3.25 1.63 0.81 0.325

Kelvin Connections

A Kelvin connection is a measurement connection that avoids the error caused by voltage drop in the power path leads.

Sense leads are attached directly across the resistance element—intentionally excluding the power path leads. Because the sense conductors carry negligible current (sense inputs are typically high impedance voltage measurement inputs), there is no voltage drop to skew the "E = I × R" measurement.



4-Lead Resistor

Wire Resistance Table (Copper Wire)

AWG Wire Size	Resistance at 20°C	
	10^{-6}Ω / cm	10^{-6}Ω / in
10	32.70	83.06
11	41.37	105.1
12	52.09	132.3
13	65.64	166.7
14	82.80	210.3
15	104.3	264.9
16	131.8	334.8
17	165.8	421.1
18	209.5	532.1
19	263.9	670.3
20	332.3	844.0
21	418.9	1064.0
22	531.4	1349.8
23	666.0	1691.6
24	842.1	2138.9
25	1062.0	2697.5
26	1345.0	3416.3
27	1687.6	4286.5
28	2142.7	5442.5
29	2664.3	6767.3
30	3402.2	8641.6
31	4294.6	10908.3
32	5314.9	13499.8
33	6748.6	17141.4
34	8572.8	21774.9
35	10849	27556.5
36	13608	34564.3
37	16801	42674.5
38	21266	54015.6
39	27775	70548.5
40	35400	89916.0
41	43405	110248.7
42	54429	138249.7
43	70308	178582.3
44	85072	216082.9

4-Lead Resistor Manufacturers

Dale Electronics, Columbus, NE	(402) 563-6506
Vishay Resistors, Malvern, PA	(215) 644-1300

Super LDO is a trademark of Micrel, Inc.

Application Hint 23

Powering AMD™ Microprocessors

By Bob Wolbert

General Description

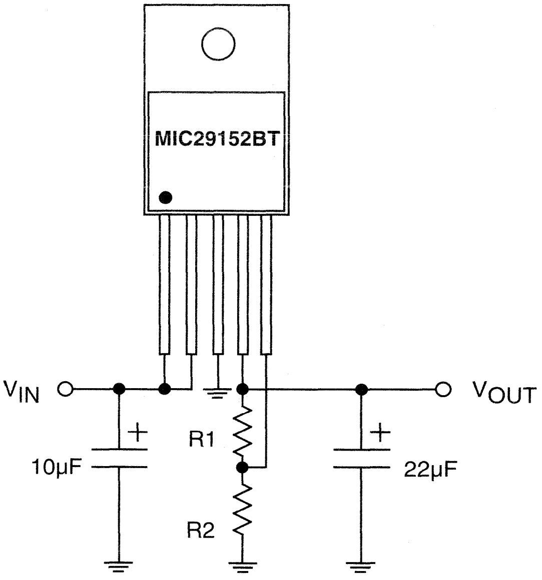
AMD™ manufactures low voltage high performance 486 microprocessors with high clock speeds.[1] These devices operate from either a 3.3V or 3.45V ±5% power supply. Some versions have a double-speed internal clock (DX2), while others have a triple speed internal clock (DX4). They dissipate up to a maximum of 3.3W, drawing nearly 1A. This power supply voltage creates a problem with PC motherboard manufacturers because a 3.3V to 3.45V supply is not available from standard computer power supplies. Micrel's MIC29152BU, in a surface mount TO-263 package, will power any present version of AMD processors from a standard 5V supply. Another power supply issue is the transient response of the supply to the microprocessor waking from "sleep mode"; the processor's supply current changes from a few milliamperes to full load in nanoseconds. This hint provides the circuit and thermal design for this application.

Circuit Design

Although Micrel offers a three terminal MIC29150-3.3 regulator that will simplify your design, building a motherboard that accepts either the 3.3V or the 3.45V processor is easier when the MIC29152 adjustable regulator is used. Figure 1 shows the schematic diagram of the power supply: two resistors and two filter capacitor comprise the entire circuit. Two resistors determine the output voltage. Since the layout remains the same, the production line can rapidly accommodate processor changes (and the required supply voltage changes) by simply changing one of the two resistors. Table 1 shows resistor values for the common processor supply voltages. The formula for resistor ratio is:

$$\frac{V_O}{1.240} - 1 = \frac{R1}{R2}$$

The pinout of the three terminal MIC29150 and the center three pins of the MIC29152 is the same, with slightly different lead spacing. This means a single motherboard layout is possible that allows *both* the 3-pin fixed and 5-pin adjustable versions. Micrel's Super ßeta PNP™ LDOs are ideal for this application for other reasons as well.[2] Unlike other regulators, Micrel's LDOs operate with dropout voltages of 300mV–often less. This is important when we consider worst case tolerances: The "5V" supply can be as low as 4.75V and still be in-specification. The MIC29152 output, when adjusted to 3.45V nominally, may be as high as 3.571V under worst case conditions (assuming worst case tolerances and 1% resistors). This gives us a worst case available drop out voltage of only 1.179V (4.75V – 3.571V). This is well within the 300mV typical performance of Micrel's LDOs as well as comfortably within the 600mV guaranteed maximum (over the full operating temperature range) specification. No NPN-pass element linear regulator can approach this performance. Additionally, Micrel LDOs feature "reverse battery" protection, protecting the microprocessor from faulty cabling by the user as well as protecting the regulator itself from reverse insertion during manufacture.



$$V_{OUT} = 1.240V \times [1 + (R1 / R2)]$$

Figure 1. MIC29152 Adjustable regulator circuit for use with AMD microprocessors. Refer to Table 1 for resistor values.

Transient Response

When the AMD microprocessor "goes to sleep", its current requirement drops to a few milliamperes. As soon as the user touches the keyboard or mouse, however, the processor wakes to full power in a few dozen nanoseconds. With older style linear or switching regulators, this sudden current surge causes the output voltage to drop significantly; often resetting the microprocessor and causing a system re-boot. Since Micrel's Super ßeta PNP regulators are guaranteed never to fall into dropout under the conditions present in this application, recovery time is very fast by comparison, as shown in Figure 2. The output filter capacitor must supply the first portion of the surge current, but need not be as large as with older style regulators. Generally, a 22µF to 47µF tantalum capacitor is sufficient. Multiple 0.1µF capacitors around the microprocessor socket provide decoupling and additional droop protection.

Thermal Calculations

Our thermal calculations are conservative and assume a worst case current of 1.0A at 3.329V (3.45V minus tolerances). Worst case differential voltage available is 1.18V (4.75V – 3.45V plus tolerances), which is well above the 0.60V guaranteed level of the MIC29150-3.6, so we have a fine match. Using the formula for power dissipation:

$$P_D = (V_{IN\,MAX} - V_{OUT\,MIN}) \times I_{OUT\,MAX} + V_{IN\,MAX} \times I_{GND}$$

the worst case power dissipation operating from a 5V ± 5% supply is:

$$P_D = (5.25\text{V} - 3.329\text{V}) \times 1.0\text{A} + (5.25\text{V} \times 20\text{mA})$$

$$= \mathbf{2.03W}$$

What size of heat sink, if any, is necessary? The thermal resistance of a heat sink is:

$$\theta_{SA} = \frac{T_J - T_A}{P_D} - (\theta_{JC} + \theta_{CS})$$

Assuming a θ_{JC} of 2°C/W, a θ_{CS} of 0.5°C/W, (the surface mount TO-263 is soldered directly to the PC board heat sink) and an ambient temperature, T_A, of 50°C, the maximum allowable heat sink thermal resistance is:

$$\theta_{SA} = \frac{125°\text{C} - 50°\text{C}}{2.03\text{W}} - (2°\text{C/W} + 0.5°\text{C/W}) = \mathbf{34°C/W}$$

Referring to Application Hint 17, we see that a square P.C. board pad of 40mm by 40mm (1.6 inches per side) is adequate. No external series dropping resistor is necessary for power sharing as this design is conservative. This pad is shown in Figure 3.

The through-hole MIC29152BT in a TO-220 package generally does not require a heat sink in this configuration.

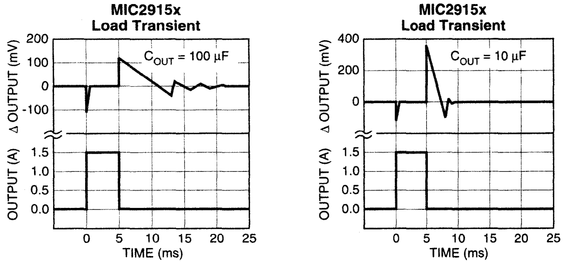


Figure 2. MIC29152 Load transient response with 10µF and 100µF capacitors.

Voltage Required	R1	R2
3.3V*	158k	95.3k
3.45V	158k	88.7k

* The MIC29150-3.3 is a three terminal replacement if production-time voltage selection is not necessary.

Table 1. Resistor values for Figure 1 calculated for AMD microprocessor operating voltages.

Future Devices

Progress in the microprocessor field generally means faster clocks. Higher speed clocks lead to higher power dissipation, with all other things equal. Micrel's MIC29302 is a 3A low dropout regulator in the same packages and with the same pinout as the MIC29152—if your current requirements increase along with microprocessor speed, you may maintain the same motherboard layout by simply changing from the MIC29152 to the MIC29302. Your heat sink might need attention, however.

Conclusion

AMD low voltage microprocessors operate from a nominal 3.3V or 3.45V supply, which can be obtained from a surface mount MIC29152BU without any heat sink other than the P.C. board itself. The entire schematic consists of only five components: the regulator, two voltage setting resistors, and two filter capacitors, as shown in Figure 1. At their 1A current level, thermal considerations are not difficult and a P.C. board heat sink pad will serve. For full details on heat sinking Micrel LDOs in this application, refer to Micrel Application Hint 17, "P.C. Board Heat Sinking", or for more stringent requirements refer to Micrel Application Note 9, "Design Considerations for 5V to 3.3V Pass Regulators".

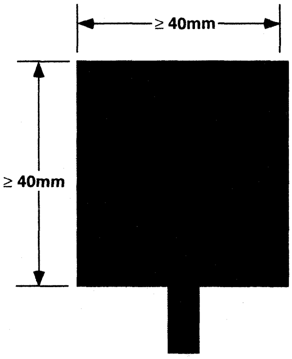


Figure 3. Suitable P.C. board heat sink for the MIC29150 powering AMD microprocessors.

Notes

NOTE 1: AMD™ is a trademark of Advanced Micro Devices Corp.

NOTE 2: Super Beta PNP is a trademark of Micrel, Inc.

MICREL

Application Hint 25

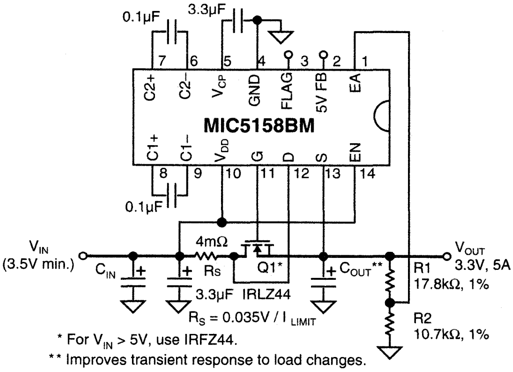
Minimum Size Copper Sense Resistors

by Jerry Kmetz

Overcurrent Sense Resistors

The Micrel MIC5156/7/8 Super LDO™ Regulator Controllers require a moderately low-value current-sensing resistor. Building the resistor from printed-circuit board (PCB) copper is attractive; arbitrary values can be provided inexpensively. The ever-shrinking world of electronic assemblies requires minimizing the physical size of this resistor, which can present a power-dissipation issue that must be resolved to provide a reliable solution. Making the resistor too small could cause excessive heat rise, leading to PCB trace damage or destruction (a fuse rather than a controlled resistor).

A demonstration board is available for evaluating the MIC5158. The circuit is designed to produce a 3.3V, 5A output from a 5V input. The design goal was to occupy as little PCB space as practical, so minimizing sense resistor area was important. In Figure 1 this resistor is shown as R_S.



* For V_{IN} > 5V, use IRFZ44.

** Improves transient response to load changes.

Figure 1. Regulator Circuit Diagram

Resistor Design Method

Three design equations provide a resistor that occupies the minimum area. This method considers current density as it relates to heat dissipation in a surface layer resistor.

$$(1)\quad \rho_s(T) = \frac{\rho\left[1 + \alpha\left(T_A + T_{RISE} - 20\right)\right]}{h}$$

where:

$\rho_s(T)$ = sheet resistance at elevated temp. (Ω/□)
ρ = 0.0172 = copper resistivity at 20°C (Ω • μm)
α = 0.00393 = temperature coefficient of ρ (per °C)
T_A = ambient temperature (°C)
T_{RISE} = allowed temperature rise (°C)
h = copper trace height (μm, see Table 1).

$$(2)\quad w = \frac{1000\, I_{MAX}}{\sqrt{\dfrac{T_{RISE} \div \theta_{SA}}{\rho_s(T)}}}$$

where:

w = minimum copper resistor trace width (mils)
I_{MAX} = maximum current for allowed T_{RISE} (A)
T_{RISE} = allowed temperature rise (°C)
θ_{SA} = resistor thermal resistance (°C • in²/W)
$\rho_s(T)$ = sheet resistance at elevated temp. (Ω/□).
Note: $\theta_{SA} \approx 55°C \bullet in^2/W$ (see Figure 3).

$$(3)\quad l = \frac{w\,R}{\rho_s(T)}$$

where:

l = resistor length (mils)
w = resistor width (mils)
R = desired resistance (Ω)
$\rho_s(T)$ = sheet resistance at elevated temp. (Ω/□).

Design Example

The 4-mΩ current-sensing resistor (R_S) of Figure 1 is designed as follows: (1) based on copper trace height and an allowed temperature rise for the resistor, calculate the sheet resistance (Equation 1); (2) based on the maximum current the resistor will have to sustain, calculate its minimum trace width (Equation 2); and (3) based on the desired resistance, calculate the required trace length (Equation 3).

Calculate Sheet Resistance

This design uses 1 oz/ft² weight PCB material, which has a copper thickness (trace height) of 35.6μm. See Table 1. It was also decided to allow the resistor to produce a 75°C temperature rise, which would place it at 100°C (worst case) when operating in a 25°C ambient environment. Then:

$$\rho_s(T) = \frac{\rho\left[1 + \alpha\left(T_A + T_{RISE} - 20\right)\right]}{h}$$

$$\rho_s(T) = \frac{0.0172\left[1 + 0.00393\,(25 + 75 - 20)\right]}{35.6}$$

$$\rho_s(T) = 635 \times 10^{-6}\ \Omega = 0.635\ m\Omega/\square.$$

Calculate Minimum Trace Width

The design example provides an output current of 5A. Because of resistor tolerance and the current-limit trip-point specification of the MIC5158 (0.028 to 0.042V), a trip-point of 8.75A is chosen. It was also decided to allow for as much as 10A of current during the sustained limiting condition. Then:

$$w = \frac{1000\ I_{MAX}}{\sqrt{\dfrac{T_{RISE} \div \theta_{SA}}{\rho_s(T)}}}$$

$$w = \frac{1000 \times 10}{\sqrt{\dfrac{75 \div 55}{635 \times 10^{-6}}}}$$

$w = 215.8$ mils ≈ 216 mils.

Calculate Required Trace Length

The length of a 4-mΩ resistor is determined via Equation 3 as follows:

$$l = \frac{w\,R}{\rho_s(T)}$$

$$l = \frac{216 \times 0.004}{635 \times 10^{-6}}$$

$l = 1360.6$ mils ≈ 1361 mils.

Resistor Layout

To avoid errors caused by voltage drops in the power leads, the resistor should include Kelvin sensing leads. Figure 2 illustrates a layout incorporating Kelvin sensing leads.

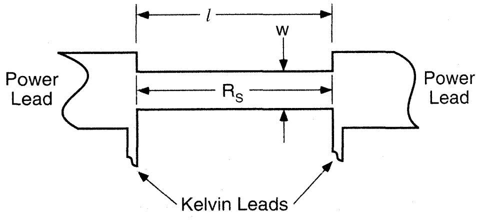


Figure 2. Typical Resistor Layout

Thermal Considerations

The above equations produce a resistance of the desired value at *elevated temperature*. It is important to consider resistance at temperature because copper has a high temperature coefficient. This design method is appropriate for current-sensing resistors because their accuracy should be optimized for the current they are intended to sense.

References

Table 1 and Figure 3 are provided as support and background information. Table 1 provides an input needed for Equation 1 (trace height), and Figure 3 indicates that 1 in^2 (645 mm^2) of solder-masked copper in still air has a thermal resistance of 55°C/W. Different situations; e.g., internal layers or plated copper, will have different thermal resistances. Other references include:

MIL-STD-275E: *Printed Wiring for Electronic Equipment.*

Application Hint 17: "Calculating P.C. Board Heat Sink Area For Surface Mount Packages," *Micrel 1995 Databook.*

Application Hint 21: "Sense Resistors for the Super LDO™ Regulator," *Micrel 1995 Databook.*

PCB Weight	**Copper Trace Height**	
(oz/in^2)	(mils)	(μm)
1/2	0.7	17.8
1	1.4	35.6
2	2.8	71.1
3	4.2	106.7

Table 1. Copper Trace Heights

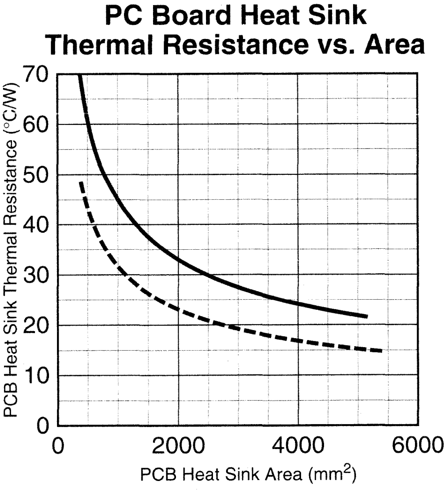


Figure 3. Thermal Resistance of Copper Trace Area

Table of Contents

Section 4: Switch-Mode Voltage Regulators

Switching Regulator Selection Guide

Device	Input Voltage Range	Preferred Topology	Maximum Switch Current	Control Mode	Maximum Frequency	Features				Package
						Front Edge Blanking	Shut-down or Sync (s)	Over Current Shutdown / Current Limit	Thermal Protection	
MIC2172 adjustable	3V to 40V	Boost	1.25A	Current	100kHz		(s)	•	•	P-DIP SOIC CerDIP
MIC3172 adjustable	3V to 40V	Boost	1.25A	Current	100kHz		•	•	•	
LM2574 3.3V, 5.0V, 12V, adjustable	4V to 40V	Buck	0.5A	Voltage	52kHz		•	•	•	P-DIP SOIC
MIC4574 3.3V, 5.0V, adjustable	4V to 24V	Buck	0.5A	Voltage	200kHz		•	•	•	P-DIP SOIC
LM2575 3.3V, 5.0V, 12V, adjustable	4V to 40V	Buck	1A	Voltage	52kHz		•	•	•	TO-220 TO-263* P-DIP SOIC
MIC4575 3.3V, 5.0V, adjustable	4V to 24V	Buck	1A	Voltage	200kHz		•	•	•	TO-220 TO-263*
LM2576 3.3V, 5.0V, 12V, adjustable	4V to 40V	Buck	3A	Voltage	52kHz		•	•	•	TO-220 TO-263*
MIC4576 3.3V, 5.0V, adjustable	4V to 24V	Buck	3A	Voltage	200kHz		•	•	•	TO-220 TO-263*
MIC3832/33	8.3V to 21V	Current-Fed Push-Pull	external FET	Current or Voltage	500kHz	•	•	•		P-DIP CerDIP SOIC
MIC38xC42/ 43/44/45 **MIC18C42/ 43/44/45**	8.4V to 20V	Flyback	external FET	Current	500kHz			•		P-DIP CerDIP SOIC

* Surface Mount Power Package

MIC2172/3172

100kHz 1.25A Switching Regulators

Preliminary Information

General Description

The MIC2172 and MIC3172 are complete 100kHz SMPS current-mode controllers with internal 65V 1.25A power switches. The MIC2172 features external frequency synchronization or frequency adjustment, while the MIC3172 features an enable/shutdown control input.

Although primarily intended for voltage step-up applications, the floating switch architecture of the MIC2172/3172 makes it practical for step-down, inverting, and Cuk configurations as well as isolated topologies.

Operating from 3V to 40V, the MIC2172/3172 draws only 7mA of quiescent current making it attractive for battery operated supplies.

The MIC3172 is for applications that require on/off control of the regulator. The MIC3172 is externally shutdown by applying a TTL low signal to EN (enable). When disabled, the MIC3172 draws only leakage current (typically less than 1µA). EN must be high for normal operation. For applications not requiring control, EN must be tied to V_{IN} or TTL high.

The MIC2172 is for applications requiring two or more SMPS regulators that operate from the same input supply. The MIC2172 features a SYNC input which allows locking of its internal oscillator to an external reference. This makes it possible to avoid the audible beat frequencies that result from the unequal oscillator frequencies of independent SMPS regulators.

A reference signal can be supplied by one MIC2172 designated as a master. To insure locking of the slave's oscillators, the reference oscillator frequency must be higher than the slave's. The master MIC2172's oscillator frequency is increased up to 135kHz by connecting a resistor from SYNC to ground (see applications information).

The MIC2172/3172 is available in an 8-pin plastic DIP or SOIC for –40°C to +85°C operation and the 8-pin ceramic DIP for –55°C to +125°C operation.

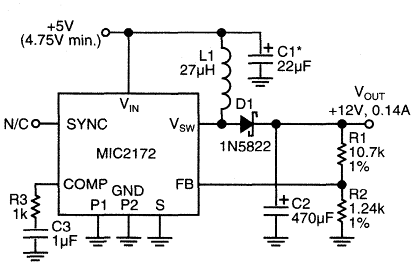
Features

- 1.25A, 65V internal switch rating
- 3V to 40V input voltage range
- Current-mode operation
- Internal cycle-by-cycle current limit
- Thermal shutdown
- Low external parts count
- Operates in most switching topologies
- 7mA quiescent current (operating)
- <1µA quiescent current, shutdown mode (MIC3172)
- TTL shutdown compatibility (MIC3172)
- External frequency synchronization (MIC2172)
- External frequency trim (MIC2172)
- Fits most LT1172 sockets (see applications info)

Applications

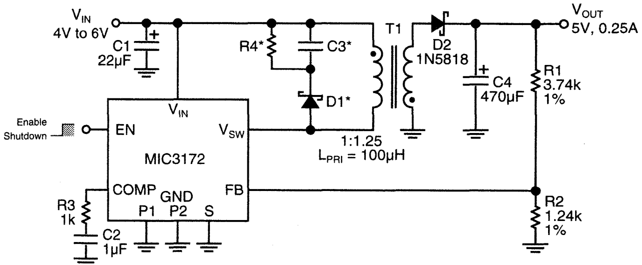
- Laptop/palmtop computers
- Toys
- Hand-held instruments
- Off-line converter up to 50W
  (requires external power switch)
- Predriver for higher power capability
- Master/slave configurations (MIC2172)

Typical Applications



* Locate near MIC2172 when supply leads > 2″

Figure 1.
MIC2172 5V to 12V Boost Converter



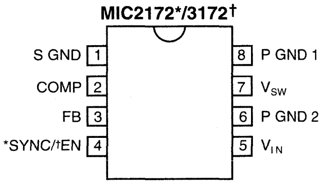
* Optional voltage clipper (may be req'd if T1 leakage inductance too high)

Figure 2.
MIC3172 5V Flyback Converter

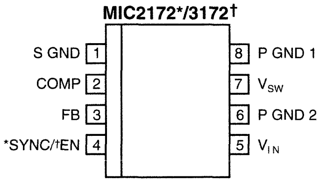
Ordering Information

Part Number	Temperature Range	Package
MIC2172BN	–40°C to +85°C	8-pin plastic DIP
MIC2172BM	–40°C to +85°C	8-lead SOIC
MIC3172BN	–40°C to +85°C	8-pin plastic DIP
MIC3172BM	–40°C to +85°C	8-lead SOIC

Pin Configuration



8-lead DIP (N)



8-lead SOIC (M)

Pin Description

Pin Number	Pin Name	Pin Function
1	S GND	Signal Ground: Internal analog circuit ground. Connect directly to the input filter capacitor for proper operation (see applications info). Keep separate from power grounds.
2	COMP	Frequency Compensation: Output of transconductance type error amplifier. Primary function is for loop stabilization. Can also be used for output voltage soft-start and current limit tailoring.
3	FB	Feedback: Inverting input of error amplifier. Connect to external resistive divider to set power supply output voltage.
4 (MIC2172)	SYNC	Synchronization/Frequency Adjust: Capacitively coupled input signal greater than device's free running frequency (up to 135kHz) will lock device's oscillator on falling edge. Oscillator frequency can be trimmed up to 135kHz by adding a resistor to ground. If unused, pin must float (no connection).
4 (MIC3172)	EN	Enable: Apply TTL high or connect to V_{IN} to enable the regulator. Apply TTL low or connect to ground to disable the regulator. Device draws only leakage current (<1µA) when disabled.
5	V_{IN}	Supply Voltage: 3.0V to 40V
6	P GND 2	Power Ground #2: One of two NPN power switch emitters with 0.3Ω current sense resistor in series. Required. Connect to external inductor or input voltage ground depending on circuit topology.
7	V_{SW}	Power Switch Collector: Collector of NPN switch. Connect to external inductor or input voltage depending on circuit topology.
8	P GND 1	Power Ground #1: One of two NPN power switch emitters with 0.3Ω current sense resistor in series. Optional. For maximum power capability connect to P GND 2. Floating pin reduces current limit by a factor of two.

Absolute Maximum Ratings MIC2172

Input Voltage	40V
Switch Voltage	65V
Sync Current	50mA
Feedback Voltage (Transient, 1ms)	±15V
Operating Temperature Range	
8-pin PDIP	–40 to +85°C
8-pin SOIC	–40 to +85°C
8-pin CerDIP	–55 to +125°C

Junction Temperature	–55°C to 150°C
Thermal Resistance	
θ_{JA} 8-pin PDIP	130°C/W
θ_{JA} 8-pin SOIC	120°C/W
θ_{JA} 8-pin CerDIP	100°C/W
Storage Temperature	–65°C to 150°C
Soldering (10 sec.)	300°C

Electrical Characteristics MIC2172 Note 1. Unless otherwise specified, V_{IN} = 5V.

Parameter	Conditions	Min	Typ	Max	Units
Reference Section	Pin 2 tied to pin 3				
Feedback Voltage (V_{FB})		1.220 **1.214**	1.240	1.264 **1.274**	V V
Feedback Voltage Line Regulation	3V ≤ V_{IN} ≤ 40V			**0.03**	%/V
Feedback Bias Current (I_{FB})			310	750 **1100**	nA nA
Error Amplifier Section					
Transconductance ($\Delta I_{COMP}/\Delta V_{FB}$)	ΔI_{COMP} = ±25µA	3.0 **2.4**	3.9	6.0 **7.0**	µA/mV µA/mV
Voltage Gain ($\Delta V_{COMP}/\Delta V_{FB}$)	0.9V ≤ V_{COMP} ≤ 1.4V	500	800	2000	V/V
Output Current	V_{COMP} = 1.5V	125 **100**	175	350 **400**	µA µA
Output Swing	High Clamp, V_{FB} = 1V Low Clamp, V_{FB} = 1.5V	1.8 0.25	2.1 0.35	2.3 0.52	V V
Compensation Pin Threshold	Duty Cycle = 0	0.8 **0.6**	0.9	1.08 **1.25**	V V
Output Switch Section					
ON Resistance	I_{SW} = 1A, V_{FB} = 0.8V		0.76	1 **1.1**	Ω Ω
Current Limit	Duty Cycle = 50%, T_J ≥ 25°C Duty Cycle = 50%, T_J < 25°C Duty Cycle = 80% **Note 2**	**1.25** **1.25** **1**		**3** **3.5** **2.5**	A A A
Breakdown Voltage (BV)	3V ≤ V_{IN} ≤ 40V I_{SW} = 5mA	**65**	75		V

NNParameter	Conditions	Min	Typ	Max	Units
Oscillator Section					
Frequency (f_O)		88 **85**	100	112 **115**	kHz kHz
Duty Cycle [δ(max)]		80	89	95	%
Sync Coupling Capacitor Required for Frequency Lock	$V_{PP} = 3.0V$ $V_{PP} = 40V$	22 2.2	51 4.7	120 10	pF pF
Peak-to-Peak Voltage Required for Frequency Lock	$C_{COUPLING} = 12pF$	2.2	12	30	V
Input Supply Voltage Section					
Minimum Operating Voltage			2.7	**3.0**	V
Quiescent Current (I_Q)	$3V \le V_{IN} \le 40V$, $V_{COMP} = 0.6V$, $I_{SW} = 0$		7	9	mA
Supply Current Increase (ΔI_{IN})	$\Delta I_{SW} = 1A$, $V_{COMP} = 1.5V$		9	20	mA

Bold type denotes specifications applicable to the full operating temperature range.

Note 1 Devices are ESD sensitive. Handling precautions required.

Note 2 For duty cycles (δ) between 50% and 95%, minimum guaranteed switch current is given by $I_{CL} = 0.833\ (2-\delta)$ for the MIC3172.

Absolute Maximum Ratings MIC3172

Input Voltage	40V
Switch Voltage	65V
Enable Voltage	40V
Feedback Voltage (Transient, 1ms)	±15V
Operating Temperature Range	
8-pin PDIP	–40 to +85°C
8-pin SOIC	–40 to +85°C
8-pin CerDIP	–55 to +125°C
Junction Temperature	–55°C to 150°C
Thermal Resistance	
θ_{JA} 8-pin PDIP	130°C/W
θ_{JA} 8-pin SOIC	120°C/W
θ_{JA} 8-pin CerDIP	100°C/W
Storage Temperature	–65°C to 150°C
Soldering (10 sec.)	300°C

Electrical Characteristics MIC3172 Note 1. *Unless otherwise specified, $V_{IN} = 5V$.*

Parameter	Conditions	Min	Typ	Max	Units
Reference Section	Pin 2 tied to pin 3				
Feedback Voltage (V_{FB})		1.224 **1.214**	1.240	1.264 **1.274**	V V
Feedback Voltage Line Regulation	$3V \le V_{IN} \le 40V$		0.07		%/V
Feedback Bias Current (I_{FB})			310	750 **1100**	nA nA

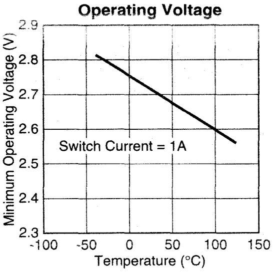
Parameter	Conditions	Min	Typ	Max	Units
Error Amplifier Section					
Transconductance ($\Delta I_{COMP}/\Delta V_{FB}$)	$\Delta I_{COMP} = \pm 25\mu A$	3.0 **2.4**	3.9	6.0 **7.0**	µA/mV µA/mV
Voltage Gain ($\Delta V_{COMP}/\Delta V_{FB}$)	$0.9V \le V_{COMP} \le 1.4V$	500	800	2000	V/V
Output Current	$V_{COMP} = 1.5V$	125 **100**	175	350 **400**	µA µA
Output Swing	High Clamp, $V_{FB} = 1V$ Low Clamp, $V_{FB} = 1.5V$	1.8 0.25	2.1 0.35	2.3 0.52	V V
Compensation Pin Threshold	Duty Cycle = 0	0.8 **0.6**	0.9	1.08 **1.25**	V V
Output Switch Section					
ON Resistance	$I_{SW} = 1A$, $V_{FB} = 0.8V$		0.76	1 **1.1**	Ω Ω
Current Limit	Duty Cycle = 50%, $T_J \ge 25°C$ Duty Cycle = 50%, $T_J < 25°C$ Duty Cycle = 80% **Note 2**	**1.25** **1.25** **1**		**3** **3.5** **2.5**	A A A
Breakdown Voltage (BV)	$3V \le V_{IN} \le 40V$ $I_{SW} = 5mA$	**65**	75		V
Oscillator Section					
Frequency (f_O)		88 **85**	100	112 **115**	kHz kHz
Duty Cycle [δ(max)]		80	89	95	%
Input Supply Voltage Section and Enable Section					
Minimum Operating Voltage			2.7	**3.0**	V
Quiescent Current (I_Q)	$3V \le V_{IN} \le 40V$, $V_{COMP} = 0.6V$, $I_{SW} = 0$ Shutdown, $V_{EN} = 0V$		7 0.1	9 **5**	mA µA
Quiescent Current Increase (ΔI_{IN})	$\Delta I_{SW} = 1A$, $V_{COMP} = 1.5V$		9	20	mA
Enable Input Threshold		**0.4**	1.2	**2.4**	V
Enable Input Current	$V_{EN} = 0V$ $V_{EN} = 2.4V$	–1	0 2	1 **10**	µA µA

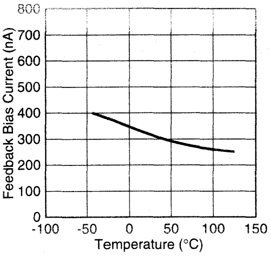
Bold type denotes specifications applicable to the full operating temperature range.

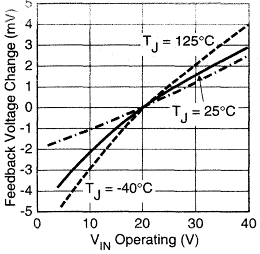
Note 1 Devices are ESD sensitive. Handling precautions required.

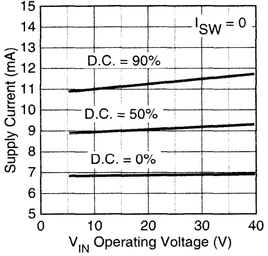
Note 2 For duty cycles (δ) between 50% and 95%, minimum guaranteed switch current is given by $I_{CL} = 0.833\,(2-\delta)$ for the MIC3172.

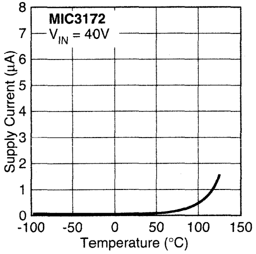
Typical Performance Characteristics

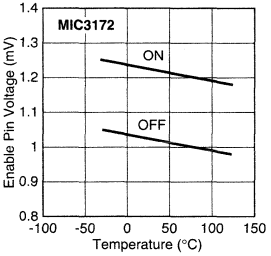

MIC2172 Minimum Operating Voltage

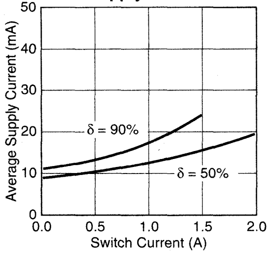

Feedback Bias Current

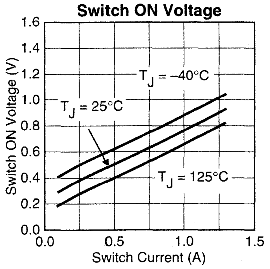

Feedback Voltage Line Regulation

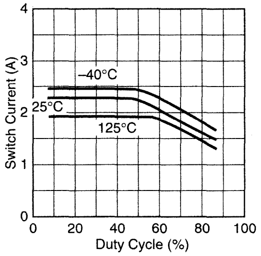

Supply Current

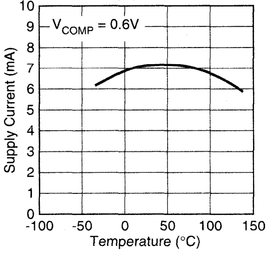

Supply Current (Shutdown Mode)

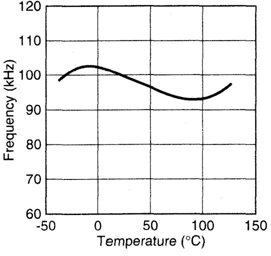

Enable Thresholds

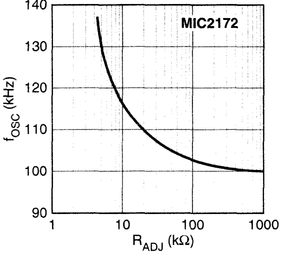

Supply Current


Switch ON Voltage

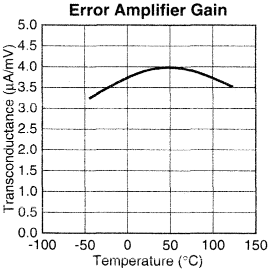

Current Limit

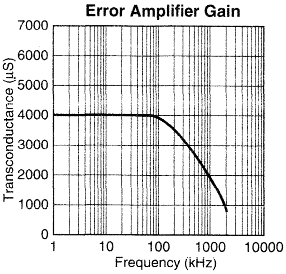

Supply Current

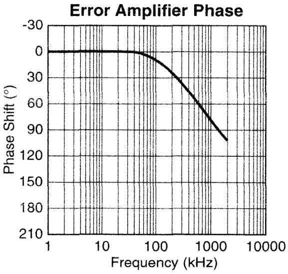

Oscillator Frequency


Oscillator Frequency

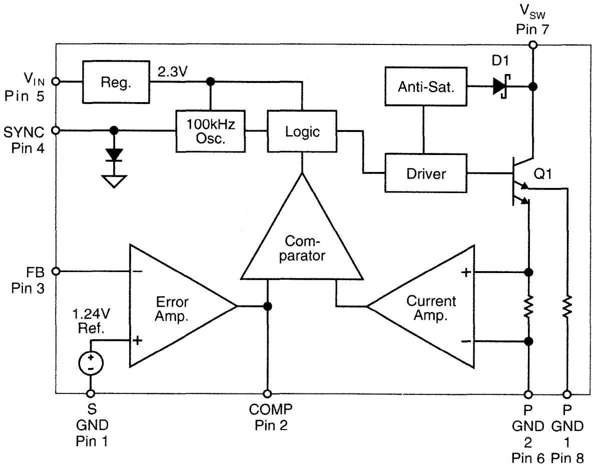
Typical Performance Characteristics



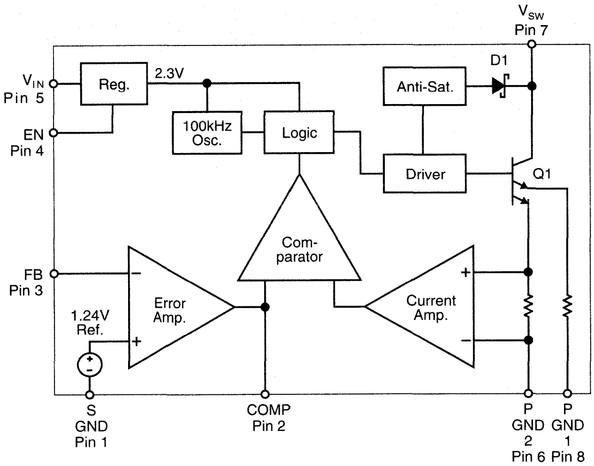




Block Diagram MIC2172



Block Diagram MIC3172



Functional Description

Refer to "Block Diagram MIC2172" and "Block Diagram MIC3172."

Internal Power

The MIC2172/3172 operates when V_{IN} is ≥ 2.6V (and $V_{EN} \geq 2.0V$ for the MIC3172). An internal 2.3V regulator supplies biasing to all internal circuitry including a precision 1.24V band gap reference.

The enable control (MIC3172 only) enables or disables the internal regulator which supplies power to all other internal circuitry.

PWM Operation

The 100kHz oscillator generates a signal with a duty cycle of approximately 90%. The current-mode comparator output is used to reduce the duty cycle when the current amplifier output voltage exceeds the error amplifier output voltage. The resulting PWM signal controls a driver which supplies base current to output transistor Q1.

Current Mode Advantages

The MIC2172/3172 operates in current mode rather than voltage mode. There are three distinct advantages to this technique. Feedback loop compensation is greatly simplified because inductor current sensing removes a pole from the closed loop response. Inherent cycle-by-cycle current limiting greatly improves the power switch reliability and provides automatic output current limiting. Finally, current-mode operation provides automatic input voltage feed forward which prevents instantaneous input voltage changes from disturbing the output voltage setting.

Anti-Saturation

The anti-saturation diode (D1) increases the usable duty cycle range of the MIC2172/3172 by eliminating the base to collector stored charge which would delay Q1's turnoff.

Compensation

Loop stability compensation of the MIC2172/3172 can be accomplished by connecting an appropriate network from either COMP to circuit ground (Typical Applications) or COMP to FB.

The error amplifier output (COMP) is also useful for soft start and current limiting. Because the error amplifier output is a transconductance type, the output impedance is relatively high which means the output voltage can be easily clamped or adjusted externally.

Applications Information

Using the MIC3172 Enable Control (New Designs)

For new designs requiring enable/shutdown control, connect EN to a TTL or CMOS control signal (figure 3). The very low driver current requirement ensures compatibility regardless of the driver or gate used.

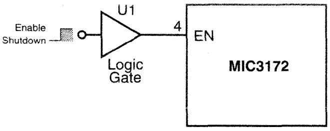


Figure 3. MIC3172 TTL Enable/Shutdown

Using the MIC3172 in LT1172 Applications

The MIC3172 can be used in most original LT1172 applications by adapting the MIC3172's enable/shutdown feature to the existing LT1172 circuit.

Unlike the LT1172 which can be shutdown by reducing the voltage on pin 2 (V_C) below 0.15V, the MIC3172 has a dedicated enable/shutdown pin. To replace the LT1172 with the MIC3172, determine if the LT1172's shutdown feature is used.

Circuits without Shutdown

If the shutdown feature is not being used, connect EN to V_{IN} to continuously enable the MIC3172 or use an MIC2172 with SYNC open (figure 4).

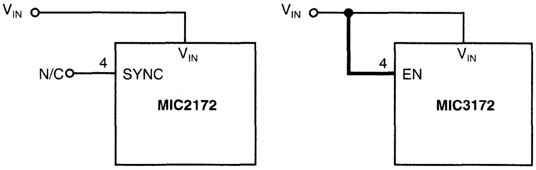


Figure 4. MIC2172/3172 Always Enabled

Circuits with Shutdown

If shutdown was used in the original LT1172 application, connect EN to a logic gate that produces a TTL logic-level output signal that matches the shutdown signal. The MIC3172 will be enabled by a logic-high input and shutdown with a logic-low input (figure 5). The actual components performing the functions of U1 and Q1 may vary according to the original application.

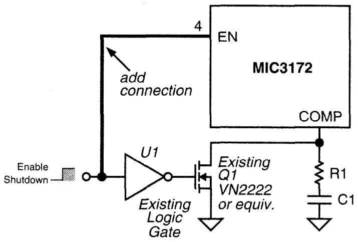


Figure 5. Adapting to the LT1172 Socket

By using the MIC3172, U1 and Q1 shown in figure 5 can be eliminated, reducing the total components count.

Synchronizing the MIC2172

Using several unsynchronized switching regulators in the same circuit will cause beat frequencies to appear on the inputs and outputs. These beat frequencies can be very low making them difficult to filter.

Micrel's MIC2172 can be synchronized to a single master frequency avoiding the possibility of undesirable beat frequencies in multiple regulator circuits. The master frequency can be an external oscillator or a designated master MIC2172. The master frequency should be 1.05 to 1.20 times the slave's 100kHz nominal frequency to guarantee synchronization.

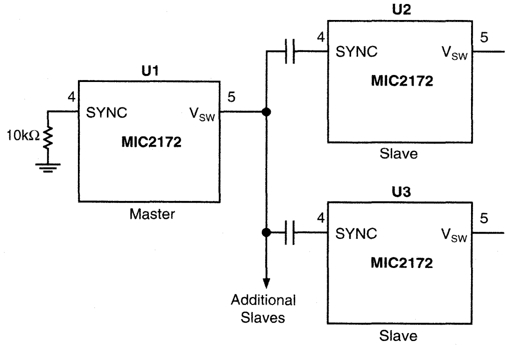


Figure 6. Master/Slave Synchronization

Figure 6 shows a typical application where several MIC2172s operate from the same supply voltage. U1's oscillator frequency is increased above U2's and U3's by connecting a resistor from SYNC to ground. U2-SYNC and U3-SYNC are capacitively coupled to the master's output (V_{SW}). The slaves lock to the negative (falling edge) of U1's output waveform.

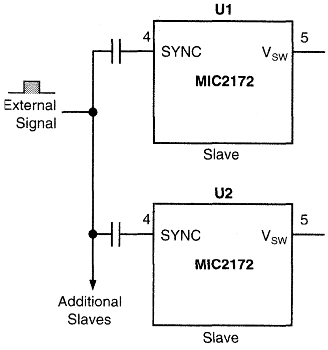


Figure 7. External Synchronization

Care must be exercised to insure that the master MIC2172 is always operating in continuous mode.

Figure 7 shows how one or more MIC2172s can be locked to an external reference frequency. The slaves lock to the negative (falling edge) of the external reference waveform.

Soft Start

A diode-coupled capacitor from COMP to circuit ground slows the output voltage rise at turn on (figure 8).

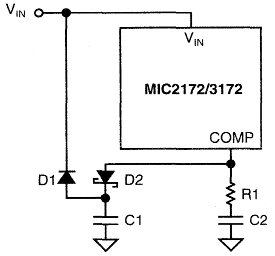
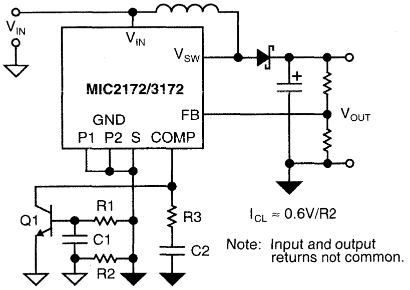


Figure 8. Soft Start

The additional time it takes for the error amplifier to charge the capacitor corresponds to the time it takes the output to reach regulation. Diode D1 discharges C1 when V_{IN} is removed.

Current Limit

For designs demanding less output current than the MIC2172/3172 is capable of delivering, P GND 1 can be left open reducing the current capability of Q1 by one-half.



$I_{CL} \approx 0.6V/R2$

Note: Input and output returns not common.

Figure 9. Current Limit

Alternatively, the maximum current limit of the MIC2172/3172 can be reduced by adding a voltage clamp to the COMP output (figure 9). This feature can be useful in applications requiring either a complete shutdown of Q1's switching action or a form of current fold-back limiting. This use of the COMP output does not disable the oscillator, amplifiers or other circuitry, therefore the supply current is never less than approximately 5mA.

Thermal Management

Although the MIC2172/3172 family contains thermal protection circuitry, for best reliability, avoid prolonged operation with junction temperatures near the rated maximum.

The junction temperature is determined by first calculating the power dissipation of the device. For the MIC2172/3172, the total power dissipation is the sum of the device operating losses and power switch losses.

The device operating losses are the dc losses associated with biasing all of the internal functions plus the losses of the power switch driver circuitry. The dc losses are calculated from the supply voltage (V_{IN}) and device supply current (I_Q). The MIC2172/3172 supply current is almost constant regardless of the supply voltage (see "Electrical Characteristics"). The driver section losses (not including the switch) are a function of supply voltage, power switch current, and duty cycle.

$$P_{(bias+driver)} = \left(V_{IN}\, I_Q\right) + V_{IN}\left[I_{SW}\left(\frac{0.004+\delta}{50}\right)\right]$$

where:

$P_{(bias+driver)}$ = device operating losses
V_{IN} = supply voltage
I_Q = quiescent supply current
I_{SW} = power switch current
(see " Design Hints: Switch Current Calculations")
δ = duty cycle

$$\delta = \frac{V_{OUT} + V_F - V_{IN}}{V_{OUT} + V_F}$$

V_{OUT} = output voltage
V_F = D1 forward voltage drop

As a practical example refer to figure 1.

$V_{IN} = 5.0V$
$I_Q = 0.006A$
$I_{SW} = 0.625A$
$\delta = 60\% \ (0.6)$

Then:

$$P_{(bias+driver)} = (5 \times 0.006) + 5\left[0.625\left(\frac{0.004+0.6}{50}\right)\right]$$

$$P_{(bias+driver)} = 0.068W$$

Power switch dissipation calculations are greatly simplified by making two assumptions which are usually fairly accurate. First, the majority of losses in the power switch are due to on-losses. To find these losses, assign a resistance value to the collector/emitter terminals of the device using the saturation voltage versus collector current curves (see Typical Performance Characteristics). Power switch losses are calculated by modeling the switch as a resistor with the switch duty cycle modifying the average power dissipation.

$$P_{SW} = (I_{SW})^2 R_{SW}\, \delta$$

From the Typical performance Characteristics:

$$R_{SW} = 1\Omega$$

Then:

$$P_{SW} = (0.625)^2 \times 1 \times 0.6$$
$$= 0.234W$$
$$P_{(total)} = 0.068 + 0.234$$
$$P_{(total)} = 0.302W$$

The junction temperature for any semiconductor is calculated using the following:

$$T_J = T_A + P_{(total)}\,\theta_{JA}$$

Where:

T_J = junction temperature
T_A = ambient temperature (maximum)
$P_{(total)}$ = total power dissipation
θ_{JA} = junction to ambient thermal resistance

For the practical example:

T_A = 70°C
θ_{JA} = 130°C/W (for plastic DIP)

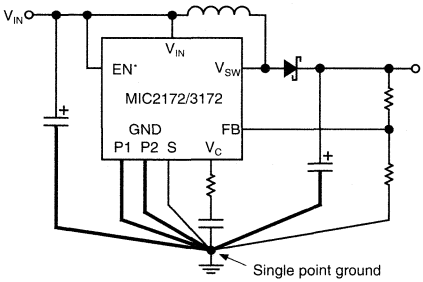
Then:

$$T_J = 70 + 0.30 \times 130$$
$$T_J = 109°C$$

This junction temperature is below the rated maximum of 150°C.

Grounding

Refer to figure 10. Heavy lines indicate high current paths.



* MIC3172 only

Figure 10. Single Point Ground

A single point ground is strongly recommended for proper operation.

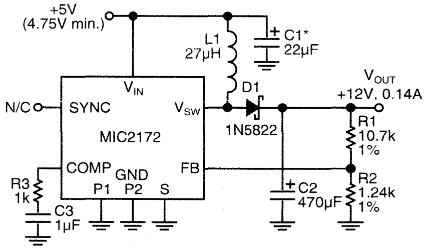
The signal ground, compensation network ground, and feedback network connections are sensitive to minor voltage variations. The input and output capacitor grounds and power ground conductors will exhibit voltage drop when carrying large currents. Keep the sensitive circuit ground traces separate from the power ground traces. Small voltage variations applied to the sensitive circuits can prevent the MIC2172/3172 or any switching regulator from functioning properly.

Applications and Design Hints

Access to both the collector and emitter(s) of the NPN power switch makes the MIC2172/3172 extremely versatile and suitable for use in most PWM power supply topologies.

Boost Conversion

Refer to figure 11 for a typical boost conversion application where a +5V logic supply is available but +12V at 0.14A is required.



* Locate near MIC2172 when supply leads > 2″

Figure 11. 5V to 12V Boost Converter

The first step in designing a boost converter is determining whether inductor L1 will cause the converter to operate in either continuous or discontinuous mode. Discontinuous mode is preferred because the feedback control of the converter is simpler.

When L1 discharges its current completely during the MIC2172/3172's off-time, it is operating in discontinuous mode.

L1 is operating in continuous mode if it does not discharge completely before the MIC2172/3172 power switch is turned on again.

Discontinuous Mode Design

Given the maximum output current, solve equation (1) to determine whether the device can operate in discontinuous mode without initiating the internal device current limit.

$$(1) \quad I_{OUT} \le \frac{\left(\frac{I_{CL}}{2}\right) V_{IN}\,\delta}{V_{OUT}}$$

$$(1a) \quad \delta = \frac{V_{OUT} + V_F - V_{IN}}{V_{OUT} + V_F}$$

Where:

I_{CL} = internal switch current limit
I_{CL} = 1.25A when $\delta < 50\%$
$I_{CL} = 0.833\,(2 - \delta)$ when $\delta \ge 50\%$
(Refer to Electrical Characteristics.)
I_{OUT} = maximum output current
V_{IN} = minimum input voltage
δ = duty cycle

V_{OUT} = required output voltage

V_F = D1 forward voltage drop

For the example in figure 11.

$I_{OUT} = 0.14A$

$I_{CL} = 1.147A$

$V_{IN} = 4.75V$ (minimum)

$\delta = 0.623$

$V_{OUT} = 12.0V$

$V_F = 0.6V$

Then:

$$I_{OUT} \le \frac{\left(\frac{1.147}{2}\right) \times 4.75 \times 0.623}{12}$$

$I_{OUT} \le 0.141A$

This value is greater than the 0.14A output current requirement so we can proceed to find the inductance value of L1.

$$\text{(2)} \quad L1 \le \frac{(V_{IN}\ \delta)^2}{2\ P_{OUT}\ f_{SW}}$$

Where:

$P_{OUT} = 12 \times 0.14 = 1.68W$

$f_{SW} = 1\times10^5Hz$ (100kHz)

For our practical example:

$$L1 \le \frac{(4.75 \times 0.623)^2}{2 \times 1.68 \times 1\times10^5}$$

$\le 26.062\mu H$ (use $27\mu H$)

Equation (3) solves for L1's maximum current value.

$$\text{(3)} \quad I_{L1(peak)} = \frac{V_{IN}\ T_{ON}}{L1}$$

Where:

$T_{ON} = \delta / f_{SW} = 6.23\times10^{-6}$ sec

$$I_{L1(peak)} = \frac{4.75 \times 6.23\times10^{-6}}{27\times10^{-6}}$$

$I_{L1(peak)} = 1.096A$

Use a 27µH inductor with a peak current rating of at least 1.4A.

Flyback Conversion

Flyback converter topology may be used in low power applications where voltage isolation is required or whenever the input voltage can be less than or greater than the output voltage. As with the step-up converter the inductor (transformer primary) current can be continuous or discontinuous. Discontinuous operation is recommended.

Figure 12 shows a practical flyback converter design using the MIC3172.

Switch Operation

During Q1's on time (Q1 is the internal NPN transistor—see block diagrams), energy is stored in T1's primary inductance. During Q1's off time, stored energy is partially discharged into C4 (output filter capacitor). Careful selection of a low ESR capacitor for C4 may provide satisfactory output ripple voltage making additional filter stages unnecessary.

C1 (input capacitor) may be reduced or eliminated if the MIC3172 is located near a low impedance voltage source.

Output Diode

The output diode allows T1 to store energy in its primary inductance (D2 nonconducting) and release energy into C4 (D2 conducting). The low forward voltage drop of a Schottky diode minimizes power loss in D2.

Frequency Compensation

A simple frequency compensation network consisting of R3 and C2 prevents output oscillations.

High impedance output stages (transconductance type) in the MIC2172/3172 often permit simplified loop-stability solutions to be connected to circuit ground, although a more conventional technique of connecting the components from the error amplifier output to its inverting input is also possible.

Voltage Clipper

Care must be taken to minimize T1's leakage inductance, otherwise it may be necessary to incorporate the voltage clipper consisting of D1, R4, and C3 to avoid second breakdown (failure) of the MIC3172's power NPN Q1.

Enable/Shutdown

The MIC3172 includes the enable/shutdown feature. When the device is shutdown, total supply current is less than 1µA. This is ideal for battery applications where portions of a system are powered only when needed. If this feature is not required, simply connect EN to V_{IN} or to a TTL high voltage.

Discontinuous Mode Design

When designing a discontinuous flyback converter, first determine whether the device can safely handle the peak primary current demand placed on it by the output power. Equation (8) finds the maximum duty cycle required for a given input voltage and output power. If the duty cycle is greater than 0.8, discontinuous operation cannot be used.

$$\text{(8)} \quad \delta \ge \frac{2\ P_{OUT}}{I_{CL}\ V_{IN(min)}}$$

For a practical example let:

$P_{OUT} = 5.0V \times 0.25A = 1.25W$

$V_{IN} = 4.0V$ to $6.0V$

$I_{CL} = 1.25A$ when $\delta < 50\%$

$0.833\ (2 - \delta)$ when $\delta \ge 50\%$

Then:

$$\delta \geq \frac{2 \times 1.25}{1.25 \times 4}$$

$\delta \geq 0.5$ (50%) Use 0.55.

The slightly higher duty cycle value is used to overcome circuit inefficiencies. A few iterations of equation (8) may be required if the duty cycle is found to be greater than 50%.

Calculate the maximum transformer turns ratio **a**, or N_{PRI}/N_{SEC}, that will guarantee safe operation of the MIC2172/3172 power switch.

$$\text{(9)} \quad \mathbf{a} \leq \frac{V_{CE}\,F_{CE} - V_{IN(max)}}{V_{SEC}}$$

Where:

a = transformer maximum turns ratio

V_{CE} = power switch collector to emitter maximum voltage

F_{CE} = safety derating factor (0.8 for most commercial and industrial applications)

$V_{IN(max)}$ = maximum input voltage

V_{SEC} = transformer secondary voltage ($V_{OUT} + V_F$)

For the practical example:

V_{CE} = 65V max. for the MIC2172/3172

$F_{CE} = 0.8$

$V_{SEC} = 5.6V$

Then:

$$\mathbf{a} \leq \frac{65 \times 0.8 - 6.0}{5.6}$$

$\mathbf{a} \leq 8.2143$

Next, calculate the maximum primary inductance required to store the needed output energy with a power switch duty cycle of 55%.

$$\text{(10)} \quad L_{PRI} \leq \frac{0.5\,f_{SW}\,{V_{IN(min)}}^2\,{T_{ON}}^2}{P_{OUT}}$$

Where:

L_{PRI} = maximum primary inductance

f_{SW} = device switching frequency (100kHz)

$V_{IN(min)}$ = minimum input voltage

T_{ON} = power switch on time

Then:

$$L_{PRI} \leq \frac{0.5 \times 1{\times}10^5 \times 4.0^2 \left(5.5{\times}10^{-6}\right)^2}{1.25}$$

$L_{PRI} \leq 19.23\mu H$

Use an 18µH primary inductance to overcome circuit inefficiencies.

To complete the design the inductance value of the secondary is found which will guarantee that the energy stored in the transformer during the power switch on time will be completed discharged into the output during the off-time. This is necessary when operating in discontinuous-mode.

$$\text{(11)} \quad L_{SEC} \leq \frac{0.5\,f_{SW}\,{V_{SEC}}^2\,{T_{OFF}}^2}{P_{OUT}}$$

Where:

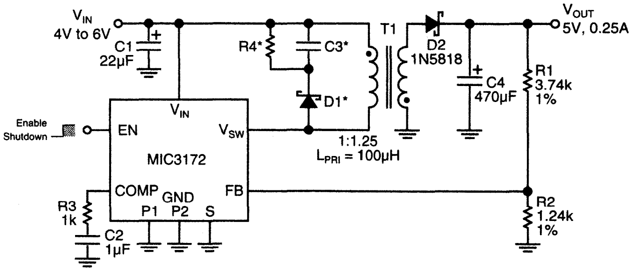
L_{SEC} = maximum secondary inductance

T_{OFF} = power switch off time

Then:

$$L_{SEC} \leq \frac{0.5 \times 1{\times}10^5 \times 5.6^2 \times \left(4.5{\times}10^{-6}\right)^2}{1.25}$$

$L_{SEC} \leq 25.4\mu H$



* Optional voltage clipper (may be req'd if T1 leakage inductance too high)

Figure 12. MIC3172 5V 0.25A Flyback Converter

Finally, recalculate the transformer turns ratio to insure that it is less than the value earlier found in equation (9).

$$(12)\quad \mathbf{a} \le \sqrt{\frac{L_{PRI}}{L_{SEC}}}$$

Then:

$$\mathbf{a} \le \sqrt{\frac{1.8 \times 10^{-5}}{2.54 \times 10^{-5}}}$$

$\mathbf{a} \le 0.84$ Use 0.8 (same as 1:1.25).

This ratio is less than the ratio calculated in equation (9). When specifying the transformer it is necessary to know the primary peak current which must be withstood without saturating the transformer core.

$$(13)\quad I_{PEAK(pri)} = \frac{V_{IN(min)}\, T_{ON}}{L_{PRI}}$$

So:

$$I_{PEAK(pri)} = \frac{4.0 \times 5.5 \times 10^{-6}}{18\mu H}$$

$$I_{PEAK(pri)} = 1.22A$$

Now find the minimum reverse voltage requirement for the output rectifier. This rectifier must have an average current rating greater than the maximum output current of 0.25A.

$$(14)\quad V_{BR} \ge \frac{V_{IN(max)} + \left(V_{OUT}\,\mathbf{a}\right)}{F_{BR}\,\mathbf{a}}$$

Where:

V_{BR} = output rectifier maximum peak reverse voltage rating

$\mathbf{a}$ = transformer turns ratio (0.8)

F_{BR} = reverse voltage safety derating factor (0.8)

Then:

$$V_{BR} \ge \frac{6.0 + (5.0 \times 0.8)}{0.8 \times 0.8}$$

$$V_{BR} \ge 15.625V$$

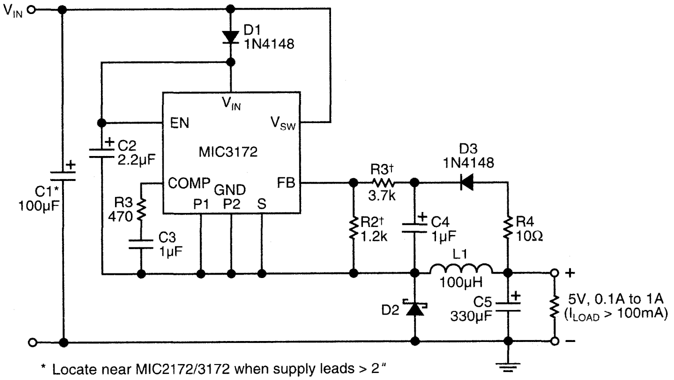
A 1N5817 will safely handle voltage and current requirements in this example.

Forward Converters

Micrel's MIC2172/3172 can be used in several circuit configurations to generate an output voltage which is less than the input voltage (buck or step-down topology). Figure 13 shows the MIC3172 in a voltage step-down application. Because of the internal architecture of these devices, more external components are required to implement a step-down regulator than with other devices offered by Micrel (refer to the LM257x or LM457x family of buck switchers). However, for step-down conversion requiring a transformer (forward), the MIC2172/3172 is a good choice.

A 12V to 5V step-down converter using transformer isolation (forward) is shown in figure 14. Unlike the isolated flyback converter which stores energy in the primary inductance during the controller's on-time and releases it to the load during the off-time, the forward converter transfers energy to the output during the on-time, using the off-time to reset the transformer core. In the application shown, the transformer core is reset by the tertiary winding discharging T1's peak magnetizing current through D2.

For most forward converters the duty cycle is limited to 50%, allowing the transformer flux to reset with only two times the input voltage appearing across the power switch. Although during normal operation this circuit's duty cycle is well below



* Locate near MIC2172/3172 when supply leads > 2″

† R3/R2 sets output voltage

Figure 13. Step-Down or Buck Converter

50%, the MIC2172 (and MIC3172) has a maximum duty cycle capability of 90%. If 90% was required during operation (start-up and high load currents), a complete reset of the transformer during the off-time would require the voltage across the power switch to be ten times the input voltage. This would limit the input voltage to 6V or less for forward converter applications.

To prevent core saturation, the application given here uses a duty cycle limiter consisting of Q1, C4 and R3. Whenever the MIC3172 exceeds a duty cycle of 50%, T1's reset winding current turns Q1 on. This action reduces the duty cycle of the MIC3172 until T1 is able to reset during each cycle.

Fluorescent Lamp Supply

An extremely useful application of the MIC3172 is generating an ac voltage for fluorescent lamps used as liquid crystal display back lighting in portable computers.

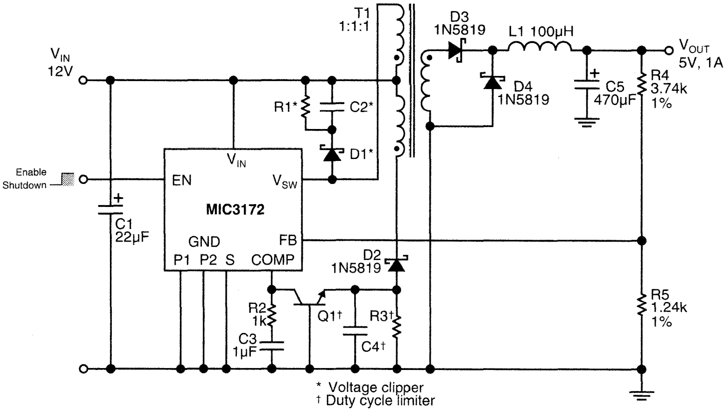
Figure 15 shows a complete power supply for lighting a fluorescent lamp. Transistors Q1 and Q2 together with capacitor C2 form a Royer oscillator. The Royer oscillator generates a sine wave whose frequency is determined by the series L/C circuit comprised of T1 and C2. Assuming that the MIC3172 and L1 are absent, and the transistors' emitters are grounded, circuit operation is described in "Oscillator Operation."

Oscillator Operation

Resistor R2 provides initial base current that turns transistor Q1 on and impresses the input voltage across one half of T1's primary winding (Pri 1). T1's feedback winding provides additional base drive (positive feedback) to Q1 forcing it well into saturation for a period determined by the Pri 1/C2 time constant. Once the voltage across C2 has reached its maximum circuit value, Q1's collector current will no longer increase. Since T1 is in series with Q1, this drop in primary current causes the flux in T1 to change and because of the mutual coupling to the feedback winding further reduces primary current eventually turning Q1 off. The primary windings now change state with the feedback winding forcing Q2 on repeating the alternate half cycle exactly as with Q1. This action produces a sinusoidal voltage wave form; whose amplitude is proportional to the input voltage, across T1's primary winding which is stepped up and capacitively coupled to the lamp.

Lamp Current Regulation

Initial ionization (lighting) of the fluorescent lamp requires several times the ac voltage across it than is required to sustain current through the device. The current through the lamp is sampled and regulated by the MIC3172 to achieve a given intensity. The MIC3172 uses L1 to maintain a constant average current through the transistor emitters. This current controls the voltage amplitude of the Royer oscillator and maintains the lamp current. During the negative half cycle, lamp current is rectified by D3. During the positive half cycle, lamp current is rectified by D2 through R4 and R5. R3 and C5 filter the voltage dropped across R4 and R5 to the MIC3172's feedback pin. The MIC3172 maintains a constant lamp current by adjusting its duty cycle to keep the feedback voltage at 1.24V. The intensity of the lamp is adjusted using potentiometer R5. The MIC3172 adjusts its duty cycle accordingly to bring the average voltage across R4 and R5 back to 1.24V.



* Voltage clipper
† Duty cycle limiter

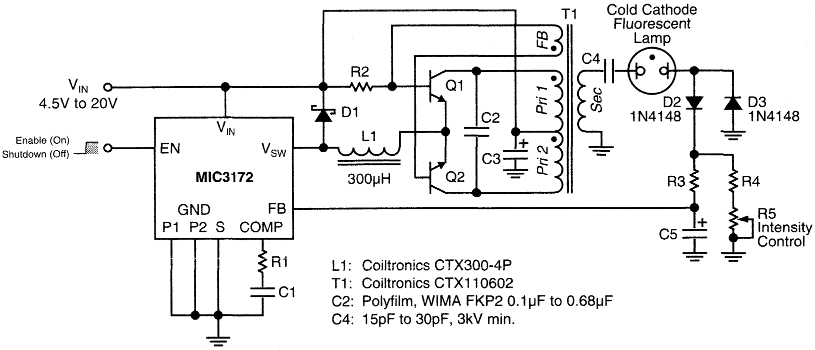
Figure 14. 12V to 5V Forward Converter

On/Off Control

Especially important for battery powered applications, the lamp can be remotely or automatically turned off using the MIC3172's EN pin. The entire circuit draws less than 1µA while shutdown.

Efficiency

To obtain maximum circuit efficiency careful selection of Q1 and Q2 for low collector to emitter saturation voltage is a must. Inductor L1 should be chosen for minimal core and copper losses at the switching frequency of the MIC3172, and T1 should be carefully constructed from magnetic materials optimized for the output power required at the Royer oscillator frequency. Suitable inductors may be obtained from Coiltronics, Inc., tel: (407) 241-7876.



L1: Coiltronics CTX300-4P
T1: Coiltronics CTX110602
C2: Polyfilm, WIMA FKP2 0.1µF to 0.68µF
C4: 15pF to 30pF, 3kV min.

Figure 15. LCD Backlight Fluorescent Lamp Supply

MIC2177/2178

Monolithic Synchronous Buck Regulator

Advance Information

General Description

Micrel's MIC2177 and MIC2178 are 100kHz and 200kHz monolithic synchronous buck (step-down) switching regulators that feature integrated power MOSFETs and are are designed for high-efficiency, battery-powered applications.

The MIC2177 and MIC2178 operate from a 4.5V to 20V supply input.

Internal low on-resistance MOSFETs allow high-efficiency power conversion of up to 2.5A. Fixed 3.3V and fixed 5V output versions are available with an initial setting accuracy of ±1% (±2% over temperature).

The MIC2177/8 maintains its high efficiency over a wide output current range by changing from PWM-mode to skip-mode control when the output current decreases below 250mA. PWM-mode and skip-mode quiescent currents are typically 1.5mA and 500µA, respectively. The MIC2177/8 is capable of 100% duty cycle.

The MIC2177/8 features current-mode control with internal current sensing. Current-mode control is easier to compensate and provides fast line transient response.

The MIC2177 and MIC2178 operate at switching frequencies of 100kHz and 200kHz respectively. Either version may be synchronized to an external TTL compatible clock signal.

The output is protected by current limit and thermal shutdown. A UVLO (undervoltage lockout) circuit inhibits start-up below 4.5V nominal input.

The MIC2177/8 is packaged in a 20-pin, wide-body, power SOIC with an operating temperature range of 0°C to +70°C.

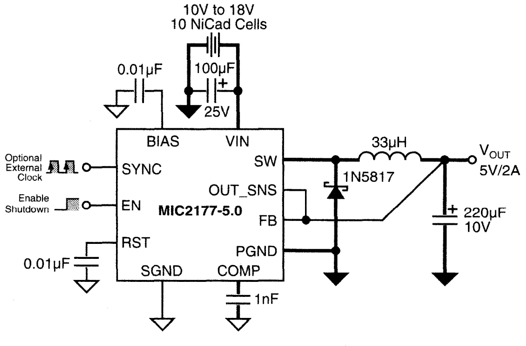
Features

- 4.5V to 20V operation
- Monolithic design includes power MOSFETs
  - 2.5A maximum output from 12V input
  - 1.5A maximum output from 5V input
- High efficiency up to 95% (12V input, 5V/1A output)
- Low quiescent current
  - 1.5mA in PWM operation
  - 500µA in skip-mode
- < 5µA shutdown current
- Dual-mode design
  - Constant-frequency PWM mode (> 250mA)
  - Skip mode (< 250mA)
- Current-mode control
  - Cycle-by-cycle current limit
  - Simplified loop compensation
  - Superior line regulation
- Oscillator frequencies
  - Internally set to 100kHz or 200kHz
  - External synchronization input
- Current limit
- Thermal Shutdown
- Undervoltage lockout

Applications

- High-efficiency battery-powered supplies
- Buck (step-down) dc-to-dc converters

Typical Application



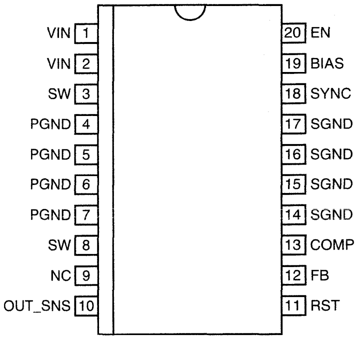
Battery Powered 5V/2A Supply

Ordering Information

Part Number	Output Voltage	Switching Frequency	Temperature Range	Package
MIC2177-3.3CWM	3.3V	100kHz	0°C to +70°C	20-lead Wide SOIC
MIC2177-5.0CWM	5.0V	100kHz	0°C to +70°C	20-lead Wide SOIC
MIC2177CWM	adj.	100kHz	0°C to +70°C	20-lead Wide SOIC
MIC2178-3.3CWM	3.3V	200kHz	0°C to +70°C	20-lead Wide SOIC
MIC2178-5.0CWM	5.0V	200kHz	0°C to +70°C	20-lead Wide SOIC
MIC2178CWM	adj.	200kHz	0°C to +70°C	20-lead Wide SOIC

Note: Advance information. All versions may not be available for production.

Pin Configuration



20-Lead Wide Power SOIC

Pin Description

Pin Number	Pin Name	Pin Function
1,2	VIN	Controller and Switch Supply (Input): Unregulated supply input to internal regulator, output switches, and control circuitry. Requires bypass capacitor to PGND. Both pins must be connected to V_{IN}.
3,8	SW	Switch (Output): Common node of internal power MOSFETs. Both pins must be externally connected together.
4,5,6,7	PGND	Power Ground: VIN high-current path. Connect all pins to C_{IN}– (negative).
10	OUT_SNS	Output Voltage Sense (Input): Senses output voltage to determine minimum switch current for PWM operation.
11	RST	PWM Reset: Connect 0.01µF timing capacitor. Regulator operates exclusively in PWM mode when pin is pulled low (no skip mode).
12	FB	Feedback (Input): Inverting input of internal error amplifier.
13	COMP	Compensation: Output of internal error amplifier. Connect capacitor or series RC network to compensate the regulator control loop.
14,15,16,17	SGND	Signal Ground: Connect all pins to C_{IN}– (negative).
18	SYNC	Frequency Synchronization (Input): Optional. Connect a TTL compatible signal to synchronize the oscillator to an external reference. Leading edge of signal terminates current cycle.
19	BIAS	Internal 3.3V Bias Supply: Decouple with 0.01µF bypass capacitor to SGND. Do not apply any external load.
20	EN	Enable (Input): TTL high enables operation. TTL low shuts down regulator.

Absolute Maximum Ratings

Supply Voltage [100ms transient] (V_{IN}) 25V
Output Switch Voltage (V_{SW}) 25V
Output Switch Current (I_{SW}) 5.5A

Operating Ratings

Junction Temperature Range (T_J) .... –40°C to +125°C
Package Thermal Resistance
SOIC θ_{JA} .... pending °C/W

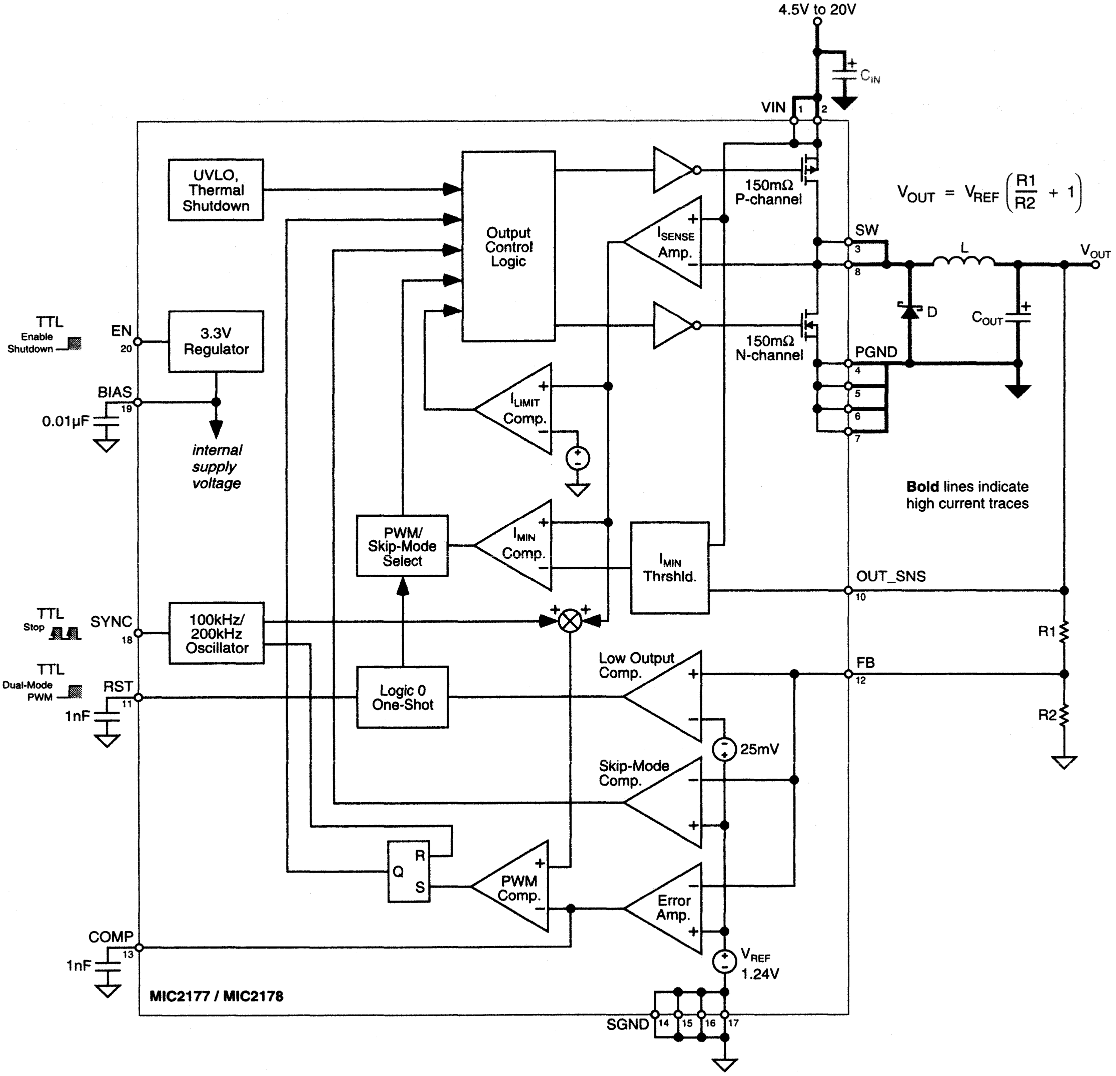
Electrical Characteristics

Parameter	Condition (Note 1)	Min	Typ	Max	Units
Supply Voltage	(V_{IN}) operating range	**4.5**		**20**	V
Supply Current	PWM mode		1.5		mA
	skip mode, switch off		500		µA
	V_{EN} = 0V		5		µA
Reference Voltage			1.240		V
Bias Regulator Output Voltage	(V_{BIAS})		3.30		V
Undervoltage Lockout	upper threshold		4.35		V
	lower threshold		4.25		V
Feedback Bias Current	(I_{FB}) adjustable versions		50		nA
	(I_{FB}) fixed versions		26		nA
Error Amplifier Gain	$0.4V \le V_{COMP} \le 1.0V$		20		
Error Amplifier Output Swing	upper limit		3.2		V
	lower limit		0.2		V
Error Amplifier Output Current	source		60		µA
	sink		60		µA
Oscillator Frequency	200kHz versions		200		kHz
Maximum Duty Cycle	V_{COMP} = 1V	**100**			%
Minimum Duty Cycle	V_{COMP} = 0.4V			**7**	%
PWM Reset Capacitor Charge Current	V_{FB} = 1.2V		10		µA
Current Limit	PWM mode		5.0		A
	skip mode		600		mA
Minimum Switch Current	$V_{IN} - V_{OUT\_SNS}$ = 0V		225		mA
for PWM Operation	$V_{IN} - V_{OUT\_SNS}$ = 3V		425		mA
Output Comparator Threshold Voltage			1.215		V
Switch On-Resistance	P- and N-channel MOSFETs, V_{IN} = 12V, I_{SW} = 1A		0.15		Ω
	P- and N-channel MOSFETs, V_{IN} = 5V, I_{SW} = 1A		0.28		Ω
Output Switch Leakage	V_{SW} = 20V		*tbd*		µA
Enable Threshold	(V_{EN}) disabled			**0.7**	V
	(V_{EN}) enabled	**2.0**			V
Enable Current	V_{IN} = 5V		9		µA

General Note: Devices are ESD sensitive. Handling precautions recommended. "*tbd*" to be determined.

Note 1: Typicals, minimums, and maximums at T_A = 25°C, except **bold** maximums and minimums at $-40°C \le T_A \le 125°C$.

Block Diagram



MIC2177/8 [adjustable] with External Components

LM2574

52kHz Simple 0.5A Buck Voltage Regulator

General Description

The LM2574 family is a series of easy to use fixed and adjustable switching voltage regulators. The LM2574 contains all of the active circuitry necessary to construct a stepdown (buck) switching regulator and requires a minimum of external components.

The LM2574 is available in 3.3V, 5V, 12V, and 15V fixed output versions, or an adjustable version with an output voltage range of 1.23V to 37V. Output voltage is guaranteed to ±4% for specified input and load conditions.

The LM2574 can supply 0.5A while maintaining excellent line and load regulation. The output switch includes cycle-by-cycle current limiting, as well as thermal shutdown for full protection under fault conditions.

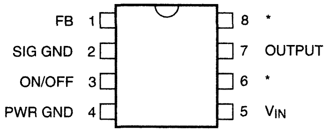
An external shutdown connection selects operating or standby modes. Standby current is less than 200µA.

Heat sinks are generally unnecessary due the regulator's high efficiency. Adequate heat transfer is usually provided by soldering all package pins to a printed circuit board.

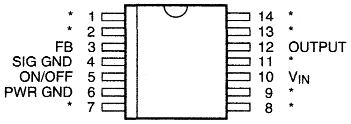
The LM2574 includes internal frequency compensation and an internal 52kHz fixed frequency oscillator guaranteed to ±10% of the frequency.

Circuits constructed around the LM2574 use a standard series of inductors which are available from several different manufacturers.

Pin Configuration



8-pin DIP (N)



14-pin SOIC (WM)

* NC: solder to printed circuit for maximum heat transfer

Features

- 3.3V, 5V, 12V, 15V, and Adjustable Output Versions
- Adjustable Version Output 1.23V to 37V ±4% Max. over Line and Load Conditions.
- Guaranteed 0.5A Output Current
- Wide Input Voltage, up to 40V
- Thermal Shutdown and Current Limit Protection
- Requires only 4 external Components.
- Shutdown Capability (Standby Mode)
- Low Power Standby Mode < 200µA Typical
- High Efficiency
- 52kHz Fixed Frequency Internal Oscillator
- Uses Standard Inductors

Applications

- Simple High-efficiency Step-down (Buck) Regulator
- Efficient Pre-Regulator for Linear Regulators
- On-card Switching Regulators
- Positive to Negative Converter (Buck-Boost)

Ordering Information

Part Number	Temp. Range	Package
LM2574BN	–40°C to +85°C	8-pin Plastic DIP
LM2574BWM	–40°C to +85°C	14-pin Wide SOIC
LM2574-3.3BN	–40°C to +85°C	8-pin Plastic DIP
LM2574-3.3BWM	–40°C to +85°C	14-pin Wide SOIC
LM2574-5.0BN	–40°C to +85°C	8-pin Plastic DIP
LM2574-5.0BWM	–40°C to +85°C	14-pin Wide SOIC
LM2574-12BN	–40°C to +85°C	8-pin Plastic DIP
LM2574-12BWM	–40°C to +85°C	14-pin Wide SOIC

Typical Application

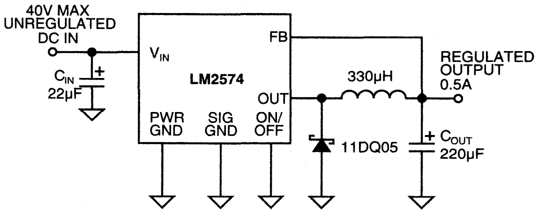


Figure 1. Fixed Output Regulator Circuit

Absolute Maximum Ratings

Maximum Supply Voltage	
LM2574	45V
OFF Pin Input Voltage	$-0.3V \le V \le V_{IN}$
Output Voltage to Ground (Steady State)	–1V
Power Dissipation	Internally Limited
Storage Temperature Range	–65°C to +150°C
Minimum ESD Rating	
C = 100pF, R = 1.5kΩ	2kV
FB Pin	1kV
Lead Temperature (soldering, 10 sec.)	260°C
Maximum Junction Temperature	150°C

Operating Ratings

Temperature Range	
LM2574	$40°C \le T_J \le +125°C$
Supply Voltage	
LM2574	40V

Electrical Characteristics

Specifications with standard typeface are for $T_J = 25°C$, and those with boldface type apply over full Operating Temperature Range. Unless otherwise specified, $V_{in} = 12V$, and $I_{LOAD} = 100mA$.

Symbol	Parameter	Condition	Min	Typ	Max	Units
SYSTEM PARAMETERS, ADJUSTABLE REGULATORS (Note 3) Test Circuit *Figure 2*						
V_{OUT}	Feedback Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.1A$, $V_{OUT} = 5V$	1.217	1.230	1.243	V
V_{OUT}	Feedback Voltage (LM2574)	$0.1A \le I_{LOAD} \le 0.5A$, $7V \le V_{IN} \le 40V$, $V_{OUT} = 5V$	1.193 **1.180**	1.230	1.267 **1.280**	V V
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 0.1A$, $V_{OUT} = 5V$		78		%
SYSTEM PARAMETERS, 3.3V REGULATORS (Note 3) Test Circuit *Figure 3*						
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.1A$, $V_{OUT} = 3.3V$	3.234	3.3	3.366	V
V_{OUT}	Output Voltage (LM2574-3.3)	$0.1A \le I_{LOAD} \le 0.5A$, $4.75V \le V_{IN} \le 40V$, $V_{OUT} = 3.3V$	3.168 **3.135**	3.3	3.432 **3.465**	V V
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 0.1A$		73		%
SYSTEM PARAMETERS, 5V REGULATORS (Note 3) Test Circuit *Figure 3*						
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.1A$, $V_{OUT} = 5V$	4.900	5.0	5.100	V
V_{OUT}	Output Voltage (LM2574-5.0)	$0.1A \le I_{LOAD} \le 0.5A$, $7V \le V_{IN} \le 40V$, $V_{OUT} = 5V$	4.800 **4.750**	5.0	5.200 **5.250**	V V
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 0.1A$, $V_{OUT} = 5V$		78		%
SYSTEM PARAMETERS, 12V REGULATORS (Note 3) Test Circuit *Figure 3*						
V_{OUT}	Output Voltage	$V_{IN} = 25V$, $I_{LOAD} = 0.1A$, $V_{OUT} = 12V$	11.760	12	12.240	V
V_{OUT}	Output Voltage (LM2574-12)	$0.1A \le I_{LOAD} \le 0.5A$, $15V \le V_{IN} \le 40V$, $V_{OUT} = 12V$	11.520 **11.400**	12	12.480 **12.600**	V V
η	Efficiency	$V_{IN} = 25V$, $I_{LOAD} = 0.1A$		88		%
SYSTEM PARAMETERS, 15V REGULATORS (Note 3) Test Circuit *Figure 3*						
V_{OUT}	Output Voltage	$V_{IN} = 30V$, $I_{LOAD} = 0.1A$, $V_{OUT} = 15V$	14.700	15	15.300	V
V_{OUT}	Output Voltage (LM2574-15)	$0.1A \le I_{LOAD} \le 0.5A$, $18V \le V_{IN} \le 40V$, $V_{OUT} = 15V$	14.400 **14.250**	15	15.600 **15.750**	V V
η	Efficiency	$V_{IN} = 30V$, $I_{LOAD} = 0.1A$		88		%

Electrical Characteristics (continued)

Symbol	Parameter	Condition	Min	Typ	Max	Units
DEVICE PARAMETERS, ADJUSTABLE REGULATOR						
I_B	Feedback Bias Current	V_{OUT} = 5V		50	100 **500**	nA nA
DEVICE PARAMETERS, FIXED and ADJUSTABLE REGULATORS						
f_o	Oscillator Frequency	**Note 8**	47 **42**	52	58 **63**	kHz kHz
V_{SAT}	Saturation Voltage	I_{OUT} = 0.5A, **Note 4**		0.8	1.2 **1.4**	V V
DC	Max Duty Cycle (ON)	**Note 5**	93	98		%
I_{CL}	Current Limit	Peak Current, $t_{ON} \le 3\mu s$, **Note 4**	0.7 **0.65**	1.0	1.6 **1.8**	A
I_L	Output Leakage Current	V_{IN}, **Note 6**, Output = 0V **Note 6**, Output = −1V		 7.5	2 30	mA
I_Q	Quiescent Current	**Note 6**		5	10	mA
I_{STBY}	Standby Quiescent Current	ON/OFF Pin = 5V (OFF)		50	200	µA
θ_{JA}	Thermal Resistance	N Package, Junction to Ambient, **Note 7** WM Package, Junction to Ambient, **Note 7**		85 100		°C/W °C/W
ON/OFF CONTROL, FIXED and ADJUSTABLE REGULATORS Test Circuit *Figures 2, 3*						
V_{IH}	ON/OFF Input Level	V_{OUT} = 0V	2.2 **2.4**	1.4		V V
V_{IL}	ON/OFF Input Level	V_{OUT} = 15V or 5V		1.2	1.0 **0.8**	V V
I_{IH}	ON/OFF Logic Current	ON/OFF = 5V (OFF)		4	30	µA
I_{IL}	ON/OFF Logic Current	ON/OFF = 0V (ON)		0.01	10	µA

Note 1 Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2 All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All room temperature limits are 100% production tested. All limits at **temperature extremes** are guaranteed via testing.

Note 3 External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2574 is used as shown in *Figure 1* test circuit, system performance will be shown in system parameters section of Electrical Characteristics.

Note 4 Output (pin 2) sourcing current. No diode, inductor, or capacitor connected to input.

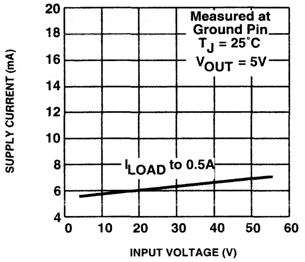
Note 5 Feedback (pin 4) removed from output and connected to 0V.

Note 6 Feedback (pin 4) removed from output and connected to 12V to force the output transistor OFF.

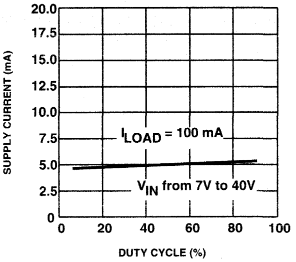
Note 7 Junction to ambient thermal resistance with approximately 1 square inches of PC board copper surrounding the leads.

Typical Performance Characteristics (Circuit of Figure 1)

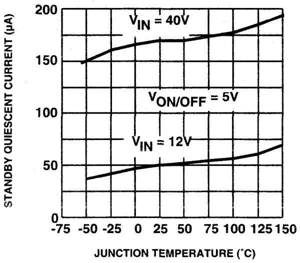
Supply Current



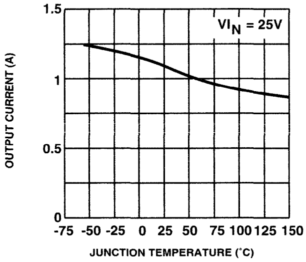
Supply Current vs. Duty Cycle



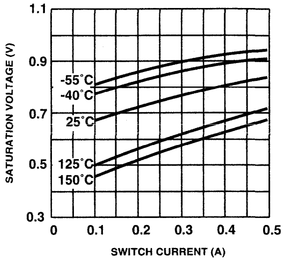
Standby Quiescent Current



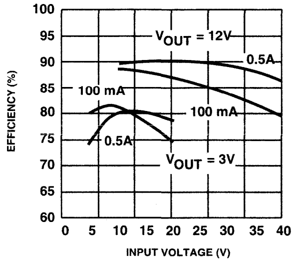
Current Limit



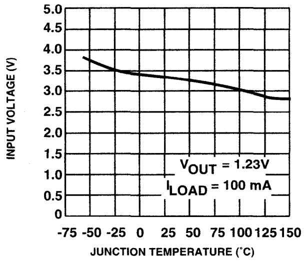
Switch Saturation Voltage



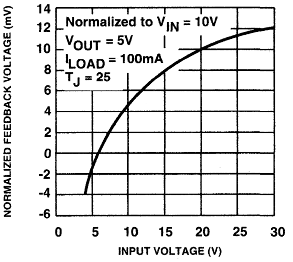
Efficiency



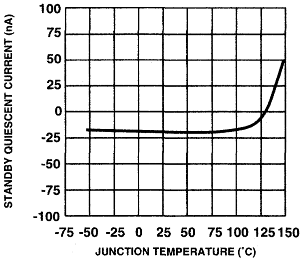
Minimum Operating Voltage



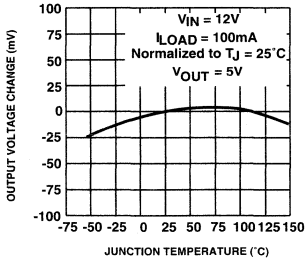
Line Regulation



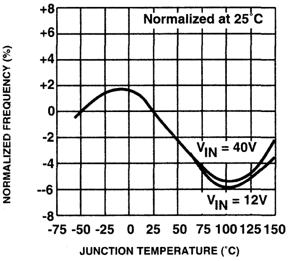
Feedback Pin Current



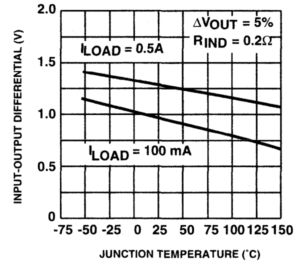
Normalized Output Voltage



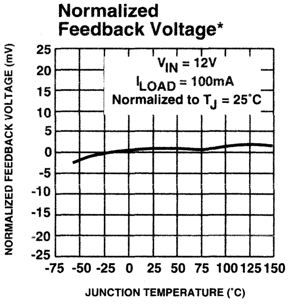
Oscillator Frequency

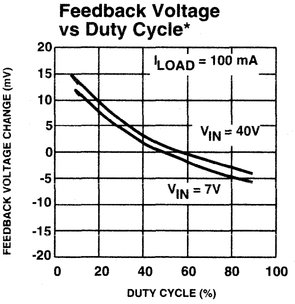


Dropout Voltage



Typical Performance Characteristics (continued)





* Adjustable version only

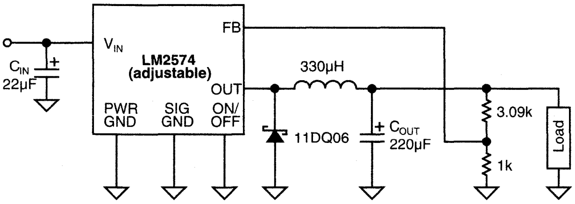


Figure 2. Adjustable Regulator Test Circuit

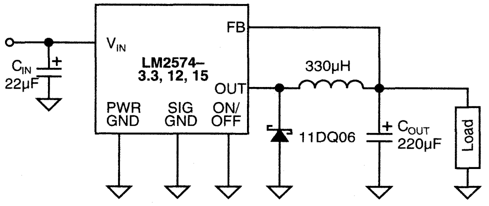
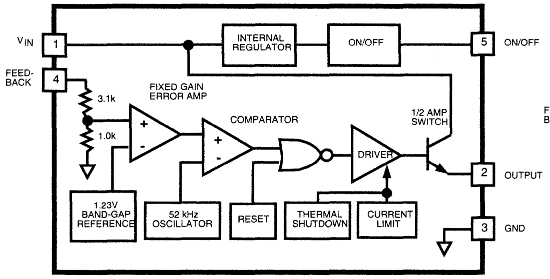
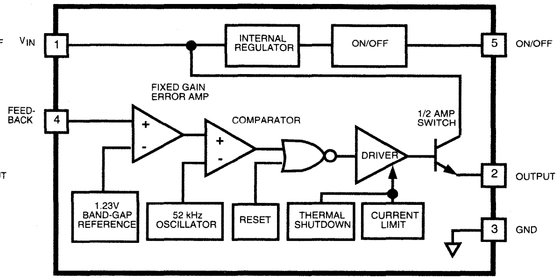


Figure 3. Fixed Regulator Test Circuit

Block Diagrams



Note: Pin numbers are for the TO-220 package



Fixed Regulator Adjustable Regulator

MIC4574

200kHz Simple 0.5A Buck Voltage Regulator

Preliminary Information

General Description

The MIC4574 is a series of easy to use fixed and adjustable BiCMOS step-down (buck) switch-mode voltage regulators. The 200kHz MIC4574 duplicates the pinout and function of the 52kHz LM2574. The higher switching frequency may allow up to a 4:1 reduction in output filter inductor values.

The MIC4574 is available in 3.3V, and 5V fixed output versions or a 1.23V to 18V adjustable output version. Both versions are capable of driving a 0.5A load with excellent line and load regulation.

The feedback voltage is guaranteed to ±2% tolerance for adjustable versions, and the output voltage is guaranteed to ±3% for fixed versions, within specified voltages and load conditions. The oscillator frequency is guaranteed to ±10%.

In shutdown mode, the regulator draws less than 200µA standby current. The regulator performs cycle-by-cycle current limiting and thermal shutdown for protection under fault conditions.

This series of simple switch-mode regulators requires a minimum number of external components and can operate using a standard series of inductors. Frequency compensation is provided internally.

The MIC4574 is available in DIP (BN) and SOIC (BWM) packages for the industrial temperature range.

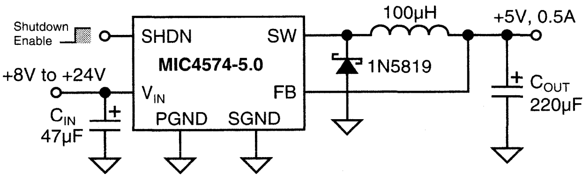
Features

- Fixed 200kHz operation
- 3.3V, 5V, and adjustable output versions
- Voltage over specified line and load conditions:
    Fixed version: ±3% max. output voltage
    Adjustable version: ±2% max. feedback voltage
- Guaranteed 0.5A switch current
- Wide input voltage range: 4V to 24V
- Wide output voltage range: 1.23V to 18V
- Requires minimum external components
- Shutdown mode < 200µA typ.
- 75% efficiency (adjustable version > 75% typ.)
- Standard inductors and capacitors are 25% of typical LM2574 values.
- Thermal shutdown
- Overcurrent protection
- 100% electrical thermal limit burn-in

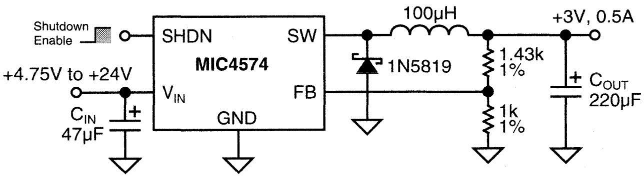
Applications

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive to negative converter (inverting buck-boost)
- Isolated flyback converter using minimum external components
- Negative boost converter

Typical Applications



Fixed Regulator



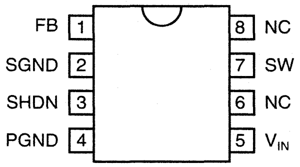
Adjustable Regulator

Ordering Information

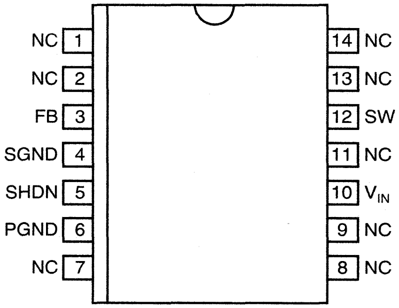
Part Number	Voltage	Temperature Range	Package
MIC4574-3.3BN	3.3V	–40°C to +85°C	8-pin DIP
MIC4574-5.0BN	5.0V	–40°C to +85°C	8-pin DIP
MIC4574BN	Adjustable	–40°C to +85°C	8-pin DIP
MIC4574-3.3BWM	3.3V	–40°C to +85°C	14-lead SOIC
MIC4574-5.0BWM	5.0V	–40°C to +85°C	14-lead SOIC
MIC4574BWM	Adjustable	–40°C to +85°C	14-lead SOIC

Pin Configuration

Drawings Not to Scale



8-Pin DIP (N)



14-Lead Wide SOIC (WM)

Pin Description

Pin Number N Package	Pin Number WM Package	Pin Name	Pin Function
	1	NC	Not internally connected. Solder to printed circuit for maximum heat transfer.
	2	NC	Not internally connected. Solder to printed circuit for maximum heat transfer.
1	3	FB	Feedback (Input): Output voltage feedback to regulator. Connect to output of supply for fixed versions. Connect to 1.23V tap of resistive divider for adjustable versions.
2	4	SGND	Signal Ground:
3	5	SHDN	Shutdown (Input): Logic low enables regulator. Logic high (> 2.4V) shuts down regulator.
4	6	PGND	Power Ground:
	7	NC	Not internally connected. Solder to printed circuit for maximum heat transfer.
	8	NC	Not internally connected. Solder to printed circuit for maximum heat transfer.
	9	NC	Not internally connected. Solder to printed circuit for maximum heat transfer.
5	10	V_{IN}	Supply Voltage (Input): Unregulated +4V to +40V supply voltage.
	11	NC	Not internally connected. Solder to printed circuit for maximum heat transfer.
7	12	SW	Switch (Output): Emitter of NPN output switch. Connect to external storage inductor and Shottky diode.
8	13	NC	Not internally connected. Solder to printed circuit for maximum heat transfer.
	14	NC	Not internally connected. Solder to printed circuit for maximum heat transfer.

Absolute Maximum Ratings

Supply Voltage (V_{IN})	45V
Shutdown (SHDN)	–0.3V to +40V
Output Switch (SW), Steady State	–1V
Operating Junction Temperature	160°C
Package Thermal Resistance	
θ_{JA} Plastic DIP	130°C/W
θ_{JC} SOIC	120°C/W
Storage Temperature	–65°C to 150°C

Electrical Characteristics T_J = 25°C. **Bold** indicates –40°C ≤ T_J ≤ +85°C. (Note 1)

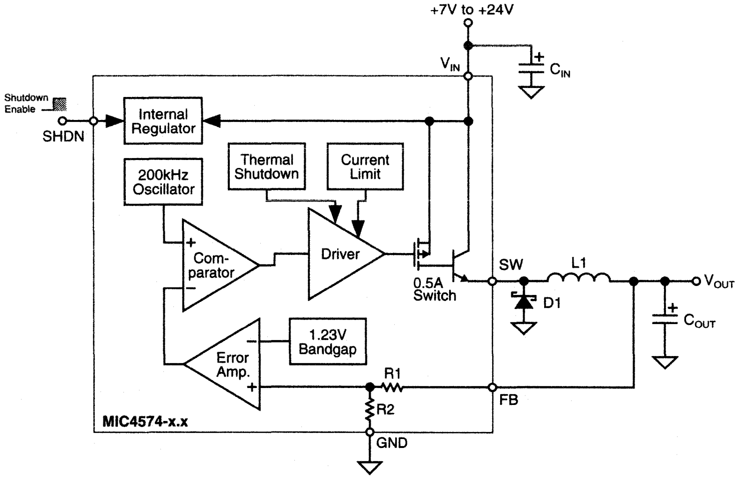
Parameter	Condition	Min	Typ	Max	Units
MIC4574 [Adjustable] Note 2					
Feedback Voltage		1.217	1.230	1.243	V
Feedback Voltage	8V ≤ V_{IN} ≤ 24V, 0.1A ≤ I_{LOAD} ≤ 0.5A	1.193 **1.180**	1.230	1.267 **1.280**	V V
Efficiency	I_{LOAD} = 0.5A		77		%
Feedback Bias Current			50	100 **500**	nA nA
MIC4574-3.3					
Output Voltage		3.234	3.3	3.366	V
Output Voltage	6V ≤ V_{IN} ≤ 24V, 0.1A ≤ I_{LOAD} ≤ 0.5A	3.168 **3.135**	3.3	3.432 **3.465**	V V
Efficiency			72		%
MIC4574-5.0					
Output Voltage		4.900	5.0	5.100	V
Output Voltage	8V ≤ V_{IN} ≤ 24V, 0.1A ≤ I_{LOAD} ≤ 0.5A	4.800 **4.750**	5.0	5.200 **5.250**	V V
Efficiency			77		%
MIC4574 / -3.3 / -5.0					
Oscillator Frequency		180	200	220	kHz
Saturation Voltage	I_{OUT} = 0.5A		1	1.3 **1.5**	V V
Maximum Duty Cycle (On)	FB connected to 0V	90	95		%
Current Limit	Peak Current, t_{ON} ≤ 3µs	0.7 **0.65**	1.0	1.6 **1.8**	A A
Output Leakage Current	V_{IN} = 24V, FB connected to 6V Output = 0V Output = –1V		 0 7.5	 2 30	 mA mA
Quiescent Current			5	10	mA
Standby Quiescent Current	SHDN = 5V (regulator off)		50	200	µA
SHDN Input Logic Level	V_{OUT} = 0V (regulator off)	2.2 **2.4**	1.4		V V
	V_{OUT} = 3.3V or 5V (regulator on)		1.2	1.0 **0.8**	V V
SHDN Input Current	SHDN = 5V (regulator off) SHDN = 0V (regulator on)	 -10	4 0.01	30 10	µA µA

General Note: Devices are ESD protected, however, handling precautions are recommended.

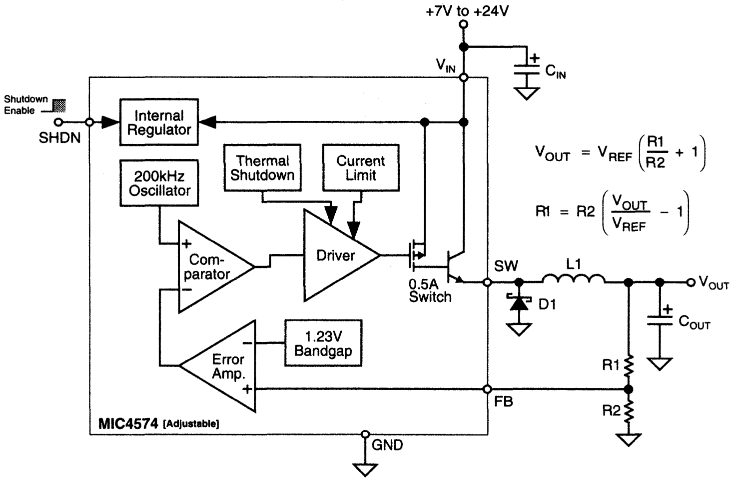
Note 1 V_{IN} = 12V, I_{LOAD} = 100mA unless noted.

Note 2 V_{OUT} = 5V

Block Diagrams



Block Diagram with External Components
Fixed Step-Down Regulator



$$V_{OUT} = V_{REF}\left(\frac{R1}{R2} + 1\right)$$

$$R1 = R2\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

Block Diagram with External Components
Adjustable Step-Down Regulator

Functional Description

The MIC4574 is a variable duty cycle switch-mode regulator with an internal power switch. Refer to the block diagrams.

Supply Voltage

The MIC4574 operates from a +4V to +24V unregulated input. Highest efficiency operation is from a supply voltage below +15V.

Enable/Shutdown

The shutdown (SHDN) input is TTL compatible. Ground the input if unused. A logic-low enables the regulator. A logic-high shuts down the internal regulator which reduces the current to typically 50µA.

Feedback

Fixed versions of the regulator have an internal resistive divider from the feedback (FB) pin. Connect FB directly to the output line.

Adjustable versions require an external resistive voltage divider from the output voltage to ground, connected from the 1.23V tap to FB.

Duty Cycle Control

A fixed-gain error amplifier compares the feedback signal with a 1.23V bandgap voltage reference. The resulting error amplifier output voltage is compared to a 200kHz sawtooth waveform to produce a voltage controlled variable duty cycle output.

A higher feedback voltage increases the error amplifier output voltage. A higher error amplifier voltage (comparator "–" input) causes the comparator to detect only the peaks of the sawtooth, reducing the duty cycle of the comparator output. A lower feedback voltage increases the duty cycle.

Output Switching

When the internal switch is on, an increasing current flows from the supply $V_{IN,}$ through external storage inductor L1, to output capacitor C_{OUT} and the load. Energy is stored in the inductor as the current increases with time.

When the internal switch is turned off, the collapse of the magnetic field in L1 forces current to flow through fast recovery diode D1, charging C_{OUT}.

Output Capacitor

External output capacitor C_{OUT} provides stabilization and reduces ripple.

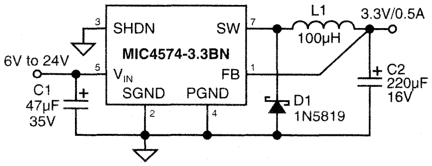
Return Paths

During the on portion of the cycle, the output capacitor and load currents return to the supply ground. During the off portion of the cycle, current is being supplied to the output capacitor and load by storage inductor L1, which means that D1 is part of the high-current return path.

Applications Information

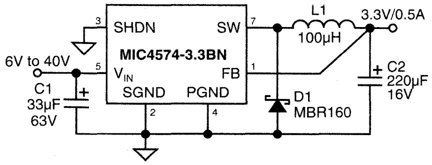
The applications circuits that follow have been constructed and tested. Refer to Application Note 15 for additional information, including efficiency graphs and manufacturer's addresses and telephone numbers for most circuits.

For a mathematical approach to component selection and circuit design, refer to Application Note 14.



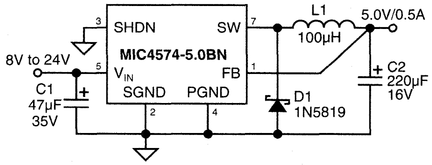
C1	Nichicon	UPL1V470MEH, ESR = 0.34Ω
C2	Nichicon	UPL1C221MPH, ESR = 0.16Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52A-100-250, DCR = 0.2Ω

Figure 1. 6V–24V to 3.3V/0.5A Buck Converter Through Hole



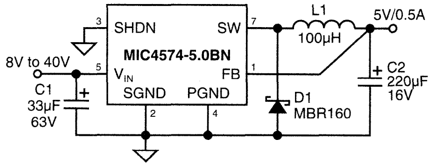
C1	Nichicon	UPL1J330MEH, ESR = 0.35Ω
C2	Nichicon	UPL1C221MPH, ESR = 0.16Ω
D1	Motorola	MBR160
L1	Coiltronics	PL52A-100-250, DCR = 0.2Ω

Figure 2. 6V–40V to 3.3V/0.5A Buck Converter Note 3 **Through Hole**



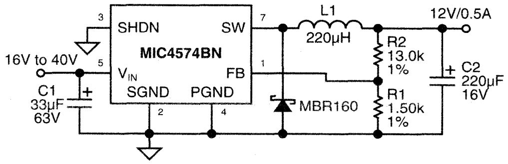
C1	Nichicon	UPL1J470MEH, ESR = 0.34Ω
C2	Nichicon	UPL1C221MPH, ESR = 0.16Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52A-100-250, DCR = 0.2Ω

Figure 3. 8V–24V to 5V/0.5A Buck Converter Through Hole



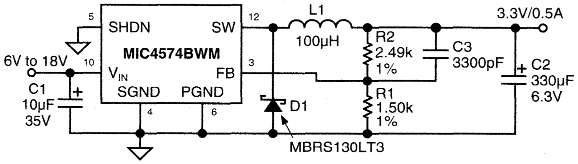
C1	Nichicon	UPL1J330MEH, ESR = 0.35Ω
C2	Nichicon	UPL1C221MPH, ESR = 0.16Ω
D1	Motorola	MBR160
L1	Coiltronics	PL52A-100-250, DCR = 0.2Ω

Figure 4. 8V–40V to 5V/0.5A Buck Converter Note 3 **Through Hole**



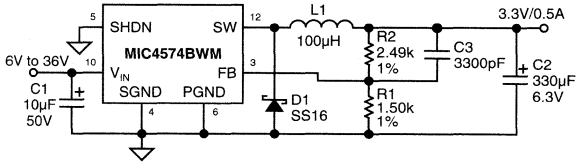
C1	Nichicon	UPL1J330MEH, ESR = 0.35Ω
C2	Nichicon	UPL1C221MPH, ESR = 0.16Ω
D1	Motorola	MBR160
L1	Coiltronics	PL52A-220-250, DCR = 0.37Ω

Figure 5. 16V–40V to 12V/0.5A Buck Converter Note 3 **Through Hole**



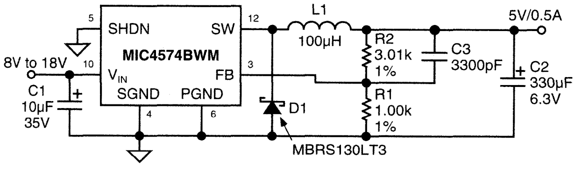
C1	AVX	TPSD106M035R0300, ESR = 0.3Ω
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	Motorola	MBRS130LT3
L1	Coiltronics	CTX-100-2P, DCR = 0.541Ω

Figure 6. 6V–18V to 3.3V/0.5A Buck Converter Low-Profile Surface Mount



C1	Tokin	C55Y5U1H106Z
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	General Instruments SS16	
L1	Coiltronics	CTX-100-2P, DCR = 0.541Ω

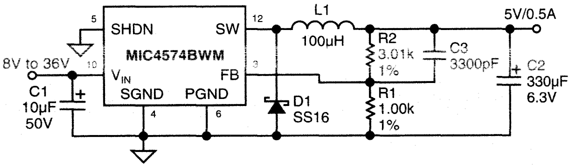
Figure 7. 6V–36V to 3.3V/0.5A Buck Converter Note 3 **Low-Profile Surface Mount**



C1	AVX	TPSD106M035R0300, ESR = 0.3Ω
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	Motorola	MBRS130LT3
L1	Coiltronics	CTX100-2P, DCR = 0.541Ω

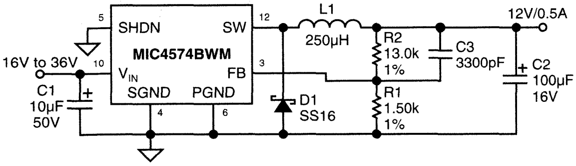
Figure 8. 8V–18V to 5V/0.5A Buck Converter Low-Profile Surface Mount

Note 3 Although the MIC457x family is functional to input voltage to 40V they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.



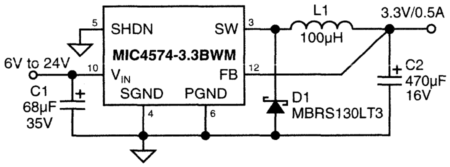
C1	Tokin	C55Y5U1H106Z
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	General Instruments SS16	
L1	Coiltronics	CTX100-2P, DCR = 0.541Ω

Figure 9. 8V–36V to 5V/0.5A Buck Converter Note 3
Low-Profile Surface Mount



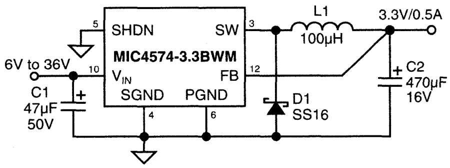
C1	Tokin	C55Y5U1H106Z
C2	AVX	TPSE107M016R0100, ESR = 0.1Ω
D1	General Instruments SS16	
L1	Coiltronics	CTX250-4P, DCR = 0.434Ω

Figure 10. 16V–36V to 12V/0.5A Buck Converter Note 3
Low-Profile Surface Mount



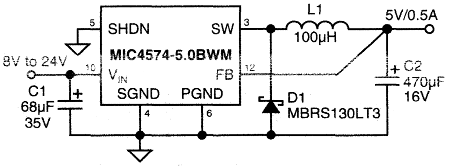
C1	Sanyo	35CV168GX, ESR = 0.34Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	Motorola	MBRS130LT3
L1	Coilcraft	DO3316P-104, DCR = 0.23Ω

Figure 11. 6V–24V to 3.3V/0.5A Buck Converter
Lower-Cost Surface Mount



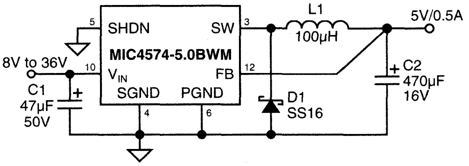
C1	Nichicon	UUX1H470MNT1GS, ESR = 0.4Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	General Instruments SS16	
L1	Coilcraft	DO3316P-104, DCR = 0.23Ω

Figure 12. 6V–36V to 3.3V/0.5A Buck Converter Note 3
Lower-Cost Surface Mount



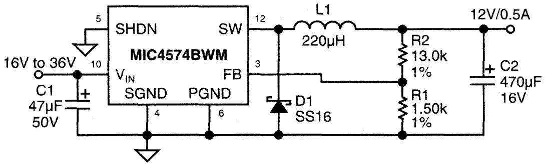
C1	Sanyo	35CV168GX, ESR = 0.34Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	Motorola	MBRS130LT3
L1	Coilcraft	DO3316P-104, DCR = 0.23Ω

Figure 13. 8V–24V to 5V/1A Buck Converter
Lower-Cost Surface Mount



C1	Nichicon	UUX1H470MNT1GS, ESR = 0.4Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	General Instruments SS16	
L1	Coilcraft	DO3316P-104, DCR = 0.23Ω

Figure 14. 8V–36V to 5V/0.5A Buck Converter Note 3
Lower-Cost Surface Mount



C1	Nichicon	UUX1H470MNT1GS, ESR = 0.4Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	General Instruments SS16	
L1	Coilcraft	DO3316-224, DCR = 0.53Ω

Figure 15. 16V–36V to 12V/0.5A Buck Converter Note 3
Lower-Cost Surface Mount

Note 3 Although the MIC457x family is functional to input voltage to 40V they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.

LM2575

52kHz Simple 1A Buck Voltage Regulator

General Description

The LM2575 series of monolithic integrated circuits provide all the active functions for a step-down (buck) switching regulator. Fixed versions are available with a 3.3V, 5V, 12V, or 15V fixed output. Adjustable versions have an output voltage range from 1.23V to 37V. Both versions are capable of driving a 1A load with excellent line and load regulation.

These regulators are simple to use because they require a minimum number of external components and include internal frequency compensation and a fixed-frequency oscillator.

The LM2575 series offers a high efficiency replacement for popular three-terminal adjustable linear regulators. It substantially reduces the size of the heat sink, and in many cases no heat sink is required.

A standard series of inductors available from several different manufacturers are ideal for use with the LM2575 series. This feature greatly simplifies the design of switch-mode power supplies.

The feedback voltage is guaranteed to ±2% tolerance for adjustable versions, and the output voltage is guaranteed to ±3% for fixed versions, within specified input voltages and output load conditions. The oscillator frequency is guaranteed to ±10%. External shutdown is included, featuring less than 200μA standby current. The output switch includes cycle-by-cycle current limiting and thermal shutdown for full protection under fault conditions.

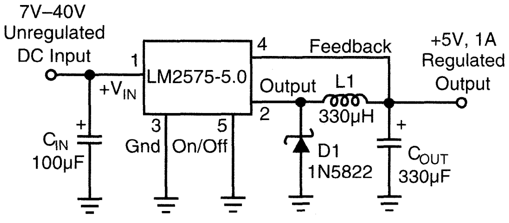
Features

- 3.3V, 5V, 12V, 15V, and adjustable output versions
- Voltage over specified line and load conditions:
  Fixed version: ±3% max. output voltage
  Adjustable version: ±2% max. feedback voltage
- Guaranteed 1A output current
- Wide input voltage range:
  4V to 40V
- Wide output voltage range
  1.23V to 37V
- Requires only 4 external components
- 52kHz fixed frequency internal oscillator
- Low power standby mode I_Q typically < 200μA
- 80% efficiency (adjustable version typically > 80%)
- Uses readily available standard inductors
- Thermal shutdown and current limit protection
- 100% electrical thermal limit burn-in

Applications

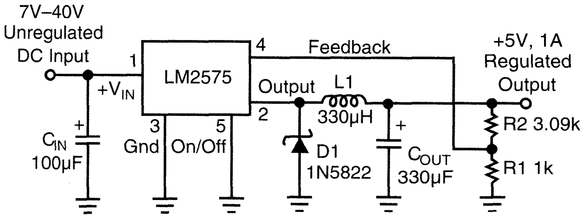
- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive to negative converter (inverting Buck-Boost)
- Isolated Flyback Converter using minimum number of external components
- Negative Boost Converter

Typical Applications



Note: Pin numbers are for TO-220 Package

Fixed Regulator in Typical Application



Note: Pin numbers are for TO-220 Package

$$V_{OUT} = 1.23\left(1 + \frac{R2}{R1}\right)$$

Adjustable Regulator in Fixed Output Application

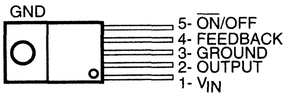
Ordering Information

Part Number†	Temperature Range	Package
LM2575BN*	–40°C to +85 °C	16-pin Plastic DIP
LM2575-3.3BN	–40°C to +85 °C	16-pin Plastic DIP
LM2575-5.0BN	–40°C to +85 °C	16-pin Plastic DIP
LM2575-12BN	–40°C to +85 °C	16-pin Plastic DIP
LM2575BWM*	–40°C to +85°C	24-pin Wide SOIC
LM2575-3.3BWM	–40°C to +85°C	24-pin Wide SOIC
LM2575-5.0BWM	–40°C to +85°C	24-pin Wide SOIC
LM2575-12BWM	–40°C to +85°C	24-pin Wide SOIC
LM2575BT*†	–40°C to +85°C	5-lead TO-220
LM2575-3.3BT†	–40°C to +85°C	5-lead TO-220
LM2575-5.0BT†	–40°C to +85°C	5-lead TO-220
LM2575-12BT†	–40°C to +85°C	5-lead TO-220
LM2575BU*	–40°C to +85°C	5-lead TO-263
LM2575-3.3BU	–40°C to +85°C	5-lead TO-263
LM2575-5.0BU	–40°C to +85°C	5-lead TO-263
LM2575-12BU	–40°C to +85°C	5-lead TO-263

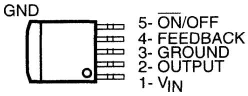
* Adjustable output regulators.
† Contact factory for bent or staggered leads option.

Pin Configurations

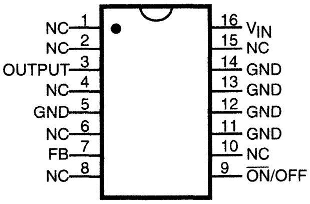
5-LEAD TO-220 (T)



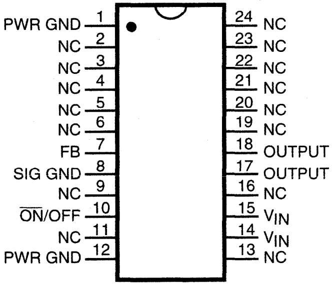
5-LEAD TO-263 (U)



16-LEAD DIP (N)



24-LEAD SOIC (WM)



Absolute Maximum Ratings (Note 1)

Maximum Supply Voltage	45V
ON/OFF Pin Input Voltage	$-0.3V \le V \le +40V$
Output Voltage to Ground (Steady State)	–1V
Power Dissipation	Internally Limited
Storage Temperature Range	–65°C to +150°C
Minimum ESD Rating	
C = 100pF, R = 1.5kΩ	2 kV
FB Pin	1 kV
Lead Temperature (soldering, 10 sec.)	260°C
Maximum Junction Temperature	150°C

Operating Ratings

Temperature Range	$-40°C \le T_J \le +125°C$
Supply Voltage	40V

Electrical Characteristics

Specifications with standard typeface are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range.** Unless otherwise specified, $V_{IN} = 12V$, and $I_{LOAD} = 200mA$.

Symbol	Parameter	Conditions	Typ	LM2575 Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS, ADJUSTABLE REGULATORS (Note 3) Test Circuit *Figure 1*					
V_{OUT}	Feedback Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.2A$	1.230		V
		$V_{OUT} = 5V$		1.217	V(min)
				1.243	V(max)
V_{OUT}	Feedback Voltage	$0.2A \le I_{LOAD} \le 1A$, $8V \le V_{IN} \le 40V$	1.230		V
	LM2575	$V_{OUT} = 5V$		1.193/**1.180**	V(min)
				1.267/**1.280**	V(max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 1A$, $V_{OUT} = 5V$	82		%
SYSTEM PARAMETERS, 3.3V REGULATORS (Note 3) Test Circuit *Figure 1*					
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.2A$	3.3		V
		$V_{OUT} = 3.3V$		3.234	V(min)
				3.366	V(max)
V_{OUT}	Output Voltage	$0.2A \le I_{LOAD} \le 1A$, $8V \le V_{IN} \le 40V$	3.3		V
	LM2575-3.3	$V_{OUT} = 3.3V$		3.168/**3.135**	V(min)
				3.432/**3.465**	V(max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 1A$	75		%
SYSTEM PARAMETERS, 5V REGULATORS (Note 3) Test Circuit *Figure 1*					
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.2A$	5.0		V
		$V_{OUT} = 5V$		4.900	V(min)
				5.100	V(max)
V_{OUT}	Output Voltage	$0.2A \le I_{LOAD} \le 1A$, $8V \le V_{IN} \le 40V$	5.0		V
	LM2575-5.0	$V_{OUT} = 5V$		4.800/**4.750**	V(min)
				5.200/**5.250**	V(max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 1A$	82		%
SYSTEM PARAMETERS, 12V REGULATORS (Note 3) Test Circuit *Figure 1*					
V_{OUT}	Output Voltage	$V_{IN} = 25V$, $I_{LOAD} = 0.2A$	12		V
		$V_{OUT} = 12V$		11.760	V(min)
				12.240	V(max)
V_{OUT}	Output Voltage	$0.2A \le I_{LOAD} \le 1A$, $15V \le V_{IN} \le 40V$	12		V
	LM2575-12	$V_{OUT} = 12V$		11.520/**11.400**	V(min)
				12.480/**12.600**	V(max)
η	Efficiency	$V_{IN} = 25V$, $I_{LOAD} = 1A$	88		%

Electrical Characteristics (continued)

Symbol	Parameter	Conditions	Typ	LM2575	Units
				Limit (Note 2)	(Limits)
SYSTEM PARAMETERS, 15V REGULATORS (Note 3) Test Circuit *Figure 1*					
V_{OUT}	Output Voltage	V_{IN} = 30V , I_{LOAD} = 0.2A	15		V
		V_{OUT} = 15V		14.700	V(min)
				15.300	V(max)
V_{OUT}	Output Voltage	0.2A ≤ I_{LOAD} ≤ 1A, 18V ≤ V_{IN} ≤ 40V	15		V
	LM2575-15	V_{OUT} = 15V		14.400/**14.250**	V(min)
				15.600/**15.750**	V(max)
η	Efficiency	V_{IN} = 30V, I_{LOAD} = 1A	88		%
DEVICE PARAMETERS, ADJUSTABLE REGULATOR					
I_B	Feedback Bias Current	V_{OUT} = 5V	50	100/**500**	nA
DEVICE PARAMETERS, FIXED and ADJUSTABLE REGULATORS					
f_O	Oscillator Frequency		52		kHz
				47/**42**	kHz (min)
				58/**63**	kHz (max)
V_{SAT}	Saturation Voltage	I_{OUT} = 1A (Note 4)	0.9		V
				1.2/**1.4**	V(max)
DC	Max Duty Cycle (ON)	(Note 5)	98		%
				93	%(min)
I_{CL}	Current Limit	Peak Current, t_{ON} ≤ 3µs (Note 4)	2.2		A
				1.7/**1.3**	A(min)
				3.0/**3.2**	A(max)
I_L	Output Leakage Current	V_{IN} = 40V, (Note 6), Output = 0V		2	mA(max)
		Output = −1V	7.5		mA
		(Note 6) Output = −1V		30	mA(max)
I_Q	Quiescent Current	(Note 6)	5		mA
				10	mA(max)
I_{STBY}	Standby Quiescent Current	ON/OFF Pin = 5V (OFF)	50		µA
				200	µA(max)
θ_{JA}	Thermal Resistance	T Package, Junction to Ambient (Note 7)	65		°C/W
θ_{JA}		T Package, Junction to Ambient (Note 8)	45		
θ_{JC}		T Package, Junction to Case	2		
θ_{JA}		N Package, Junction to Ambient (Note 9)	85		
θ_{JA}		WM Package, Junction to Amb. (Note 9)	100		

Electrical Characteristics (continued)

Symbol	Parameter	Conditions	Typ	LM2575 Limit (Note 2)	Units (Limits)
ON/OFF CONTROL, FIXED and ADJUSTABLE REGULATORS Test Circuit *Figure 1*					
V_{IH}	ON/OFF Pin Logic Input Level	V_{OUT} = 0V	1.4	2.2/**2.4**	V(min)
V_{IL}		V_{OUT} = 5V	1.2	1.0/**0.8**	V(max)
I_{IH}	ON /OFF Pin Logic Current	ON /OFF Pin = 5V (OFF)	4		µA
				30	µA(max)
I_{IL}		ON/OFF Pin = 0V (ON)	0.01		µA
				10	µA(max)

Note 1: Absolute Maximum Rating indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All room temperature limits are 100% production tested. All limits at **temperature extreme** are guaranteed via testing.

Note 3: External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2575/LM1575 is used as shown in *Figure 1* test circuit, system performance will be shown in system parameters section of Electrical Characteristics.

Note 4: Output (pin 2) sourcing current. No diode, inductor or capacitor connected to output.

Note 5: Feedback (pin 4) removed from output and connected to 0V.

Note 6: Feedback (pin 4) removed from output and connected to 12V to force the output transistor OFF.

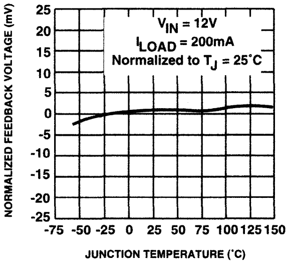
Note 7: Junction to ambient thermal resistance (no external heat sink) for the 5-lead TO-220 package mounted vertically, with 1/2" leads in a socket, or on PC board with minimum copper area.

Note 8: Junction to ambient thermal resistance (no external heat sink) for the 5-lead TO-220 package mounted vertically, with 1/4" leads soldered to PC board containing approximately 4 square inches of copper area surrounding the leads.

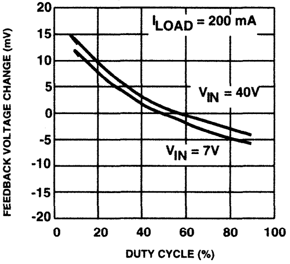
Note 9: Junction to ambient thermal resistance with approximately 1 square inch of pc board copper surrounding the leads. Additional copper will lower thermal resistance further.

Typical Performance Characteristics

Normalized Feedback Voltage*



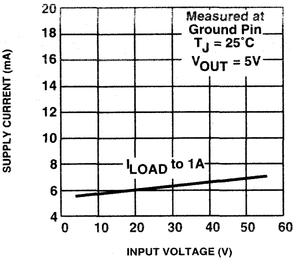
Feedback Voltage vs Duty Cycle*



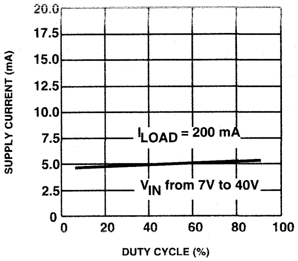
* Adjustable version only

Typical Performance Characteristics (continued) (Circuit of *Figure 1*)

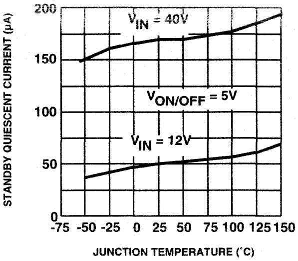
Supply Current



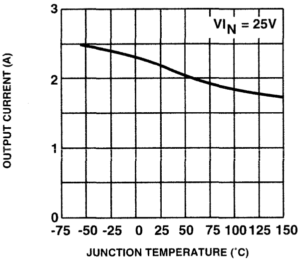
Supply Current vs. Duty Cycle



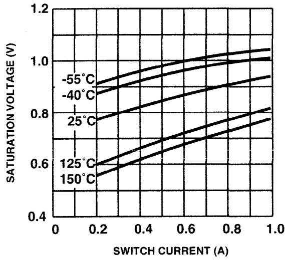
Standby Quiescent Current



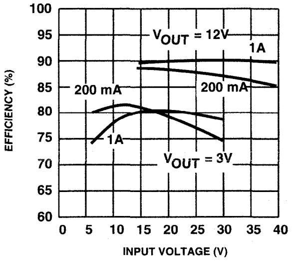
Current Limit



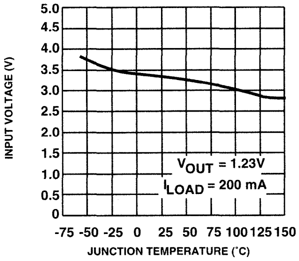
Switch Saturation Voltage



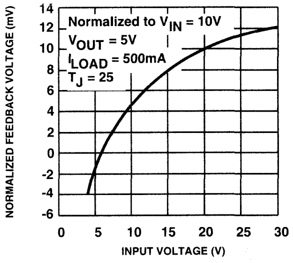
Efficiency



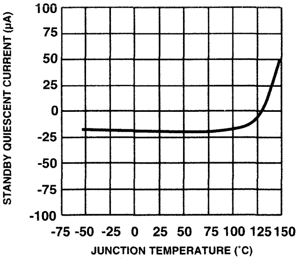
Minimum Operating Voltage



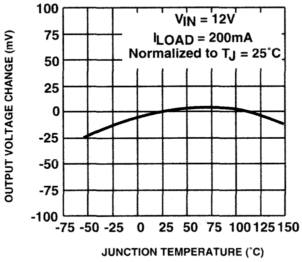
Line Regulation



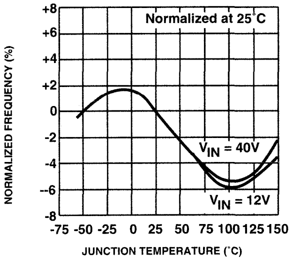
Feedback Pin Current



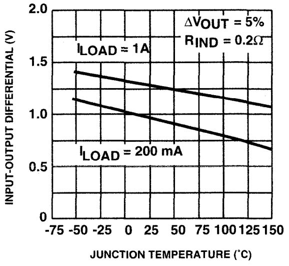
Normalized Output Voltage



Oscillator Frequency

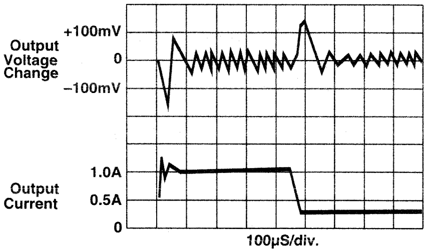


Dropout Voltage



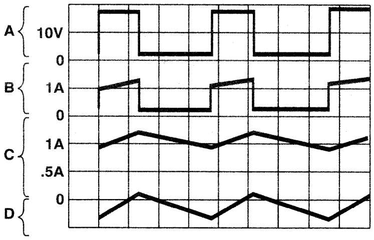
Typical Performance Characteristics (Circuit of *Figure 1*)

Load Transient Response



$V_{OUT} = 5V$

Switching Waveforms

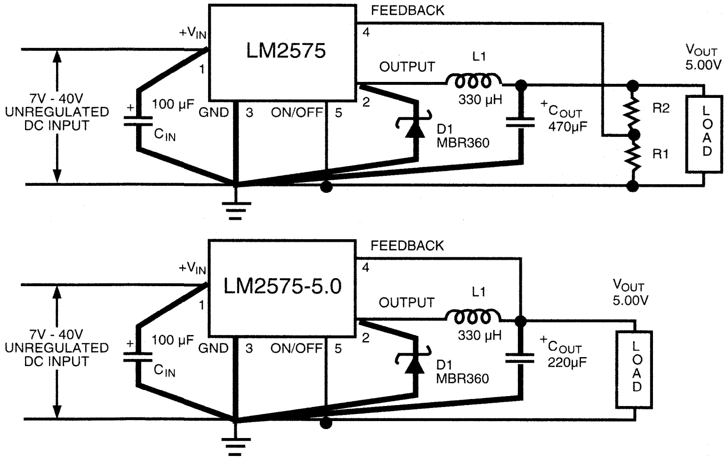


$V_{OUT} = 5V$ $V_{IN} = 20V$

A: Output pin voltage 10V/div
B: Output pin current 1A/div
C: Inductor current 0.5A/div
D: Output ripple voltage 20 mV/div. AC coupled

Horizontal Time Base: 5μs/div

Test Circuits and Layout Guidelines



C_{IN} — 100μF, 75V Aluminum Electrolytic
C_{OUT} — 470μF, 15V Aluminum Electrolytic
D1 — Schottky, MBR360
L1 — 330μH, 415-0926 (AIE)
R1 — 1k, 0.01%
R2 — 3.065k, 0.01%
5-pin TO-220 socket—2936 (Loranger Mfg. Co.)
4-pin TO-3 socket—8112-AG7 (Augat Inc.)

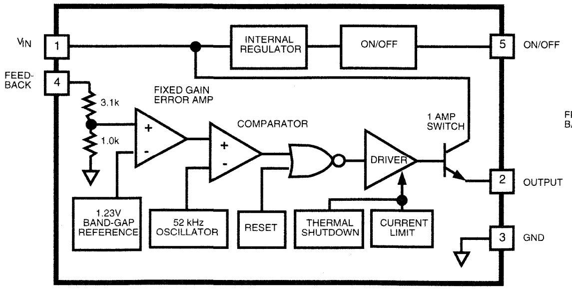
C_{IN} — 100μF, 75V Aluminum Electrolytic
C_{OUT} — 330μF, 15V Aluminum Electrolytic
D1 — Schottky, MBR360
L1 — 330μH, 415-0926 (AIE)
5-pin TO-220 socket—2936 (Loranger Mfg. Co.)
4-pin TO-3 socket—8112-AG7 (Augat Inc.)

Note: Pin numbers are for TO-220 Package

Figure 1.

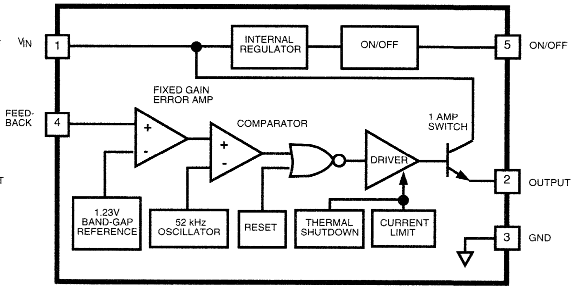
As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance generate voltage transients which can cause problems. For minimal stray inductance and ground loops, the length of the leads indicated by heavy lines should be kept as short as possible. Single-point grounding (as indicated) or ground plane construction should be used for best results.

Block Diagrams



Note: Pin numbers are for the TO-220 package

Fixed Regulator



Adjustable Regulator

MIC4575

200kHz Simple 1A Buck Voltage Regulator

Preliminary Information

General Description

The MIC4575 is a series of easy to use fixed and adjustable BiCMOS step-down (buck) switch-mode voltage regulators. The 200kHz MIC4575 duplicates the pinout and function of the 52kHz LM2575. The higher switching frequency may allow up to a 4:1 reduction in output filter inductor values.

The MIC4575 is available in 3.3V, and 5V fixed output versions or a 1.23V to 18V adjustable output version. Both versions are capable of driving a 1A load with excellent line and load regulation.

The feedback voltage is guaranteed to ±2% tolerance for adjustable versions, and the output voltage is guaranteed to ±3% for fixed versions, within specified voltages and load conditions. The oscillator frequency is guaranteed to ±10%.

In shutdown mode, the regulator draws less than 200µA standby current. The regulator performs cycle-by-cycle current limiting and thermal shutdown for protection under fault conditions.

This series of simple switch-mode regulators requires a minimum number of external components and can operate using a standard series of inductors. Frequency compensation is provided internally.

The MIC4575 is available in TO-220 (BT) and TO-263 (BU) packages for the industrial temperature range.

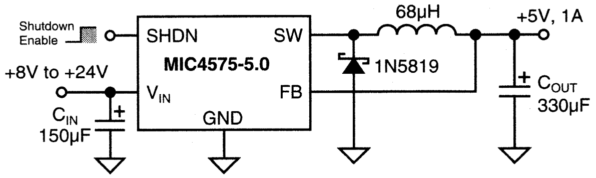
Features

- Fixed 200kHz operation
- 3.3V, 5V, and adjustable output versions
- Voltage over specified line and load conditions:
  Fixed version: ±3% max. output voltage
  Adjustable version: ±2% max. feedback voltage
- Guaranteed 1A switch current
- Wide input voltage range: 4V to 24V
- Wide output voltage range: 1.23V to 18V
- Requires minimum external components
- Shutdown mode < 200µA typ.
- 75% efficiency (adjustable version > 75% typ.)
- Standard inductors and capacitors are 25% of typical LM2575 values.
- Thermal shutdown
- Overcurrent protection
- 100% electrical thermal limit burn-in

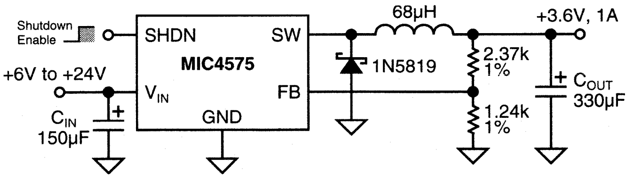
Applications

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive to negative converter (inverting buck-boost)
- Isolated flyback converter using minimum external components
- Negative boost converter
- Step-down 6V to 3.3V for Intel Pentium™ and similar microprocessors

Typical Applications



Fixed Regulator

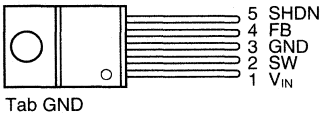


Adjustable Regulator

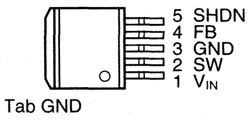
Ordering Information

Part Number	Voltage	Temperature Range	Package
MIC4575-3.3BT	3.3V	–40°C to +85°C	5-lead TO-220
MIC4575-5.0BT	5.0V	–40°C to +85°C	5-lead TO-220
MIC4575BT	Adjustable	–40°C to +85°C	5-lead TO-220
MIC4575-3.3BU	3.3V	–40°C to +85°C	5-lead TO-263
MIC4575-5.0BU	5.0V	–40°C to +85°C	5-lead TO-263
MIC4575BU	Adjustable	–40°C to +85°C	5-lead TO-263

Pin Configuration



5-Lead TO-220 (T)



5-Lead TO-263 (U)

Pin Description

Pin Number	Pin Name	Pin Function
1	V_{IN}	Supply Voltage (Input): Unregulated +4V to +40V supply voltage.
2	SW	Switch (Output): Emitter of NPN output switch. Connect to external storage inductor and Shottky diode.
3	GND	Ground
4	FB	Feedback (Input): Output voltage feedback to regulator. Connect to output of supply for fixed versions. Connect to 1.23V tap of resistive divider for adjustable versions.
5	SHDN	Shutdown (Input): Logic low enables regulator. Logic high (> 2.4V) shuts down regulator.

Absolute Maximum Ratings

Supply Voltage (V_{IN})	45V
Shutdown (SHDN)	–0.3V to +40V
Output Switch (SW), Steady State	–1V
Operating Junction Temperature	160°C
Package Thermal Resistance	
θ_{JA} TO-220, TO-263	65°C/W
θ_{JC} TO-220, TO-263	2°C/W
Storage Temperature	–65°C to 150°C

Electrical Characteristics $T_J = 25°C$. **Bold** indicates $-40°C \le T_J \le +85°C$. (Note 1)

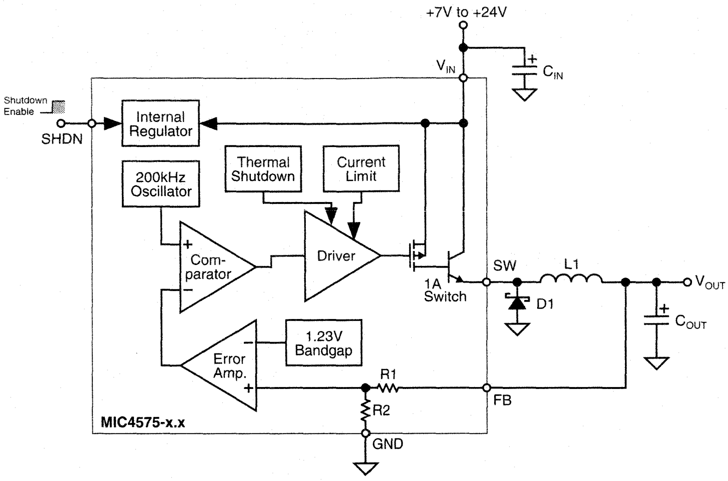
Parameter	Condition	Min	Typ	Max	Units
MIC4575 [Adjustable] Note 2					
Feedback Voltage		1.217	1.230	1.243	V
Feedback Voltage	$8V \le V_{IN} \le 24V$, $0.2A \le I_{LOAD} \le 1A$	1.193 **1.180**	1.230	1.267 **1.280**	V V
Efficiency	$I_{LOAD} = 1A$		77		%
Feedback Bias Current			50	100 **500**	nA nA
MIC4575-3.3					
Output Voltage		3.234	3.3	3.366	V
Output Voltage	$6V \le V_{IN} \le 24V$, $0.2A \le I_{LOAD} \le 1A$	3.168 **3.135**	3.3	3.432 **3.465**	V V
Efficiency	$I_{LOAD} = 1A$		72		%
MIC4575-5.0					
Output Voltage		4.900	5.0	5.100	V
Output Voltage	$8V \le V_{IN} \le 24V$, $0.2A \le I_{LOAD} \le 1A$	4.800 **4.750**	5.0	5.200 **5.250**	V V
Efficiency	$I_{LOAD} = 1A$		77		%
MIC4575 / -3.3 / -5.0					
Oscillator Frequency		180	200	220	kHz
Saturation Voltage	$I_{OUT} = 1A$		1	1.3 **1.5**	V V
Maximum Duty Cycle (On)	FB connected to 0V	90	95		%
Current Limit	Peak Current, $t_{ON} \le 3\mu s$	1.7 **1.3**	2.2	3.0 **3.2**	A A
Output Leakage Current	$V_{IN} = 24V$, FB connected to 0V Output = 0V Output = –1V		 0 7.5	 2 30	 mA mA
Quiescent Current			5	10	mA
Standby Quiescent Current	SHDN = 5V (regulator off)		50	200	µA
SHDN Input Logic Level	$V_{OUT} = 0V$ (regulator off)	2.2 **2.4**	1.4		V V
	$V_{OUT} = 3.3$ or 5V (regulator on)		1.2	1.0 **0.8**	V V
SHDN Input Current	SHDN = 5V (regulator off) SHDN = 0V (regulator on)	 -10	4 0.01	30 10	µA µA

General Note: Devices are ESD protected, however, handling precautions are recommended.

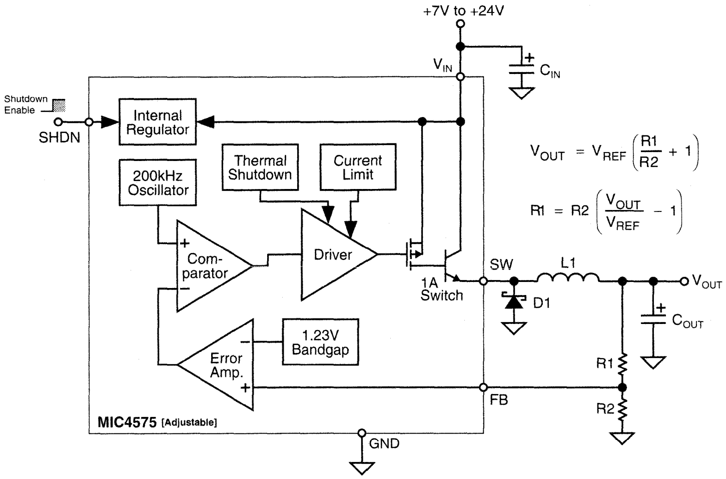
Note 1 $V_{IN} = 12V$, $I_{LOAD} = 200mA$ unless noted.

Note 2 $V_{OUT} = 5V$

Block Diagrams



Block Diagram with External Components
Fixed Step-Down Regulator



$$V_{OUT} = V_{REF}\left(\frac{R1}{R2} + 1\right)$$

$$R1 = R2\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

Block Diagram with External Components
Adjustable Step-Down Regulator

Functional Description

The MIC4575 is a variable duty cycle switch-mode regulator with an internal power switch. Refer to the block diagrams.

Supply Voltage

The MIC4575 operates from a +4V to +24V unregulated input. Highest efficiency operation is from a supply voltage around +15V.

Enable/Shutdown

The shutdown (SHDN) input is TTL compatible. Ground the input if unused. A logic-low enables the regulator. A logic-high shuts down the internal regulator which reduces the current to typically 50µA.

Feedback

Fixed versions of the regulator have an internal resistive divider from the feedback (FB) pin. Connect FB directly to the output line.

Adjustable versions require an external resistive voltage divider from the output voltage to ground, connected from the 1.23V tap to FB.

Duty Cycle Control

A fixed-gain error amplifier compares the feedback signal with a 1.23V bandgap voltage reference. The resulting error amplifier output voltage is compared to a 200kHz sawtooth waveform to produce a voltage controlled variable duty cycle output.

A higher feedback voltage increases the error amplifier output voltage. A higher error amplifier voltage (comparator "–" input) causes the comparator to detect only the peaks of the sawtooth, reducing the duty cycle of the comparator output. A lower feedback voltage increases the duty cycle.

Output Switching

When the internal switch is on, an increasing current flows from the supply $V_{IN,}$ through external storage inductor L1, to output capacitor C_{OUT} and the load. Energy is stored in the inductor as the current increases with time.

When the internal switch is turned off, the collapse of the magnetic field in L1 forces current to flow through fast recovery diode D1, charging C_{OUT}.

Output Capacitor

External output capacitor C_{OUT} provides stabilization and reduces ripple.

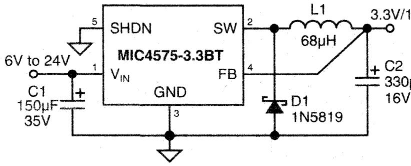
Return Paths

During the on portion of the cycle, the output capacitor and load currents return to the supply ground. During the off portion of the cycle, current is being supplied to the output capacitor and load by storage inductor L1, which means that D1 is part of the high-current return path.

Applications Information

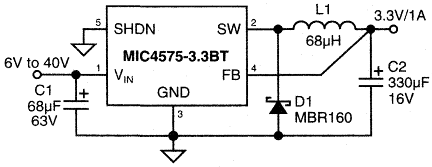
The applications circuits that follow have been constructed and tested. Refer to Application Note 15 for additional information, including efficiency graphs and manufacturer's addresses and telephone numbers for most circuits.

For a mathematical approach to component selection and circuit design, refer to Application Note 14.



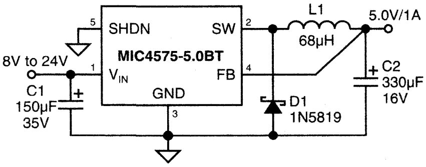
C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω

Figure 1. 6V–24V to 3.3V/1A Buck Converter Through Hole



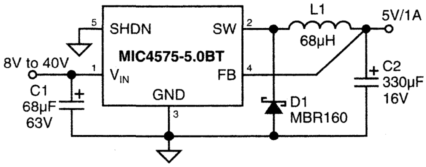
C1	Nichicon	UPL1J680MPH, ESR = 0.17Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	MBR160
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω

Figure 2. 6V–40V to 3.3V/1A Buck Converter Note 3 Through Hole



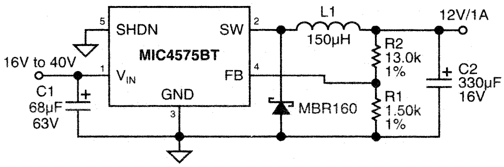
C1	Nichicon	UPL1J151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω

Figure 3. 8V–24V to 5V/1A Buck Converter Through Hole



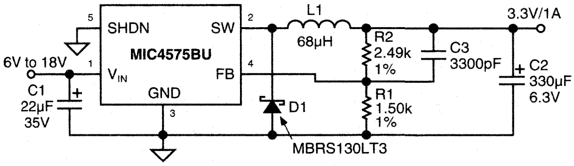
C1	Nichicon	UPL1J680MPH, ESR = 0.17Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	MBR160
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω

Figure 4. 8V–40V to 5V/1A Buck Converter Note 3 Through Hole



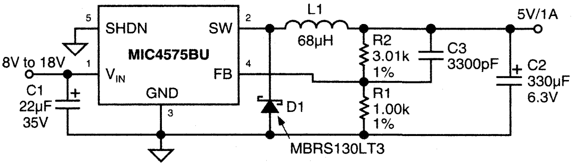
C1	Nichicon	UPL1J680MPH, ESR = 0.17Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	MBR160
L1	Coiltronics	PL52B-150-500, DCR = 0.166Ω

Figure 5. 16V–40V to 12V/1A Buck Converter Note 3 Through Hole



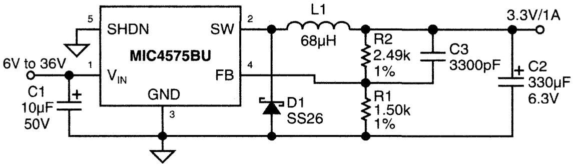
C1	AVX	TPSE226M035R0300, ESR = 0.3Ω
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	Motorola	MBRS130LT3
L1	Coiltronics	CTX68-4P, DCR = 0.238Ω

Figure 6. 6V–18V to 3.3V/1A Buck Converter Low-Profile Surface Mount



C1	AVX	TPSE226M035R0300, ESR = 0.3Ω
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	Motorola	MBRS130LT3
L1	Coiltronics	CTX68-4P, DCR = 0.238Ω

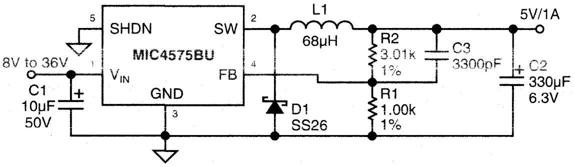
Figure 7. 8V–18V to 5V/1A Buck Converter Low-Profile Surface Mount



C1	Tokin	C55Y5U1H106Z
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	General Instruments SS26	
L1	Coiltronics	CTX-68-4P, DCR = 0.238Ω

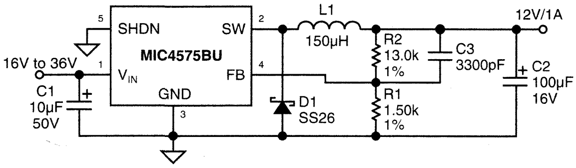
Figure 8. 6V–36V to 3.3V/1A Buck Converter Note 3 Low-Profile Surface Mount

Note 3 Although the MIC457x family is functional to input voltage to 40V they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.



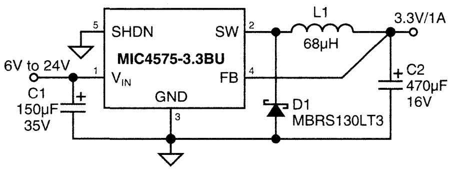
C1	Tokin	C55YU1H106Z
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	General Instuments SS26	
L1	Coiltronics	CTX-68-4P, DCR = 0.238Ω

Figure 9. 8V–36V to 5V/1A Buck Converter Note 3
Low-Profile Surface Mount



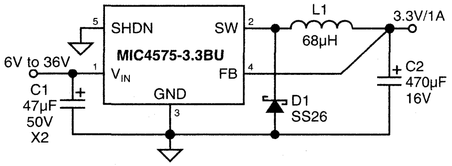
C1	Tokin	C55YU1H106Z
C2	AVX	TPSE107M016R0100, ESR = 0.1Ω
D1	General Instruments SS26	
L1	Coiltronics	CTX-150-4, DCR = 0.372Ω

Figure 10. 16V–36V to 12V/1A Buck Converter Note 3
Low-Profile Surface Mount



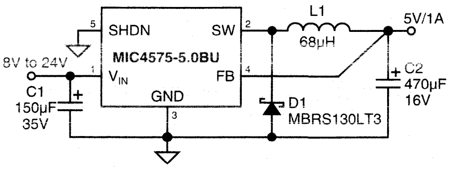
C1	Sanyo	35CV150GX, ESR = 0.17Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	Motorola	MBRS130LT3
L1	Coilcraft	DO3316P-683, DCR = 0.16Ω

Figure 11. 6V–24V to 3.3V/1A Buck Converter
Lower-Cost Surface Mount



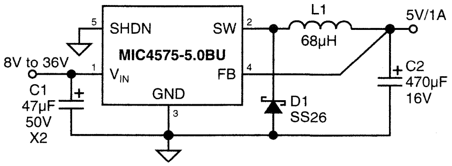
C1	Nichicon	UUX1H470MNT1GS, ESR = 0.4Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	General Instruments SS26	
L1	Coilcraft	DO3316P-683, DCR = 0.16Ω

Figure 12. 6V–36V to 3.3V/1A Buck Converter Note 3
Lower-Cost Surface Mount



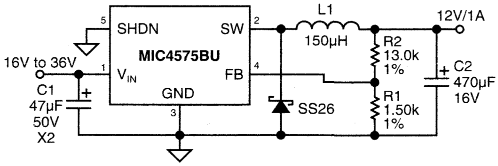
C1	Sanyo	35CV150GX, ESR = 0.17Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	Motorola	MBRS130LT3
L1	Coilcraft	DO3316P-683, DCR = 0.16Ω

Figure 13. 8V–24V to 5V/1A Buck Converter
Lower-Cost Surface Mount



C1	Nichicon	UUX1H470MNT1GS, ESR = 0.4Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	General Instruments SS26	
L1	Coilcraft	DO3316P-683, DCR = 0.16Ω

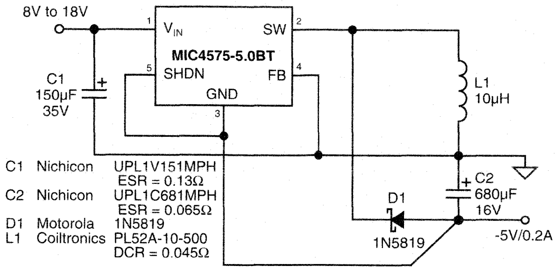
Figure 14. 8V–36V to 5V/1A Buck Converter Note 3
Lower-Cost Surface Mount



C1	Nichicon	UUX1H470MT1GS, ESR = 0.4Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	General Instruments SS26	
L1	Coiltcraft	DO5022P-154, DCR = 0.218Ω

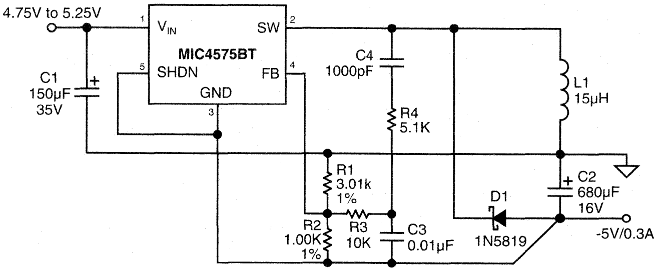
Figure 15. 16V–36V to 12V/1A Buck Converter Note 3
Lower-Cost Surface Mount

Note 3 Although the MIC457x family is functional to input voltage to 40V they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.



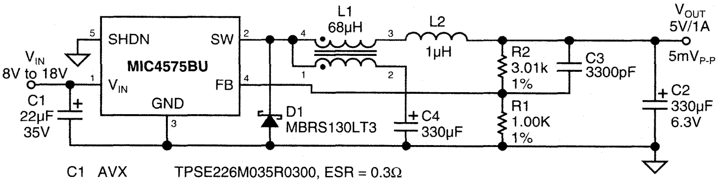
C1	Nichicon	UPL1V151MPH ESR = 0.13Ω
C2	Nichicon	UPL1C681MPH ESR = 0.065Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52A-10-500 DCR = 0.045Ω

Figure 16. 8V–18V to –5V/0.2A Buck-Boost Converter Through Hole



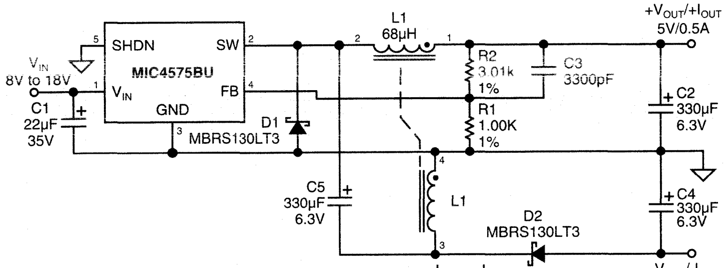
C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C681MPH, ESR = 0.065Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52A-15-500, DCR = 0.054Ω

Figure 17. 5V to –5V/0.3A Buck-Boost Converter Through Hole



C1	AVX	TPSE226M035R0300, ESR = 0.3Ω
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
C4	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	Motorola	MBRS130LT3
L1	Coiltronics	CTX68-4P, DCR = 0.238Ω
L2	Coilcraft	DO1608C-102

Figure 18. Low Output-Noise Regulator (5mV Output Ripple)



$+I_{OUT} + |-I_{OUT}| \le 1A$

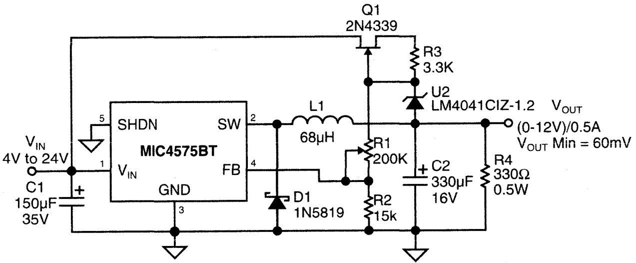
C1	AVX	TPSE226M035R0300, ESR = 0.3Ω
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
C4	AVX	TPSE337M006R0100, ESR = 0.1Ω
C5	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	Motorola	MBRS130LT3
D2	Motorola	MBRS130LT3
L1	Coiltronics	CTX68-4P, DCR = 0.238Ω

$$DC \approx \frac{+V_{OUT} + 0.5V}{V_{IN} - 0.5V}$$

$DC \le 40\%$ then $-I_{OUT} \le +I_{OUT}$

$DC \ge 40\%$ then $-I_{OUT} \le +I_{OUT} \times (1 - DC)$

Figure 19. Split ±5V Supply



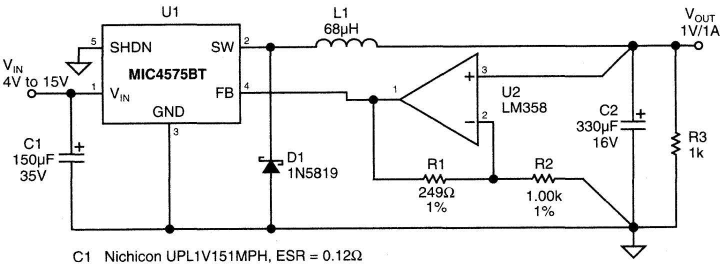
C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω
U2	Micrel	LM4041CIZ-1.2

$$V_{IN\ min} \ge \frac{V_{OUT}}{0.9} + 1.5V$$

and

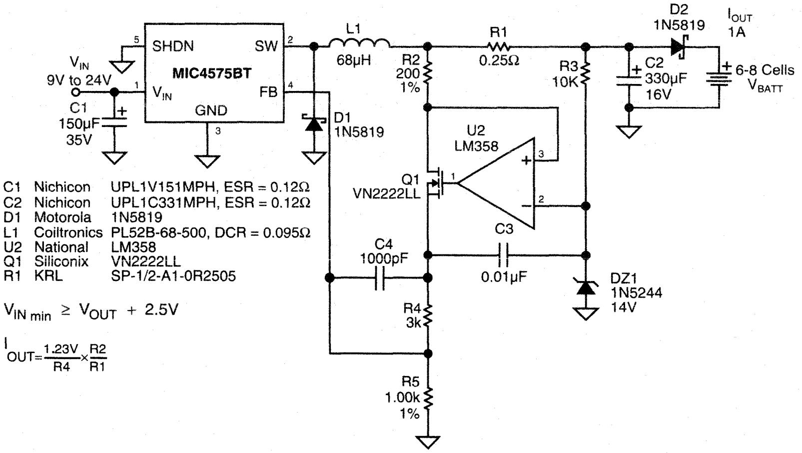
$$V_{IN\ min} \ge V_{OUT} + 2.5V$$

Figure 20. Adjustable (0V–12V) Output-Voltage Regulator



C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω
U2	National	LM358

Figure 21. Low Output-Voltage Regulator (1V)

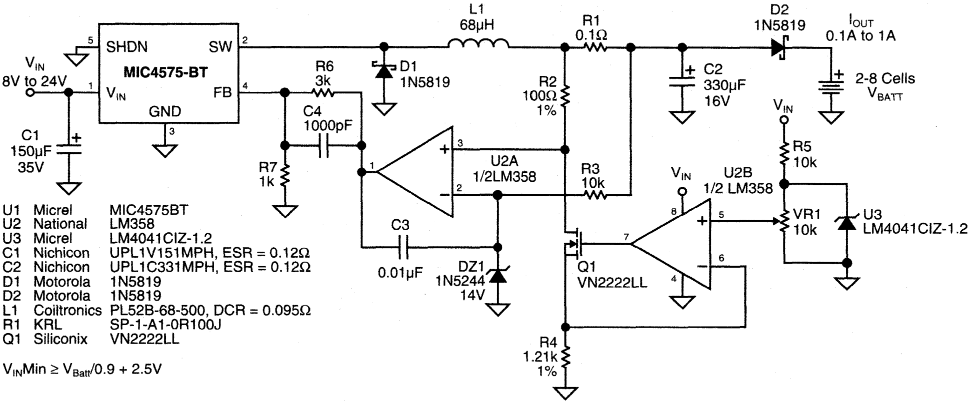


C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω
U2	National	LM358
Q1	Siliconix	VN2222LL
R1	KRL	SP-1/2-A1-0R2505

$V_{IN\,min} \geq V_{OUT} + 2.5V$

$I_{OUT} = \frac{1.23V}{R4} \times \frac{R2}{R1}$

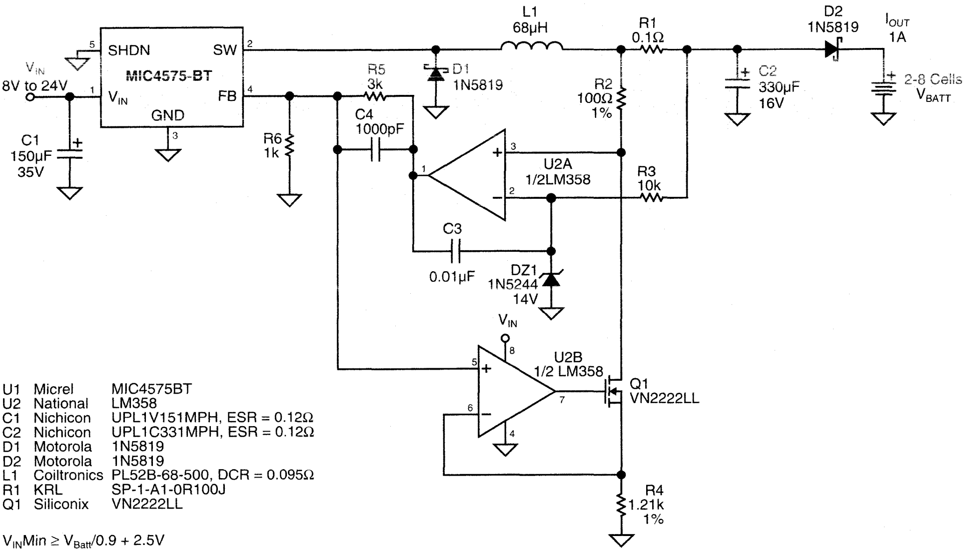
Figure 22. 1A Battery Charger (6–8 cells)



U1	Micrel	MIC4575BT
U2	National	LM358
U3	Micrel	LM4041CIZ-1.2
C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
D2	Motorola	1N5819
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω
R1	KRL	SP-1-A1-0R100J
Q1	Siliconix	VN2222LL

$V_{IN}Min \geq V_{Batt}/0.9 + 2.5V$

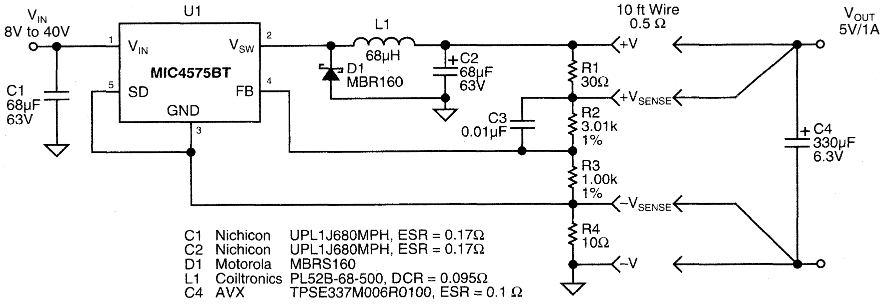
Figure 23. 0.1A–1A Variable Current Battery Charger



U1	Micrel	MIC4575BT
U2	National	LM358
C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
D2	Motorola	1N5819
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω
R1	KRL	SP-1-A1-0R100J
Q1	Siliconix	VN2222LL

$V_{IN}Min \geq V_{Batt}/0.9 + 2.5V$

Figure 24. 1A Battery Charger (2–8 Cells)



C1	Nichicon	UPL1J680MPH, ESR = 0.17Ω
C2	Nichicon	UPL1J680MPH, ESR = 0.17Ω
D1	Motorola	MBRS160
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω
C4	AVX	TPSE337M006R0100, ESR = 0.1 Ω

Figure 46. Remote Sensing Regulator Note 3

LM2576

52kHz Simple 3A Buck Voltage Regulator

General Description

The LM2576 series of monolithic integrated circuits provide all the active functions for a step-down (buck) switching regulator. Fixed versions are available with a 3.3V, 5V, 12V, or 15V fixed output. Adjustable versions have an output voltage range from 1.23V to 37V. Both versions are capable of driving a 3A load with excellent line and load regulation.

These regulators are simple to use because they require a minimum number of external components and include internal frequency compensation and a fixed-frequency oscillator.

The LM2576 series offers a high efficiency replacement for popular three-terminal adjustable linear regulators. It substantially reduces the size of the heat sink, and in many cases no heat sink is required.

A standard series of inductors available from several different manufacturers are ideal for use with the LM2576 series. This feature greatly simplifies the design of switch-mode power supplies.

The feedback voltage is guaranteed to ±2% tolerance for adjustable versions, and the output voltage is guaranteed to ±3% for fixed versions, within specified input voltages and output load conditions. The oscillator frequency is guaranteed to ±10%. External shutdown is included, featuring less than 200μA standby current. The output switch includes cycle-by-cycle current limiting and thermal shutdown for full protection under fault conditions.

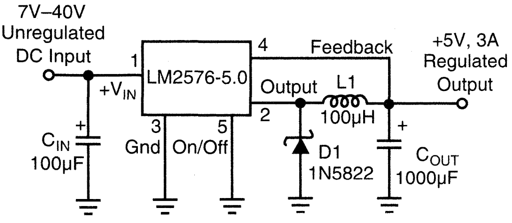
Features

- 3.3V, 5V, 12V, 15V, and adjustable output versions
- Voltage over specified line and load conditions:
  Fixed version: ±3% max. output voltage
  Adjustable version: ±2% max. feedback voltage
- Guaranteed 3A output current
- Wide input voltage range:
  4V to 40V
- Wide output voltage range
  1.23V to 37V
- Requires only 4 external components
- 52kHz fixed frequency internal oscillator
- Low power standby mode I_Q typically < 200μA
- 80% efficiency (adjustable version typically > 80%)
- Uses readily available standard inductors
- Thermal shutdown and current limit protection
- 100% electrical thermal limit burn-in

Applications

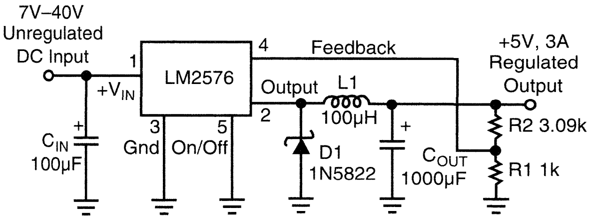
- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive to negative converter (inverting Buck-Boost)
- Isolated Flyback Converter using minimum number of external components
- Negative Boost Converter

Typical Applications



Note: Pin numbers are for TO-220 Package

Fixed Regulator in Typical Application



Note: Pin numbers are for TO-220 Package

$$V_{OUT} = 1.23\left(1 + \frac{R2}{R1}\right)$$

Adjustable Regulator in Fixed Output Application

Ordering Information

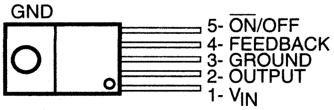
Part Number‡	Temperature Range	Package
LM2576BT*†	–40°C to +85°C	5-lead TO-220
LM2576-3.3BT†	–40°C to +85°C	5-lead TO-220
LM2576-5.0BT†	–40°C to +85°C	5-lead TO-220
LM2576-12BT†	–40°C to +85°C	5-lead TO-220
LM2576BU*	–40°C to +85°C	5-lead TO-263
LM2576-3.3BU	–40°C to +85°C	5-lead TO-263
LM2576-5.0BU	–40°C to +85°C	5-lead TO-263
LM2576-12BU	–40°C to +85°C	5-lead TO-263

* Adjustable output regulators.

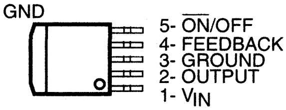
† Contact factory for bent or staggered leads option.

Pin Configurations

5-LEAD TO-220 (T)



5-LEAD TO-263 (U)



Absolute Maximum Ratings (Note 1)

Maximum Supply Voltage	45V
ON/OFF Pin Input Voltage	$-0.3V \le V \le +40V$
Output Voltage to Ground (Steady State)	–1V
Power Dissipation	Internally Limited
Storage Temperature Range	–65°C to +150°C
Minimum ESD Rating	
C = 100pF, R = 1.5kΩ	2 kV
FB Pin	1 kV
Lead Temperature (soldering, 10 sec.)	260°C
Maximum Junction Temperature	150°C

Operating Ratings

Temperature Range	$-40°C \le T_J \le +125°C$
Supply Voltage	40V

Electrical Characteristics

Specifications with standard typeface are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range.** Unless otherwise specified, $V_{IN} = 12V$, and $I_{LOAD} = 500mA$.

Symbol	Parameter	Conditions	Typ	LM2576	Units (Limits)
				Limit (Note 2)	
SYSTEM PARAMETERS, ADJUSTABLE REGULATORS (Note 3) Test Circuit *Figure 1*					
V_{OUT}	Feedback Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.5A$ $V_{OUT} = 5V$	1.230	1.217 1.243	V V(min) V(max)
V_{OUT}	Feedback Voltage LM2576	$0.5A \le I_{LOAD} \le 3A$, $6V \le V_{IN} \le 40V$ $V_{OUT} = 5V$	1.230	1.193/**1.180** 1.267/**1.280**	V V(min) V(max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 3A$, $V_{OUT} = 5V$	82		%
SYSTEM PARAMETERS, 3.3V REGULATORS (Note 3) Test Circuit *Figure 1*					
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.5A$ $V_{OUT} = 3.3V$	3.3	3.234 3.366	V V(min) V(max)
V_{OUT}	Output Voltage LM2576-3.3	$0.5A \le I_{LOAD} \le 3A$, $6V \le V_{IN} \le 40V$ $V_{OUT} = 3.3V$	3.3	3.168/**3.135** 3.432/**3.465**	V V(min) V(max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 3A$	75		%
SYSTEM PARAMETERS, 5V REGULATORS (Note 3) Test Circuit *Figure 1*					
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.5A$ $V_{OUT} = 5V$	5.0	4.900 5.100	V V(min) V(max)
V_{OUT}	Output Voltage LM2576-5.0	$0.5A \le I_{LOAD} \le 3A$, $8V \le V_{IN} \le 40V$ $V_{OUT} = 5V$	5.0	4.800/**4.750** 5.200/**5.250**	V V(min) V(max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 3A$	82		%
SYSTEM PARAMETERS, 12V REGULATORS (Note 3) Test Circuit *Figure 1*					
V_{OUT}	Output Voltage	$V_{IN} = 25V$, $I_{LOAD} = 0.5A$ $V_{OUT} = 12V$	12	11.760 12.240	V V(min) V(max)
V_{OUT}	Output Voltage LMLM2576-12	$0.5A \le I_{LOAD} \le 3A$, $15V \le V_{IN} \le 40V$ $V_{OUT} = 12V$	12	11.520/**11.400** 12.480/**12.600**	V V(min) V(max)
η	Efficiency	$V_{IN} = 25V$, $I_{LOAD} = 3A$	88		%

Electrical Characteristics (continued)

Symbol	Parameter	Conditions	Typ	LM2576 Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS, 15V REGULATORS (Note 3) Test Circuit *Figure 1*					
V_{OUT}	Output Voltage	V_{IN} = 30V , I_{LOAD} = 0.5A	15		V
		V_{OUT} = 15V		14.700	V(min)
				15.300	V(max)
V_{OUT}	Output Voltage LM2576-15	0.5A ≤ I_{LOAD} ≤ 3A, 18V ≤ V_{IN} ≤ 40V	15		V
		V_{OUT} = 15V		14.400/**14.250**	V(min)
				15.600/**15.750**	V(max)
η	Efficiency	V_{IN} = 30V, I_{LOAD} = 3A	88		%
DEVICE PARAMETERS, ADJUSTABLE REGULATOR					
I_B	Feedback Bias Current	V_{OUT} = 5V	50	100/**500**	nA
DEVICE PARAMETERS, FIXED and ADJUSTABLE REGULATORS					
f_O	Oscillator Frequency		52		kHz
				47/**42**	kHz (min)
				58/**63**	kHz (max)
V_{SAT}	Saturation Voltage	I_{OUT} = 3A (Note 4)	1.4		V
				1.8/**2.0**	V(max)
DC	Max Duty Cycle (ON)	(Note 5)	98		%
				93	%(min)
I_{CL}	Current Limit	Peak Current, t_{ON} ≤ 3µs (Note 4)	5.8		A
				4.2/**3.5**	A(min)
				6.9/**7.5**	A(max)
I_L	Output Leakage Current	V_{IN} = 40V, (Note 6), Output = 0V		2	mA(max)
		Output = −1V	7.5		mA
		(Note 6) Output = −1V		30	mA(max)
I_Q	Quiescent Current	(Note 6)	5		mA
				10	mA(max)
I_{STBY}	Standby Quiescent Current	ON/OFF Pin = 5V (OFF)	50		µA
				200	µA(max)
θ_{JA}	Thermal Resistance	T,U Package, Junction to Ambient (Note 7)	65		°C/W
θ_{JA}		T,U Package, Junction to Ambient (Note 8)	45		
θ_{JC}		T,U Package, Junction to Case	2		

Electrical Characteristics (continued)

Symbol	Parameter	Conditions	Typ	LM2576 Limit (Note 2)	Units (Limits)
ON/OFF CONTROL, FIXED and ADJUSTABLE REGULATORS Test Circuit *Figure 1*					
V_{IH}	ON/OFF Pin Logic Input Level	V_{OUT} = 0V	1.4	2.2/**2.4**	V(min)
V_{IL}		V_{OUT} = 5V	1.2	1.0/**0.8**	V(max)
I_{IH}	ON /OFF Pin Logic Current	ON /OFF Pin = 5V (OFF)	4	 30	µA µA(max)
I_{IL}		ON/OFF Pin = 0V (ON)	0.01	 10	µA µA(max)

Note 1: Absolute Maximum Rating indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All room temperature limits are 100% production tested. All limits at **temperature extreme** are guaranteed via testing.

Note 3: External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2576/LM1576 is used as shown in *Figure 1* test circuit, system performance will be shown in system parameters section of Electrical Characteristics.

Note 4: Output (pin 2) sourcing current. No diode, inductor or capacitor connected to output.

Note 5: Feedback (pin 4) removed from output and connected to 0V.

Note 6: Feedback (pin 4) removed from output and connected to 12V to force the output transistor OFF.

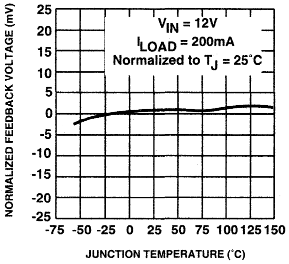
Note 7: Junction to ambient thermal resistance (no external heat sink) for the 5-lead TO-220 package mounted vertically, with 1/2" leads in a socket, or on PC board with minimum copper area.

Note 8: Junction to ambient thermal resistance (no external heat sink) for the 5-lead TO-220 package mounted vertically, with 1/4" leads soldered to PC board containing approximately 4 square inches of copper area surrounding the leads.

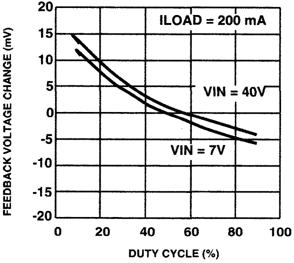
Note 9: Junction to ambient thermal resistance with approximately 1 square inch of pc board copper surrounding the leads. Additional copper will lower thermal resistance further.

Typical Performance Characteristics

Normalized Feedback Voltage*

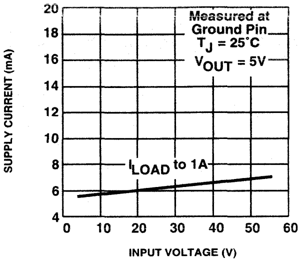


Feedback Voltage vs Duty Cycle*

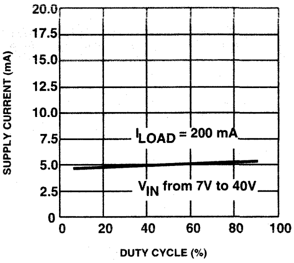


* Adjustable version only

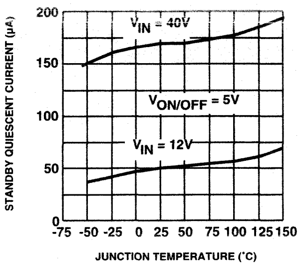
Typical Performance Characteristics (continued) (Circuit of *Figure 1*)



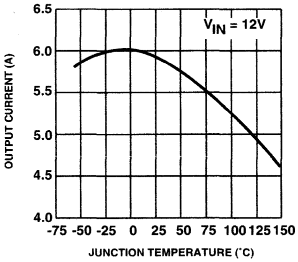
Supply Current



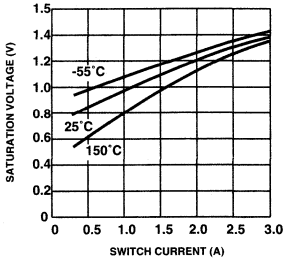
Supply Current vs. Duty Cycle



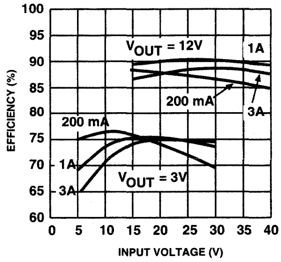
Standby Quiescent Current



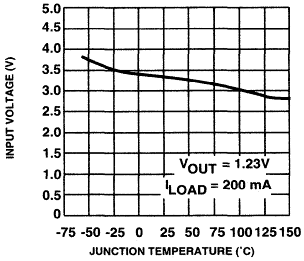
Current Limit



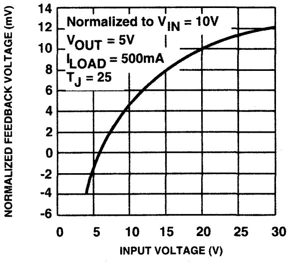
Switch Saturation Voltage



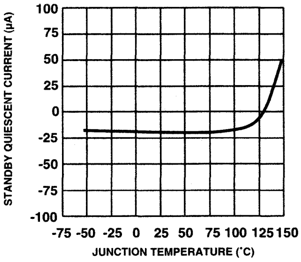
Efficiency



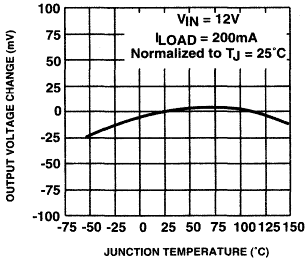
Minimum Operating Voltage



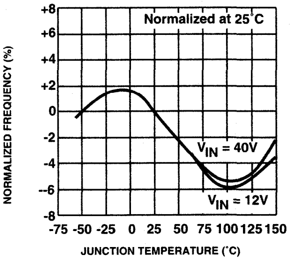
Line Regulation



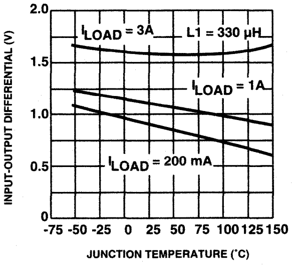
Feedback Pin Current



Normalized Output Voltage

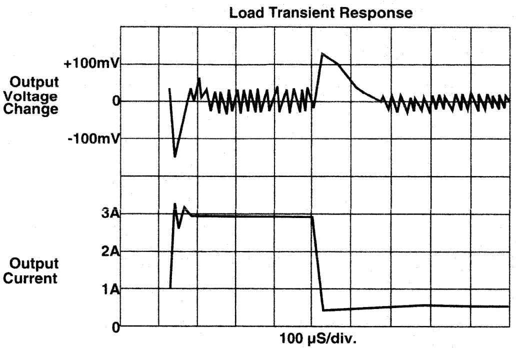


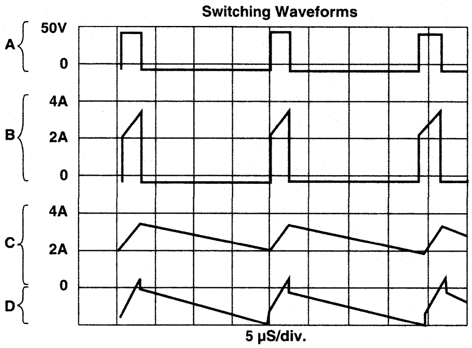
Oscillator Frequency



Dropout Voltage

Typical Performance Characteristics (Circuit of *Figure 1*)



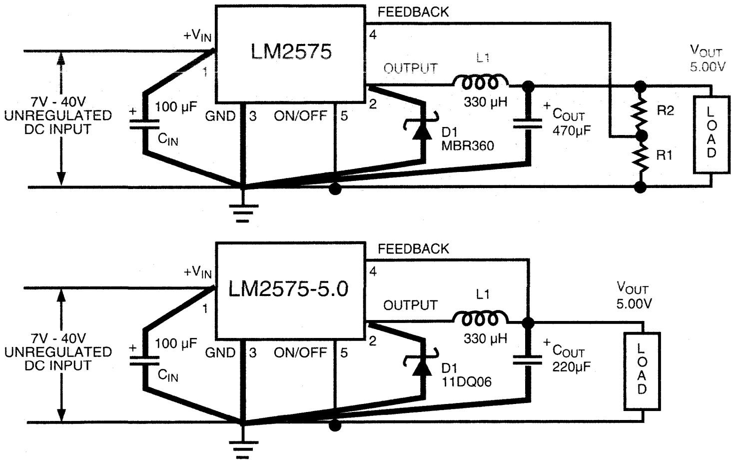


V_{OUT} = 5V V_{IN} = 45V

A: Output pin voltage 50V/div
B: Output pin current 2A/div
C: Inductor current 2A/div
D: Output ripple voltage 50 mV/div., AC coupled

Horizontal Time Base: 5µS/div

Test Circuits and Layout Guidelines



C_{IN} — 100µF, 75V Aluminum Electrolytic
C_{OUT} — 470µF, 15V Aluminum Electrolytic
D1 — Schottky, MBR360
L1 — 330µH, 415-0926 (AIE)
R1 — 1k, 0.01%
R2 — 3.065k, 0.01%
5-pin TO-220 socket—2936 (Loranger Mfg. Co.)
4-pin TO-3 socket—8112-AG7 (Augat Inc.)

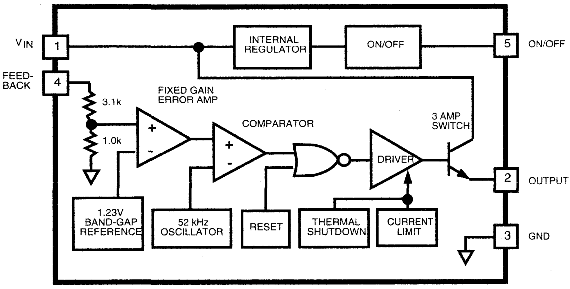
C_{IN} — 100µF, 75V Aluminum Electrolytic
C_{OUT} — 330µF, 15V Aluminum Electrolytic
D1 — Schottky, 11DQ06
L1 — 100µH, 415-0926 (AIE)
5-pin TO-220 socket—2936 (Loranger Mfg. Co.)
4-pin TO-3 socket—8112-AG7 (Augat Inc.)

Note: Pin numbers are for TO-220 Package

Figure 1.

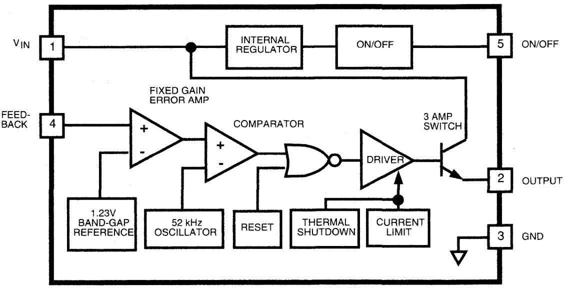
As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance generate voltage transients which can cause problems. For minimal stray inductance and ground loops, the length of the leads indicated by heavy lines should be kept as short as possible. Single-point grounding (as indicated) or ground plane construction should be used for best results.

Block Diagrams



Note: Pin numbers are for the TO-220 package

Fixed Regulator



Adjustable Regulator

MIC4576

200kHz Simple 3A Buck Voltage Regulator

Preliminary Information

General Description

The MIC4576 is a series of easy to use fixed and adjustable BiCMOS step-down (buck) switch-mode voltage regulators. The 200kHz MIC4576 duplicates the pinout and function of the 52kHz LM2576. The higher switching frequency may allow up to a 4:1 reduction in output filter inductor values.

The MIC4576 is available in 3.3V, and 5V fixed output versions or a 1.23V to 18V adjustable output version. Both versions are capable of driving a 3A load with excellent line and load regulation.

The feedback voltage is guaranteed to ±2% tolerance for adjustable versions, and the output voltage is guaranteed to ±3% for fixed versions, within specified voltages and load conditions. The oscillator frequency is guaranteed to ±10%.

In shutdown mode, the regulator draws less than 200µA standby current. The regulator performs cycle-by-cycle current limiting and thermal shutdown for protection under fault conditions.

This series of simple switch-mode regulators requires a minimum number of external components and can operate using a standard series of inductors. Frequency compensation is provided internally.

The MIC4576 is available in TO-220 (BT) and TO-263 (BU) packages for the industrial temperature range.

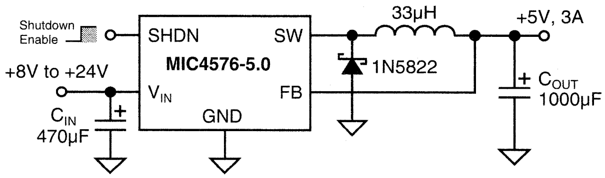
Features

- Fixed 200kHz operation
- 3.3V, 5V, and adjustable output versions
- Voltage over specified line and load conditions:
  - Fixed version: ±3% max. output voltage
  - Adjustable version: ±2% max. feedback voltage
- Guaranteed 3A switch current
- Wide input voltage range: 4V to 24V
- Wide output voltage range: 1.23V to 18V
- Requires minimum external components
- Shutdown mode < 200µA typ.
- 75% efficiency (adjustable version > 75% typ.)
- Standard inductors and capacitors are 25% of typical LM2576 values.
- Thermal shutdown
- Overcurrent protection
- 100% electrical thermal limit burn-in

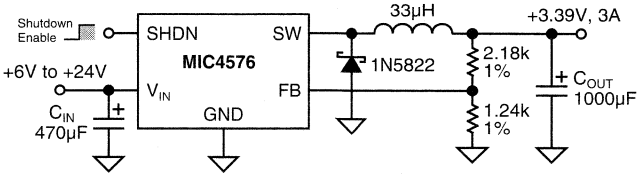
Applications

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive to negative converter (inverting buck-boost)
- Isolated flyback converter using minimum external components
- Negative boost converter
- Step-down to 3.3V for Intel Pentium™ and similar microprocessors

Typical Applications



Fixed Regulator

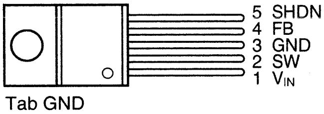


Adjustable Regulator

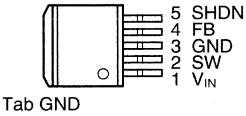
Ordering Information

Part Number	Voltage	Temperature Range	Package
MIC4576-3.3BT	3.3V	–40°C to +85°C	5-lead TO-220
MIC4576-5.0BT	5.0V	–40°C to +85°C	5-lead TO-220
MIC4576BT	Adjustable	–40°C to +85°C	5-lead TO-220
MIC4576-3.3BU	3.3V	–40°C to +85°C	5-lead TO-263
MIC4576-5.0BU	5.0V	–40°C to +85°C	5-lead TO-263
MIC4576BU	Adjustable	–40°C to +85°C	5-lead TO-263

Pin Configuration



5-Lead TO-220 (T)



5-Lead TO-263 (U)

Pin Description

Pin Number	Pin Name	Pin Function
1	V_{IN}	Supply Voltage (Input): Unregulated +4V to +40V supply voltage.
2	SW	Switch (Output): Emitter of NPN output switch. Connect to external storage inductor and Shottky diode.
3	GND	Ground
4	FB	Feedback (Input): Output voltage feedback to regulator. Connect to output of supply for fixed versions. Connect to 1.23V tap of resistive divider for adjustable versions.
5	SHDN	Shutdown (Input): Logic low enables regulator. Logic high (> 2.4V) shuts down regulator.

Absolute Maximum Ratings

Supply Voltage (V_{IN}) 45V
Shutdown (SHDN) .... –0.3V to +40V
Output Switch (SW), Steady State .... –1V
Operating Junction Temperature .... 160°C
Package Thermal Resistance
θ_{JA} TO-220, TO-263 .... 65°C/W
θ_{JC} TO-220, TO-263 .... 2°C/W
Storage Temperature .... –65°C to 150°C

Electrical Characteristics $T_J = 25°C$. **Bold** indicates $-40°C \le T_J \le +85°C$. (Note 1)

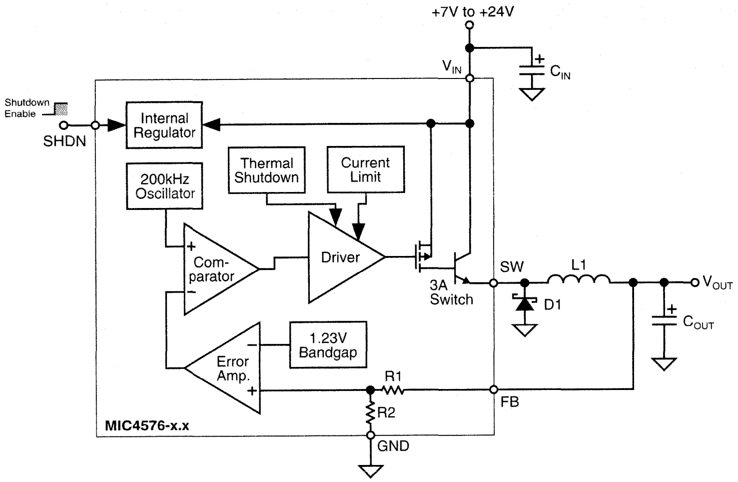
Parameter	Condition	Min	Typ	Max	Units
MIC4576 [Adjustable] (Note 2)					
Feedback Voltage		1.217	1.230	1.243	V
Feedback Voltage	$8V \le V_{IN} \le 24V$, $0.5A \le I_{LOAD} \le 3A$	1.193 **1.180**	1.230	1.267 **1.280**	V V
Efficiency	$I_{LOAD} = 3A$		77		%
Feedback Bias Current			50	100 **500**	nA nA
MIC4576-3.3					
Output Voltage		3.234	3.3	3.366	V
Output Voltage	$6V \le V_{IN} \le 24V$, $0.5A \le I_{LOAD} \le 3A$	3.168 **3.135**	3.3	3.432 **3.465**	V V
Efficiency	$I_{LOAD} = 3A$		72		%
MIC4576-5.0					
Output Voltage		4.900	5.0	5.100	V
Output Voltage	$8V \le V_{IN} \le 24V$, $0.5A \le I_{LOAD} \le 3A$	4.800 **4.750**	5.0	5.200 **5.250**	V V
Efficiency	$I_{LOAD} = 3A$		77		%
MIC4576 / -3.3 / -5.0					
Oscillator Frequency		180	200	220	kHz
Saturation Voltage	$I_{OUT} = 3A$		1.7	2.3 **2.5**	V V
Maximum Duty Cycle (On)	FB connected to 0V	90	95		%
Current Limit	Peak Current, $t_{ON} \le 3\mu s$	4.2 **3.5**	5.2	6.9 **7.5**	A A
Output Leakage Current	$V_{IN} = 24V$, FB connected to 0V Output = 0V Output = –1V		 0 7.5	 2 30	 mA mA
Quiescent Current			5	10	mA
Standby Quiescent Current	SHDN = 5V (regulator off)		50	200	µA
SHDN Input Logic Level	$V_{OUT} = 0V$ (regulator off)	2.2 **2.4**	1.4		V V
	$V_{OUT} = 3.3V$ or 5V (regulator on)		1.2	1.0 **0.8**	V V
SHDN Input Current	SHDN = 5V (regulator off) SHDN = 0V (regulator on)	 –10	4 0.01	30 10	µA µA

General Note: Devices are ESD protected, however, handling precautions are recommended.

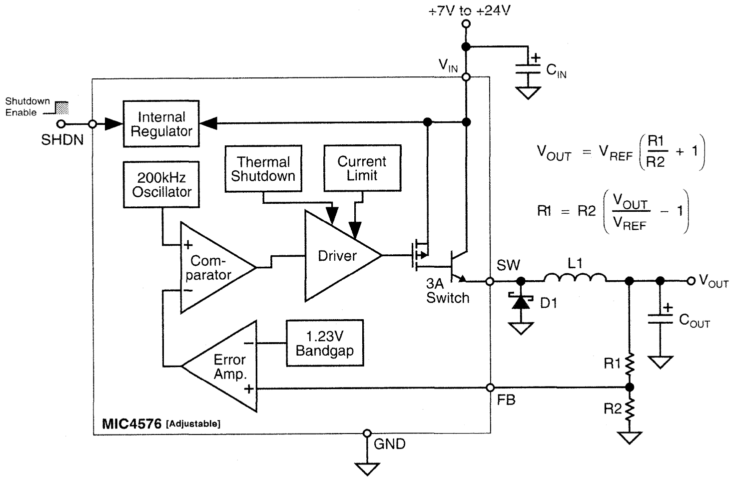
Note 1 $V_{IN} = 12V$, $I_{LOAD} = 500mA$ unless noted.

Note 2 $V_{OUT} = 5V$

Block Diagrams



Block Diagram with External Components
Fixed Step-Down Regulator



$$V_{OUT} = V_{REF}\left(\frac{R1}{R2} + 1\right)$$

$$R1 = R2\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

Block Diagram with External Components
Adjustable Step-Down Regulator

Functional Description

The MIC4576 is a variable duty cycle switch-mode regulator with an internal power switch. Refer to the block diagrams.

Supply Voltage

The MIC4576 operates from a +4V to +24V unregulated input. Highest efficiency operation is from a supply voltage around +15V.

Enable/Shutdown

The shutdown (SHDN) input is TTL compatible. Ground the input if unused. A logic-low enables the regulator. A logic-high shuts down the internal regulator which reduces the current to typically 50μA.

Feedback

Fixed versions of the regulator have an internal resistive divider from the feedback (FB) pin. Connect FB directly to the output line.

Adjustable versions require an external resistive voltage divider from the output voltage to ground, connected from the 1.23V tap to FB.

Duty Cycle Control

A fixed-gain error amplifier compares the feedback signal with a 1.23V bandgap voltage reference. The resulting error amplifier output voltage is compared to a 200kHz sawtooth waveform to produce a voltage controlled variable duty cycle output.

A higher feedback voltage increases the error amplifier output voltage. A higher error amplifier voltage (comparator "–" input) causes the comparator to detect only the peaks of the sawtooth, reducing the duty cycle of the comparator output. A lower feedback voltage increases the duty cycle.

Output Switching

When the internal switch is on, an increasing current flows from the supply $V_{IN,}$ through external storage inductor L1, to output capacitor C_{OUT} and the load. Energy is stored in the inductor as the current increases with time.

When the internal switch is turned off, the collapse of the magnetic field in L1 forces current to flow through fast recovery diode D1, charging C_{OUT}.

Output Capacitor

External output capacitor C_{OUT} provides stabilization and reduces ripple.

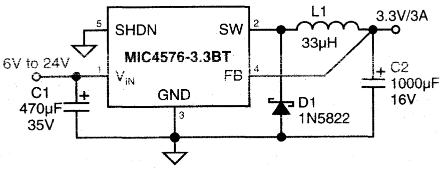
Return Paths

During the on portion of the cycle, the output capacitor and load currents return to the supply ground. During the off portion of the cycle, current is being supplied to the output capacitor and load by storage inductor L1, which means that D1 is part of the high-current return path.

Applications Information

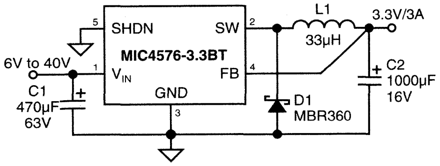
The applications circuits that follow have been constructed and tested. Refer to Application Note 15 for additional information, including efficiency graphs and manufacturer's addresses and telephone numbers for most circuits.

For a mathematical approach to component selection and circuit design, refer to Application Note 14.



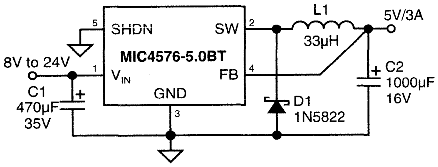
C1	Nichicon	UPL1V471MPH, ESR = 0.046Ω
C2	Nichicon	UPL1C221MPH, ESR = 0.047Ω
D1	Motorola	1N5822
L1	Coiltronics	PL52C-33-1000, DCR = 0.036Ω

Figure 1. 6V–24V to 3.3V/3A Buck Converter Through Hole



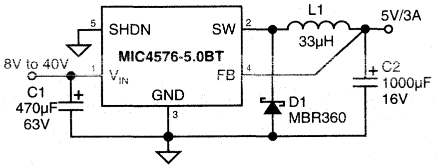
C1	Nichicon	UPL1J471MRH, ESR = 0.039Ω
C2	Nichicon	UPL1C102MPH, ESR = 0.047Ω
D1	Motorola	MBR360
L1	Coiltronics	PL52C-33-1000, DCR = 0.036Ω

Figure 2. 6V–40V to 3.3V/3A Buck Converter Note 3 Through Hole



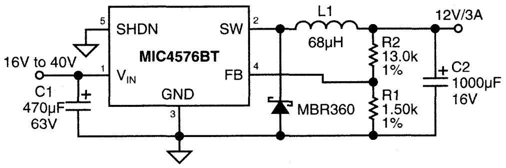
C1	Nichicon	UPL1J471MPH, ESR = 0.046Ω
C2	Nichicon	UPL1C102MPH, ESR = 0.047Ω
D1	Motorola	MBR5822
L1	Coiltronics	PL52C-33-1000, DCR = 0.036Ω

Figure 3. 8V–24V to 5V/3A Buck Converter Through Hole



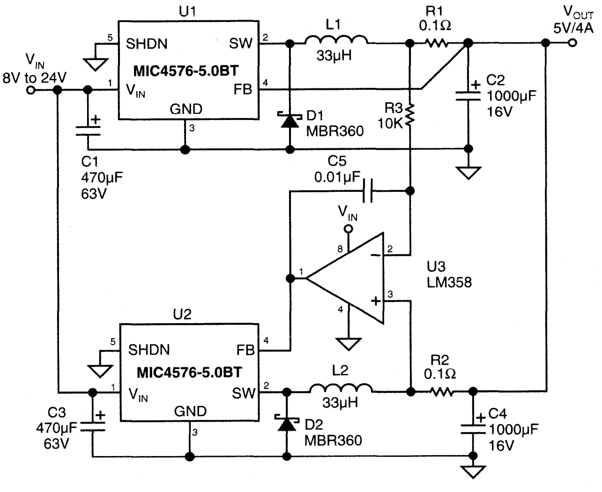
C1	Nichicon	UPL1J471MRH, ESR = 0.039Ω
C2	Nichicon	UPL1C102MPH, ESR = 0.047Ω
D1	Motorola	MBR360
L1	Coiltronics	PL52C-33-1000, DCR = 0.036Ω

Figure 4. 8V–40V to 5V/3A Buck Converter Note 3 Through Hole



C1	Nichicon	UPL1J471MPH, ESR = 0.039Ω
C2	Nichicon	UPL1C102MPH, ESR = 0.047Ω
D1	Motorola	MBR360
L1	Coiltronics	PL52D-68-2000, DCR = 0.045Ω

Figure 5. 16V–40V to 12V/3A Buck Converter Note 3 Through Hole



C1, C3	Nichicon	UPL1J471MRH, ESR = 0.039Ω
C2, C4	Nichicon	UPL1C102MPH, ESR = 0.047Ω
D1, D2	Motorola	MBR360
L1, L2	Coiltronics	PL52C-33-1000, DCR = 0.036
R1, R2	KRL	SP-1-A1-0R100J
U3	National	LM358

Figure 6. Parallel Switching Regulators

Note 3 Although the MIC457x family is functional to input voltage to 40V they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.

MIC3832/3833

Current-Fed PWM Controllers

Preliminary Information

General Description

The MIC3832 and MIC3833 are unique PWM controllers designed for current-fed, multiple-output or push-pull, switched-mode power supply applications.

The MIC3832/3 features UVLO (undervoltage lockout) with hysteresis, soft start with a programmable time constant, cycle-by-cycle current limiting, a PWM latch to prevent multiple outputs due to noise or ringing, and front-edge blanking.

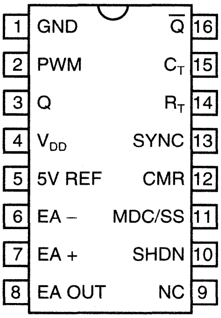
Current-fed topologies eliminate core saturation problems caused by shoot through (cross conduction) of push-pull circuits and reduce stress on the switching transistors.

The MIC3832/3 has one PWM stage capable of operating up to 500kHz and two output stages, Q and $\overline{Q}$, that operate at one-half of the system frequency at a fixed 50% duty cycle.

The MIC3832 UVLO circuit permits startup when the supply is above 15.9V and forces shutdown when the supply drops below 9.8V. The MIC3833 starts up above 8.3V and shuts down below 7.8V. An internal 22V zener diode provides low power overvoltage protection.

The three output stages are totem-pole drivers capable of 1A peak current to external power MOSFETs, BJTs, or IGBTs. The Q and $\overline{Q}$ outputs have an intentional 50ns overlap (no dead time).

Pin Configuration



DIP (N) or Wide SOIC (WM)

Features

- 15.9V startup, up to 21V operation (MIC3832)
  8.3V startup, up to 21V operation (MIC3833)
- 9.8V undervoltage lockout (MIC3832)
  7.8V undervoltage lockout (MIC3833)
- 0.5mA maximum startup current (40μA typical)
- 17mA typical operating current
- 50ns maximum rise and fall times
- 30kHz to 500kHz RC oscillator
- Voltage or current-mode control
- Cycle-by-cycle current limit
- Soft start function
- 5V 2% reference sources 20mA
- Totem-pole output drive stages
  1A peak output drive current
- 22V zener clamp on supply pin
- PWM latch eliminates false outputs from noise or ringing
- Adjustable maximum duty-cycle limit
- 5MHz bandwidth error amplifier

Applications

- High-power, multiple-output, switched-mode power supplies and dc-to-dc Converters
- Current-fed, push-pull, switched-mode power supplies or dc-to-dc converters
- Isolated high-voltage supplies

Ordering Information

Part Number	Temperature Range	Package
MIC3832AJB*	–55°C to +125°C	16-pin Ceramic DIP
MIC3832BN	–40°C to +85°C	16-pin Plastic DIP
MIC3832BWM	–40°C to +85°C	16-pin Wide SOIC
MIC3833AJB*	–55°C to +125°C	16-pin Ceramic DIP
MIC3833BN	–40°C to +85°C	16-pin Plastic DIP
MIC3833BWM	–40°C to +85°C	16-pin Wide SOIC

* Order Note: AJB indicates units screened to MIL-STD 883, Method 5004, condition B, and burned-in for 1-week.

Pin Description

Pin Number	Pin Name	Pin Function
1	GND	Ground: Use as single-point ground tie point.
2	PWM	PWM Output: Variable duty-cycle totem pole output.
3	Q	Switch (Output): Totem pole output. Noninverting 50% duty cycle output (180° out-of-phase with $\overline{Q}$ with no dead time).
4	V_{DD}	Supply Voltage (Input): Clamped to 22V by internal zener diode.
5	5V REF	5V Bandgap Reference (Output)
6	EA –	Inverting Error Amplifier Input
7	EA +	Noninverting Error Amplifier Input
8	EA OUT	Error Amplifier Output: Connect to the appropriate feedback network to adjust the open loop gain or frequency response.
9	NC	No Connection: Do not use—leave open.
10	SHDN	Overcurrent Shutdown (Input): >1 V disables outputs, >1.25V initiates soft-start restart. For cycle-by-cycle current limiting, even in voltage-mode control applications, connect to current sensor. If current sense is not used, connect to GND.
11	MDC/SS	Maximum Duty Cycle/Soft Start (Input): Apply a dc voltage to adjust maximum duty cycle (see chart). Adjust soft start by adding capacitance to increase turn-on time during initial start up or restart after overcurrent shutdown.
12	CMR	Current Mode Ramp: Feed point for a sample of inductor current when using current mode control. For voltage-mode control, connect directly to the C_T pin.
13	SYNC	Synchronization (Input): AC coupled input from an external master clock (reference) signal. If not used, leave unconnected. A high (>1.5V) resets the C_T ramp.
14	R_T	Oscillator Timing Resistor: Connect 4kΩ minimum resistor to GND.
15	C_T	Oscillator Timing Capacitor: Connect capacitor to GND. See "Typical Characteristics: Discharge Time" graph for capacitor value. $\text{Maximum oscillator frequency} = \dfrac{1}{2 \times (\text{discharge time})}$
16	$\overline{Q}$	Switch (Output): Totem pole output. Inverting 50% duty cycle output (180° out-of-phase with Q with no deadtime).

Absolute Maximum Ratings (Note 1)

Supply Voltage, V_{DD} (continuous)	22V
Source/Sink Load Current (peak)	1A
Maximum Supply (Zener) Current	50mA
Junction Temperature	150°C
Lead Temperature, Soldering	260°C for 10s
θ_{JA}CerDIP	100°C/W
θ_{JA}Plastic DIP	130°C/W

Operating Ratings

Storage Temperature Range	–65°C to +150°C
Operating Temperature Range	–40°C to +85°C
Reference Load Current	25mA
Supply Voltage (V_{DD}): MIC3832	16V to 21V
Supply Voltage (V_{DD}): MIC3833	7.6V to 21V
Oscillator Frequency Range	10kHz to 500kHz
Oscillator Timing Resistor	3kΩ to 100kΩ
Oscillator Timing Capacitor	1nF to 10nF

Electrical Characteristics (Notes 2, 3)

T_A = –40°C to +85°C, V_{DD} = 15V, f = 52kHz unless otherwise specified.

Parameter	Conditions	Min	Typical	Max	Units
Reference Section					
Output Voltage	I_o = 1mA, T_A = 25°C	4.90	5.0	5.10	V
Input Regulation	V_{CC} = 12V to 20V		5	20	mV
Output Regulation	I_O = 1mA to 20mA		6	25	mV
Temperature Stability			–0.2		mV/°C
Total Output Variation			50		mV
Output Noise Voltage	f = 10Hz to 10kHz, T_A = 25°C		50		µV
Long Term Stability	T_A = 125°C, 1000hrs.		5.0		mV
Output Short Circuit Current	V_{REF} = 0	25	60	160	mA
Oscillator Section					
Frequency	T_A = 25°C, R_T = 10kΩ, C_T = 1nF	47	52	57	kHz
Voltage Stability	V_{CC} = 12V to 20V		0.5		%
Amplitude (C_t)			1.7		V_{P-P}
Discharge Current	T_A = 25°C	1	2.3	5	mA
Synchronization	ac coupled		1.5		V
Error Amplifier Section					
Input Offset Voltage		–15	±2	15	mV
Input Bias Current			0.6	3.0	µA
Input Offset Current			0.1	1.0	µA
Open Loop Gain	$1V < V_O < 4V$	60	82		dB
CMRR	$1.5V < V_{CM} < 4.5V$	75	95		dB
PSRR	$12V < V_{DD} < 20V$	85	120		dB
Output Sink Current	$V_{EA\ OUT}$ = 1V	1.0	2.5		mA
Output Source Current	$V_{EA\ OUT}$ = 4V	–0.5	–1.3		mA
Output High Voltage	$I_{EA\ OUT}$ = –0.5mA	4.0	4.9	5.0	V
Output Low Voltage	$I_{EA\ OUT}$ = 1mA		0.6	1.0	V
Soft Start/Max Duty Cycle Section					
Bias Current			–0.05		µA
Discharge Current		1	3		mA
Duty Cycle Clamp Accuracy		40	50	60	%

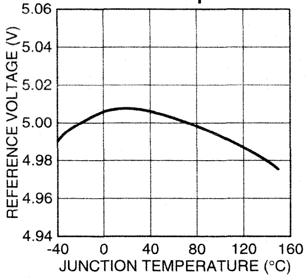
Parameter	Conditions	Min	Typical	Max	Units
Current Limit/Shutdown Section					
Bias Current			–0.02		µA
Current Limit Threshold		0.9	1.0	1.1	V
Shutdown Threshold		1.125	1.25	1.375	V
Delay to Output			400	600	ns
Front Edge Blanking Time			140		ns
PWM Comparator Section					
Bias Current	measured at CMR (pin 12)	–2	–0.05	2	µA
Duty Cycle Range	C = 2.2nF	0		85	%
Delay to Output			300	500	ns
Output Sections					
Output Low Level	I_{SINK} = 20mA		0.1	0.4	V
	I_{SINK} = 200mA		1.5	2.5	V
Output High Level	I_{SOURCE} = 20mA	12.5			V
	I_{SOURCE} = 200mA	12	13.1		V
Rise Time	C_L = 1000pF		50	150	ns
Fall Time	C_L = 1000pF		50	150	ns
UVLO Saturation	I_{SINK} = 1mA		0.7	1.1	V
Q to $\overline{Q}$ Overlap	Q rising, $\overline{Q}$ falling, 50%		50		ns
$\overline{Q}$ to Q Overlap	$\overline{Q}$ rising, Q falling, 50%		50		ns
Undervoltage Lockout Section					
Upper Threshold—Startup	MIC3832		15.9		V
	MIC3833		8.3		V
Lower Threshold—Operating (Shutdown)	MIC3832		9.8		V
	MIC3833		7.8		V
Total Standby Current					
Startup Current			0.04	0.2	mA
Operating Supply			17		mA
V_{CC} Zener Voltage	I_{CC} = 25mA		22		V

Note 1 **Absolute Maximum Ratings** indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its specified **Operating Ratings**.

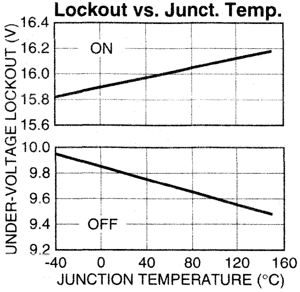
Note 2 Minimum and maximum Electrical Characteristics are 100% tested at T_A = 25°C and T_A = 85°C, and 100% guaranteed over the entire range. Typicals are characterized at 25°C and represent the most likely parametric norm.

Note 3 All pins ESD protected to 2kV. Test conditions: Supply pin grounded; all other pins floating.

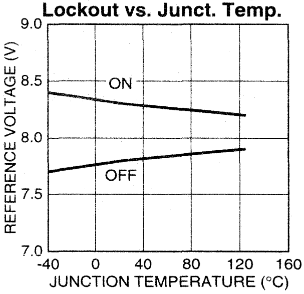
Typical Characteristics



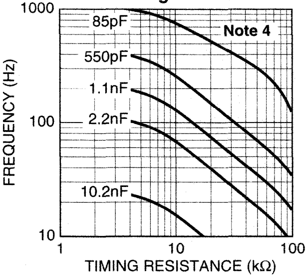
Reference Voltage vs. Junction Temperature



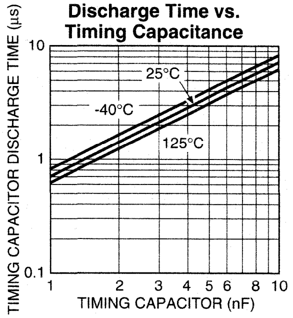
MIC3832 Undervoltage Lockout vs. Junct. Temp.



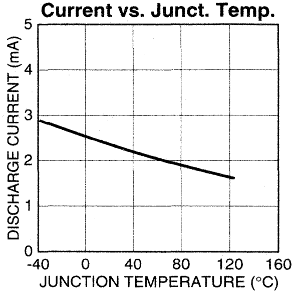
MIC3833 Undervoltage Lockout vs. Junct. Temp.



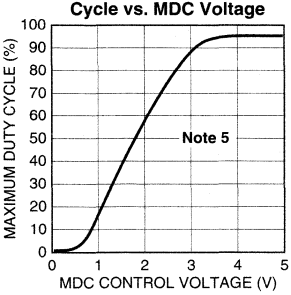
Oscillator Frequency vs. Timing Resistance



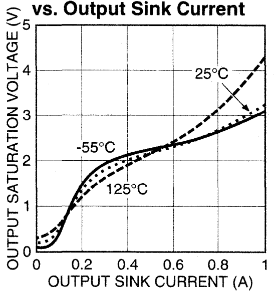
Discharge Time vs. Timing Capacitance



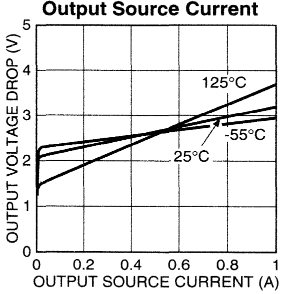
Oscillator Discharge Current vs. Junct. Temp.



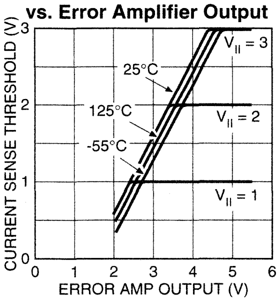
Voltage-Mode Max. Duty Cycle vs. MDC Voltage



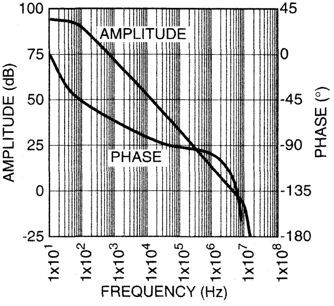
Output Saturation Voltage vs. Output Sink Current



Output Voltage Drop vs. Output Source Current



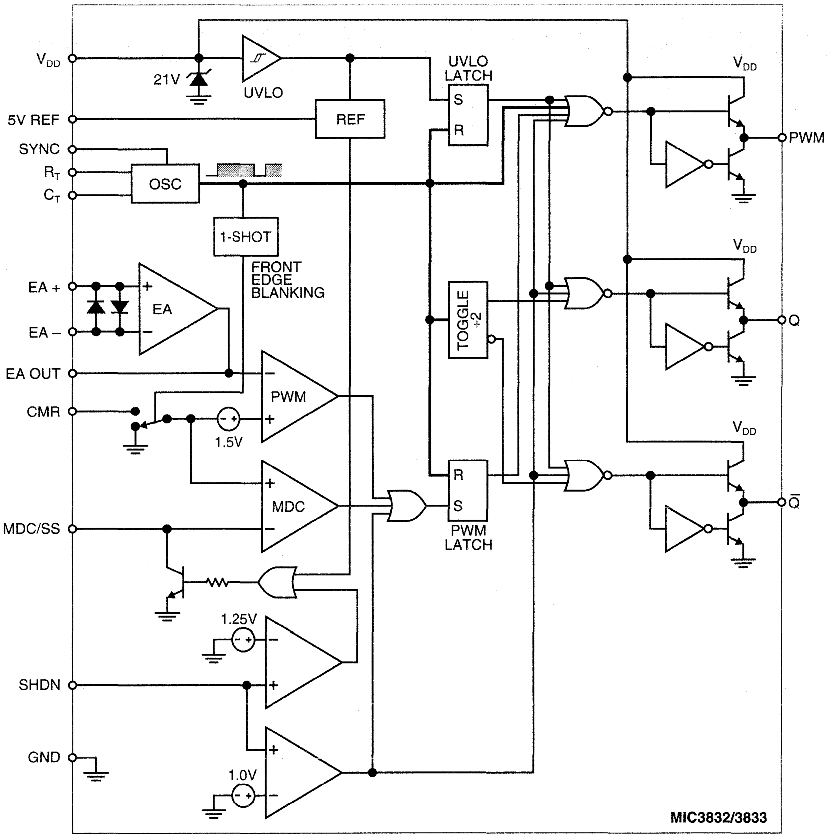
Current Sense Threshold vs. Error Amplifier Output



Error Amplifier Open-Loop Frequency Response

Note 4:	CMR (pin 12) connected to C_T (pin 15).
Note 5:	CMR (pin 12) connected to C_T (pin 15). MDC voltage measured at MDC/SS (pin 11). C_T = 1nF, R_T = 10kΩ.

Block Diagram



Functional Description

Refer to the block diagram and Figure 5.

The MIC3832 and MIC3833 are self-contained controllers, with a voltage reference, voltage-mode error amplifier; current-mode, maximum duty cycle, overcurrent, and shutdown comparators; and an undervoltage lockout circuit. Three control loops are provided: voltage-mode through the error amplifier, current-mode through the PWM comparator, and overcurrent through the shutdown comparator. Three totem-pole outputs provide up to 1A peak synchronized drive to external FETs for current-fed push-pull or bridge transformer applications.

Undervoltage Lockout (UVLO)

Undervoltage lockout (UVLO) requires that the input voltage rise above 15.9V (MIC3832) or 8.3V (MIC3833) before the startup circuit is energized. Once operating, the controller will not shut down until the supply drops to 9.8V (MIC3832) or 7.8V (MIC3833). There is an internal 22V zener between V_{DD} and ground for overvoltage clamping. Zener current should be limited to less than 20mA.

Voltage Reference (REF)

The reference consists of a 5V bandgap reference internally trimmed to 2% accuracy. It provides an internal reference and can be used to supply up to 25mA to external circuits.

Oscillator (R_T/C_T)

The oscillator stage performs two functions. First, it provides a linear sawtooth waveform which is fed to the PWM comparator in voltage-mode control. Second, it toggles the flip-flop which provides the Q and $\overline{Q}$ outputs. The oscillator frequency is configured using an external timing resistor and capacitor. A nominal voltage of 3.6V appears on the R_T pin; the resulting current is then mirrored through the C_T pin which charges the timing capacitor and generates the linear ramp.

It is important to select an appropriate capacitor. At high frequencies effective series resistance, effective series inductance, dielectric loss and dielectric absorption all affect frequency stability and accuracy. RF capacitors such as silver mica, glass, polystyrene, or COG ceramics are recommended. High K ceramics should not be used.

Front-Edge Blanking

This feature provides a fixed delay time prior to current sensing becoming active. This prevents the overcurrent sensing function from being falsely tripped by initial system transients. Timing is set to a nominal 140ns.

Error Amplifier (EA)

The error amplifier is an opamp with a low impedance output that is used to sense output conditions and provide a dc output based on those conditions to the PWM comparator. The output of this stage is brought out to allow tailoring of the closed loop gain or frequency response. The open loop gain of this stage is typically 95dB. The inputs are diode clamped to each other.

PWM Comparator

A sawtooth waveform is compared to the output of the error amplifier. The sawtooth is generally the oscillator waveform on C_T in voltage-mode control systems. In current-mode control systems, it is often the inductor current waveform. Both systems result in a square wave output which, after being NOR'ed with the MDC output (see below), is used to drive the main (PWM) output stage.

PWM Latch and Output

The PWM latch is reset by an oscillator rising cycle, turning the PWM output on if SHDN or UVLO are inactive. The PWM comparator trips when the CMR rising ramp voltage exceeds the error amplifier output voltage, setting the PWM latch and terminating the PWM output, after a minimum time set by the front edge blanking one-shot. If the output voltage is below the setpoint, the PWM cycle is terminated at a maximum duty cycle set by the voltage on the MDC/SS pin. If the output voltage is above the setpoint, the error amplifier output is low, and the PWM cycle terminates after the minimum set by the front edge blanking one-shot. The PWM output is designed to source and sink 1A peak into 1,000 pF loads. The output is disabled when SHDN is enabled.

Push-Pull Outputs (Q and $\overline{Q}$)

Two push-pull outputs are provided, with their leading edge synchronized to alternating PWM rising ramp initiation. The two outputs are 180° out of phase, with a slight (50ns typ.) overlap. The push-pull outputs are designed to source and sink 1A peak into 1,000 pF loads. This peak current was chosen to provide the designer with the option of using bipolar, MOSFET, or IGBT switching elements. To minimize ringing on the output waveform, the series inductance seen by the drivers should be as low as possible. This can be accomplished by keeping the distance between the MIC3832/3 and the switching elements as short as possible, or by using carbon composition resistors in series with the FET gates. The Q and $\overline{Q}$ outputs have a small overlap with no dead time. While advantageous to current-fed topologies, other topologies may require slight modification to accommodate this overlap. The outputs are disabled when SHDN is enabled.

Maximum Duty Cycle (MDC)

This feature, which uses the same pin as soft start (MDC/SS), provides another method of limiting duty cycle. The voltage seen by this pin determines the maximum duty cycle that can be obtained from the PWM output. As this feature can vary by as much as 15% over temperature, it is not recommended that it be used in place of a well designed feedback loop.

The voltage on MDC/SS, the inverting input of the MDC comparator, is compared to the voltage on CMR, with internal front edge blanking.

For voltage-mode operation, refer to the graph, "Typical Characteristics: Voltage-Mode Max. Duty Cycle vs. MDC Voltage." Voltage-mode operation requires the timing capacitor ramp, from C_T, be connected directly to CMR.

If a voltage-divided portion of the timing capacitor ramp (from C_T) is fed to CMR (to slope compensate for current-mode subharmonic oscillation, for example), the corresponding maximum duty cycle control voltage must be proportionally reduced to achieve the same duty cycle control.

Soft Start

This feature prevents damage due to large inrush currents generated upon initial application of system power or when the device attempts to restart after an overcurrent shutdown by the current limit function. When soft start is activated, the PWM comparator output duty cycle will increase slowly, with a time constant determined by the size of the external capacitor connected to MDC/SS. (Timing is $R_{TH}C$, where R_{TH} is the Thevenin equivalent resistance seen by this pin.)

Overcurrent Sensing and Shutdown

Overcurrent sensing and shutdown is accomplished via a current sense transformer or an external sense resistor connected from the switching element (power transistor) to ground. The current ramp is fed into the noninverting input of two sensing comparators (SHDN). If the sensed voltage equals or exceeds 1.0V, the corresponding input to the logic gates is pulled low, and the PWM comparator output is overridden. This provides a current limited output. If 1.25V is exceeded, the other comparator is also tripped activating the soft start feature.

Application Information

Voltage Mode

Voltage mode control has a single feedback path, comparing the oscillator voltage ramp with the output of an error amplifier which is comparing a sample of the dc output voltage to a reference. The MIC3832/3 may be operated in voltage mode by connecting C_T directly to CMR. Excessive current may be controlled indirectly by driving SHDN. Input voltage changes are sensed as output voltage changes, with delayed response. The ESR (effective series resistance) of each output capacitor adds a pole, requiring a compensating zero or low-frequency roll-off in the error amplifier. Loop gain varies with input voltage.

Current Mode

Current-mode control samples the inductor current waveform. It provides feedback from the output stage, limits peak switching transistor current, removes one pole (the LC filter pole) from the output, provides input voltage feedforward with good rejection of input line transients, and reduces the problem of core saturation. The CMR pin monitors the inductor current.

Current-mode control uses a current sense resistor or transformer to provide a voltage ramp which is compared the output of an error amplifier/comparator which is comparing a sample of the dc output voltage to a reference.

The MIC3832/3 may be operated in current mode by connecting the current sample to the CMR pin. Input voltage variations affect the inductor current slope, providing fast response. Two feedback loops complicate circuit analysis. The error amplifier controls the output current, with a single pole from the output filter.

Multiple supplies may be connected in parallel without concern for current-hogging.

Slope Compensation

At duty cycles above 50% subharmonic oscillations may occur due to the negative resistance effect of the input, for example, current decreasing as input voltage increases. Slope compensation, adding a portion of the oscillator ramp to the CMR pin, is used to remove this error. Power circuit resonances may introduce instability due to output current variations. Internal front edge blanking reduces the effect of leading edge inductive current spikes.

Push-Pull Cross Conduction

Push-Pull power stages have a problem when both power switches are on simultaneously, creating a short-circuit path from rail to rail. In order to eliminate this cross-conduction, or shoot-through, a dead-time is usually added at each transition, allowing the energized switch to fully turn off before the opposite switch is energized. This dead time decreases efficiency as the available duty cycle time is reduced, making the input current larger than optimum for a given input voltage, with higher conduction losses.

In a push-pull (forward) converter, an output inductor operates like a buck converter to store and provide energy to the load and output capacitor during the deadtime. Both output rectifier diodes are pulled into conduction by the output inductor during the deadtime, draining the magnetic field from the output transformer. At the start of each power cycle the energized input switch sees a virtual short-circuit in the transformer, until the opposite diode is pulled out of conduction.

Current Fed

If a constant current source is added to the feedpoint of a push-pull power stage, no deadtime is needed between power cycles, since the switches may be designed to handle the limited cross-conduction current. No output inductor is needed to store energy during the deadtime, and the related problem of simultaneously conducting output rectifiers is eliminated.

Buck-Derived Current Fed

Refer to Figure 5.

If a supply is designed to operate from a widely varying input voltage, such as the power line, a PWM step-down (buck) regulator may be used as the constant current input to the push-pull stage by omitting the customary output capacitor from the buck circuit. A bifilar wound pulse transformer is used to provide high-side drive to the PWM switch. A slightly overlapping drive is provided to the push-pull switches, so the output side of the buck inductor will swing toward ground during cross-conduction, limiting dissipated power.

The push-pull cycles are synchronized to run at half of the PWM frequency, so a soft or zero voltage switch transition may be obtained, reducing spikes and EMI. Feeding a sample of the PWM oscillator ramp to the current-mode comparator along with the input current sample allows slope compensation to be obtained for PWM duty cycles above 50%, preventing subharmonic oscillation at low input voltages.

Boost-Derived Current Fed

If a regulator is designed to run at higher push-pull voltage than the input line voltage, a step-up (boost) PWM regulator, with an inductor switched to ground, minus the normal output capacitor, will provide a current limited input to the push-pull stage. In this configuration all three power switches may be operated low-side, simplifying their drive circuitry. An input fuse is needed to guard against short-circuits since there is no high-side series switch.

Construction Hints

Careful prototyping techniques are required to prevent oscillations. Traditional solderless breadboards are a source of noise, and should be avoided. Use double-sided, copper-clad boards with a large area used as a single-point ground plane.

All timing and loop compensation capacitors and resistors should be star connected to GND (ground). Wire lengths along the high-current path should be kept as short as possible, with appropriate wire gauges being used. Do not socket the switching transistors as this can add to the voltage drop and power losses.

Current-Fed Push-Pull SMPS

Figure 3 illustrates this basic topology, a standard push-pull configuration where the center tap of the primary is fed with an inductor current instead of a voltage. This constant current reduces cross conduction and catastrophic transformer core saturation. Push-pull topologies are often used in 100W and larger power supplies as they allow more efficient use of the transformer. The entire range of the B-H curve is used in a push-pull supply, so a transformer that is one-half the size of a transformer used in a single-ended, forward-mode topology can be used. This topology can be extended to a full bridge where the two 50% duty cycle stages would be used to drive two MOSFETs each, one for each half of the bridge.

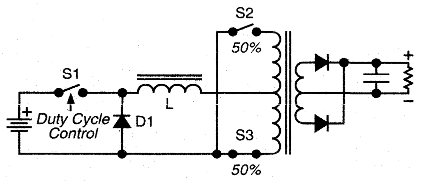


Figure 3: Current-Fed Push-Pull Topology

Current-Fed Multiple-Output SMPS

Figure 4 illustrates this topology. The absence of output inductors improves cross-regulation and simplifies the construction of isolated or high-voltage output supplies.

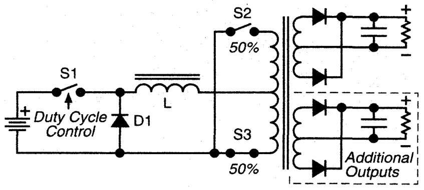


Figure 4: Current-Fed Multiple-Output Topology

100kHz 100W Current-Fed Converter

Refer to Figure 5.

A 5V, 20A dc-to-dc converter uses the current-fed, push-pull configuration for increased safety and reduced size and transformer core area.

The input is an unregulated 14V to 32Vdc supply. An MIC2951 low-dropout regulator supplies 12V to the MIC3833.

The main PWM switching element is an IRF540, with gate drive provided by transformer T1. The two 50% duty cycle outputs each drive an IRF540 directly, which in turn drive respective sides of T2's center tapped primary. The 1N6291A transzorb is used to protect the MOSFETs from spikes.

Current-mode control simplifies the stability analysis, with the 0.2Ω, 5W resistor being used as the sensing element. As the maximum duty cycle at light loads is greater than 50%, the well characterized problem of subharmonic oscillations found when using current-mode control was evident. A ramp, introduced at the sensing element, provides slope compensation. The 10kΩ and 470kΩ divider from the oscillator (ramp source) to the sensing element provides the proper slope. A large resistor value from C_T to CMR makes buffering unnecessary.

Front-edge blanking eliminates the need for a filter network around the sensing element and decreases the possibility of turn-on transients that cause system instabilities.

Four inexpensive output capacitors in parallel reduce ESR to an acceptable level of 80mΩ without adding too much size or cost.

Error amplifier compensation uses a simple lead-lag network. With current-mode control there is no need to compensate for the LC filter pole.

Soft start is implemented to allow slow turn-on in the event of a short circuit.

All magnetics were chosen to minimize losses at 100 kHz. T2 and L1 are wound using Siemen's N87 material and T1 using Magnetics Inc.'s P-type material. T2 and L1 use Siemen's EFD core and bobbin assemblies which are designed to reduce the height/form factor of the finished supply. T1 is a bifilar-wound toroid used as a 200kHz pulse transformer. T2 is not gapped, since a push-pull transformer has a minimum dc current component, being a forward converter.

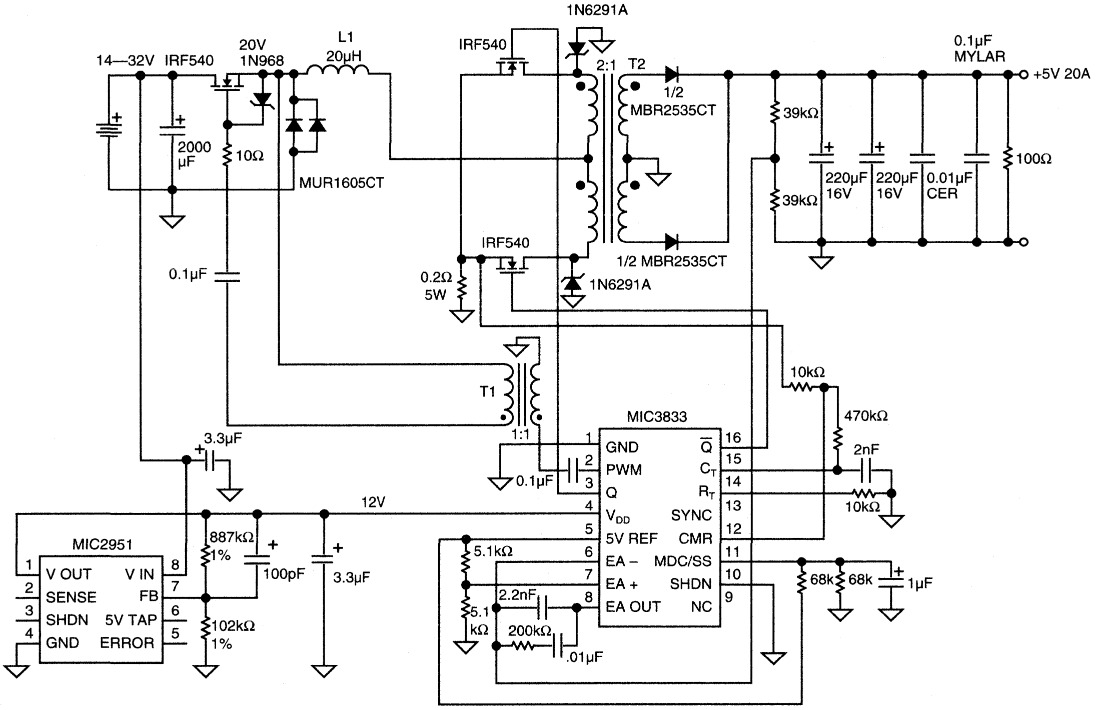


Figure 5: 100W Current-Fed, Push-Pull DC-to-DC Converter (Efficiency ~75%)

Magnetics Design

T1 : Magnetics Inc # 41303 – TC, P material, Primary = 26 turns 30 gauge wire, Secondary = 26 turns 30 gauge wire

T2: Seimen's EFD25, N87 material. Primary = 20 turns 20 gauge wire, Secondary = 10 turns trifilar wound 20 gauge wire. Both are center tapped.

L1: Seimen's EFD20, N87 material. 13 turns 20 gauge wire. Gap for 20µH

MIC38C/HC42/3/4/5, MIC18C42/3/4/5

BiCMOS Current-Mode PWM Controller

General Description

The MIC38C4x and MIC38HC4x are fixed frequency, high performance, current-mode PWM controllers. Micrel's BiCMOS devices are pin compatible with 384x bipolar devices but feature several improvements. 'HC' versions support even faster rise and fall times than 'C' versions.

Undervoltage lockout circuitry allows the '42 and '44 versions to start up at 14.5V and operate down to 9V, and the '43 and '45 versions start at 8.4V with operation down to 7.6V. All versions operate up to 20V.

When compared to bipolar 384x devices operating from a 15V supply, start-up current has been reduced to 50µA typical and operating current has been reduced to 4.0 mA typical. Decreased output rise and fall times drive larger MOSFETs, and rail-to-rail output capability increases efficiency, especially at lower supply voltages. The MIC38C4x and MIC38HC4x also feature a trimmed oscillator discharge current and bandgap reference.

MIC38xC4x denotes 8-pin plastic DIP and SOIC packages. MIC38HC4x-1 denotes 14-pin plastic DIP and SOIC packages. Devices identified as MIC18xC4x are military temperature range 8-pin ceramic DIPs. 8-pin devices feature small size, while 14-pin devices separate the analog and power connections for improved performance and power dissipation.

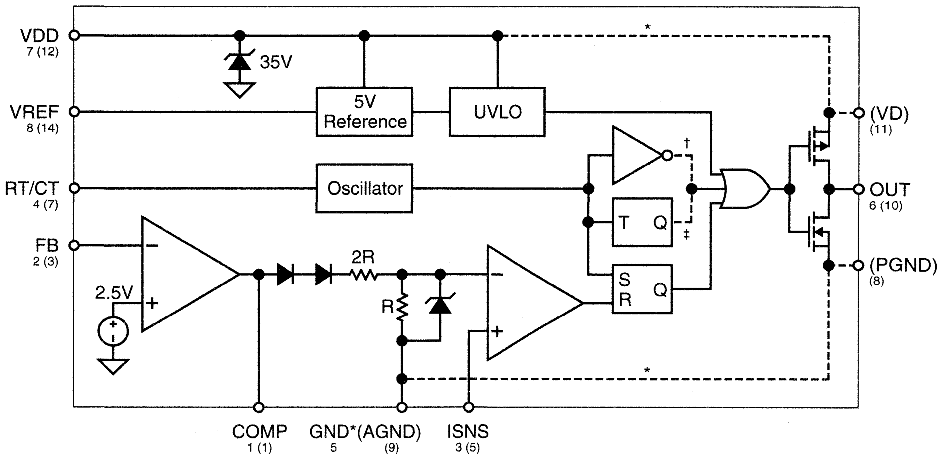
Features

- Fast output rise/fall times:
  40ns rise/30ns fall for the MIC38C42
  20ns rise/15ns fall for the MIC38HC42
- –40°C to +85°C temperature range
  meets UC284x specifications
- High-performance, low-power BiCMOS Process
- Ultra-low start-up current (50µA typical)
- Low operating current (4mA typical)
- High output drive (1A peak current, HC version)
- CMOS outputs with rail-to-rail swing
- Current-mode operation ≥500kHz
- Trimmed 5V bandgap reference
- Pin-for-pin compatible with UC3842/3843/3844/3845(A)
- Trimmed oscillator discharge current
- UVLO with hysteresis
- Low cross-conduction currents

Applications

- Current-mode, off-line, switched-mode power supplies
- Current-mode, dc-to-dc converters.
- Step-down "buck" regulators
- Step-up "boost" regulators
- Flyback, isolated regulators
- Forward converters
- Synchronous FET converters

Functional Diagram



( ) pins are on MIC38C/HC4x-1 (14-lead) versions only
* MICx8C/HC4x (8-lead) versions only
† MICx8C/HC42, MICx8C/HC43 (96% max. duty cycle) versions only
‡ MICx8C/HC44, MICx8C/HC45 (50% max. duty cycle) versions only

Ordering Information

Part Number	Temperature Range	Package
MIC18C42AJB*	–55°C to +125°C	8-pin CerDIP
MIC18C43AJB*	–55°C to +125°C	8-pin CerDIP
MIC18C44AJB*	–55°C to +125°C	8-pin CerDIP
MIC18C45AJB*	–55°C to +125°C	8-pin CerDIP
MIC38C42BN	–40°C to +85°C	8-pin Plastic DIP
MIC38C43BN	–40°C to +85°C	8-pin Plastic DIP
MIC38C44BN	–40°C to +85°C	8-pin Plastic DIP
MIC38C45BN	–40°C to +85°C	8-pin Plastic DIP
MIC38C42-1BN	–40°C to +85°C	14-pin Plastic DIP
MIC38C43-1BN	–40°C to +85°C	14-pin Plastic DIP
MIC38C44-1BN	–40°C to +85°C	14-pin Plastic DIP
MIC38C45-1BN	–40°C to +85°C	14-pin Plastic DIP
MIC38C42BM	–40°C to +85°C	8-pin SOIC
MIC38C43BM	–40°C to +85°C	8-pin SOIC
MIC38C44BM	–40°C to +85°C	8-pin SOIC
MIC38C45BM	–40°C to +85°C	8-pin SOIC
MIC38C42-1BM	–40°C to +85°C	14-pin SOIC
MIC38C43-1BM	–40°C to +85°C	14-pin SOIC
MIC38C44-1BM	–40°C to +85°C	14-pin SOIC
MIC38C45-1BM	–40°C to +85°C	14-pin SOIC

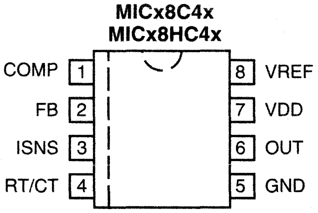
Part Number	Temperature Range	Package
MIC38HC42BN	–40°C to +85°C	8-pin Plastic DIP
MIC38HC43BN	–40°C to +85°C	8-pin Plastic DIP
MIC38HC44BN	–40°C to +85°C	8-pin Plastic DIP
MIC38HC45BN	–40°C to +85°C	8-pin Plastic DIP
MIC38HC42-1BN	–40°C to +85°C	14-pin Plastic DIP
MIC38HC43-1BN	–40°C to +85°C	14-pin Plastic DIP
MIC38HC44-1BN	–40°C to +85°C	14-pin Plastic DIP
MIC38HC45-1BN	–40°C to +85°C	14-pin Plastic DIP
MIC38HC42BM	–40°C to +85°C	8-pin SOIC
MIC38HC43BM	–40°C to +85°C	8-pin SOIC
MIC38HC44BM	–40°C to +85°C	8-pin SOIC
MIC38HC45BM	–40°C to +85°C	8-pin SOIC
MIC38HC42-1BM	–40°C to +85°C	14-pin SOIC
MIC38HC43-1BM	–40°C to +85°C	14-pin SOIC
MIC38HC44-1BM	–40°C to +85°C	14-pin SOIC
MIC38HC45-1BM	–40°C to +85°C	14-pin SOIC

Refer to the Part Number Cross Reference for a listings of Micrel devices equivalent to UC284x and UC384x devices.
*AJB indicates units screened to MIL–STD–883, class B, and burned in for 168 hours minimum.

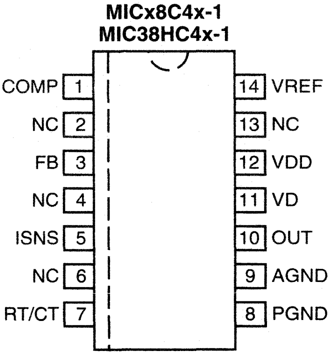
Selection Guide

	UVLO Thresholds	
Duty Cycle	Startup 8.4V Minimum Operating 7.6V	Startup 14.5V Minimum Operating 9V
0% to 96%	MIC18C43 MIC38C43/HC43	MIC18C42 MIC38C42/HC42
0% to 50%	MIC18C45 MIC38C45/HC45	MIC18C44 MIC38C44/HC44

Pin Configuration



8-Pin DIP (N, J)
8-Lead SOIC (M)



14-Pin DIP (-1xN)
14-Lead SOIC (-1xM)

Pin Description

Pin Number N, J, M	Pin Number -1xN, -1xM	Pin Name	Pin Function
1	1	COMP	Compensation: Connect external compensation network to modify the error amplifier output.
	2	NC	Not internally connected.
2	3	FB	Feedback (Input): Error amplifier input. Feedback is 2.5V at desired output voltage.
	4	NC	Not internally connected.
3	5	ISNS	Current Sense (Input): Current sense comparator input. Connect to current sensing resistor or current transformer.
	6	NC	Not internally connected.
4	7	RT/CT	Timing Resistor/Timing Capacitor: Connect external RC network to select switching frequency.
5		GND	Ground: Combined analog and power ground.
	8	PGND	Power Ground: N-channel driver transistor ground.
	9	AGND	Analog Ground: Controller circuitry ground.
6	10	OUT	Power Output: Totem-pole output.
	11	VD	Power Supply (Input): P-channel driver transistor supply input. Return to power ground (PGND).
7	12	VDD	Analog Supply (Input): Controller circuitry supply input. Return to analog ground (AGND).
	13	NC	Not internally connected.
8	14	VREF	5V Reference (Output): Connect external RC network.

Absolute Maximum Ratings

Zener Current	30mA

Operation at ≥18V may require special precautions (see Applications Information).

VDD	20V
VD (x8C4x-1, 38HC4x-1)	20V
ISNS	–0.3V to 5.5V
FB	–0.3V to 5.5V
Output Current (x8C42/43/44/45)	0.5A
Output Current (x8HC42/43/44/45)	1A
Operating Junction Temperature	150°C
Package Thermal Resistance	
θ_{JA} 8-Pin Plastic DIP	100°C/W
θ_{JA} 8-Pin Ceramic DIP	125°C/W
θ_{JA} 8-Pin SOIC	170°C/W
θ_{JA} 14-Pin Plastic DIP	90°C/W
θ_{JA} 14-Pin Ceramic DIP	110°C/W
θ_{JA} 14-Pin SOIC	145°C/W
Storage Temperature	–65°C to 150°C

Electrical Characteristics

V_{DD} = 15V (Note 4), R_T = 10kΩ, C_T = 3.3nF

$-55 \le T_A \le 125°C$ for MIC18C42/43/44/45; $-40 \le T_A \le 85°C$ for MIC38C42/43/44/45, 38HC42/43/44/45

		MIC18C42/43/44/45 MIC18HC42/43/44/45			**MIC38C42/43/44/45 MIC38HC42/43/44/45**			
Parameter	**Test Conditions**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Units**
Reference Section								
Output Voltage	T_A = 25°C, I_O = 1mA	4.95	5.00	5.05	4.90	5.00	5.10	V
Line Regulation	$12V \le V_{DD} \le 18V$, $I_O = 5\ \mu A$ (Note 6)		2	20		2	20	mV
Load Regulation	$1 \le I_O \le 20$ mA		1	25		1	25	mV
Temp. Stability	(Note 1)		0.2			0.2		mV/°C
Total Output Variation	Line, Load, Temp. (Note 1)	4.9		5.1	4.82		5.18	V
Output Noise Voltage	$10Hz \le f \le 10kHz$, T_A = 25°C (Note 1)		50			50		µV
Long Term Stability	T_A = 125 °C, 1000 Hrs. (Note 1)		5	25		5	25	mV
Output Short Circuit		–30	–80	–180	–30	–80	–180	mA
Oscillator Section								
Initial Accuracy	T_A = 25°C (Note 5)	49	52	55	49	52	55	kHz
Voltage Stability	$12 \le V_{DD} \le 18V$ (Note 6)		0.2	1.0		0.2	1.0	%
Temp. Stability	$T_{MIN} \le T_A \le T_{MAX}$ (Note 1)		0.04			0.04		%/°C
Clock Ramp	T_A = 25°C, $V_{RT/CT}$ = 2V	7.7	8.4	9.0	7.7	8.4	9.0	mA
Reset Current	T_A = T_{MIN} to T_{MAX}	7.2	8.4	9.5	7.2	8.4	9.5	mA
Amplitude	$V_{RT/CT}$ peak to peak		1.9			1.9		Vp-p
Error Amp Section								
Input Voltage	V_{COMP} = 2.5V	2.45	2.50	2.55	2.42	2.50	2.58	V
Input Bias Current	$V_{FEEDBACK}$ = 5.0V		–0.1	–1		–0.1	–2	µA
A_{VOL}	$2 \le V_O \le 4V$	65	90		65	90		dB
Unity Gain Bandwidth	(Note 1)	0.7	1.0		0.7	1.0		MHz
PSRR	$12 \le V_{DD} \le 18V$	60			60			dB
Output Sink Current	$V_{FEEDBACK}$ = 2.7V, V_{COMP} = 1.1V	2	14		2	14		mA
Output Source Current	$V_{FEEDBACK}$ = 2.3V, V_{COMP} = 5V	–0.5	–1		–0.5	–1		mA
V_{OUT} High	$V_{FEEDBACK}$ = 2.3V, R_L = 15k to ground	5	6.8		5	6.8		V
V_{OUT} Low	$V_{FEEDBACK}$ = 2.7V, R_L = 15k to V_{REF}		0.1	1.1		0.1	1.1	V

		MIC18C42/43/44/45 MIC18HC42/43/44/45			MIC38C42/43/44/45 MIC38HC42/43/44/45			
Parameter	**Test Conditions**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Units**
Current Sense								
Gain	(Notes 2 & 3)	2.85	3.0	3.15	2.85	3.0	3.15	V/V
MaximumThreshold	V_{COMP} = 5V (Note 2)	0.9	1	1.1	0.9	1	1.1	V
PSRR	$12 \le V_{DD} \le 18V$ (Note 2)		70			70		dB
Input Bias Current			–0.1	–1		–0.1	–2	µA
Delay to Output			120	250		120	250	ns
Output								
$R_{DS(ON)}$ 'C' High	I_{SOURCE} = 200 mA		20			20		Ω
$R_{DS(ON)}$ 'C' Low	I_{SINK} = 200 mA		11			11		Ω
$R_{DS(ON)}$ 'HC' High	I_{SOURCE} = 200 mA		10			10		Ω
$R_{DS(ON)}$ 'HC' Low	I_{SINK} = 200 mA		5.5			5.5		Ω
Rise Time: 'C' version	T_A = 25°C, C_L = 1 nF		40	80		40	80	ns
Fall Time: 'C' version	T_A = 25°C, C_L = 1 nF		30	60		30	60	ns
Rise Time: 'HC' version	T_A = 25°C, C_L = 1 nF		20	50		20	50	ns
Fall Time: 'HC' version	T_A = 25°C, C_L = 1 nF		15	40		15	40	ns
Undervoltage Lockout								
Start Threshold	38C42/4, 18C42/4, 38HC42/4, 18HC42/4	13.5	14.5	15.5	13.5	14.5	15.5	V
	38C43/5, 18C43/5, 38HC43/5, 18HC43/5	7.8	8.4	9.0	7.8	8.4	9.0	V
Min. Operating Voltage	38C42/4, 18C42/4, 38C42/4, 18HC42/4	8	9	10	8	9	10	V
	38C43/5, 38C43/5, 38HC43/5, 38HC43/5	7.0	7.6	8.2	7.0	7.6	8.2	V
Pulse Width Modulator								
Maximum Duty Cycle	38C42/3, 18C42/3, 38HC42/3, 18HC42/3	94	96		94	96		%
	38C44/5, 18C44/5, 38HC44/5, 18HC44/5	46	50		46	50		%
Minimum Duty Cycle				0			0	%
Total Standby Current								
Start-Up Current	V_{DD} = 13V for x8C42/44, x8HC42/44 V_{DD} = 7.5V for x8C43/45, x8HC43/45		50	150		50	200	µA
Operating Supply Current	$V_{FEEDBACK} = V_{I\ SENSE}$ = 0V		4.0	6.0		4.0	6.0	mA
Zener Voltage (V_{DD})	I_{DD} = 25mA (Note 6)	30	37		30	37		V

Note 1: These parameters, although guaranteed, are not 100% tested in production.

Note 2: Parameter measured at trip point of latch with $V_{EA} = 0$.

Note 3: Gain defined as:

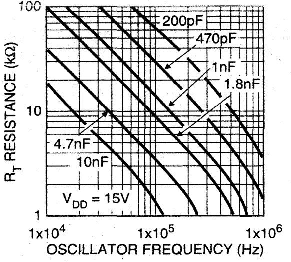
$$A = \frac{\Delta V_{PIN1}}{V_{TH}(I_{SENSE})}\ ;\ 0 \le V_{TH}(I_{SENSE}) \le 0.8V$$

Note 4: Adjust V_{DD} above the start threshold before setting at 15V.

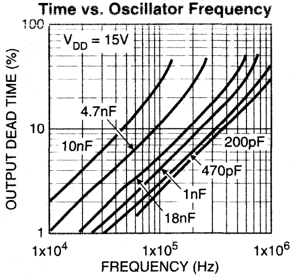
Note 5: Output frequency equals oscillator frequency for the '8C42 and '8C43. Output frequency for the '8C44, and '8C45 equals one half the oscillator frequency.

Note 6: On 8-pin version, 20V is maximum input on pin 7, as this is also the supply pin for the output stage. On 14-pin version, 40V is maximum for pin 12 and 20V maximum for pin 11.

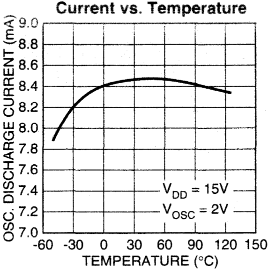
Typical Characteristics



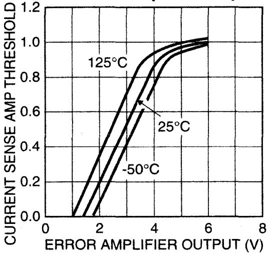
Oscillator Frequency Configuration



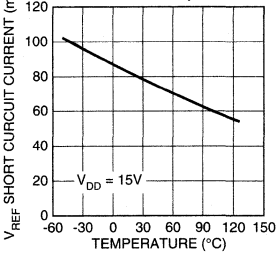
MICx8C/HC42/43 Output Dead Time vs. Oscillator Frequency



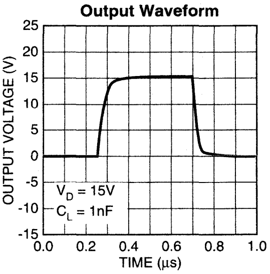
Oscillator Discharge Current vs. Temperature



Current Sense Amplifier vs. Error Amplifier Output



Short-Circuit Reference Current vs. Temperature



MICx8C4x Output Waveform

Application Information

Familiarity with 384x converter designs is assumed.

The MICx8C4x and MICx8HC4x have been designed to be compatible with 384xA series controllers. Micrel's 'C' and 'HC' controllers are intended for existing and new designs.

MIC38C4x and MIC38HC4x Advantages

Start-up Current

Start-up current has been reduced to an ultra-low 50µA (typical) permitting higher-valued, lower-wattage, start-up resistors (powers controller during power supply start-up). The reduced resistor wattage reduces cost and printed circuit space.

Operating Current

Operating current has been reduced to 4mA compared to 11mA for a typical bipolar controller. The controller runs cooler and the V_{DD} hold-up capacitance required during start-up may be reduced.

Output Driver

Complementary internal P- and N-channel MOSFETs produce rail-to-rail output voltages for better performance driving external power MOSFETs. The driver transistor's low on-resistance and high peak current capability can drive gate capacitances of greater than 1000pF. The value of output capacitance which can be driven is determined only by the rise/fall time requirements. Within the restrictions of output capacity and controller power dissipation, switching frequencies can approach 1MHz.

Design Precautions

When operating near 20V, circuit transients can easily exceed the 20V absolute maximum rating, permanently damaging the controller's CMOS construction. To reduce transients, use a 0.1µF low-ESR capacitor to next to the controller's supply V_{DD} (or V_D for '-1' versions) and ground connections. Film type capacitors, such as Wima MKS2, are recommended.

When designing high-frequency converters, avoid capacitive and inductive coupling of the switching waveform into high-impedance circuitry such as the error amplifier, oscillator, and current sense amplifier. Avoid long printed-circuit traces and component leads. Locate oscillator and compensation circuitry near the IC. Use high frequency decoupling capacitors on V_{REF}, and if necessary, on V_{DD}. Return high di/dt currents directly to their source and use large area ground planes.

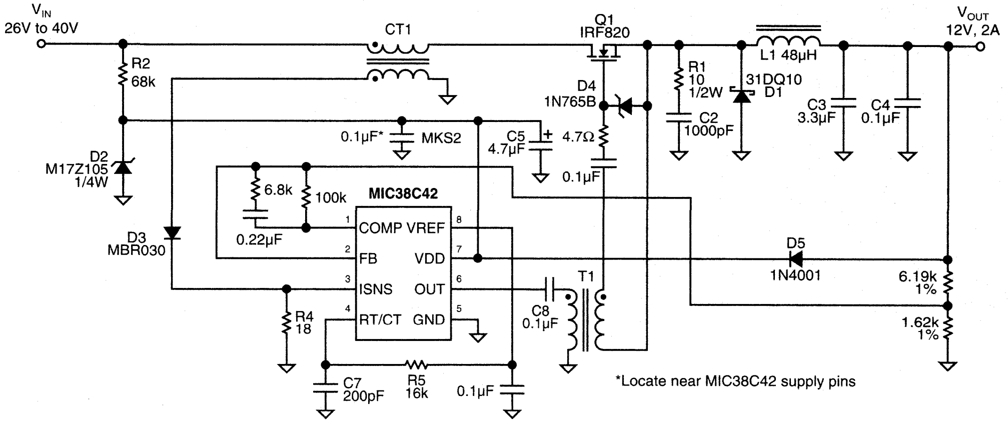
Buck Converter

Refer to figure 1. When at least 26V is applied to the input, C5 is charged through R2 until the voltage V_{DD} is greater than 14.5V (the undervoltage lockout value of the MIC38C42). Output switching begins when Q1 is turned on by the gate drive transformer T1, charging the output filter capacitor C3 through L1. D5 supplies a regulated +12V to V_{DD} once the circuit is running.

Current sense transformer CT1 provides current feedback to ISNS for current-mode operation and cycle-by-cycle current limiting. This is more efficient than a high-power sense resistor and provides the required ground-referenced level shift.

When Q1 turns off, current flow continues from ground through D1 and L1 until Q1 is turned on again.

The 100V Schottky diode D1 reduces the forward voltage drop in the main current path, resulting in higher efficiency than could be accomplished using an ultra-fast-recovery diode. R1 and C2 suppress parasitic oscillations from D1.



*Locate near MIC38C42 supply pins

Figure 1. 500kHz, 25W, Buck Converter

Using a high-value inductance for L1 and a low-ESR capacitor for C3 permits small capacitance with minimum output ripple. This inductance value also improves circuit efficiency by reducing the flux swing in L1.

Test	Conditions	Results
Line Regulation	V_{IN} = 26V to 80V, I_O = 2A	0.5%
Load Regulation	V_{IN} = 48V, I_O = 0.2A to 2A	0.6%
Efficiency	V_{IN} = 48V, I_O = 2A	90%
Output Ripple	V_{IN} = 48V, I_O = 2A (20MHz BW)	100mV

Magnetic components are carefully chosen for minimal loss at 500kHz. CT1 and T1 are wound on Magnetics, Inc. P-type material toroids. L1 is wound on a Siemens N49 EFD core.

Symbol	Custom Coil[1]	ETS[2]
CT1	4923	ETS 92420
T1	4924	ETS 92419
L1	4925	ETS 92421

1. Custom Coils, Alcester, SD tel: (605) 934-2460
2. Energy Transformation Systems, Inc. tel: (415) 324-4949.

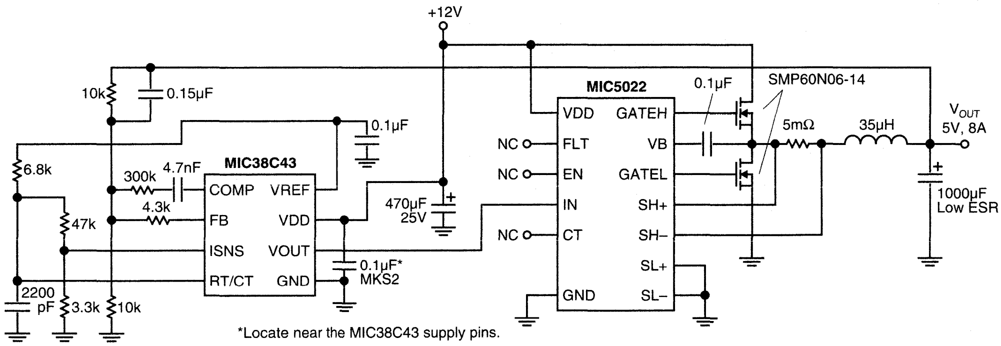
Synchronous Buck Converter

Refer to figure 2. This MIC38C43 synchronous buck converter uses an MIC5022 half-bridge driver to alternately drive the PWM switch MOSFET (driven by GATEH, or high-side output) and a MOSFET which functions as a synchronous rectifier (driven by the GATEL, or low-side output).

The low-side MOSFET turns on when the high-side MOSFET is off, allowing current to return from ground. Current flows through the low-side MOSFET in the source to drain direction.

The on-state voltage drop of the low-side MOSFET is lower than the forward voltage drop of an equivalent Schottky rectifier. This lower voltage drop results in higher efficiency.

A sense resistor (5mΩ) is connected to the driver's high-side current sense inputs to provide overcurrent protection. Refer to the MIC5020, MIC5021, and MIC5022 data sheets for more information.



*Locate near the MIC38C43 supply pins.

Figure 2. 100kHz, Synchronous Buck Converter

MICREL Design Solutions

DESIGN SOLUTION 1

200KHZ SWITCHING REGULATOR REDUCES BOARD SPACE

by Brian Huffman

The Micrel MIC4574, MIC4575 and MIC4576 are enhanced versions of the popular LM257x family of 52kHz, step-down (buck), switching regulators. They feature a 200kHz switching frequency that reduces the inductor size by a factor of four, freeing up precious board space, and allows conversion from 12V to 5V/1A in under one square inch of board space.

The MIC457x series operates from input voltages ranging from 4V to 24V and a maximum output current of 3A (MIC4576), making the parts ideal for distributed power applications.

Just like their predecessors, these devices are easy to use requiring only four external components to build a complete power supply. The MIC457x series integrates all the control and protection circuitry as well as the power transistor, frequency compensation, and a fixed-frequency oscillator.

A 52kHz design can be upgraded easily by replacing the inductor with one that is one-fourth its value (maintaining dc current rating). No additional changes are required. *Application Note 15* provides design solutions for 45 common power supply designs, greatly simplifying the design of switch-mode power supplies.

The 200kHz switching frequency allows for a complete surface-mount solution without the associated EMI problems that can plague higher switching-frequency designs. Note that radiated emissions increase with the square of the switching frequency. Therefore, a 1MHz switching regulator can generate 25 times more EMI, making it more difficult to meet FCC or European radiated emissions requirements.

Many digital systems require the supply be powered up in a predetermined sequence to avoid either latching the main supply or preventing the microprocessor from coming up in an undefined state. A logic-level signal shuts off the regulator when a "high" is applied to the shutdown input. To disable the shutdown feature, the shutdown pin (SHDN) must be connected to the ground pin (GND), as in Figure 1. In shutdown, the MIC4575 draws less than 200µA of quiescent current.

Many analog systems require a negative supply voltage for powering op-amps. This split-supply requirement can be fulfilled easily by using the standard buck circuit of Figure 1 for the positive supply and the positive-to-negative converter of Figure 2 or Figure 3 for the negative supply.

Although a multiple output flyback topology could be used to produce the split-supply voltages, this would require a linear regulator on the output of the unregulated winding to meet the

MIC4574 / MIC4575 / MIC4576 Summary

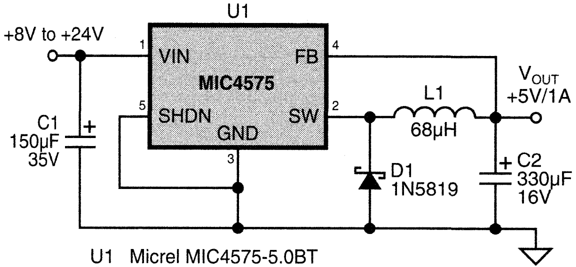
- 4V to 24V input
- 3.3V, 5V, or adjustable output

Features

- 80% efficiency
- 200µA shutdown
- 200kHz PWM control
- Only 4 external components
- Internal frequency compensation
- –40°C to +85°C ambient operating range
- *Application Note 15* for sample designs
- MIC4575 evaluation board available

Applications

- On-card switching regulators
- Positive-to-negative converters
- Low-noise switching regulators
- Split ±5V or ±12V supplies



U1 Micrel MIC4575-5.0BT
C1 Nichicon UPL1V151MPH
C2 Nichicon UPL1C331MPH
D1 Motorola 1N5819
L1 Coiltronics PL52B-68-500

Figure 1. MIC4575 Buck Converter (8V–24V to 5V/1A)

output regulation performance of the positive-to-negative converter. Also, the flyback converter uses a transformer that is not an off-the-shelf component. It must be customized for the particular application, which could add weeks to the design process. Inductors are preferred in many converter designs because they are economical and more readily available.

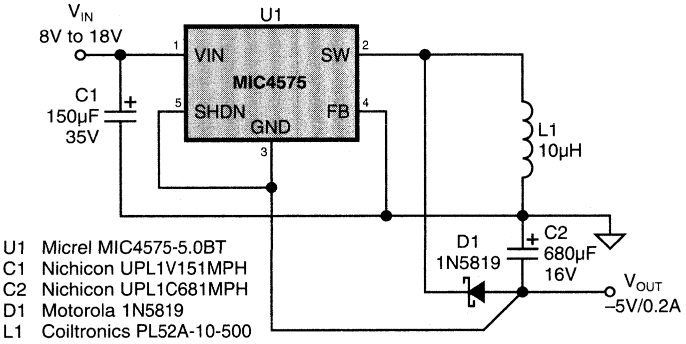
Figure 2 shows a design that eliminates a level-shifting op amp by connecting the MIC4575 ground pin (GND) to the negative output voltage and the feedback pin (FB) to ground. The only drawback to this scheme is that the shutdown signal is now referred to the –5V output instead of to ground, requiring a level-shifting transistor to implement this function.

If stability analysis of a positive-to-negative converter is not considered during the design process, there almost certainly will be loop stability problems in which the output voltage will oscillate. Oscillation problems are characterized by a nonrepetitive duty cycle and a pseudo-sinewave between 100Hz to 1kHz superimposed on the output voltage. This instability is caused by a RHP (right-half-plane) zero in the transfer function, which makes frequency compensation very difficult.

A discontinuous design, as in Figure 2, eliminates the RHP zero because an RHP zero occurs only in continuous mode. This produces the simplest circuit, although output current is one-half and peak current is about double when compared to a equivalent continuous design.

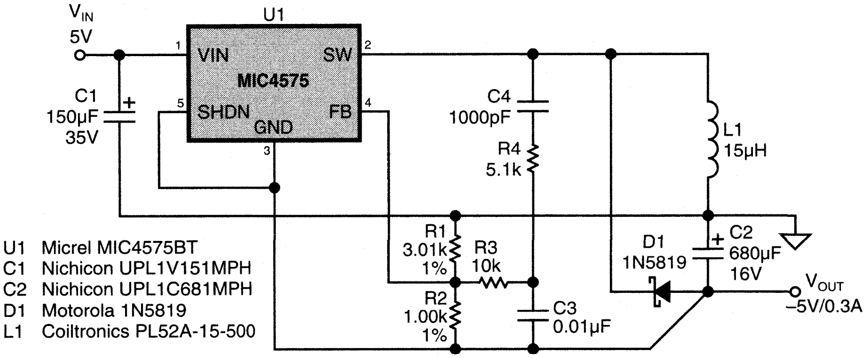
For a continuous design, as in Figure 3, an RC network must be used to provide enough phase lead to give adequate frequency compensation. This circuit is a little more complex, but produces higher output currents.

For literature on our switching regulators, call **(408) 944-0800**. For application help call **(408) 944-0800. ext. 336**.



U1	Micrel MIC4575-5.0BT
C1	Nichicon UPL1V151MPH
C2	Nichicon UPL1C681MPH
D1	Motorola 1N5819
L1	Coiltronics PL52A-10-500

Figure 2. MIC4575 Discontinuous Design (8V–18V to –5V/0.2A)



U1	Micrel MIC4575BT
C1	Nichicon UPL1V151MPH
C2	Nichicon UPL1C681MPH
D1	Motorola 1N5819
L1	Coiltronics PL52A-15-500

Figure 3. MIC4575 Continuous Design (5V to –5V/0.3A)

Application Note 13

52kHz LM2574/5/6 Family Design Guide

by Kevin Lynn

Introduction

Micrel's LM257x family of BiCMOS simple buck voltage regulators feature faster rise/fall time, faster response to fault conditions, and improved efficiency at light loads.

Description

The LM257x switching regulator is basically a PWM (pulse width modulation) controller IC with a fixed gain error amplifier, a 52kHz oscillator, and internal compensation network. The non-inverting side of the error amplifier is tied to a 1.23V bandgap reference.

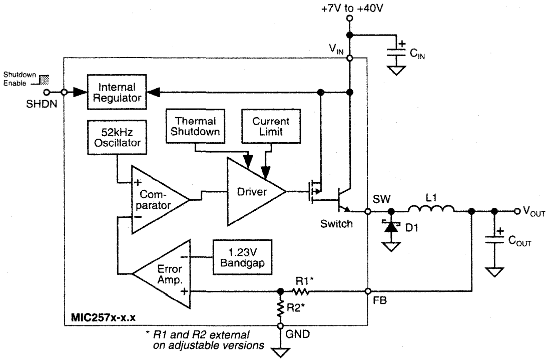


Figure 1. Block Diagram (Fixed Version)

Buck Regulator Design Procedure

Select the LM2574 (0.5A), LM2575 (1A), or LM2576 (3A) based on the required output current. If higher current rated regulators are chosen for low current applications, make sure the current limit range is appropriate for that application.

Output Voltage

For fixed output voltages, 3.3V, 5.0V, 12V, or 15V versions are available.

The output voltage of the adjustable regulators is configured using an external resistive divider.

$$V_{OUT} = 1.23V\left(1 + \frac{R2}{R1}\right)$$

For best performance, R1 should be between 1k and 10k.

Inductor Selection Criteria

The following criteria is used for inductor selection:

Mode of operation (continuous or discontinuous).
Peak inductor current
Volt-seconds (V·s) applied to the inductor

Definitions

Critical Inductance Condition The critical inductance condition is when the current through the inductor decays to zero just prior to the next "on" time of the regulator switch. This occurs at the boundary between continuous and discontinuous operation.

Discontinuous Operation Discontinuous operation occurs when, for any condition of input voltage or output current, the inductor current decays to zero before the next "on" time of the regulator switch.

Continuous Operation Continuous operation occurs when, for any condition of input voltage or output current, the inductor current does not decay to zero before the next "on" time of the regulator switch.

Continuous Conduction Operation

Critical Inductance

Compute the value of critical inductance required for the application at the worst case combination of input voltage and output load current. This will be the minimum value of inductance that will guarantee continuous conduction operation over all input voltage and output load conditions.

At the critical inductance condition, the peak inductor current is twice the average current. The average current is the current delivered to the load. The peak current at the critical inductance condition is:

$$(1) \quad I_{PEAK} = \frac{D\left(V_{IN} - V_{OUT}\right)}{L\, f_S}$$

Where:

D = duty cycle
D = switch on time/switch cycle time, T_{ON} / τ
τ = switch cycle time, $1 / f_S$, (s)
V_{IN} = input (supply) voltage (V)
V_{OUT} = regulator output voltage (V)
L = inductance of filter inductor (H)
f_S = switching frequency (Hz)

The input power will be assumed to be equal to the output power.

$$(2) \quad E_{FF}\, V_{IN}\, I_L\, D = \frac{{V_{OUT}}^2}{R_{LOAD}}$$

Where:

E_{FF} = estimated efficiency
reasonable initial estimate 80% (0.8)
R_{LOAD} = load resistance (Ω)

and,

$$(3)\quad L_{CRITICAL} = \frac{R_{LOAD}\,(1 - D)}{2\,f_S}$$

Duty Cycle

Compute the duty cycle required at the maximum required input voltage and minimum load current. If your cannot guarantee a minimum load current, an additional resistive load may be required at the regulator output.

$$D_{MIN} = \frac{V_{OUT}}{V_{IN(max)}}$$

Use this value of D_{MIN} and the minimum value of R_{LOAD} in equation (3) to determine the value of critical inductance. This is the minimum value of inductance required. Changing the minimum load and/or the maximum input voltage requirement changes the minimum required critical inductance.

The value of inductance can be chosen to allow the regulator to operate in discontinuous mode under certain conditions. Discontinuous mode typically occurs at maximum input and minium load current. In many cases this may not present a problem, however, it should be verified that operation in discontinuous mode still allows the circuit to satisfy the load regulation requirement.

Maximum V·s

Compute the maximum volt-microseconds applied to the inductor:

$$V \cdot s = \left(V_{IN} - V_{OUT}\right) \frac{V_{OUT}}{V_{IN(max)}}\,\tau$$

Inductor Peak Current

Compute the peak current through the inductor. This is the sum of the maximum load current and peak ripple current though the inductor.

$$I_{PEAK} = \frac{1}{2}\left(\frac{V_{IN(max)} - V_{OUT}}{L}\right)\tau\,\frac{V_{OUT}}{V_{IN(max)}} + \frac{V_{OUT}}{R_{LOAD}}$$

Inductor Selection

Refer to the "Inductor Selection and Cross Reference" table to select the appropriate inductor for your application. The selection should satisfy the following:

Inductance > Calculated Critical Inductance

Volt-second Capability > Calculated V·µs
(if applicable)

I_{DC} > Calculated I_{PEAK} Current × 0.85

Output Capacitor Selection

For stable operation, the output capacitor must satisfy the following:

$$C_{OUT} \geq 13300\left(\frac{V_{IN(max)}}{V_{OUT}\,L}\right)$$

Where:

C_{OUT} = output capacitance (µF)
L = inductance (µH)

This guarantees that the dominant pole pair of the LC filter does not occur at a frequency that is too high for the regulator's internal loop compensation circuitry. This computation may result in a capacitor value that is too small to provide adequate peak-to-peak output ripple reduction.

Peak-to-peak ripple voltage is a function of the capacitor value and type. A low ESR/ESL (equivalent series resistance/equivalent series inductance) capacitor should be used for lower ripple voltage. (Standard capacitors may be paralleled to reduce the effective ESR/ESL value.) Low ESR electrolytic capacitors are available from Panasonic, Nichicon, and United Chemicon.

Maximum peak-to-peak ripple voltage (assuming no ESR or ESL in the filter capacitor) can be estimated as follows:

$$V_{P\text{-}P} = \frac{1}{C}\,\frac{\left(V_{IN(max)} - V_{OUT}\right)}{L}\,\frac{1}{2}\,\frac{V_{OUT}^2}{V_{IN}^2}\,\tau^2$$

Input Capacitor Selection

The input bypass capacitor must be at least 47µF to maintain stability. Low ESR capacitors are recommended. If the operating temperature range is below –25°C, the value of this capacitor should be increased. Adding a ceramic or solid tantalum capacitor near the input pin will also increase regulator stability at low temperatures. The capacitor's ripple current rating should be more than the ripple component of the inductor current:

$$I_{RIPPLE} = \frac{\tau}{2}\left(\frac{V_{IN(max)} - V_{OUT}}{L}\right)$$

Catch Diode Selection

Although either a Schottky or a fast recovery diode can be used, a Schottky diode will provide the best performance because its lower voltage drop and faster switching speed will result in higher efficiency. Fast recovery diodes with abrupt turn-off characteristics may cause EMI problems and/or instabilities.

The reverse voltage rating of the catch diode should be at least 1.25 × the maximum input voltage.

Standard 1N400x series diodes should not be used. The reverse recovery time of this type of diode is excessive which will cause additional noise and heat dissipation in the diode and the regulator's internal power switch.

Typical Applications

Fixed 3.3V Buck Regulator

Figure 2 shows a 3.3V buck regulator using inexpensive standard components.

The high efficiency (~80%) and low form factor afforded by the use of a new TO-263 surface mount package makes this ideal for battery operated designs.

If lower ripple voltage is desired, the standard 220µF capacitor can be replaced with a standard 330µF. For lower ripple at a small size, an Oscon 105A220M capacitor (220µF, 35mΩ ESR) can be used.

Isolated 24V to 5V Flyback Regulator

When isolation is desired (required for many telecommunications applications), an isolated flyback scheme can be used. See figure 4.

Isolation between the input and load is provided by a 4N35 optoisolator and a 1:1 transformer.

A TL431 shunt regulator creates the feedback signal which is sent through the optical isolator to the regulator IC.

To prevent the output pin from being forced much below ground (and forward biasing the substrate diode), a floating ground scheme is used.

The Schottky, resistor, and diode combination also serves as a snubber for the flyback transformer.

Both the pseudo-ground and the system ground are bypassed to remove noise.

Discontinuous mode operation avoids conditions that would otherwise require phase and gain compensation (The LM257x family does not support external compensation.) Specifically, this avoids the right half-plane zero that occurs in the open loop gain and phase when operated in the continuous conduction mode.

External compensation is required in this application because the additional elements in the feedback loop (optoisolator and shunt regulator) have changed the overall open-loop gain and phase. A simple RC compensation network is added around the shunt regulator.

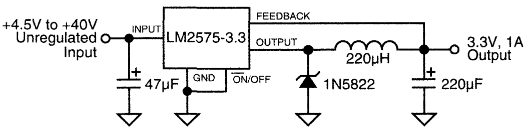


Figure 2. 3.3V Buck Regulator

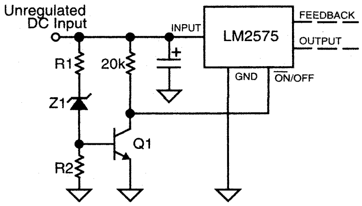


Figure 3. Undervoltage Lockout

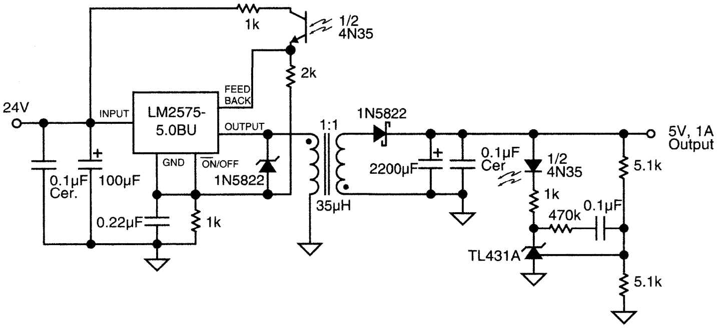


Figure 4. Isolated Flyback DC-DC Converter

Inductor Selection and Cross Reference

Custom Coils[1] Part No.	Renco Part[2] Part No.	I_{OC} (A)	V·µs (V·µs)	L (µH)	Description	
CCI-5023	RL5022	1.2	*	68	power line choke	
CCI-5024	RL5023	0.9	*	100		
CCI-4929	RL5024	0.75	*	150		
CCI-5025	RL5025	0.65	*	220		
CCI-5026	RL5026	0.5	*	330		
CCI-5027	RL5027	0.45	*	470		
CCI-4930	RL5028	0.9	*	220	power line choke	
CCI-4931	RL5029	0.75	*	330		
CCI-4932	RL5030	0.6	*	470		
CCI-4933	RL5031	0.5	*	680		
CCI-5028	RL5032	0.65	*	1000	power line choke	
CCI-5029	RL5033	0.5	*	1500		
CCI-5030	RL5034	0.45	*	2200		
CCI-4926	RL5035	12.0	*	47	cylindrical bobbin choke	
CCI-4927	RL5036	9.0	*	68		
CCI-4928	RL5037	7.5	*	100		
CCI-4934	RL5038	6.0	*	150		
CCI-4938	RL5039	2.5	*	680	cylindrical bobbin choke	
CCI-4939	RL5040	2.25	*	100		
CCI-4940	RL5041	TBD	*	TBD		
CCI-4941	RL5042	1	*	2200	cylindrical bobbin choke	
CCI-4935	RL5043	5	*	220		
CCI-4936	RL5044	4	*	330		
CCI-4937	RL5045	4	*	470	cylindrical bobbin choke	
CCI-4948	RL5046	1	44	20	powdered iron toroid	
CCI-5031	RL5047	3	38	20		
CCI-4949	RL5048	1	40	48		
CCI-4967	RL5049	3	105	48		
CCI-4951	RL5050	1	83	68		
CCI-4968	RL5051	3	130	68		
CCI-4952	RL5052	1	102	100		
CCI-4969	RL5053	3	165	100		
CCI-4953	RL5054	1	166	220		
CCI-4970	RL5055	3	342	220		
CCI-4954	RL5056	1	208	330		
CCI-4971	RL5057	3	437	330		
CCI-4942	RL5058	1	*	20	MPP toroid	
CCI-4961	RL5059	3	*	20		
CCI-4943	RL5060	1	*	48		
CCI-4962	RL5061	3	*	48		
CCI-4944	RL5062	1	*	68		
CCI-4963	RL5063	3	*	68		
CCI-4945	RL5064	1	*	100		
CCI-4964	RL5065	3	*	100		
CCI-4946	RL5066	1	*	220		
CCI-4965	RL5067	3	*	220		
CCI-4947	RL5068	1	*	330		
CCI-4966	RL5069	3	*	330		

1. Custom Coils, Alcester, South Dakota; tel: (605) 934-2460

2. Renco Electronics Inc., Deer Park, New York; tel: (516) 586-5566

Application Note 14

200kHz MIC4574/5/6 Family Design Guide

by Kevin Lynn

Introduction

Micrel's MIC457x family of BiCMOS simple buck voltage regulators feature faster rise/fall time, faster response to fault conditions, and improved efficiency at light loads.

Description

The MIC457x switching regulator is basically a PWM (pulse width modulation) controller IC with a fixed gain error amplifier, a 200kHz oscillator, and internal compensation network. The non-inverting side of the error amplifier is tied to a 1.23V bandgap reference.

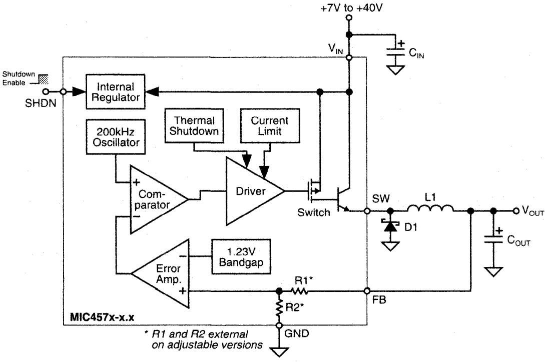


Figure 1. Block Diagram (Fixed Version)

Buck Regulator Design Procedure

Select the MIC4574 (0.5A), MIC4575 (1A), or MIC4576 (3A) based on the required output current. If higher current rated regulators are chosen for low current applications, make sure the current limit range is appropriate for that application.

Output Voltage

For fixed output voltages, 3.3V or 5.0V versions are available.

The output voltage of the adjustable regulators is configured using an external resistive divider.

$$V_{OUT} = 1.23V\left(1 + \frac{R2}{R1}\right)$$

For best performance, R1 should be between 1k and 10k.

Inductor Selection Criteria

The following criteria is used for inductor selection:

Mode of operation (continuous or discontinuous).

Peak inductor current

Volt-seconds (V·s) applied to the inductor

Definitions

Critical Inductance Condition The critical inductance condition is when the current through the inductor decays to zero just prior to the next "on" time of the regulator switch. This occurs at the boundary between continuous and discontinuous operation.

Discontinuous Operation Discontinuous operation occurs when, for any condition of input voltage or output current, the inductor current decays to zero before the next "on" time of the regulator switch.

Continuous Operation Continuous operation occurs when, for any condition of input voltage or output current, the inductor current does not decay to zero before the next "on" time of the regulator switch.

Continuous Conduction Operation

Critical Inductance

Compute the value of critical inductance required for the application at the worst case combination of input voltage and output load current. This will be the minimum value of inductance that will guarantee continuous conduction operation over all input voltage and output load conditions.

At the critical inductance condition, the peak inductor current is twice the average current. The average current is the current delivered to the load. The peak current at the critical inductance condition is:

$$(1) \quad I_{PEAK} = \frac{D\left(V_{IN} - V_{OUT}\right)}{L f_S}$$

Where:

D = duty cycle

D = switch on time/switch cycle time, T_{ON} / τ

τ = switch cycle time, $1 / f_S$, (s)

V_{IN} = input (supply) voltage (V)

V_{OUT} = regulator output voltage (V)

L = inductance of filter inductor (H)

f_S = switching frequency (Hz)

The input power will be assumed to be equal to the output power.

$$(2) \quad E_{FF} V_{IN} I_L D = \frac{V_{OUT}^2}{R_{LOAD}}$$

Where:

E_{FF} = estimated efficiency
reasonable initial estimate 80% (0.8)

R_{LOAD} = load resistance (Ω)

and,

$$(3)\quad L_{CRITICAL} = \frac{R_{LOAD}(1 - D)}{2\,f_S}$$

Duty Cycle

Compute the duty cycle required at the maximum required input voltage and minimum load current. If your cannot guarantee a minimum load current, an additional resistive load may be required at the regulator output.

$$D_{MIN} = \frac{V_{OUT}}{V_{IN(max)}}$$

Use this value of D_{MIN} and the minimum value of R_{LOAD} in equation (3) to determine the value of critical inductance. This is the minimum value of inductance required. Changing the minimum load and/or the maximum input voltage requirement changes the minimum required critical inductance.

The value of inductance can be chosen to allow the regulator to operate in discontinuous mode under certain conditions. Discontinuous mode typically occurs at maximum input and minium load current. In many cases this may not present a problem, however, it should be verified that operation in discontinuous mode still allows the circuit to satisfy the load regulation requirement.

Maximum V·s

Compute the maximum volt-microseconds applied to the inductor:

$$V \cdot s = \left(V_{IN} - V_{OUT}\right) \frac{V_{OUT}}{V_{IN(max)}} \tau$$

Inductor Peak Current

Compute the peak current through the inductor. This is the sum of the maximum load current and peak ripple current though the inductor.

$$I_{PEAK} = \frac{1}{2}\left(\frac{V_{IN(max)} - V_{OUT}}{L}\right) \tau \frac{V_{OUT}}{V_{IN(max)}} + \frac{V_{OUT}}{R_{LOAD}}$$

Inductor Selection

Refer to the "Inductor Selection and Cross Reference" table to select the appropriate inductor for your application. The selection should satisfy the following:

Inductance > Calculated Critical Inductance

Volt-second Capability > Calculated V·µs
(if applicable)

I_{DC} > Calculated I_{PEAK} Current × 0.85

Output Capacitor Selection

For stable operation, the output capacitor must satisfy the following:

$$C_{OUT} \geq 13300 \left(\frac{V_{IN(max)}}{V_{OUT}\,L}\right)$$

Where:

C_{OUT} = output capacitance (µF)

L = inductance (µH)

This guarantees that the dominant pole pair of the LC filter does not occur at a frequency that is too high for the regulator's internal loop compensation circuitry. This computation may result in a capacitor value that is too small to provide adequate peak-to-peak output ripple reduction.

Peak-to-peak ripple voltage is a function of the capacitor value and type. A low ESR/ESL (equivalent series resistance/equivalent series inductance) capacitor should be used for lower ripple voltage. (Standard capacitors may be paralleled to reduce the effective ESR/ESL value.) Low ESR electrolytic capacitors are available from Panasonic, Nichicon, and United Chemicon.

Maximum peak-to-peak ripple voltage (assuming no ESR or ESL in the filter capacitor) can be estimated as follows:

$$V_{P\text{-}P} = \frac{1}{C} \frac{\left(V_{IN(max)} - V_{OUT}\right)}{L} \frac{1}{2} \frac{V_{OUT}^2}{V_{IN}^2} \tau^2$$

Input Capacitor Selection

The input bypass capacitor must be at least 47µF to maintain stability. Low ESR capacitors are recommended. If the operating temperature range is below –25°C, the value of this capacitor should be increased. Adding a ceramic or solid tantalum capacitor near the input pin will also increase regulator stability at low temperatures. The capacitor's ripple current rating should be more than the ripple component of the inductor current:

$$I_{RIPPLE} = \frac{\tau}{2}\left(\frac{V_{IN(max)} - V_{OUT}}{L}\right)$$

Catch Diode Selection

Although either a Schottky or a fast recovery diode can be used, a Schottky diode will provide the best performance because its lower voltage drop and faster switching speed will result in higher efficiency. Fast recovery diodes with abrupt turn-off characteristics may cause EMI problems and/or instabilities.

The reverse voltage rating of the catch diode should be at least 1.25 × the maximum input voltage.

Standard 1N400x series diodes should not be used. The reverse recovery time of this type of diode is excessive which will cause additional noise and heat dissipation in the diode and the regulator's internal power switch.

Typical Applications

Fixed 3.3V Buck Regulator

Figure 2 shows a 3.3V buck regulator using inexpensive standard components.

The high efficiency (~80%) and low form factor afforded by the use of a new TO-263 surface mount package makes this ideal for battery operated designs.

If lower ripple voltage is desired, the standard 220µF capacitor can be replaced with a standard 330µF. For lower ripple at a small size, an Oscon 105A220M capacitor (220µF, 35mΩ ESR) can be used.

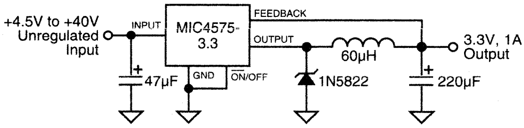


Figure 2. 3.3V Buck Regulator

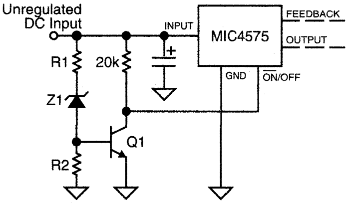


Figure 3. Undervoltage Lockout

Inductor Selection and Cross Reference

	Renco Part[1] Part No.	**I_{PC} (A)**	**V·µs (V·µs)**	**L (µH)**	**Description**	
	RL5341-20-1	1	43	20	powdered iron	
	RL5341-48-1	1	51	48		
	RL5341-68-1	1	155	68		
	RL5341-100-1	1	200	100		
	RL5341-150-1	1	330	150		
	RL5341-220-1	1	400	220		
	RL5341-330-1	1	680	330		
	RL5341-470-1	1	796	470		
	RL5341-680-1	1	1500	680		
	RL5341-1000-1	1	2000	1000		
	RL5342-20-1	1	26	20	moly permalloy	
	RL5342-48-1	1	60	48		
	RL5342-68	1	88	68		
	RL5342-100-1	1	116	100		
	RL5342-150-1	1	193	150		
	RL5342-220-1	1	285	220		
	RL5342-330-1	1	400	470		
	RL5342-470-1	1	604	470		
	RL5342-680-1	1	888	680		
	RL5342-1000-1	1	1200	1000		
	RL5341-20-3	3	140	20	powdered iron	
	RL5341-48-3	3	257	48		
	RL5341-68-3	3	471	68		
	RL5341-100-3	3	640	100		
	RL5341-150-3	3	885	150		
	RL5341-220-3	3	1272	220		
	RL5341-330-3	3	2155	330		
	RL5341-470-3	3	3221	470		
	RL5341-680-3	3	4784	680		
	RL5341-1000-3	3	6000	1000		
	RL5342-20-3	3	81	20	moly permalloy	
	RL5342-48-3	3	177	48		
	RL5342-68-3	3	273	68		
	RL5342-100-3	3	392	100		
	RL5342-150-3	3	591	150		
	RL5342-220-3	3	872	220		
	RL5342-330-3	3	1202	470		
	RL5342-470-3	3	1946	470		
	RL5342-680-3	3	2837	680		
	RL5342-1000-3	3	3900	1000		

[1] Renco Electronics Inc., Deer Park, New York; tel: (516) 586-5566

Application Note 15

Practical Switching Regulator Circuits

by Brian Huffman

Overview

A golden power supply that will satisfy every design requirement does not exist. Size, cost, and efficiency are the driving factors for selecting a design, causing each design to be different. This application note covers real-world circuit designs by showing a collection of the most commonly used power supply circuits. Some of the application circuits utilize ow-profile surface mount components, while others employ ow-cost components.

Every circuit in this application note has been designed, built, and evaluated for stability, temperature, component life, and tolerance (see Figure 1). Judicious design practices have been followed to ensure that the solutions are robust.

Efficiency is often a main concern with switching regulators. To allow a preliminary performance evaluation, efficiency plots for various input and output conditions accompany most circuits.

If the components specified in the schematic are not readily available, alternative components can be found in the cross-reference list in Appendix A. The components in the list are not exact replacements. Their electrical characteristics and physical sizes may be slightly different, but the electrical performance in the circuits will be the same. Appendix A also provides detailed electrical specifications for each power component, making the selection of alternate components easy.

Instead of publishing the operating equations for the buck (step-up) and buck-boost (inverting) topologies in this application note, Micrel chose to put them into easy-to-use Microsoft® Excel spreadsheets. This dramatically speeds up the design time when there is a need to modify one of the existing circuits.

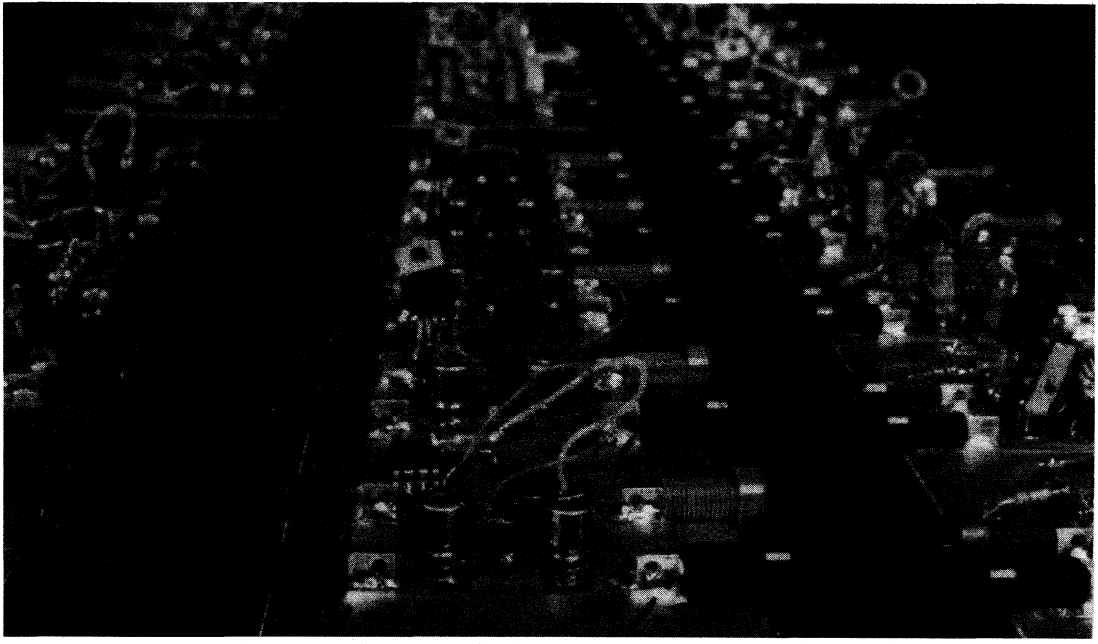
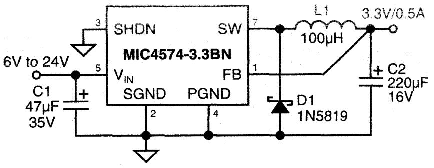


Figure 1. Designed, Built, and Tested

Table of Contents

Special Feature Circuits

6V–24V to 3.3V/0.5A Buck Converter Through Hole



C1	Nichicon	UPL1V470MEH, ESR = 0.34Ω	
C2	Nichicon	UPL1C221MPH, ESR = 0.16Ω	
D1	Motorola	1N5819	
L1	Coiltronics	PL52A-100-250, DCR = 0.2Ω	

Figure 1a. Schematic

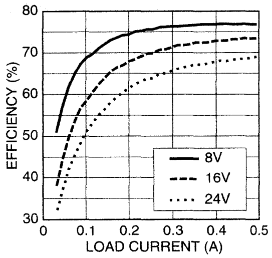
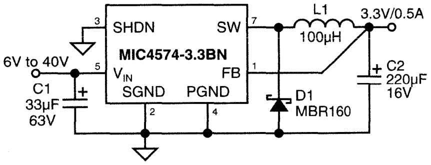


Figure 1b. Efficiency

6V–40V to 3.3V/0.5A Buck Converter Note 1 Through Hole



C1	Nichicon	UPL1J330MEH, ESR = 0.35Ω	
C2	Nichicon	UPL1C221MPH, ESR = 0.16Ω	
D1	Motorola	MBR160	
L1	Coiltronics	PL52A-100-250, DCR = 0.2Ω	

Figure 2a. Schematic

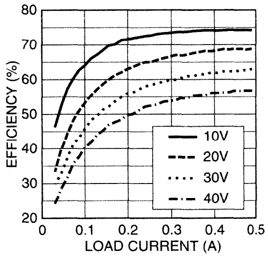
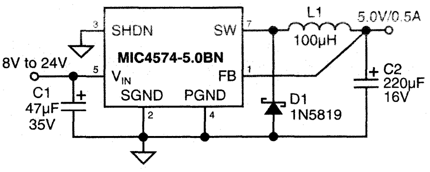


Figure 2b. Efficiency

8V–24V to 5V/0.5A Buck Converter Through Hole



C1	Nichicon	UPL1J470MEH, ESR = 0.34Ω	
C2	Nichicon	UPL1C221MPH, ESR = 0.16Ω	
D1	Motorola	1N5819	
L1	Coiltronics	PL52A-100-250, DCR = 0.2Ω	

Figure 3a. Schematic

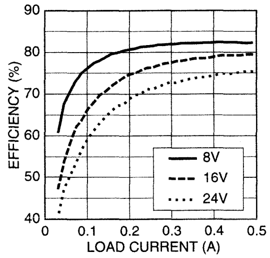
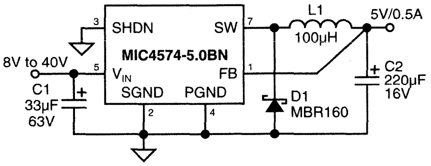


Figure 3b. Efficiency

8V–40V to 5V/0.5A Buck Converter Note 1 Through Hole



C1	Nichicon	UPL1J330MEH, ESR = 0.35Ω	
C2	Nichicon	UPL1C221MPH, ESR = 0.16Ω	
D1	Motorola	MBR160	
L1	Coiltronics	PL52A-100-250, DCR = 0.2Ω	

Figure 4a. Schematic

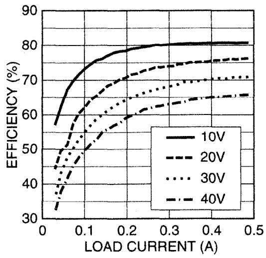
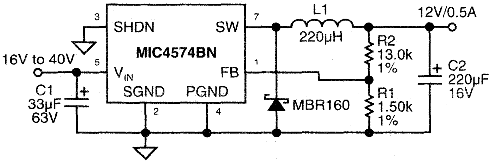


Figure 4b. Efficiency

Note 1: Although the MIC457x family is functional to input voltage to 40V, they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.

16V–40V to 12V/0.5A Buck Converter Note 1 Through Hole



C1	Nichicon	UPL1J330MEH, ESR = 0.35Ω
C2	Nichicon	UPL1C221MPH, ESR = 0.16Ω
D1	Motorola	MBR160
L1	Coiltronics	PL52A-220-250, DCR = 0.37Ω

Figure 5a. Schematic

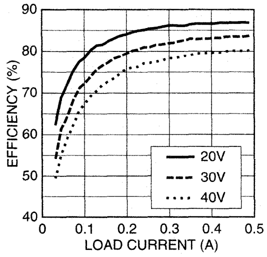
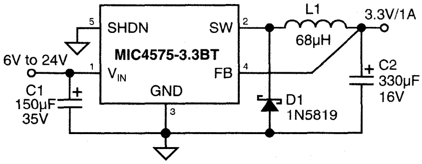


Figure 5b. Efficiency

6V–24V to 3.3V/1A Buck Converter Through-Hole



C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω

Figure 6a. Schematic

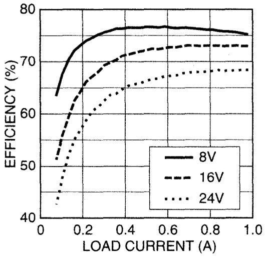
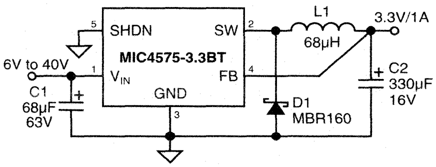


Figure 6b. Efficiency

6V–40V to 3.3V/1A Buck Convereter Note 1 Through Hole



C1	Nichicon	UPL1J680MPH, ESR = 0.17Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	MBR160
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω

Figure 7a. Schematic

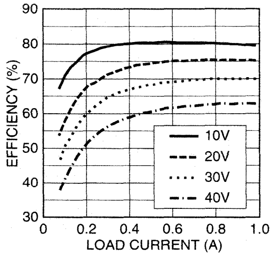
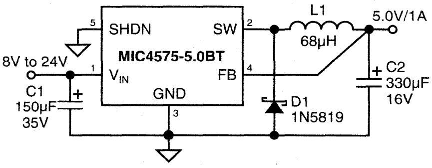


Figure 7b. Efficiency

8V–24V to 5V/1A Buck Converter Through Hole



C1	Nichicon	UPL1J151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω

Figure 8a. Schematic

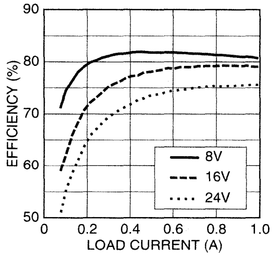
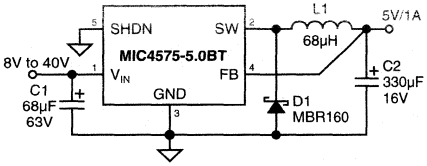


Figure 8b. Efficiency

Note 1: Although the MIC457x family is functional to input voltage to 40V, they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.

8V–40V to 5V/1A Buck Converter Note 1 Through-Hole



C1	Nichicon	UPL1J680MPH, ESR = 0.17Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	MBR160
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω

Figure 9a. Schematic

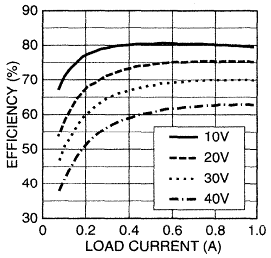
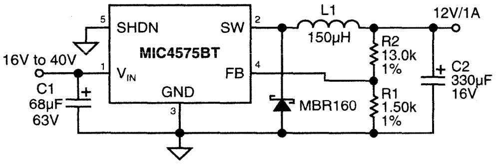


Figure 9b. Efficiency

16V–40V to 12V/1A Buck Coverter Note 1 Through-Hole



C1	Nichicon	UPL1J680MPH, ESR = 0.17Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	MBR160
L1	Coiltronics	PL52B-150-500, DCR = 0.166Ω

Figure 10a. Schematic

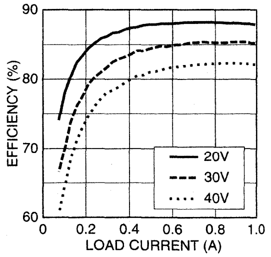
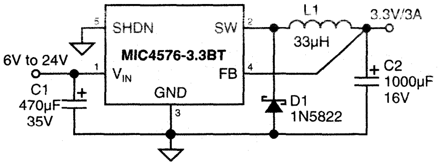


Figure 10b. Efficiency

6V–24V to 3.3V/3A Buck Converter Through Hole



C1	Nichicon	UPL1V471MPH, ESR = 0.046Ω
C2	Nichicon	UPL1C221MPH, ESR = 0.047Ω
D1	Motorola	1N5822
L1	Coiltronics	PL52C-33-1000, DCR = 0.036Ω

Figure 11a. Schematic

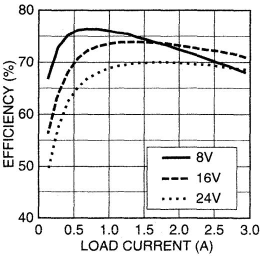
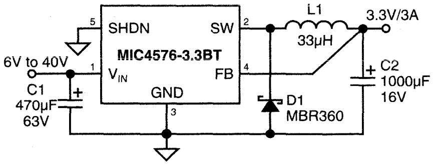


Figure 11b. Efficiency

6V–40V to 3.3V/3A Buck Converter Note 1 Through Hole



C1	Nichicon	UPL1J471MRH, ESR = 0.039Ω
C2	Nichicon	UPL1C102MPH, ESR = 0.047Ω
D1	Motorola	MBR360
L1	Coiltronics	PL52C-33-1000, DCR = 0.036Ω

Figure 12a. Schematic

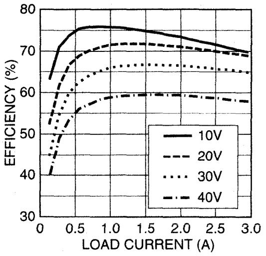
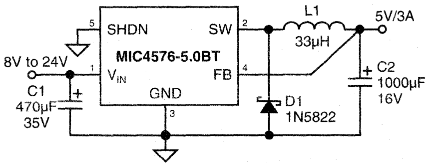


Figure 12b. Efficiency

Note 1: Although the MIC457x family is functional to input voltage to 40V, they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.

8V–24V to 5V/3A Buck Converter
Through Hole



C1	Nichicon	UPL1J471MPH, ESR = 0.046Ω
C2	Nichicon	UPL1C102MPH, ESR = 0.047Ω
D1	Motorola	MBR5822
L1	Coiltronics	PL52C-33-1000, DCR = 0.036Ω

Figure 13a. Schematic

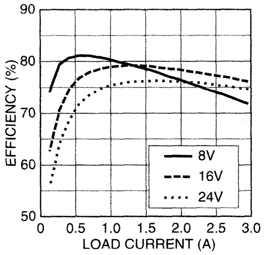
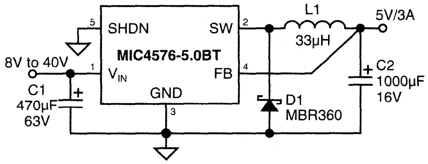


Figure 13b. Efficiency

8V–40V to 5V/3A Buck Converter Note 1
Through Hole



C1	Nichicon	UPL1J471MRH, ESR = 0.039Ω
C2	Nichicon	UPL1C102MPH, ESR = 0.047Ω
D1	Motorola	MBR360
L1	Coiltronics	PL52C-33-1000, DCR = 0.036Ω

Figure 14a. Schematic

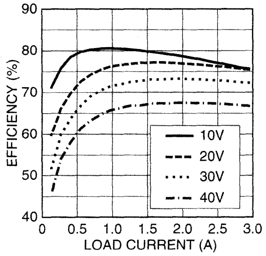
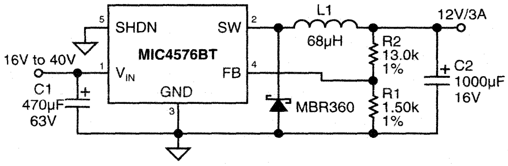


Figure 14b. Efficiency

16V–40V to 12V/3A Buck Converter Note 1
Through Hole



C1	Nichicon	UPL1J471MPH, ESR = 0.039Ω
C2	Nichicon	UPL1C102MPH, ESR = 0.047Ω
D1	Motorola	MBR360
L1	Coiltronics	PL52D-68-2000, DCR = 0.045Ω

Figure 15a. Schematic

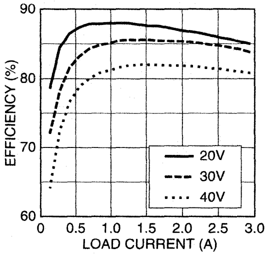
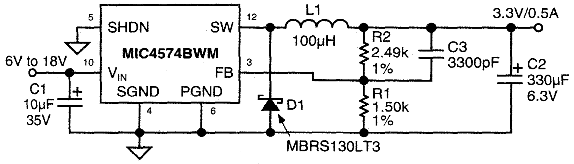


Figure 15b. Efficiency

6V–18V to 3.3V/0.5A Buck Converter
Low-Profile Surface Mount



C1	AVX	TPSD106M035R0300, ESR = 0.3Ω
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	Motorola	MBRS130LT3
L1	Coiltronics	CTX100-2P, DCR = 0.541Ω

Figure 16a. Schematic

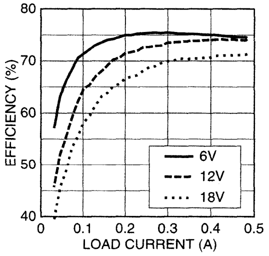
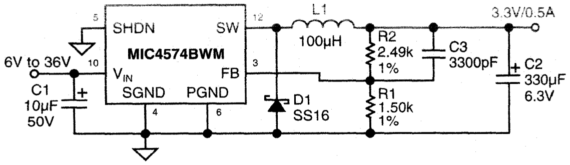


Figure 16b. Efficiency

Note 1: Although the MIC457x family is functional to input voltage to 40V, they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.

6V–36V to 3.3V/0.5A Buck Converter Note 1 Low-Profile Surface Mount



C1	Tokin	C55Y5U1H106Z
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	General Instruments SS16	
L1	Coiltronics CTX100-2P, DCR = 0.541Ω	

Figure 17a. Schematic

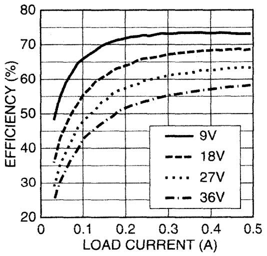
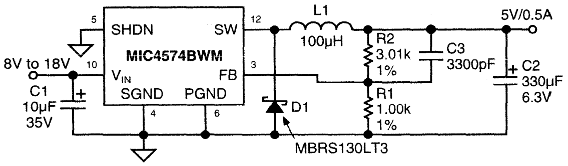


Figure 17b. Efficiency

8V–18V to 5V/0.5A Buck Converter Low-Profile Surface Mount



C1	AVX	TPSD106M035R0300, ESR = 0.3Ω
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	Motorola	MBRS130LT3
L1	Coiltronics CTX100-2P, DCR = 0.541Ω	

Figure 18a. Schematic

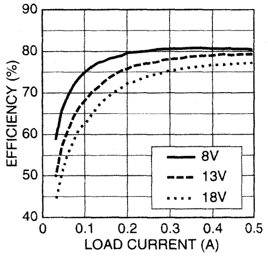
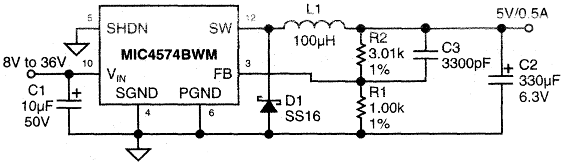


Figure 18b. Efficiency

8V–36V to 5V/0.5A Buck Converter Note 1 Low-Profile Surface Mount



C1	Tokin	C55Y5U1H106Z
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	General Instruments SS16	
L1	Coiltronics CTX100-2P, DCR = 0.541Ω	

Figure 19a. Schematic

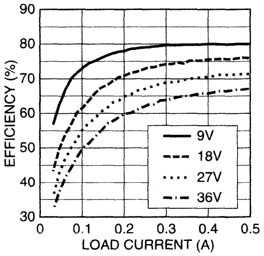
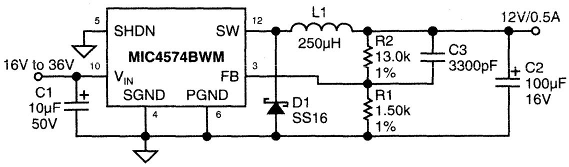


Figure 19b. Efficiency

16v–36V to 12V/0.5A Buck Converter Note 1 Low-Profile Surface Mount



C1	Tokin	C55Y5U1H106Z
C2	AVX	TPSE107M016R0100, ESR = 0.1Ω
D1	General Instruments SS16	
L1	Coiltronics CTX250-4P, DCR = 0.434Ω	

Figure 20a. Schematic

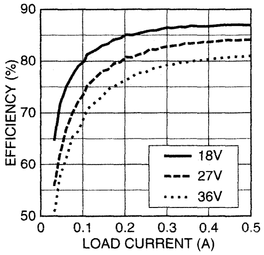
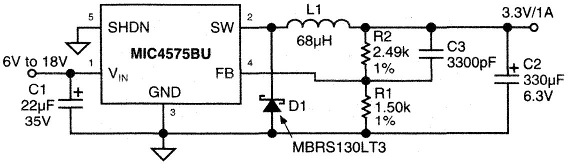


Figure 20b. Efficiency

Note 1: Although the MIC457x family is functional to input voltage to 40V, they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.

6V–18V to 3.3V/1A Buck Converter Low-Profile Surface Mount



C1	AVX	TPSE226M035R0300, ESR = 0.3Ω
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	Motorola	MBRS130LT3
L1	Coiltronics	CTX68-4P, DCR = 0.238Ω

Figure 21a. Schematic

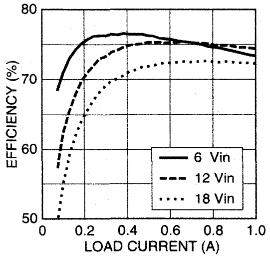
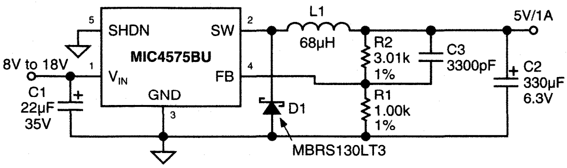


Figure 21b. Efficiency

8V–18V to 5V/1A Buck Converter Low-Profile Surface Mount



C1	AVX	TPSE226M035R0300, ESR = 0.3Ω
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	Motorola	MBRS130LT3
L1	Coiltronics	CTX68-4P, DCR = 0.238Ω

Figure 22a. Schematic

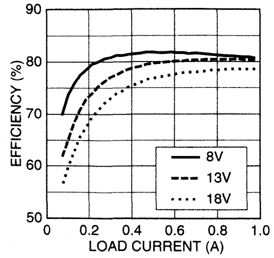
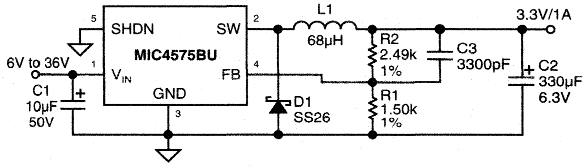


Figure 22b. Efficiency

6V–36V to 3.3V/1A Buck Converter Note 1 Low-Profile Surface Mount



C1	Tokin	C55Y5U1H106Z
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	General Instruments SS26	
L1	Coiltronics	CTX68-4P, DCR = 0.238Ω

Figure 23a. Schematic

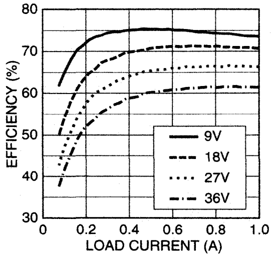
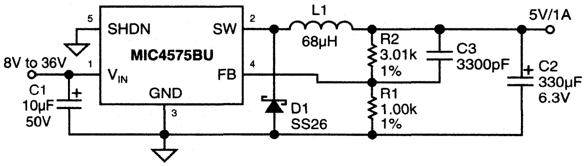


Figure 23b. Efficiency

8V–36V to 5V/1A Buck Converter Note 1 Low-Profile Surface Mount



C1	Tokin	C55YU1H106Z
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	General Instuments SS26	
L1	Coiltronics	CTX68-4P, DCR = 0.238Ω

Figure 24a. Schematic

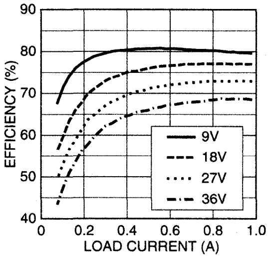
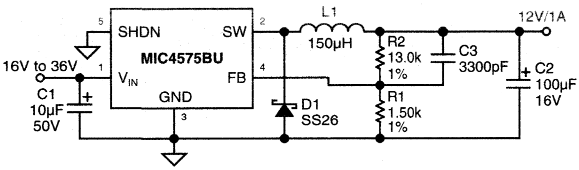


Figure 24b. Efficiency

Note 1: Although the MIC457x family is functional to input voltage to 40V, they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.

16V–36V to 12V/1A Buck Converter Note 1 Low-Profile Surface Mount



C1	Tokin	C55YU1H106Z
C2	AVX	TPSE107M016R0100, ESR = 0.1Ω
D1	General Instruments	SS26
L1	Coiltronics	CTX150-4, DCR = 0.372Ω

Figuure 25a. Schematic

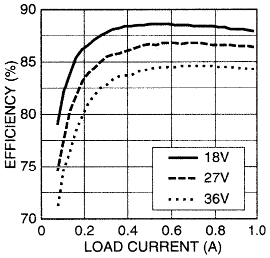
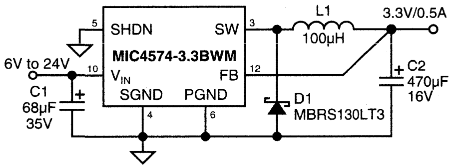


Figure 25b. Efficiency

6V–24V to 3.3V/0.5A Buck Converter Lower-Cost Surface Mount



C1	Sanyo	35CV168GX, ESR = 0.34Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	Motorola	MBRS130LT3
L1	Coilcraft	DO3316P-104, DCR = 0.23Ω

Figure 26a. Schematic

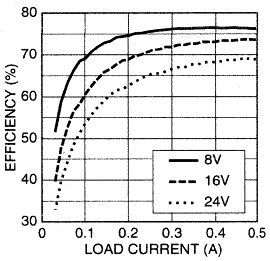
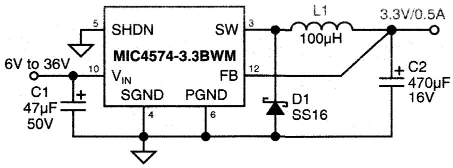


Figure 26b. Efficiency

6V–36V to 3.3V/0.5A Buck Converter Note 1 Lower-Cost Surface Mount



C1	Nichicon	UUX1H470MNT1GS, ESR = 0.4Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	General Instruments	SS16
L1	Coilcraft	DO3316P-104, DCR = 0.23Ω

Figure 27a. Schematic

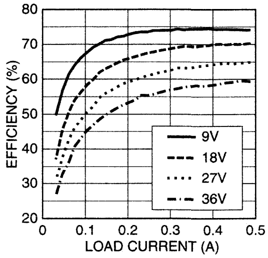
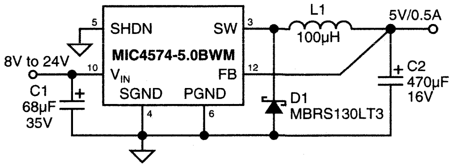


Figure 27b. Efficiency

8V–24V to 5V/0.5A Buck Converter Lower-Cost Surface Mount



C1	Sanyo	35CV168GX, ESR = 0.34Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	Motorola	MBRS130LT3
L1	Coilcraft	DO3316P-104, DCR = 0.23Ω

Figure 28a. Schematic

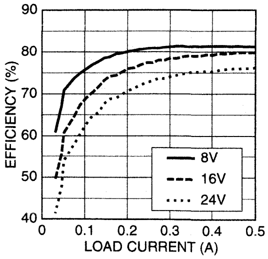
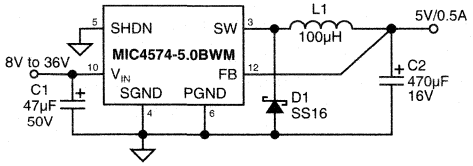


Figure 28b. Efficiency

Note 1: Although the MIC457x family is functional to input voltage to 40V, they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.

8V–36V to 5V/0.5A Buck Converter Note 1 Lower-Cost Surface Mount



C1	Nichicon	UUX1H470MNT1GS, ESR = 0.4Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	General Instruments SS16	
L1	Coilcraft	DO3316P-104, DCR = 0.23Ω

Figure 29a. Schematic

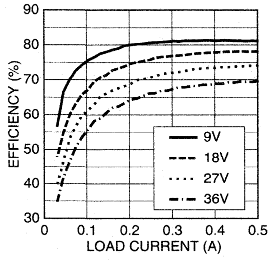
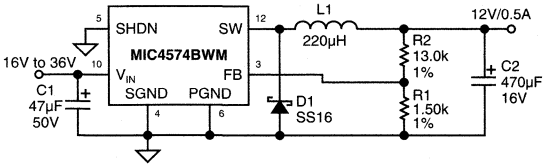


Figure 29b. Efficiency

16V–36V to 12V/0.5A Buck Converter Note 1 Lower-Cost Surface Mount



C1	Nichicon	UUX1H470MNT1GS, ESR = 0.4Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	General Instruments SS16	
L1	Coilcraft	DO3316-224, DCR = 0.53Ω

Figure 30a. Schematic

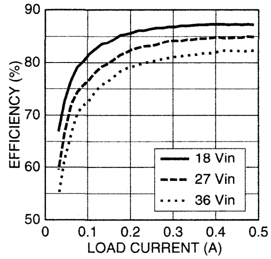
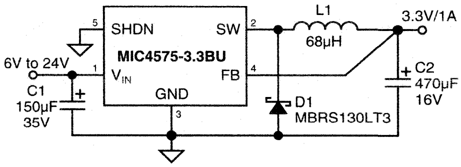


Figure 30b. Efficiency

6V–24V to 3.3V/1A Buck Converter Lower-Cost Surface Mount



C1	Sanyo	35CV150GX, ESR = 0.17Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	Motorola	MBRS130LT3
L1	Coilcraft	DO3316P-683, DCR = 0.16Ω

Figure 31a. Schematic

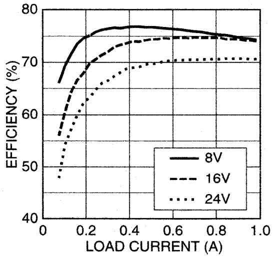
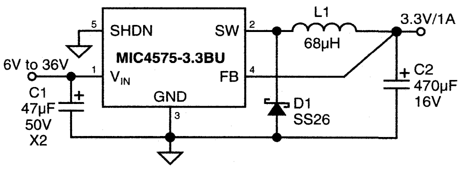


Figure 31b. Efficiency

6V–36V to 3.3V/1A Buck Converter Note 1 Lower-Cost Surface Mount



C1	Nichicon	UUX1H470MNT1GS, ESR = 0.4Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	General Instruments SS26	
L1	Coilcraft	DO3316P-683, DCR = 0.16Ω

Figure 32a. Schematic

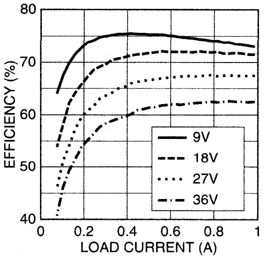
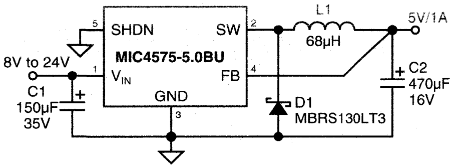


Figure 32b. Efficiency

Note 1: Although the MIC457x family is functional to input voltage to 40V, they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.

8V–24V to 5V/1A Buck Converter Lower-Cost Surface Mount



C1	Sanyo	35CV150GX, ESR = 0.17Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	Motorola	MBRS130LT3
L1	Coilcraft	DO3316P-683, DCR = 0.16Ω

Figure 33a. Schematic

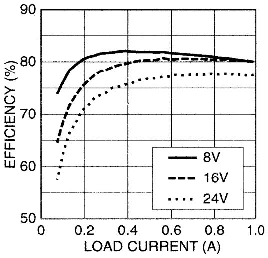
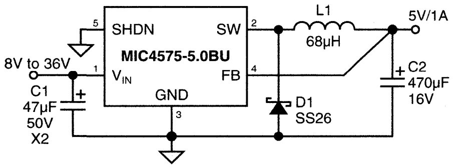


Figure 33b. Efficiency

8V–36V to 5V/1A Buck Converter Note 1 Lower-Cost Surface Mount



C1	Nichicon	UUX1H470MNT1GS, ESR = 0.4Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	General Instruments SS26	
L1	Coilcraft	DO3316P-683, DCR = 0.16Ω

Figure 34a. Schematic

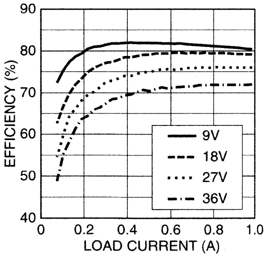
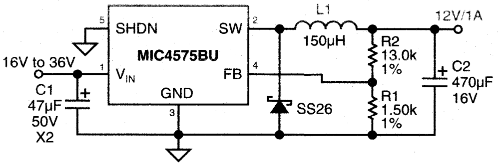


Figure 34b. Efficiency

16V–36V to 12V/1A Buck Converter Note 1 Lower-Cost Surface Mount



C1	Nichicon	UUX1H470MT1GS, ESR = 0.4Ω
C2	Sanyo	16CV470GX, ESR = 0.17Ω
D1	General Instruments SS26	
L1	Coiltcraft	DO5022P-154, DCR = 0.218Ω

Figure 35a. Schematic

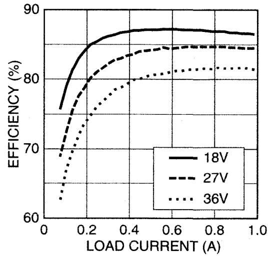
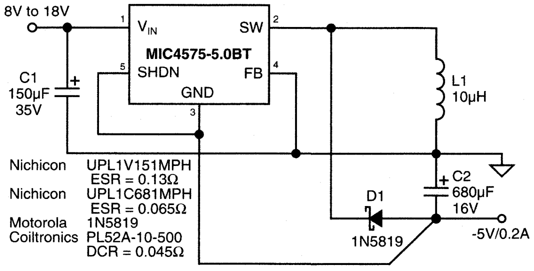


Figure 35b. Efficiency

8V–18V to –5V/0.2A Buck-Boost Converter Through Hole



C1	Nichicon	UPL1V151MPH ESR = 0.13Ω
C2	Nichicon	UPL1C681MPH ESR = 0.065Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52A-10-500 DCR = 0.045Ω

Figure 36a. Schematic

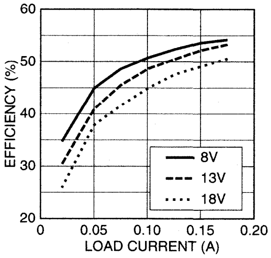
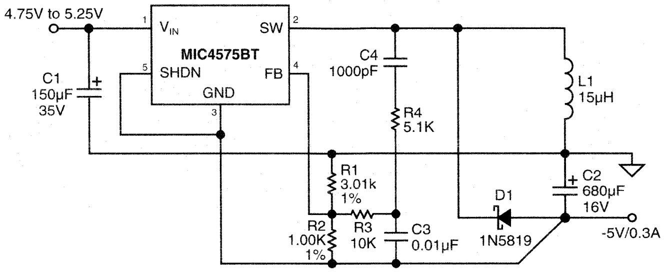


Figure 36b. Efficiency

Note 1: Although the MIC457x family is functional to input voltage to 40V, they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.

5V to –5V/0.3A Buck-Boost Converter Through Hole



C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C681MPH, ESR = 0.065Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52A-15-500, DCR = 0.054Ω

Figure 37a. Schematic

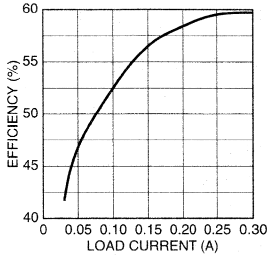
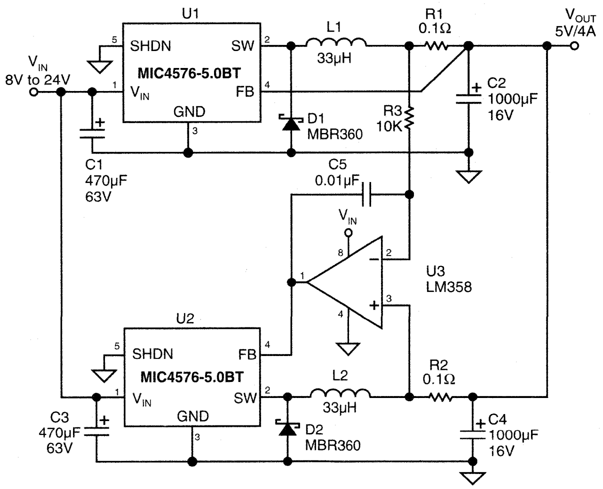


Figure 37b. Efficiency

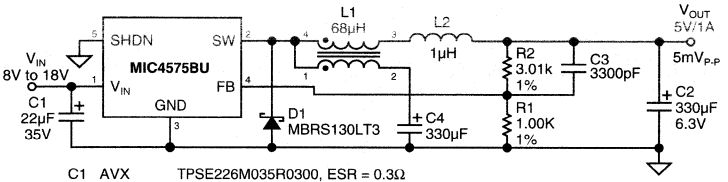
Parallel Switching Regulators



C1, C3	Nichicon	UPL1J471MRH, ESR = 0.039Ω
C2, C4	Nichicon	UPL1C102MPH, ESR = 0.047Ω
D1, D2	Motorola	MBR360
L1, L2	Coiltronics	PL52C-33-1000, DCR = 0.036
R1, R2	KRL	SP-1-A1-0R100J
U3	National	LM358

Figure 38.

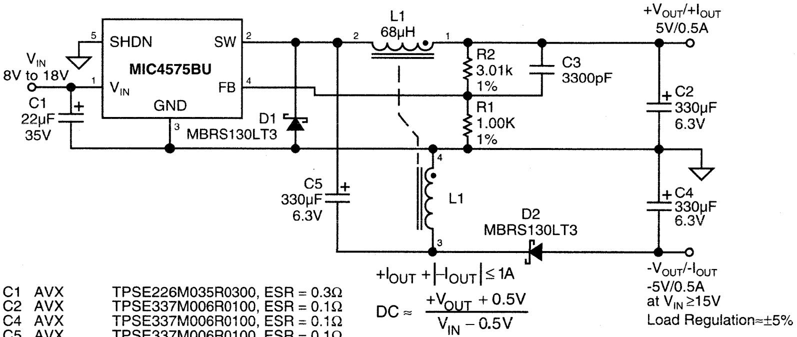
Low Output-Noise Regulator (5mV Output Ripple)



C1	AVX	TPSE226M035R0300, ESR = 0.3Ω
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
C4	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	Motorola	MBRS130LT3
L1	Coiltronics	CTX68-4P, DCR = 0.238Ω
L2	Coilcraft	DO1608C-102

Figure 39.

Split ±5V Supply



C1	AVX	TPSE226M035R0300, ESR = 0.3Ω
C2	AVX	TPSE337M006R0100, ESR = 0.1Ω
C4	AVX	TPSE337M006R0100, ESR = 0.1Ω
C5	AVX	TPSE337M006R0100, ESR = 0.1Ω
D1	Motorola	MBRS130LT3
D2	Motorola	MBRS130LT3
L1	Coiltronics	CTX68-4P, DCR = 0.238Ω

$$+I_{OUT} + \left|-I_{OUT}\right| \le 1A$$

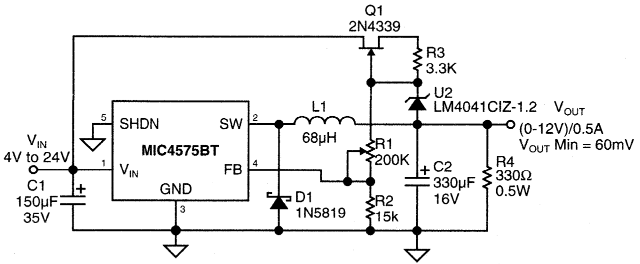
$$DC \approx \frac{+V_{OUT} + 0.5V}{V_{IN} - 0.5V}$$

$DC \le 40\%$ then $-I_{OUT} \le +I_{OUT}$

$DC \ge 40\%$ then $-I_{OUT} \le +I_{OUT} \times (1 - DC)$

Figure 40.

Adjustable Output-Voltage Regulator (0V–12V)



C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω
U2	Micrel	LM4041CIZ-1.2

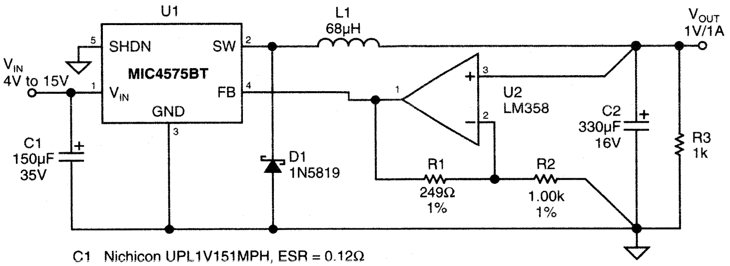
$$V_{IN\,min} \ge \frac{V_{OUT}}{0.9} + 1.5V$$

and

$$V_{IN\,min} \ge V_{OUT} + 2.5V$$

Figure 41.

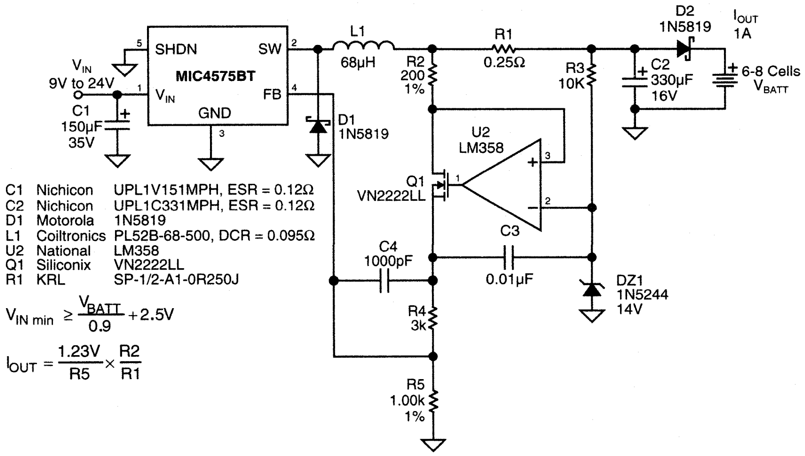
Low Output-Voltage Regulator (1V)



C1	Nichicon UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon UPL1C331MPH, ESR = 0.12Ω
D1	Motorola 1N5819
L1	Coiltronics PL52B-68-500, DCR = 0.095Ω
U2	National LM358

Figure 42.

1A Battery Charger (6–8 cells)



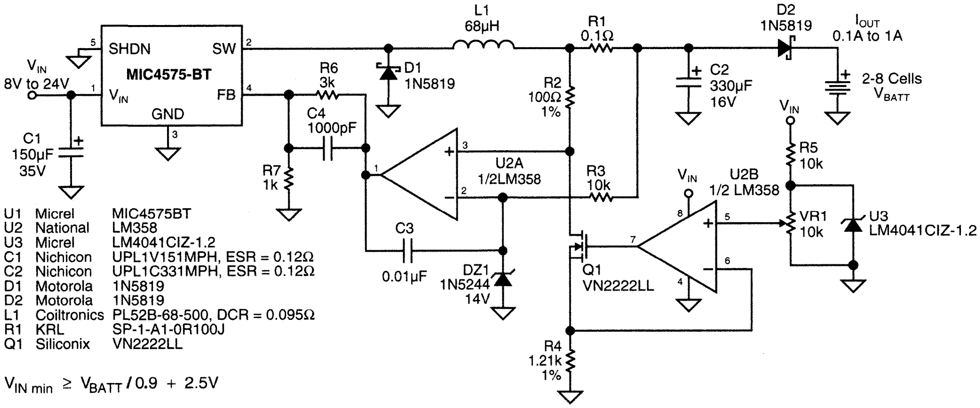
C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω
U2	National	LM358
Q1	Siliconix	VN2222LL
R1	KRL	SP-1/2-A1-0R250J

$$V_{IN\,min} \geq \frac{V_{BATT}}{0.9} + 2.5V$$

$$I_{OUT} = \frac{1.23V}{R5} \times \frac{R2}{R1}$$

Figure 43.

0.1A–1A Variable Current Battery Charger

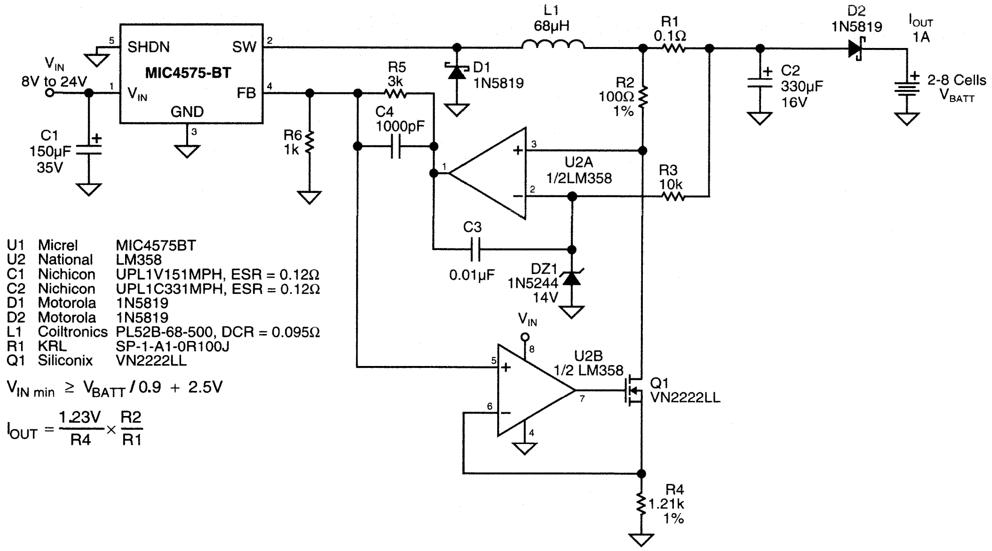


U1	Micrel	MIC4575BT
U2	National	LM358
U3	Micrel	LM4041CIZ-1.2
C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
D2	Motorola	1N5819
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω
R1	KRL	SP-1-A1-0R100J
Q1	Siliconix	VN2222LL

$$V_{IN\,min} \geq V_{BATT}/0.9 + 2.5V$$

Figure 44.

1A Battery Charger (2–8 Cells)



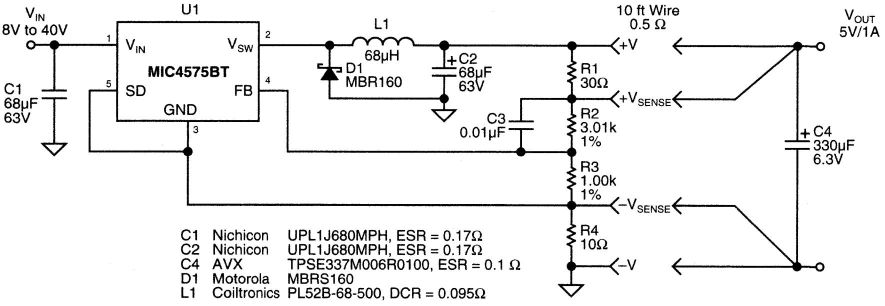
U1	Micrel	MIC4575BT
U2	National	LM358
C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
D2	Motorola	1N5819
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω
R1	KRL	SP-1-A1-0R100J
Q1	Siliconix	VN2222LL

$$V_{IN\,min} \geq V_{BATT}/0.9 + 2.5V$$

$$I_{OUT} = \frac{1.23V}{R4} \times \frac{R2}{R1}$$

Figure 45.

Remote Sensing Regulator [Note 1]



C1	Nichicon	UPL1J680MPH, ESR = 0.17Ω
C2	Nichicon	UPL1J680MPH, ESR = 0.17Ω
C4	AVX	TPSE337M006R0100, ESR = 0.1 Ω
D1	Motorola	MBRS160
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω

Figure 46.

Note 1: Although the MIC457x family is functional to input voltage to 40V, they are not guaranteed to survive a short circuit to ground for input voltage above 24V. However, the 40V part will be available during the third quarter of 1996.

Appendix A

Component Cross-Reference List

Micrel provides this cross-reference list to make it easier to choose alternate power components. This becomes necessary when the standard components are not readily available or the manufacturer is not an approved vendor.

The components in this list are not exact replacements. Their electrical characteristics and physical sizes may be slightly different, but their performance in the circuit will be the same. Also, detailed electrical specifications are provided for each power component so that if you need an alternate component, you can choose it intelligently.

Through-Hole Components

Capacitors

	Nichicon (Electrolytic)	Sanyo (Electrolytic)	Panasonic (Electrolytic)	United Chemi-Con (Electrolytic)
220µF/16V/0.16Ω/0.460A	UPL1C221MPH	16MV220GX	ECA1CFQ271	LXF16VB271M10x12.5
330µF/16V/0.12Ω/0.595A	UPL1C331MPH	16MV330GX	ECA1CFQ331L	LXF16VB331M8x15
680µF/16V/0.065Ω/1.02A	UPL1C681MPH	16MV560GX	ECA1CFQ681L	LXF16VB681M10x20
1000µF/16V/0.047Ω/1.41A	UPL1C102MPH	16MV1000GX	ECA1CFQ122L	LXF16VB102M10x30
47µF/35V/0.34Ω/0.27A	UPL1V470MEH	35MV68GX	ECA1VFQ560	LXF35VB680M6.3x11.5
150µF/35V/0.12Ω/0.595A	UPL1V151MPH	35MV150GX	ECA1VFQ151L	LXF35VB181M8x15
470µF/35V/0.046Ω/1.42A	UPL1V471MPH	35MV680GX	ECA1VFQ561L	LXF35VB5611M10x30
33µF/63V/0.35Ω/0.33A	UPL1J330MEH	63MV82GX	ECA1JFQ390	LXF63VB33M6.3x15
68µF/63V/0.17Ω/0.5A	UPL1J680MPH	63MV150GX	ECA1JFQ680	LXF63VB820M8x20
470µF/63V/0.039Ω/1.42A	UPL1J471MRH	63MV680GX	ECA1JFQ471L	LXF63VB561M12.5x40

Diodes

	Motorola (Schottky)	GI (Schottky)	IR (Schottky)
1A/40V	1N5819	1N5819	11DQ04
1A/60V	MBR160	SB160	11DQ06
3A/40V	1N5822	1N5822	31DQ04
3A/60V	MBR360	SB360	31DQ06

Inductors

	Coiltronics (Toroidal Cores)	Renco (Rod Cores)
10µH/0.5A	PL52A-10-500	
15µH/0.5A	PL52A-15-500	
33µH/3A	PL52C-33-1000	
68µH/1A	PL52B-68-500	RL-1283-68-43
68µH/3A	PL52D-68-2000	
100µH/0.5A	PL52A-100-250	RL-1284-100-43
150µH/1A	PL52B-150-500	RL-1283-150-43
220µH/0.5A	PL52A-220-250	RL-1284-220-43

Surface-Mount

Capacitors

Low Profile	AVX (Tantalum)	Tokin (Ceramic)
330μF/6.3V/0.1Ω/1.149A	TPSE337M006R0100	
10μF/35V/0.3Ω/0.663A	TPSD106M035R0300	
22μF/35V/0.3Ω/0.632A	TPSE226M035R0300	
10μF/35V		C55Y5U1E106Z
22μF/35V		C25Y5U1E226Z
10μF/50V		C55Y5U1H106Z

Lower-Cost	Sanyo (Electrolytic)	Nichicon (Electrolytic)
470μF/16V/0.17Ω/0.45A	16CV470GX	
68μF/35V/0.34Ω/0.28A	35CV68GX	
220μF/35V/0.17Ω/0.45A	35CV220GX	
47μF/50V/0.4Ω/0.18A		UUX1H470MNT1GS

Diodes

	Motorola (Schottky)	GI (Schottky)	IR (Schottky)
1A/30V	MBRS130LT3		
1A/40V	MBRS140T3	SS14/SS24	10MQ040
1A/60V		SS16/SS26	
3A/40V	MBRS340T3	SS34	330WQ04F
3A/60V	MBRS360T3	SS36	330WQ06F

Inductors

	Coiltronics (Toroidal Cores)	Coilcraft (Button Cores)	Coilcraft (Shielded Button Cores)
100μH/0.5A	CTX100-2P	DO3316P-104	DT3316P-104
220μH/0.5A	CTX250-4P	DO3316P-224	DT3316P-224
68μH/1A	CTX68-4P	DO3316P-683	
150μH/1A	CTX150-4	DO5022P-154	

Appendix B

Suggested Manufacturers List

Micrel supplies this list of manufacturers to save you time in selecting components. Micrel makes no claims about these companies except that they provide components necessary in switching power supplies.

Capacitors

AVX Corp.
801 17th Ave. South
Myrtle Beach, SC 29577
Tel: (803) 448-9411
Fax: (803) 448-1943

Nichicon (America) Corporation
927 East State Parkway
Schaumburg, IL 60173
Tel: (708) 843-7500
Fax: (708) 843-2798

Panasonic
6550 Katella Avenue
PANAZIP 17A-11
Cypress, CA 90630
Tel: (714) 373-7857
Fax: (714) 373-7102

Sanyo Video Components (USA) Corp.
2001 Sanyo Avenue
San Diego, CA 92173
Tel: (619) 661-6835
Fax: (619) 661-1055

Tokin America, Inc.
155 Nicholson Lane
San Jose, CA 95134
Tel: (408) 432-8020
Fax: (408) 434-0375

United Chemi-Con Inc.
9801 West Higgins Road, Suite 430
Rosemount, IL 60018
Tel: (708) 696-2000
Fax: (708) 696-9278

Core Materials

Micrometals, Inc.
1190 North Hawk Circle
Anaheim, CA 92807
Tel: (800) 356-5977
Fax: (714) 630-4562

Diodes

General Instruments (GI)
10 Melville Park Road
Melville, NY 11747
Tel: (516) 847-3222
Fax: (516) 847-3150

International Rectifier Corp.
233 Kansas Streeet
El Segundo, CA 90245
Tel: (310) 322-3331
Fax: (310) 322-3332

Motorola Inc.
3102 North 56th St., MS 56-126
Phoenix, AZ 85018
Tel: (800) 521-6274
Fax: (602) 952-4190

Heat Sinks

Aavid Engineering, Inc.
67 Primrose Drive
Laconia, NH 03246
Tel: (603) 528-3400
Fax: (603) 528-1478

Thermalloy
2021 West Valley View Lane
P.O. Box 810839
Dallas, TX 75381
Tel: (214) 243-4321
Fax: (214) 241-4656

Inductors

Coilcraft
1102 Silver Lake Road
Cary, IL 60013
Tel: (708) 639-2361
Fax: (708) 639-1469

Coiltronics
6000 Park of Commerce Boulevard
Boca Raton, FL 33487
Tel: (407) 241-7876
Fax: (407) 241-9335

Dale Electronics
East Highway 50
Yankton, SD 57078
Tel: (605) 665-9301
Fax: (605) 665-0817

Hurricane Electronics Lab
P.O. Box 1280
Hurricane Industrial Park
Hurricane, UT 84737
Tel: (801) 635-2003
Fax: (801) 635-2495

Pulse Engineering
12220 World Trade Drive
San Diego, CA 92128
Tel: (619) 674-8100
Fax: (619) 674-8262

Renco
60 Jefryn Boulevard East
Deerpark, NY 11729
Tel: (516) 586-5566
Fax: (516) 586-5562

Resistors

KRL/Bantry Components, Inc.
160 Bouchard Street
Manchester, NH 03103
Tel: (603) 668-3210
Fax: (603) 624-0634

Appendix C

Microsoft® Excel Spreadsheet Summary

Determining the operating conditions for a switching regulator requires dozens of calculations. Doing this with a handheld calculator can take hours, but when the equations are put into a spreadsheet, this takes only a few seconds. Micrel provides Microsoft® Excel spreadsheets for both buck (step-up) and buck-boost (inverting) switching regulator topologies. The spreadsheets perform computer aided design, not computer generated design. It is the responsibility of the user to verify spreadsheet results by building the circuit and measuring component stress under all expected operating conditions.

Figure C1 shows the buck regulator spreadsheet. It is divided into three columns. The first column contains all the input variables. You can change any variable in this column, such as input voltage, switching frequency, and inductor value. You might change these variables to observe the sensitivity of the circuit, to test for worst-case conditions, or to set a tolerance on component characteristics.

The second column contains the resulting operating conditions for all power components. You select the power components based upon these values. Most worst-case operating conditions occur at the minimum input voltage, but not in every case. To ensure a reliable design, vary the input voltage over its entire operating range and use the worst-case value to select components.

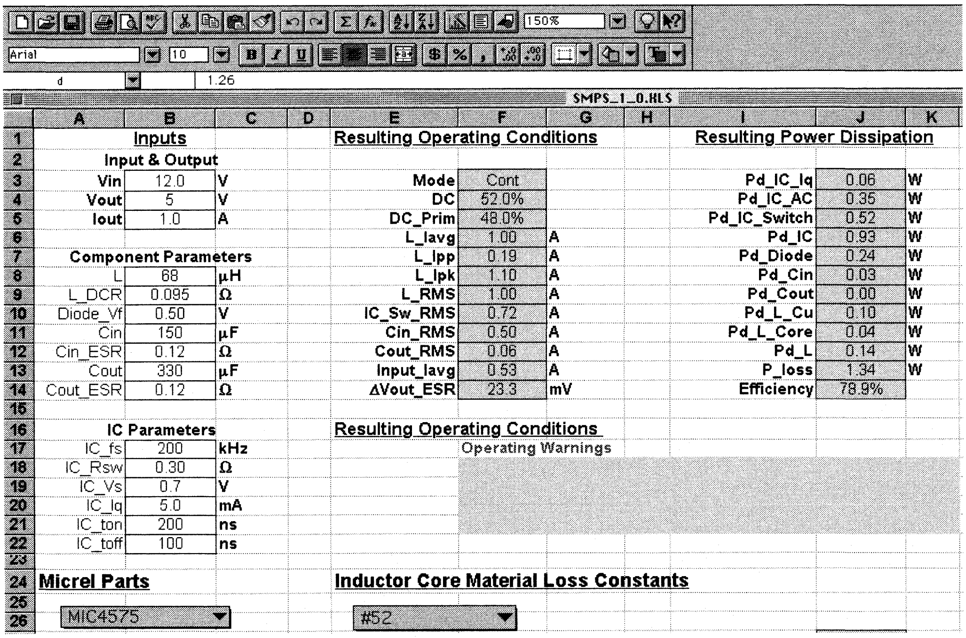
The third column itemizes the power losses. The largest contributors to efficiency losses are the IC switch (Pd_IC_Switch) and diode (Pd_Diode). For heat sink design, the IC's power dissipation result (Pd_IC) makes sizing of the heat sink quick and easy.

There are two pull-down menus, one for selecting a Micrel IC and the other for selecting an inductor core material. The Micrel parts list shows all the devices that are available for a design. The list includes both the 52kHz (LM257X) and the 200kHz (MIC457X) parts. The operating warning window uses the selected IC's peak switch current, input voltage range, and output voltage range to determine if an operating condition exceeds its limit.

The second pull-down menu has two core materials to choose from, either a powdered iron type 52 (#52) or a ferrite (Fe). The inductor core material has a minuscule effect on the overall efficiency and was included only for completeness.

Equations in the second and third columns are protected and cannot be inadvertently changed. You can defeat the protection feature, however, by selecting the Tools button from the top menu bar, clicking the protection menu item, selecting the unprotect sheet option, and entering "Micrel" for the password. Now any equation or formatting in the active spreadsheet can be changed. It is advisable to make a backup copy of the spreadsheet program prior to removing the protection.

The spreadsheets were created in Microsoft® Excel 5.0 for Windows™ and runs under Windows™3.1, Windows NT™, and Windows 95™. To run it under Microsoft® Excel 5.0 for the Macintosh®, copy the file using Apple® File Exchange (included with System 7.1 or earlier) or PC Exchange (included with System 7.5).



	A	B	C	D	E	F	G	H	I	J	K
1		**Inputs**			**Resulting Operating Conditions**				**Resulting Power Dissipation**		
2		**Input & Output**									
3	**Vin**	12.0	V		**Mode**	Cont			**Pd_IC_Iq**	0.06	W
4	**Vout**	5	V		**DC**	52.0%			**Pd_IC_AC**	0.35	W
5	**Iout**	1.0	A		**DC_Prim**	48.0%			**Pd_IC_Switch**	0.52	W
6					**L_Iavg**	1.00	A		**Pd_IC**	0.93	W
7		**Component Parameters**			**L_Ipp**	0.19	A		**Pd_Diode**	0.24	W
8	L	68	µH		**L_Ipk**	1.10	A		**Pd_Cin**	0.03	W
9	L_DCR	0.095	Ω		**L_RMS**	1.00	A		**Pd_Cout**	0.00	W
10	Diode_Vf	0.50	V		**IC_Sw_RMS**	0.72	A		**Pd_L_Cu**	0.10	W
11	Cin	150	µF		**Cin_RMS**	0.50	A		**Pd_L_Core**	0.04	W
12	Cin_ESR	0.12	Ω		**Cout_RMS**	0.06	A		**Pd_L**	0.14	W
13	Cout	330	µF		**Input_Iavg**	0.53	A		**P_loss**	1.34	W
14	Cout_ESR	0.12	Ω		**ΔVout_ESR**	23.3	mV		**Efficiency**	78.9%	
15											
16		**IC Parameters**			**Resulting Operating Conditions**						
17	IC_fs	200	kHz			Operating Warnings					
18	IC_Rsw	0.30	Ω								
19	IC_Vs	0.7	V								
20	IC_Iq	5.0	mA								
21	IC_ton	200	ns								
22	IC_toff	100	ns								
23											
24	**Micrel Parts**				**Inductor Core Material Loss Constants**						
25											
26	MIC4575 ▼				#52 ▼						

Figure C1. Buck Regulator Excel Spreadsheet

Definition of Terms

Input & Output

Vin: input voltage

Vout: output voltage

Iout: output current

Component Parameters

L: inductance

L_DCR: inductor DC resistance

Diode_Vf: catch diode forward voltage drop

Cin: input capacitor value

Cin_ESR: input capacitor equivalent series resistance

Cout: output capacitor value

Cout_ESR: output capacitor equivalent series resistance

IC Parameters

IC_fs: switching frequency

IC_Rsw: internal switch equivalent resistance

IC_Vs: internal switch equivalent voltage

IC_Iq: quiescent current

IC_ton: switch turn-on time

IC_toff: switch turn-off time

Inductor Core Loss Constants

Ci: core loss contant

d: core loss frequency exponent

p: core loss flux density exponent

U: permeability of core

Resulting Operating Conditions

Mode: indicates whether the regulator is in continuous or discontinuous mode

DC: duty cycle

DC_Prim: (1 – duty cycle)

L_Iavg: average inductor current

L_Ipp: peak-to-peak inductor ripple current

L_Ipk: peak inductor current

L_RMS: inductor RMS current

IC_Sw_RMS: IC Switch RMS current

Diode_RMS: diode RMS current

Cin_RMS: input capacitor RMS current

Cout_RMS: output capacitor RMS current

Input_Iavg: average input current

ΔVout_ESR: output ripple voltage caused by the ESR of the output capacitor

Resulting Power Dissipation

Pd_IC_Iq: power loss due to quiescent current

Pd_IC_AC: power loss due to switching times

Pd_IC_Switch: switch conduction loss

Pd_IC: total IC loss

Pd_Diode: diode power loss

Pd_Cin: input capacitor power loss

Pd_Cout: output capacitor power loss

Pd_L_Cu: power loss due to the DCR of the inductor

Pd_L_Core: power loss due to core material

Pd_L: total inductor loss

P_loss: sum of all the power losses

Efficiency: output power divided by input power

Appendix D

Package Thermal Characteristics

Designing the proper heat sink requires defining the thermal resistance of the package and heat sink. This is relatively straightforward for a TO-220 package in which the heat sink is attached to the part, but not for DIP and SO packages in which the external heat sink is the PC board. The physical size of the PC board can dramatically affect the thermal dissipation of the package.

The heat sink manufacturers have thoroughly characterized their heat sinks for TO-220 packages. For these packages, you can choose either a clip-on or screw-mount heat sink. The clip-on heat sinks offer the lowest labor cost to mount, but they can attain only about a 15° to 30°C/W case-to-ambient thermal coefficient. Alternatively, screw-mount types can reach a 5° to 10°C/W case-to-ambient thermal coefficient. The following Thermalloy part numbers are examples of each mounting option.

Heat-Sink Style	Thermalloy No.	θ_{CA}
Clip on	6045	30°C/W
Screw mount	6099B	12°C/W

Most data sheets give the worst-case thermal resistance coefficients of TO-220, DIP, and SO packages. That is, the packages are characterized in free air, and the thermal resistance coefficients do not take into account the heat-sinking effect of the PC board. Table D1 gives a more reasonable junction-to-ambient thermal resistance for the various package types. Note that one square inch of PC board copper area was used to make these measurements. Additional copper area will lower the thermal resistance further.

Package Style	θ_{JA}
TO-220	50°C/W
TO-263	50°C/W
8-Pin DIP	90°C/W
16-Pin SO	100°C/W

Table D1. Package Thermal Coefficients (1 in^2 Cu)

The numbers in Table C1 are a good starting point to determine the IC's junction temperature rise, but they can vary widely. Many factors affect these numbers, including PC board size and thickness as well as the number of layers, copper area, and copper thickness. Furthermore, a component like the diode or inductor can either heat up the IC or act as a heat sink.

For best thermal performance use as much copper as possible. Every pin should have a generous amount of PC board copper, especially the ground (GND) and input pin (VIN). One exception to this rule is the switch pin (SW), which should be designed just wide enough to handle the switch current, minimizing the radiated EMI. Copper provides the best transfer of heat to the surrounding area. Even double-sided or multilayered boards help in removing the heat from the IC.

Appendix E

Suggested PC Board Layouts

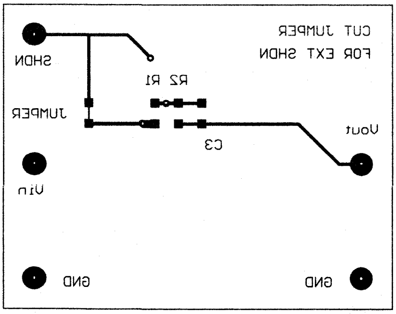
To achieve proper performance, printed circuit (PC) board layouts are provided for the various IC package types. Poor PC board layout can have dramatic effects on the operation of a power supply. Reduced efficiency, increased EMI, and spurious oscillations are just some of the results of a poor layout. Here are a few recommendations that should be followed:

1) The inductor, filter capacitors, diode, and IC should be physically close to one another and on the same side of the PC board. Keep the trace length between these components below 0.25 inches.
2) All the high-current traces must be on the same PC board layer. Do not use vias to connect the power traces.
3) Use a single-point ground, not a ground plane.
4) For the adjustable parts, connect the center tap of the voltage divider network (R1, R2 in Figure 15a) as close to the feedback pin as possible. Stray capacitance and pickup on this node can cause erratic switching behavior.
5) Connect the ground return of the divider network as close to the ground pin as possible. Bizarre switching action can occur if the ground is returned through a high-current path.

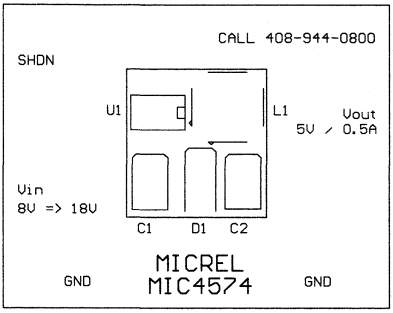
In 95 percent of the cases where a power supply is malfunctioning, the cause is more than likely that the inductor is physically too small rather than poor PC board layout.

The inductor is a power component and is selected based upon its value and current rating. An inductor's current-handling capability is directly related to its physical size. A physically large inductor can handle higher peak currents than a small one of the same value. Just like a 10Ω, 10W resistor can handle more current than a 10Ω, 1/4W resistor. A 100µH, 3A inductor should be at least the size of your thumb. If it is not, its value can rapidly decrease or even go to zero (saturate the core) when operated beyond its rated limit. When this occurs, the DC-DC converter can exhibit erratic behavior.

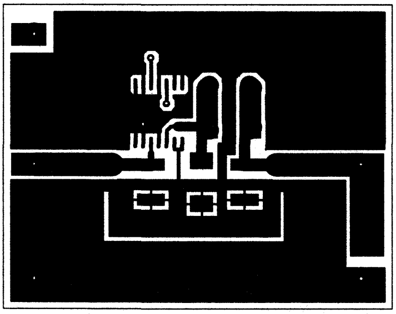
Figure 1.
MIC4574-5.0BWM
14-lead SOIC
(Layout for Figure 18A)



Component Side

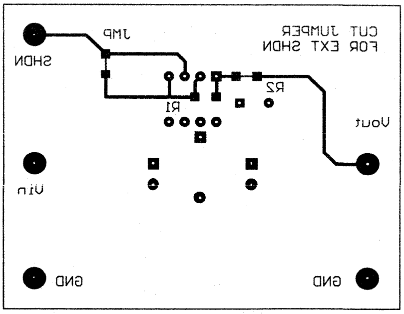


Silk Screen

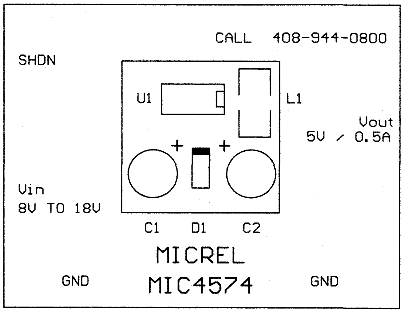


Solder Side

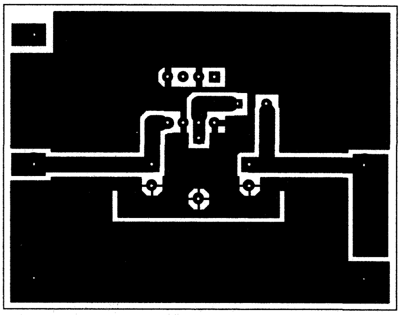
Figure 2.
MIC4574-5.0BN
8-pin DIP
(Layout for Figure 4A)



Component Side

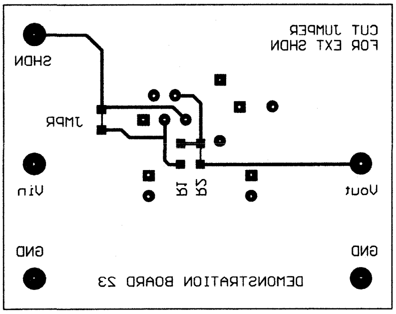


Silk Screen

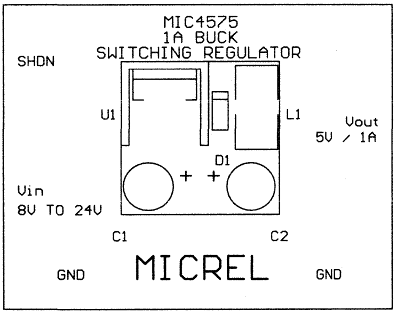


Solder Side

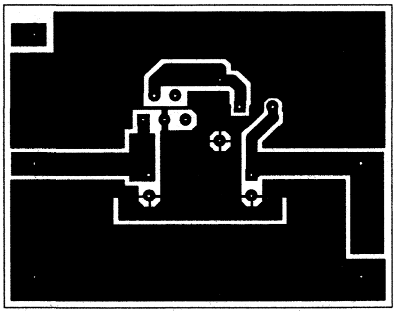
Figure 3.
MIC4575-5.0BT/MIC4576-5.0BT
5-lead TO-220
(Layout for Figure 9A)



Component Side

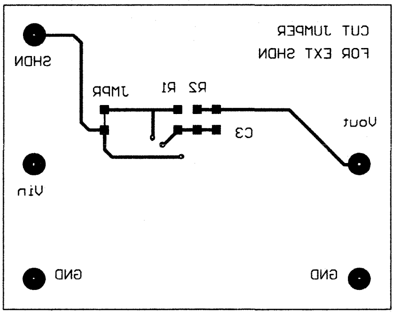


Silk Screen

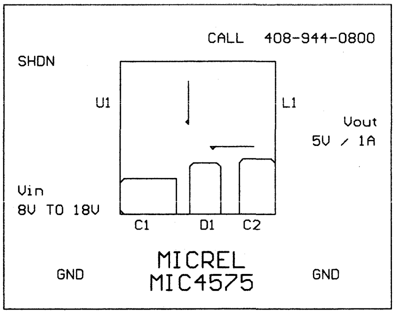


Solder Side

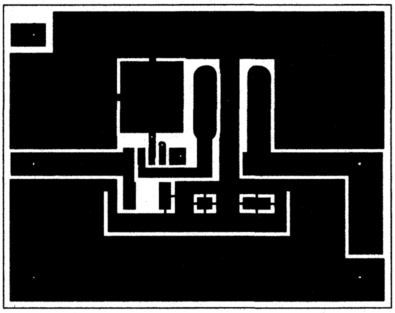
Figure 4.
MIC4575-5.0BU/MIC4576-5.0BU
5-lead TO-263
(Layout for Figure 22A)



Component Side



Silk Screen



Solder Side

Appendix F

Manufacturer's Distributors List

Micrel provides this list of distributors to make it easier for you to acquire components. An attempt has been made to ensure that the information is accurate; however, this list is subject to change without notice.

Coiltronics Distributors

Armor Electronics (North-East Area)
1055 East Street
Tweksbury, MA 01876
Tel: (508) 640-1499
Fax: (506) 640-1570

Component Distributors Inc. (Alabama Area)
908 B Merchant Walk
Huntsville, AL 35801
Tel: (800) 888-0331
Tel: (205) 536-8850
Fax: (800) 808-2067
Fax: (205) 533-3919

(Georgia Area)
5950 Crooked Creek Road
Suite 150
Norcross, GA 30092
Tel: (800) 874-7029
Tel: (770) 441-3320
Fax: (770) 449-1712

(Texas Area)
710 East Park Blvd.
Suite 108
Plano, TX 75074
Tel: (800) 848-4234
Tel: (214) 578-2644
Fax: (214) 578-2208

(Colorado Area)
3979 East Arapahoe Road
Suite 102, Bidg. 1
Littleton, CO 80122
Tel: (800) 551-7357
Tel: (303) 770-6214
Fax: (303) 770-6057

(Florida Area)
2510 Kirby Ave. N.E.
Suite 109
Palm Bay, FL 32905
Tel: (800) 558-2351
Tel: (407) 724-9910
Fax: (800) 292-6579
Fax: (407) 729-6579

(Virginia Area)
1111 Knoll Mist Lane
Gaitherburg, MD 20879
Tel: (800) 293-2080
Tel: (301) 527-0113
Fax: (301) 527-0115

(California Area)
1028 Opal Street
San Diego, CA 92109
Tel: (800) 372-1580
Tel: (619) 272-1580
Fax: (619) 272-2362

Bravo Electronics (West Coast Area)
610 Palomar Ave.
Sunnyvale, CA 94086-2913
Tel: (800) 392-6318
Tel: (408) 733-9090
Fax: (408) 733-8555

Alcom Electronics (Belgium)
Singel 3
2550 Kontich
Tel: + 32 (34) 58.30.33
Fax: + 32 (34) 58.31.26

E V Johanssen Electronik (Denmark)
Titangade 15
2200 Copenhagen N
Tel: + 45 35 86 90 22
Fax: + 45 35 86 90 00

Hy-Line Power Components (Germany)
Inseklammerstr. 10
82008 Unterhaching
Tel: + 49 (89) 6 14 90 10
Fax: + 49 (89) 6 14 09 60

Metl (United Kingdom)
Countax House
Haseley Trading Estate
Stadhampton Road
Great Haseley
Oxford OX44 7PF
Tel: + 44 (1844) 278781
Fax: + 44 (1844) 278746

Westech Electronics (Pte.), Ltd. (Singapore)
12 Lorong Bakar BATU #05-07
Kolam Ayer Industrial Park
Singapore 1334
Tel: + 65 743 63 55
Fax: + 65 746 13 96

TCE Sel (Italy)
Via Trento 59
20021 Ospiate Di Bollate
Milano
Tel: + 39 (2) 3501203
Tel: + 39 (2) 3501205
Fax: + 39 (2) 3501924

Tritech Ltd. (Israel)
4, Ha'Yetzira St.
P.O. Box 2436
43100 Ra'Anana
Tel: +972 (9) 917277
Fax: +972 (9) 982616

Application Hint 11

500kHz 30W Off-Line Switching Power Supply

by George Hall

Circuit Description

Line Input

Alternating line voltage is rectified by D1 and filtered by C1 to provide a dc bus voltage for the main transformer T1 and MIC38HC43 controller IC1.

Thermistor RT1 limits the in-rush current to C1, protecting D1, and reducing the chance of an unacceptable momentary voltage drop on the ac input line during turn-on.

PWM Operation

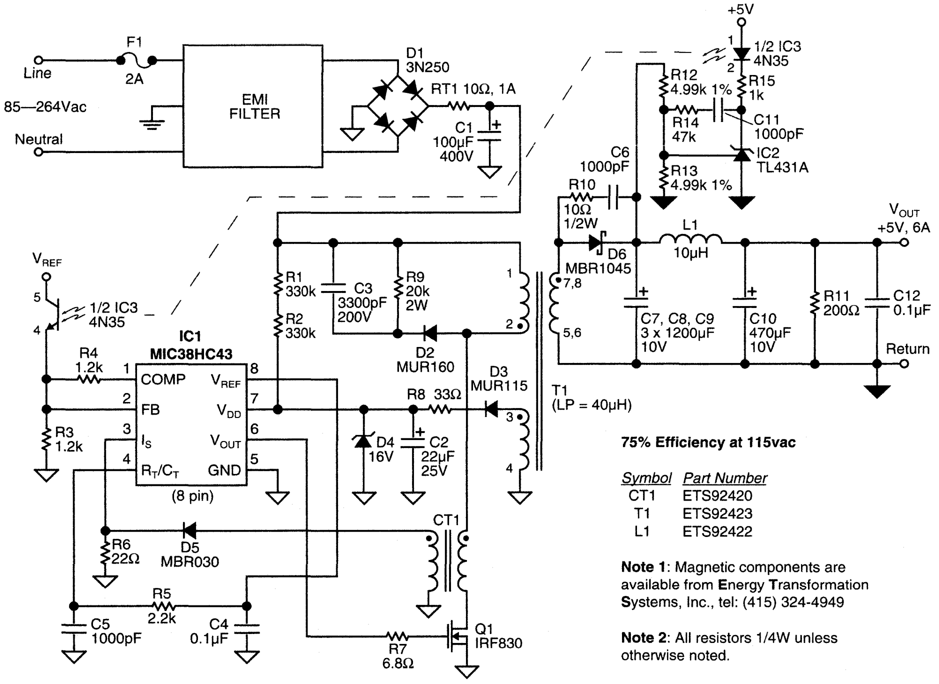
Resistors R1 and R2 charge C2 until its voltage exceeds the UVLO (undervoltage lockout) of IC1 which causes output drive to be applied to Q1. This lowers Q1's drain voltage and charges T1's primary until the current sense voltage at pin 3 of IC1 exceeds 1V. IC1 then removes drive from Q1.

With Q1 off, T1 discharges into both the output (T1 pins 7,8 and 5,6) and tertiary (T1 pins 3 and 4) circuits and causes Q1's drain voltage to rise above C1's voltage. IC1 voltage is now supplied from the low impedance winding of T1 (pins 3 and 4).

The output voltage rises until IC2's reference voltage reaches approximately 2.5V where it begins drawing current through the diode of optocoupler IC3. IC3's detector transistor conducts, raising the voltage on pin 2 of IC1. When the output voltage equals 5V, pin 2 of IC1 will be 2.5V and current mode PWM operation will regulate the output precisely over varying line and load changes. R14 and C11 provide stability compensation for IC2.

Q1 Protection

Components D2, C3, and R9 protect Q1 from avalanche breakdown and possible destruction by clamping the leakage inductance spike to a safe level. C6 and R10 suppress parasitic oscillations from D6.



75% Efficiency at 115vac

Symbol	*Part Number*
CT1	ETS92420
T1	ETS92423
L1	ETS92422

Note 1: Magnetic components are available from **E**nergy **T**ransformation **S**ystems, Inc., tel: (415) 324-4949

Note 2: All resistors 1/4W unless otherwise noted.

500kHz 30W Off-Line Switching Power Supply

EMI Filter

Electromagnetic interference feedback into the ac input line from the operation of switched mode power supplies requires EMI filtering to comply with national and international standards. Use these standards to determine the acceptable levels of line conducted emissions for the specific application and location.

EMI filtering may be simplified by procuring several packaged EMI filters from a reputable source. Select the appropriate filter by EMI measurement. Include the selected filter in the final design or substitute the individual components (from the filter's parts list). Printed circuit board layout and component placement will affect conducted emissions. If you are not qualified in the this area consult an expert.

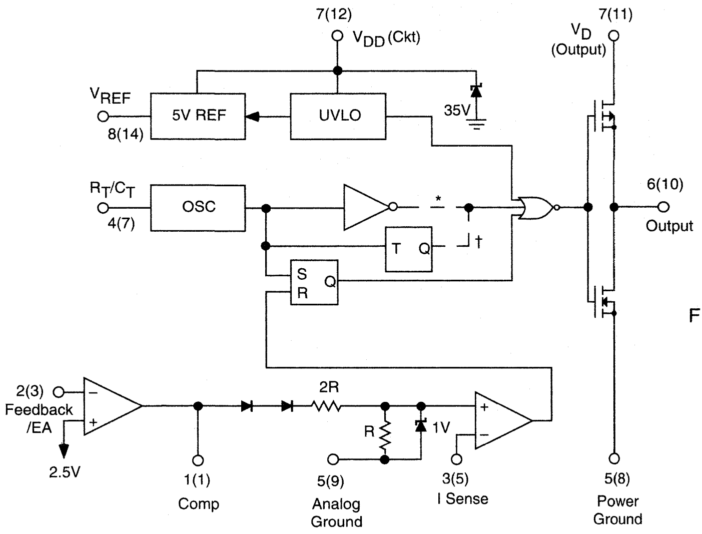
Circuit Layout

Care should be taken when designing high frequency converters to avoid capacitive and inductive coupling of the switching waveform into high impedance circuitry such as the error amplifier, oscillator, and current sense amplifier. Avoid long printed circuit traces and component lead lengths. Locate oscillator and compensation circuitry near the IC. Use high frequency decoupling capacitors on V_{REF} and, if necessary, on V_{DD}. Return high di/dt currents directly to the source and use large area ground planes where possible.

Safety

Always proceed with caution when working on off-line supplies as lethal voltages are present. Never work on the supply without someone nearby who is aware of the hazards and can take steps to avoid serious injury to yourself in the event of an accident.

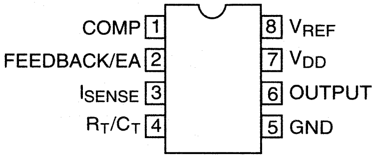
Block Diagram



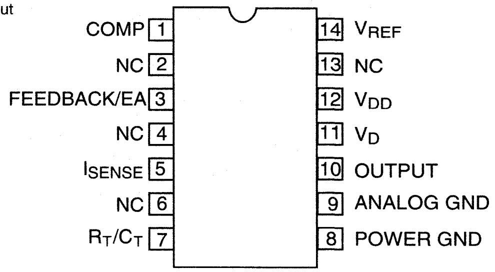
* MICx8C42, 43 / MICx8HC42, 43

† MICx8C44, 45 / MICx8HC44, 45

Pin Configurations



8-pin DIP



14-pin DIP
(suffix -1, full featured parts)

Also available in 8-pin and 14-pin SOIC packages.

Application Hint 12

Designing with the MIC3832/3833

by Kevin Lynn

Introduction

The MIC3832 and MIC3833 are PWM (pulse-width modulation) switching regulator controllers optimized for current-fed topology power supplies. Most PWM power supplies are designed using a constant voltage input, varying the on-time of a power switch to control the output voltage. A capacitor across the input provides a low impedance **voltage-fed** source. If a PWM power supply has an inductor in series with the input, with no parallel capacitor on the load side, abrupt changes in average input current are impeded. This is the **current-fed** topology.

Current-fed systems are inherently safer and more efficient than voltage-fed topologies, since a controlled current source feeds a push-pull or bridge driven transformer. Stresses on power transistors are greatly reduced, since the voltage-fed problems of transformer saturation, dead-time conduction and power switch cross-conduction are eliminated. Frequency compensation is also simplified.

In the case of push-pull or H-bridge power output stages, a current-fed system may simplify circuit design by removing the necessity for a dead-time or other means of preventing cross-conduction or shoot-through current in the power switches.

Buck Derived Current-Fed

Placing a PWM buck (step-down) regulator at the input of a push-pull power stage allows the power switches to be optimized for highest efficiency. The PWM buck switch is rated for the highest input voltage, while the push-pull switches are rated for double the regulated PWM output, which is the primary voltage of the transformer. This topology is ideal for designing off-line power supplies, with wide input voltage ranges, above 100W. No capacitor is used at the output of the buck regulator stage, allowing the input inductor to swing to ground during push-pull cross-conduction periods.

Micrel has combined a 500kHz current-mode PWM controller and FET driver with a synchronized pair of slightly overlapping push-pull FET drivers, a 5V reference and overcurrent shutdown to provide a single device which can control 30 to 300W dc-to-dc or line powered supplies. The MIC3832/3 family provides an integrated solution for current-fed topologies, eliminating the need for separate flip-flops and external drivers for bipolar or power FET switching transistors. The MIC3832 has a 15.9V startup, operating down to a minimum of 9.8V, while the MIC3833 starts above 8.3V and operates down to 7.8V.

The circuit's three totem-pole output stages are each capable of providing up to one ampere peak current to drive the external power switch transistors of high power push-pull or bridge switching voltage regulators. One stage provides a controlled current-mode PWM output, up to 500kHz, configured to drive a buck-type regulator. A pair of matched bipolar drivers provides slightly overlapping outputs with 50% duty cycle and no dead-time. These two stages, Q and $\overline{Q}$, are designed to drive the power switch transistors of a push-pull or bridge transformer with one or more secondary windings.

The MIC3832 and MIC3833 divide the PWM frequency by 2, permitting synchronized zero dead-time drive of 250kHz transformer magnetics. Current-fed regulators do not have output inductor filters, simplifying parallel connection for distributed power applications. They also do not have a filter capacitor at the output of the PWM section, further reducing parts count.

Other key features include programmable front-edge blanking, programmable soft-start, and overcurrent shutdown. Voltage-mode control may be provided if desired. An internal 21V zener diode clamps the device input voltage.

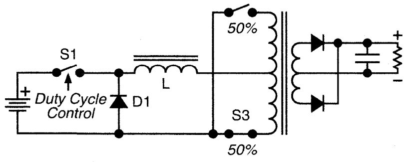


Figure 1. Current-Fed Push-Pull Topology

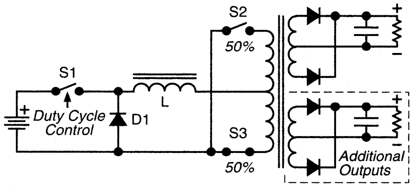


Figure 2. Current-Fed Multiple Output Topology

Practical Considerations

EMI

The magnitude of EMI (electro-magnetic interference) generated by an SMPS (switch-mode power supply) is generally proportional to the peak current spikes. Cross-conduction in a voltage-fed design causes fast high-current spikes at double the clock frequency, radiating EMI and heating the switches. For the same output power, a push-pull or dual forward topology should produce less EMI than a flyback or forward converter.

Layout

High frequency circuits are very sensitive to layout and grounding. Switch-mode power supplies have fast rise-time voltage and current spikes which are easily coupled to nearby circuit traces or elements. Measurements are complicated by pickup of radiated energy by test leads and probes, especially ground wires.

Do not use solderless breadboards as a prototyping tool. The distributed capacitance of the parallel multiple connection strip rows makes them impractical for designs operating above audio frequencies.

Likewise, the switching elements (FETs or power transistors) should be kept very close to the drive outputs. Stray capacitance/inductances can cause undue noise on the switching waveforms. Oscillator and loop compensation components should be kept as close to the pins as possible.

Grounding

A single-point ground system should be used. Pin 1 (GND) of the IC should have a very short connection to all wave-shaping and voltage reference components, such as R_T, C_T, and the error amplifier. All high current-carrying traces should be made as short, straight and wide as possible, routed directly to the negative terminal of the input filter capacitor, located near pin 1.

All components should be mounted as close to the circuit board, laying flat if possible. A ground plane on the component side should reduce coupling, while a ground plane on the solder side may use guard rings to isolate components.

Frequency

Raising the switching frequency directly reduces the required inductance, which is a function of the number of inductor turns squared. Quadrupling the frequency reduces the turns count by two, which may not have a great effect on inductor size, but does simplify winding.

Turn-On and Turn-Off Switching Losses

Fast turn-on losses include charging the gate capacitance of the power MOSFETs, and are limited by series and leakage inductance. Fast turn-off losses include discharging the gate capacitance and spikes caused by series and leakage inductance field collapse. A small resistor in series with each MOSFET gate may reduce both losses by slowing the turn-on and turn-off times. Layered and bifilar winding techniques can reduce leakage inductance in inductors, while balanced push-pull windings equalize current flow.

Rectifiers

At faster switching speeds the reverse recovery time of rectifier diodes is a major limitation. Schottky Barrier diodes (1N5817-22, 11DQ03-09, UF4001-7, etc.) have good recovery times and low forward drop, but are generally limited to below 60V. Fast Recovery Rectifiers (1N 4933-37, FR301-307, etc.) have higher breakdown voltage, with higher forward drop. High speed signal diodes (1N914, 1N4148) may be used for medium voltage, low current applications, such as spike clamping, if their peak current ratings are not exceeded. Do not use standard rectifier diodes (e.g.,1N4001-7) above 200Hz.

Bypassing

Proper bypassing is essential. In addition to the chosen bootstrap capacitor, a 0.1μF ceramic disc capacitor should be used both between V_{DD} and ground, and V_{REF} and ground. The additional bypassing of V_{REF} ensures less noisy operation of the error amplifier, and gives better regulation as a result.

Component Choice

Switching regulator systems as a rule are very sensitive to component quality. The oscillator components, C_T and R_T, require careful attention. R.F. capacitors such as silver mica, glass, polystyrene, or COG ceramics are recommended. High K ceramic capacitors should not be used.

Careful attention to the SOA (safe operating area) curves of the chosen power FETs will pay off in increased reliability. It is important to make sure that inductive spikes do not create conditions that exceed the SOA of these devices. If a P-channel FET is used as the main switching element, be sure to accommodate the higher dissipation [due to higher $R_{DS(on)}$] by using adequate heat sinks.

Inductors and transformers should be carefully designed following either magnetics texts or manufacturer instructions. Careful attention should be paid to core size so that saturation of the core doesn't occur. Losses should be minimized by using appropriate wire type and size (litz wire or copper foil minimizes skin effects at high frequency) and winding the cores tightly.

If low cost powdered iron cores are used for, calculate the thermal characteristics. They can get quite hot and can cause temperature coefficient related parameter shifts in other parts of the circuit.

Gapping of the cores during prototyping should always be done using spacers, since hand grinding can be inaccurate and lead to shifts in material properties. The push-pull transformer is ungapped.

Output capacitor quality is crucial to the stability and output ripple of the completed supply. The critical parameter to be minimized is the ESR (equivalent series resistance).

This can be minimized by paralleling several types of capacitors (all become series resonant at different frequencies), using a special low ESR aluminum electrolytic (available from Nichicon, United Chemicon, and Panasonic), using a very large aluminum electrolytic (ESR varies inversely with size), or using a new polymeric capacitor available from Sanyo; the Oscon series (max. value = 220μF).

Features

Max. Duty Cycle/Soft Start

This pin provides a double function, both as an input for the max duty cycle limiting voltage and for the soft start capacitor, so it must be handled with care. The NPN pull down for soft start or overcurrent shutdown is located on this pin; if turned on it will pull down the output and effectively turn off the part. It will draw several mA in this state. For this reason (and to prevent the max. duty cycle from being 0%!), this pin cannot be allowed to float. It must be tied to a non-zero voltage through a pull-up resistor (5V and up gives 100% max. duty cycle). The main use of this function is to provide a fail-safe to keep a current mode power supply below 50% duty cycle (to prevent the well-known subharmonic oscillation problem from occurring). It is important that a well designed compensation network also be in place, as this limiting point will vary quite a bit over temperature.

Soft start prevents damage to the system by starting the MIC3832/3 slowly after an overcurrent condition has happened. It is **only** operative if the shutdown pin is used; if current mode control is used, both the shutdown and current mode ramp pins should be connected to the external sense resistor. The time constant is set by R_{TH} C, where R_{TH} is the Thevenin equivalent resistance seen by this pin, and C is the capacitor placed from this pin to ground. To prevent interaction effects with the front edge blanking feature, this capacitor should be larger by 1.5× than the front edge blanking capacitor.

Current Limit/Shutdown

If current mode control is used, cycle-by-cycle current limiting is a fringe benefit. It should be noted that the MIC3832/3 family has a higher threshold than most: 3.5V (1.5V + error amplifier output). If voltage mode control is used, then the shutdown pin is tied to an external sense resistor to provide a one time current shutdown (not cycle-by-cycle). The threshold is 1.0V for current limiting, and 1.25V for a full shutdown. If current mode control is used and no soft start function is desired, then the overcurrent shutdown pin **must** be tied to ground. Letting it float will lead to noise induced shutdowns.

Voltage Reference

The 5V bandgap, trimmed to 2% accuracy, is available as a source to power the soft start/max. duty cycle pin, front edge blanking pin, and positive error amplifier input. Even though the short circuit current is 60mA typical, it is important to keep from pulling down the reference. Larger resistance values (10k and up) should be used for pull-ups and voltage division from this pin.

Error Amplifier

The error amplifier of the MIC3832/3 is extremely sensitive; all components used should be tied as closely as possible to the error amplifier pins. As it has a very high open loop gain, ~95dB, the compensation network gain should be kept lower. It also has an open loop pole at around 110Hz that should be taken into account in designing any stability network. Bandwidth is around 5MHz. If common mode range is exceeded, the polarity of the inputs may reverse.

A good rule of thumb for stability networks is to keep the unity gain crossover point from 1⁄5 to 1⁄6 of the switching frequency, and to keep the phase margin above 45°.

Design Example

100kHz Current-Fed Converter

A 5V, 20A max dc-to-dc converter was designed using the current fed push-pull configuration for increased safety and reduced size/transformer core area.

The input is an unregulated 14V to 32V dc supply, such as is commonly found in aircraft environments. This supply is fed to an MIC2951 low drop out regulator which acts as a housekeeping supply; supplying a steady, well regulated 12V to the MIC3833.

The main PWM switching element is an IRF540, with gate drive provided by transformer T1. The two 50% duty cycle outputs each drive an IRF540 directly, which in turn drive their respective sides of T2's center tapped primary. The 1N6291A is a transzorb used to protect the FETs from spikes generated by the transformer.

Current mode control was chosen to simplify the stability analysis; with the 0.2Ω 5W resistor being used as the sensing element. As the maximum duty cycle at light loads is greater than 50%, the well characterized problem of subharmonic oscillations found when using current mode control was evident. A ramp was introduced at the sensing element to correct this; the 10kΩ and 470kΩ divider from the oscillator (ramp source) to the sensing element provide the proper slope. As a large resistor value was chosen on the oscillator pin, no buffering was necessary.

Four inexpensive capacitors were paralleled to lower ESR to an acceptable level of 80mΩ without adding too much size or cost.

Error amp compensation was performed using a simple lead-lag network. As current mode control was used, there was no need to compensate the LC filter pole.

A voltage of 2.5V derived from the reference was fed to the Max. duty cycle pin to provide a failsafe. This prevents the PWM out from attaining greater than 75% duty cycle.

Soft start was also implemented to allow slow turn-on in the event of a short circuit.

All magnetics were chosen to minimize losses at 100kHz. T2 and L1 were wound using Seimen's new N87 material, and T1 using Magnetics Inc's P-type material. T2 and L1 were made using Seimen's new EFD core and bobbin assemblies, which were designed to reduce the height/form factor of the finished supply. T1 is a simple toroid.

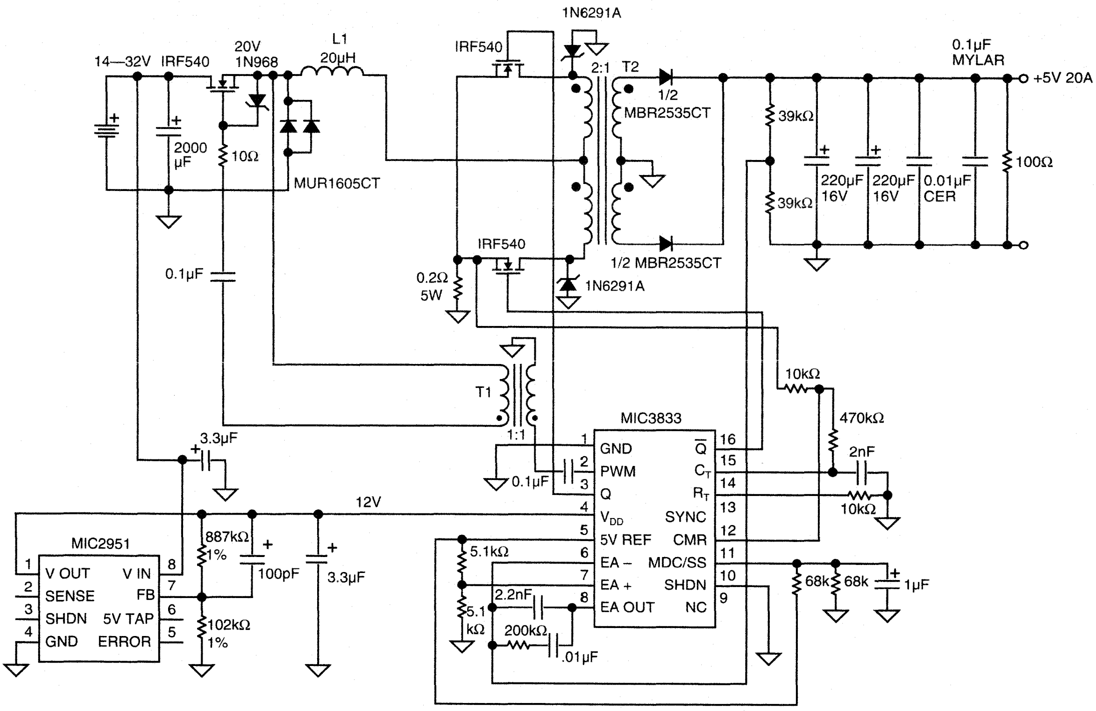


Figure 3. 100W Current-Fed Push-Pull DC-to-DC Converter

Magnetics Design

T1: Magnetics Inc # 41303 – TC, P material, Primary = 26 turns 30 gauge wire, Secondary = 26 turns 30 gauge wire
T2: Seimen's EFD40, N87 material. Primary = 20 turns 20 gauge wire, Secondary = 10 turns trifilar wound 20 gauge wire. Both are center tapped
L1: Seimen's EFD30, N87 material. 13 turns 20 gauge wire. Gap for 20µH

Application Hint 14

Current-Fed Push-Pull SMPS using the MIC3833

Introduction

Most DC-DC and off-line converters have utilized the voltage fed transformer approach to convert input voltages to useful output voltages. Transformer saturation (flux imbalance) in push-pull and bridge type topologies was of concern as it could lead to catastrophic switch failure. Additional circuitry was required to correct transformer flux imbalances by enforcing constant volt-seconds across the transformer primary.

Current mode controllers with their inherent cycle-by-cycle current limiting monitor and compensate for flux imbalances but are still a voltage-fed topology. They remain candidates for switch failure due to the low impedance voltage source. The use of current-fed topologies reduces or eliminates switch failures.

Theory

Figure 1 shows the basic elements of a typical current-fed push-pull topology. Variable duty cycle pulses are applied to S1 forcing a current to be fed to T1. The duty cycle is controlled to provide an average voltage to T1's center tap. S2 and S3 are operating 180° out of phase with each other and at one-half S1's frequency. The average voltage from the primary of T1 is transformed to the secondary voltage required by the output section.

Line and load changes to the output(s) are monitored and used to adjust S1's duty cycle to maintain a steady output voltage. Output inductors are not needed (a cost savings) since filtering is accomplished by the input inductor.

Advantages

Reliability

Current fed topologies deliver current from a high impedance source, inductor L1, to the main transformer T1. The high source impedance makes destruction of the switches unlikely even with a transformer flux imbalance.

Transformer Utilization

The main transformer is 100% utilized (no dead-time) which gives multiple output designs excellent cross regulation from master to slaves. This simplifies or eliminates the need for post regulation schemes.

Reduced Parts Count

Since the buck inductor is in the primary, the output rectifiers do not support inductor current during the dead-time normally associated with voltage-fed designs. This means the inverter switches (S2 and S3) do not experience the high initial current spike required to suppress the output inductor current flowing in the rectifiers. Also since there is no output inductor current flowing in the output rectifiers there is no leakage energy stored in the output winding. This means that snubbers are not required (a cost savings) to protect the output rectifiers.

The Micrel MIC383x Family

Micrel Semiconductor has introduced a family of current-fed controllers which can operate in current or voltage mode. This single IC controller can operate up to 500kHz and supplies 1 amp of drive current on both the $\overline{Q}$ and PWM drive outputs. Cycle-by-cycle current limiting, front edge blanking, soft start, shutdown, maximum duty cycle programming, and external synchronization have been incorporated. All error amplifier connections and a 5V ±2% reference are made available.

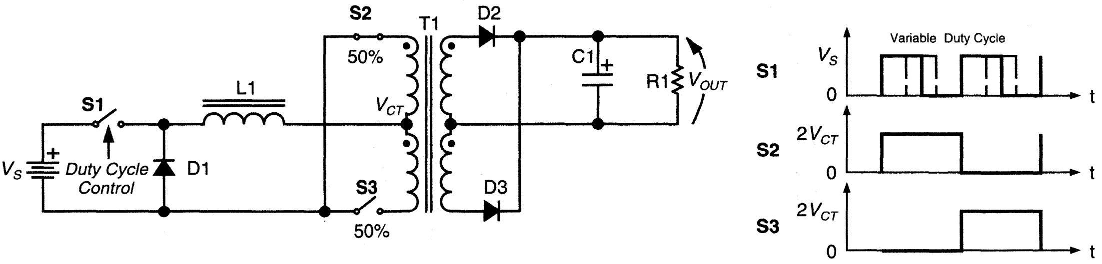


Figure 1. Basic Elements of a Current-Fed Push-Pull Topology

MICREL

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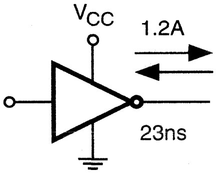
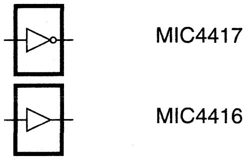
Section 5: MOSFET Drivers

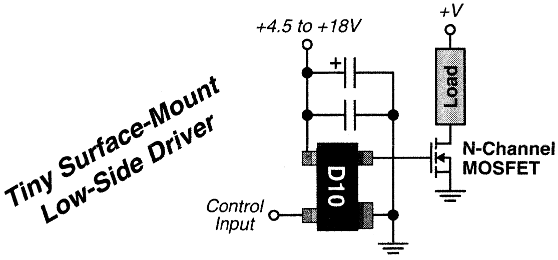
MOSFET Driver Selection Guide



MIC4416/4417

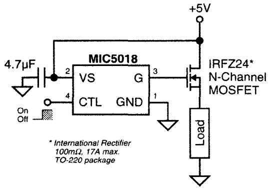
- IttyBitty™ Low-Side Driver
- 1.2A Peak Output
- 3.5Ω Output Impedance
- 23ns into 1000pF
- 4.5V to 18V Supply
- Tiny SOT-143 Surface Mount Package




Tiny Surface-Mount Low-Side Driver

Low-Side Power Switch

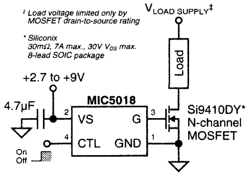
MIC5018



* International Rectifier
100mΩ, 17A max.
TO-220 package

High-Side Configuration

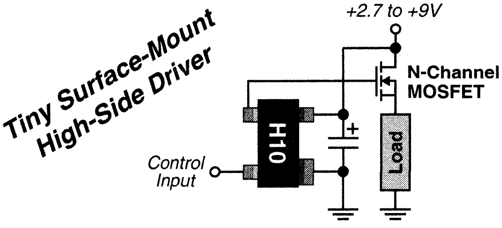
- IttyBitty™ High- and Low-Side Driver
- 2.7V to 9V Supply
- Internal Charge Pump
- 2.1ms turn-on into 3000pF
- ≤ 1μA Standby (Off) Current
- Tiny SOT-143 Surface Mount Package



‡ Load voltage limited only by MOSFET drain-to-source rating

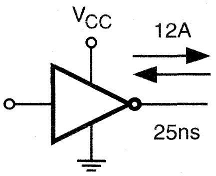
* Siliconix
30mΩ, 7A max., 30V V_{DS} max.
8-lead SOIC package

Low-Side Configuration


Tiny Surface-Mount High-Side Driver

High-Side Power Switch

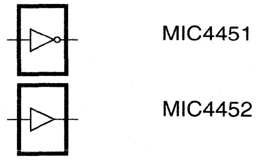
MOSFET Driver Selection Guide

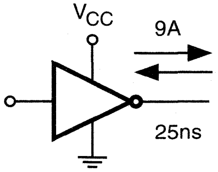


1500pF to 62,000pF

MIC4451/4452

- 12A Peak Output
- 0.8Ω Output Impedance
- 25ns into 15,000pF
- 4.5V to 18V Supply
- Latch-Up Protected
- Withstands 5V Negative Swing
- Surface Mount and High Power Package Available

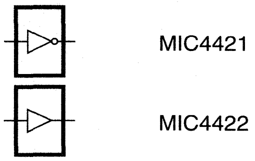


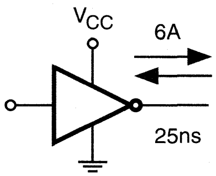


1500pF to 47,000pF

MIC4421/4422

- 9A Peak Output
- 1.0Ω Output Impedance
- 25ns into 10,000pF
- 4.5V to 18V Supply
- Latch-Up Protected
- Withstands 5V Negative Swing
- Surface Mount and High Power Package Available

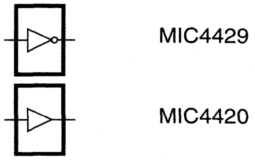


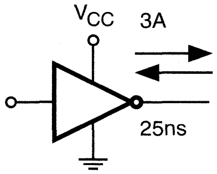


Drives a hex 6—hex 7 size
MOSFET: 1500pF to 16,000pF

MIC4420/4429

- 6A Peak Output
- 2.5Ω Output Impedance
- 4.5V to 18V Supply
- 25ns into 2500pF
- Latch-Up Protected
- Withstands 5V Negative Swing
- Surface Mount and High Power Package Available

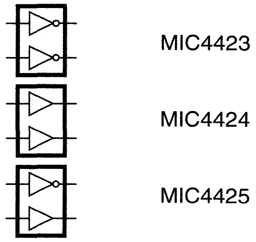


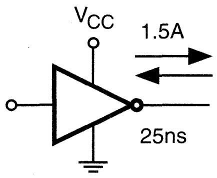


Drives a hex 4—hex 5 size
MOSFET: 6000pF to 12,000pF

MIC4423/4424/4425

- 3A Peak Output
- 3.5Ω Output Impedance
- 25ns into 1800pF
- 4.5V to 18V Supply
- Latch-Up Protected
- Withstands 5V Negative Swing
- Surface Mount Available

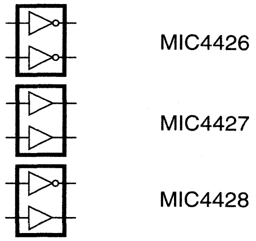




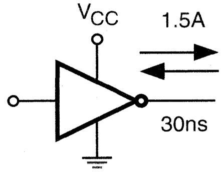
Drives a hex 0—hex 3 size
MOSFET: 400pF to 3000pF

MIC4426/4427/4428

- 1.5A Peak Output
- 7Ω Output Impedance
- 25ns into 1000pF
- 4.5V to 18V Supply
- Latch-Up Protected
- Withstands 5V Negative Swing
- Surface Mount Available



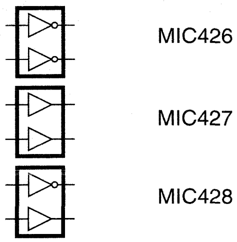
MOSFET Driver Selection Guide

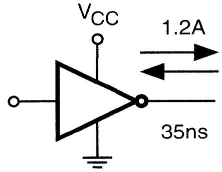


Drives a hex 0—hex 3 size
MOSFET: 400pF to 3000pF

MIC426/427/428

- 1.5A Peak Output
- 6Ω Output Impedance
- 30ns into 1000pF
- 4.5V to 18V Supply
- Surface Mount Available

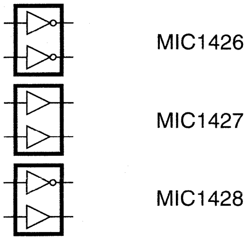


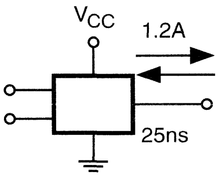


Drives a hex 0—hex 3 size
MOSFET: 400pF to 3000pF

MIC1426/1427/1428

- 1.2A Peak Output
- 8Ω Output Impedance
- 35ns into 1000pF
- 4.75V to 16V Supply
- Low-Cost Driver
- Surface Mount Available

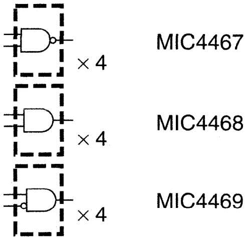


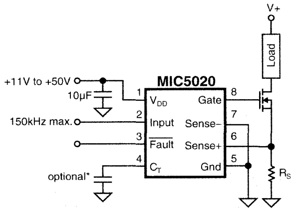


Drives a hex 0—hex 3 size
MOSFET: 400pF to 3000pF

MIC4467/4468/4469

- 1.2A Peak Output
- 10Ω Output Impedance
- 25ns into 470pF
- 4.5V to 18V Supply
- Latch-Up Protected
- Withstands 5V Negative Swing
- Surface Mount Available
- Three Logic Choices

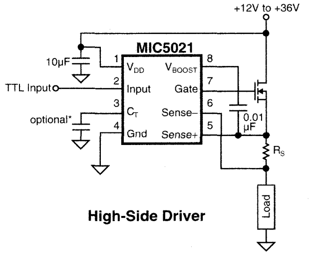




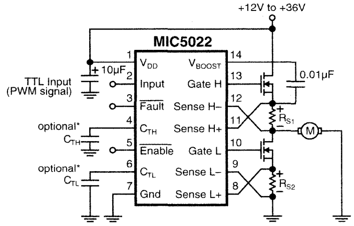
Low-Side Driver

MIC5020/5021

- 11V to 50V Supply (MIC5020)
- 12V to 36V Supply (MIC5021)
- 175ns into 2000pF (MIC5020)
- 550ns into 2000pF (MIC5021)
- Programmable Overcurrent Shutdown
- Internal Charge Pump
- Surface Mount Available



High-Side Driver

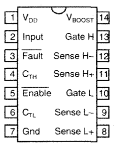


Half-Bridge Driver

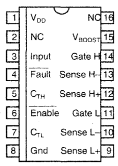
MIC5022

- 12V to 36V Supply
- 500ns into 1000pF
- Programmable Overcurrent Shutdown
- Internal Charge Pump
- Surface Mount Available

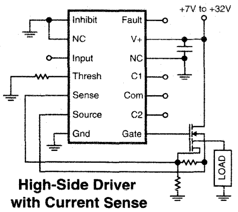
14-pin DIP



16-pin SOIC



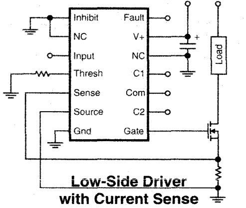
MOSFET Driver Selection Guide



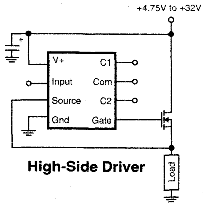
High-Side Driver with Current Sense

MIC5010

- 60µs into 1nF
- 7V to 32V Supply
- Full-featured Driver
- Optional Speed-up Capacitors
- Internal Charge Pump
- Dynamic Sensing Threshold
- Surface Mount Available



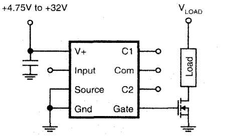
Low-Side Driver with Current Sense



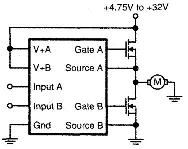
High-Side Driver

MIC5011

- 60µs into 1nF
- 4.5V to 32V Supply
- Minimum Parts Count
- Optional Speed-up Capacitors
- Internal Charge Pump
- Surface Mount Available



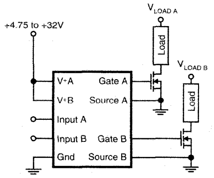
Low-Side Driver



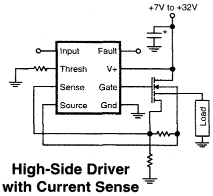
Push-Pull Driver

MIC5012

- 60µs into 1nF
- 4.75V to 32V Supply
- Dual Driver
- Provides High and Low Side drive for H-bridge
- Internal Charge Pump
- Surface Mount Available



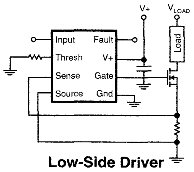
Dual Low-Side Driver



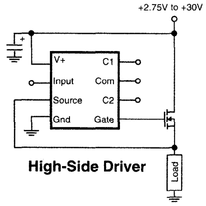
High-Side Driver with Current Sense

MIC5013

- 60µs into 1nF
- 7V to 32V Supply
- Overcurrent Sensing
- Internal Charge Pump
- Dynamic Sensing Threshold
- Surface Mount Available



Low-Side Driver with Current Sense

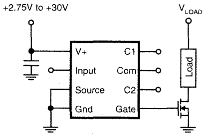


High-Side Driver

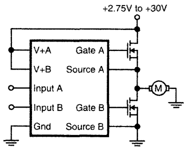
MIC5014/5015

- 2.75V to 30V Supply
- Minimum Parts Count
- "Load Dump" Protected
- Reverse Battery Protected to –20V
- Internal Charge Pump
- Surface Mount Available

* Low Cost



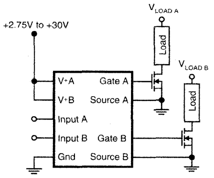
Low-Side Driver



Push-Pull Driver

MIC5016/5017

- 2.75V to 30V Supply
- Minimum Parts Count
- "Load Dump" Protected
- Reverse Battery Protected to –20V
- Internal Charge Pump
- Surface Mount Available
- Low Cost



Dual Low-Side Driver

MIC426/427/428

Dual 1.5A-Peak Low-Side MOSFET Driver

Bipolar/CMOS/DMOS Process

General Description

The MIC426/427/428 are dual high speed drivers. A TTL/CMOS input voltage level is translated into an output voltage level swing equalling the supply. The DMOS output will be within 25mV of ground or positive supply. Bipolar designs are capable of swinging only within 1 volt of the supply.

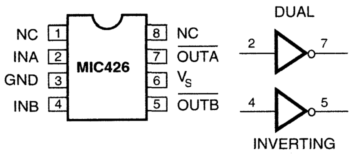
The low impedance high current driver outputs will swing a 1000pF load 18V in 30ns. The unique current and voltage drive qualities make the MIC426/427/428 ideal power MOSFET drivers, line drivers and DC to DC converter building blocks.

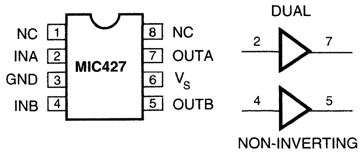
Input logic signals may equal the power supply voltage. Input current is a low 1µA making direct interface to CMOS/BIPOLAR switch mode power supply control integrated circuits possible as well as open collector analog comparators.

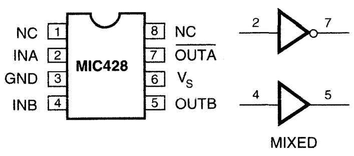
Features

- High Speed Switching (C_L = 1000pF) 30ns
- High Peak Output Current 1.5A
- High Output Voltage Swing .... V_S – 25mV
  GND + 25mV
- Low Input Current (Logic “0” or “1”) 1µA
- Low Equivalent Input Capacitance (typ) 6pF
- TTL/CMOS Input Compatible
- Available in Inverting & Non-Inverting Configurations
- Wide Operating Supply Voltage .... 4.5V to 18V
- Low Power Consumption
  (Inputs Low) 0.4mA
  (Inputs High) 8mA
- Single Supply Operation
- Low Output Impedance (typ) 6Ω
- Pin Out Equivalent to DS0026 & MMH0026

Pin Configuration

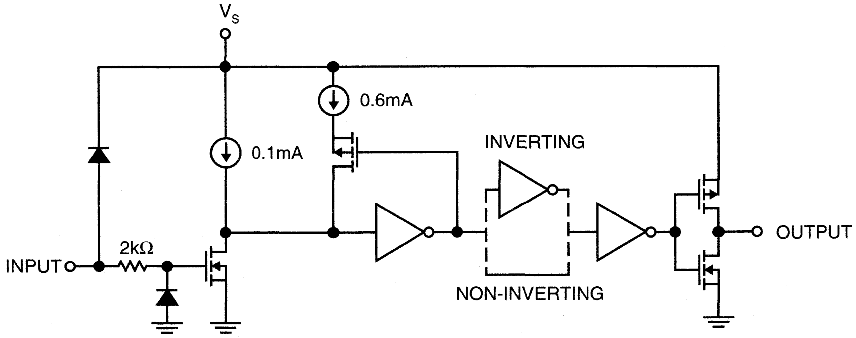






Functional Diagram

Integrated Component Count:
4 Resistors
4 Capacitors
52 Transistors



Functional Diagram for One Driver (Two Drivers per Package—Ground Unused Inputs)

Quiescent power supply current is 8mA maximum. The MIC426 requires 1/5 the current of the pin compatible bipolar DS0026 device. This is important in DC to DC converter applications with power efficiency constraints and high frequency switch mode power supply applications. Quiescent current is typically 6mA when driving a 1000pF load 18V at 100kHz.

The inverting MIC426 driver is pin compatible with the bipolar DS0026 and MMH0026 devices. The MIC427 is non-inverting; the MIC428 contains an inverting and non-inverting driver.

Ordering Information

Part Number	Temperature Range	Package	Configuration
MIC426CM MIC426BM	0°C to +70°C –40°C to +85°C	8-pin SOIC	Dual Inverting
MIC426CN MIC426BN	0°C to +70°C –40°C to +85°C	8-pin plastic DIP	Dual Inverting
MIC426AJ 5962-8850301PA[1]	–55°C to +125°C –55°C to +125°C	8-pin CerDIP	Dual Inverting
MIC427CM MIC427BM	0°C to +70°C –40°C to +85°C	8-pin SOIC	Dual Non-Inverting
MIC427CN MIC427BN	0°C to +70°C –40°C to +85°C	8-pin plastic DIP	Dual Non-Inverting
MIC427AJ 5962-8850302PA[2]	–55°C to +125°C –55°C to +125°C	8-pin CerDIP	Dual Non-Inverting
MIC428CM MIC428BM	0°C to +70°C –40°C to +85°C	8-pin SOIC	Non-Inv. & Inverting
MIC428CN MIC428BN	0°C to +70°C –40°C to +85°C	8-pin plastic DIP	Non-Inv. & Inverting
MIC428AJ 5962-8850303PA[3]	–55°C to +125°C –55°C to +125°C	8-pin CerDIP	Non-Inv. & Inverting

[1] Standard Military Drawing number for MIC426AJBQ

[2] Standard Military Drawing number for MIC427AJBQ

[3] Standard Military Drawing number for MIC428AJBQ

Absolute Maximum Ratings (Notes 1, 2, and 3)

If Military/Aerospace specified devices are required, contact Micrel for availability and specifications.

Supply Voltage	20V
Input Voltage Any Terminal	V_S + 0.3V to GND – 0.3V
Maximum Chip Temperature	150°C
Storage Temperature	–65°C to 150°C
Lead Temperature (10 sec)	300°C
Package Thermal Resistance	
CerDIP $R_{\theta J\text{-}A}$ (°C/W)	100
CerDIP $R_{\theta J\text{-}C}$ (°C/W)	50
PDIP $R_{\theta J\text{-}A}$ (°C/W)	130
PDIP $R_{\theta J\text{-}C}$ (°C/W)	42
SOIC $R_{\theta J\text{-}A}$ (°C/W)	120
SOIC $R_{\theta J\text{-}C}$ (°C/W)	75
Operating Temperature Range	
C Version	0°C to +70°C
B Version	–40°C to +85°C
A Version	–55°C to +125°C

MIC426/427/428 Electrical Characteristics: T_A = 25°C with 4.5V ≤ V_S ≤ 18V unless otherwise specified.

No.	Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT							
1	V_{IH}	Logic 1 Input Voltage		2.4	1.4		V
2	V_{IL}	Logic 0 Input Voltage			1.1	0.8	V
3	I_{IN}	Input Current	0 ≤ V_{IN} ≤ V_S	–1		1	µA
OUTPUT							
4	V_{OH}	High Output Voltage		V_S–0.025			V
5	V_{OL}	Low Output Voltage				0.025	V
6	R_O	Output Resistance	V_{IN} = 0.8V I_{OUT} = 10mA, V_S = 18V		6	15	Ω
7	R_O	Output Resistance	V_{IN} = 2.4V I_{OUT} = 10mA, V_S = 18V		6	10	Ω
8	I_{PK}	Peak Output Current			1.5		A
SWITCHING TIME							
9	T_R	Rise Time	Test Figures 1, 2		18	30	ns
10	T_F	Fall Time	Test Figures 1, 2		15	20	ns
11	T_{D1}	Delay TIme	Test Figures 1, 2		17	40	ns
12	T_{D2}	Delay Time	Test Figures 1, 2		23	75	ns
POWER SUPPLY							
13	I_S	Power Supply Current	V_{IN} = 3.0V (Both Inputs)		1.4	8.0	mA
14	I_S	Power Supply Current	V_{IN} = 0.0V (Both Inputs)		0.18	0.4	mA

MIC426/427/428 Electrical Characteristics:

Over operating temperature range with 4.5V ≤ V_S ≤ 18V unless otherwise specified.

No.	Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT							
1	V_{IH}	Logic 1 Input Voltage		2.4	1.5		V
2	V_{IL}	Logic 0 Input Voltage			1.0	0.8	V
3	I_{IN}	Input Current	0 ≤ V_{IN} ≤ V_S	–10		10	µA

MIC426/427/428 Electrical Characteristics:

Over operating temperature range with $4.5V \le V_S \le 18V$ unless otherwise specified (Continued).

No.	Symbol	Parameter	Conditions	Min	Typ	Max	Units
OUTPUT							
4	V_{OH}	High Output Voltage		V_S–0.025			V
5	V_{OL}	Low Output Voltage				0.025	V
6	R_O	Output Resistance	V_{IN} = 0.8V I_{OUT} = 10mA, V_S = 18V		8	20	Ω
7	R_O	Output Resistance	V_{IN} = 2.4V I_{OUT} = 10mA, V_S = 18V		10	15	Ω
SWITCHING TIME							
8	T_R	Rise Time	Test Figures 1, 2		20	60	ns
9	T_F	Fall Time	Test Figures 1, 2		29	40	ns
10	T_{D1}	Delay TIme	Test Figures 1, 2		19	60	ns
11	T_{D2}	Delay Time	Test Figures 1, 2		27	120	ns
POWER SUPPLY							
12	I_S	Power Supply Current	V_{IN} = 3.0V (Both Inputs)		1.5	12.0	mA
13	I_S	Power Supply Current	V_{IN} = 0.0V (Both Inputs)		0.19	0.6	mA

Note 1: Functional operation above the absolute maximum stress ratings is not implied.

Note 2: Static Sensitive device (above 2kV). Unused devices must be stored in conductive material to protect devices from static discharge and static fields.

Note 3: Switching times guaranteed by design.

Switching Time Test Circuits

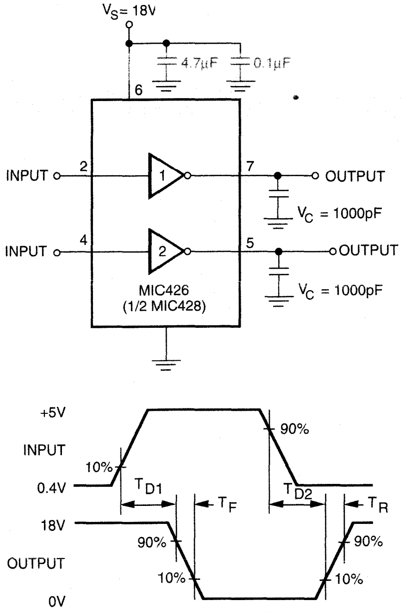


Figure 1. Inverting Driver Switching Time

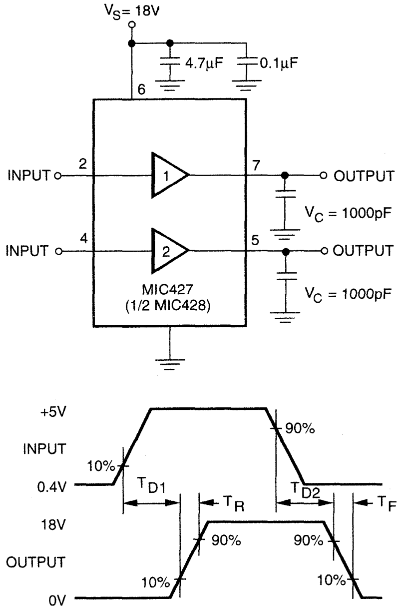
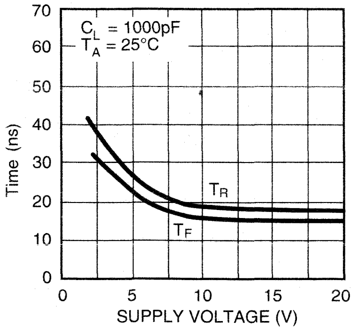


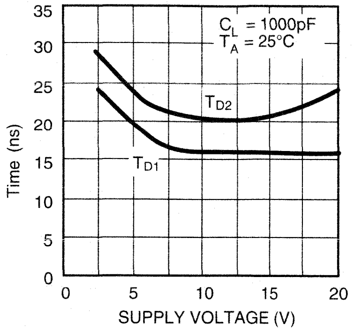
Figure 2. Non-Inverting Driver Switching Time

Typical Characteristic Curves

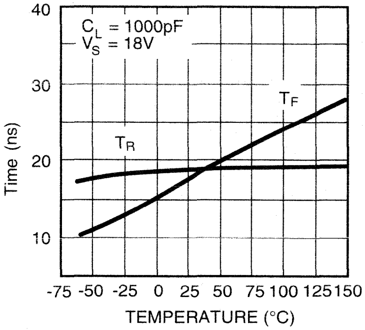
Rise and Fall Time vs. Supply Voltage



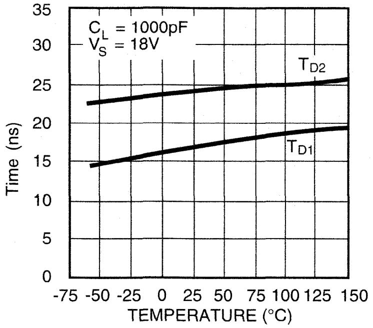
Delay Time vs. Supply Voltage



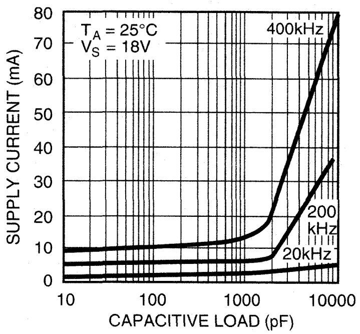
Rise and Fall Time vs. Temperature



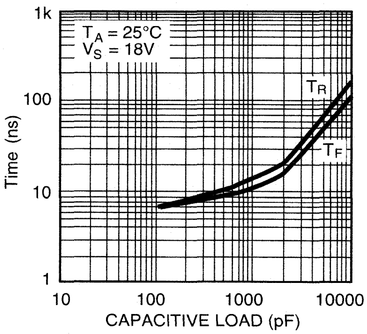
Delay Time vs. Temperature



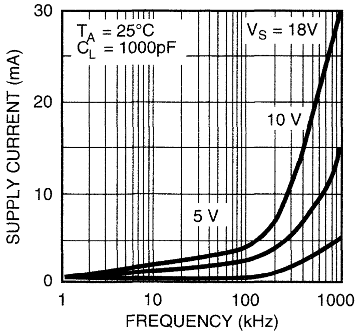
Supply Current vs. Capacitive Load



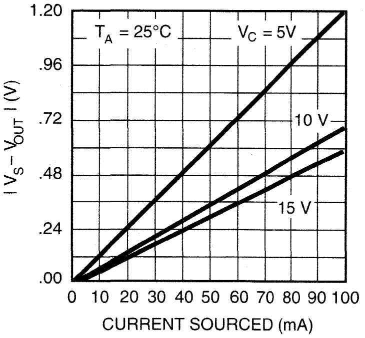
Rise and Fall Time vs. Capacitive Load



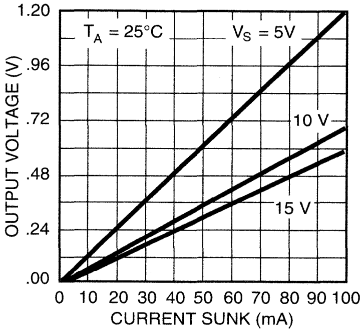
Supply Current vs. Frequency



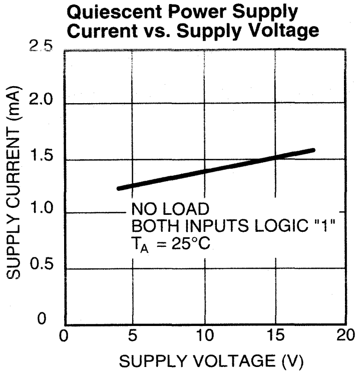
High Output vs. Current

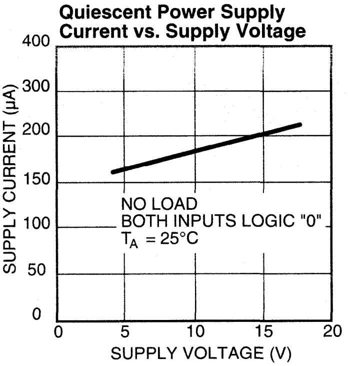


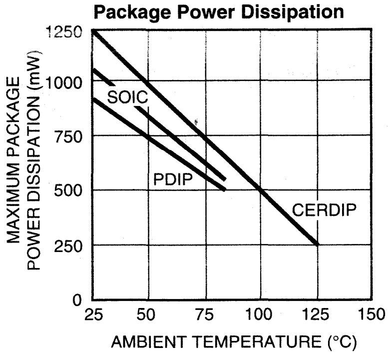
Low Output vs. Current



Typical Characteristic Curves (Continued)


Quiescent Power Supply Current vs. Supply Voltage


Quiescent Power Supply Current vs. Supply Voltage


Package Power Dissipation

Supply Bypassing

Charging and discharging large capacitive loads quickly requires large currents. For example, changing a 1000pF load 18 volts in 25ns requires a 0.8A current from the device power supply.

To guarantee low supply impedance over a wide frequency range, a parallel capacitor combination is recommended for supply bypassing. Low inductance ceramic disk capacitors with short lead lengths (< 0.5 inch) should be used. A 4.7µF solid tantalum capacitor in parallel with one or two 0.1µF ceramic disk capacitors normally provides adequate bypassing.

Grounding

The MIC426 and MIC428 contain inverting drivers. Ground potential drops developed in common ground impedances from input to output will appear as negative feedback and degrade switching speed characteristics.

Individual ground returns for the input and output circuits or a ground plane should be used.

Input Stage

The input voltage level changes the no load or quiescent supply current. The N channel MOSFET input stage transistor drives a 2.5mA current source load. With a logic "1" input, the maximum quiescent supply current is 8mA. Logic "0" input level signals reduce quiescent current to 400µA maximum. Minimum power dissipation occurs for logic "0" inputs for the MIC426/427/428; unused driver inputs **must be grounded or tied to the positive supply.**

The drivers are designed with 100mV of hysteresis. This provides clean transitions and minimizes output stage current spiking when changing states. Input voltage thresholds are approximately 1.5V making the device TTL compatible over the 4.5V to 18V operating supply range. Input current is less than 1µA over this range.

The MIC426/427/428 may be directly driven by the TL494, SG1526/1527, SG1524, SE5560 and similar switch mode power supply integrated circuits.

Power Dissipation

The supply current vs. frequency and supply current vs. capacitive load characteristic curves will aid in performing power dissipation calculations.

The MIC426/427/428 CMOS drivers have greatly reduced quiescent DC power consumption. Maximum quiescent current is 8mA compared to the DS0026 40mA specification. For a 15V supply, power dissipation is typically 40mW.

Two other power dissipation components are:

- Output stage AC and DC load power.
- Transition state power.

Output stage power is:

$$\begin{aligned} P_O &= P_{DC} + P_{AC} \\ &= V_O (I_{DC}) + f\, C_L\, V_S^2 \end{aligned}$$

Where: V_O = DC output voltage
I_{DC} = DC output load current
f = Switching frequency
V_S = Supply voltage

In power MOSFET drive applications, the P_{DC} term is negligible. MOSFET power transistors are high impedance, capacitive input devices. In applications where resistive loads or relays are driven, the P_{DC} component will normally dominate.

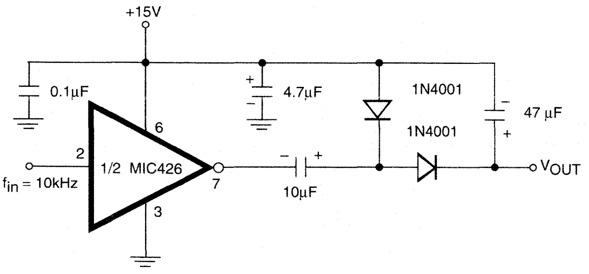
The magnitude of P_{AC} is readily estimated for several cases:

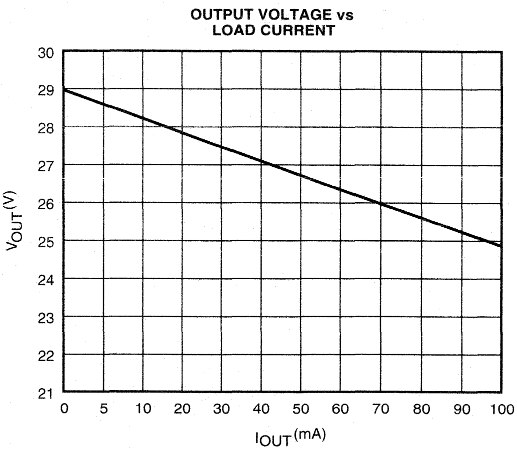
A. 1. f = 200kHz
2. C_L = 1000pF
3. V_S = 18V
4. P_{AC} = 65mW

B. 1. f = 200kHz
2. C_L = 1000pF
3. V_S = 15V
4. P_{AC} = 45mW

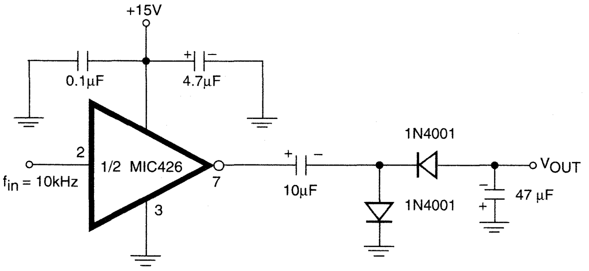
During output level state changes, a current surge will flow through the series connected N and P channel output MOSFETs as one device is turning "ON" while the other is turning "OFF." The current spike flows only during output transitions. The input levels should not be maintained between the logic "0" and logic "1" levels. **Unused driver inputs must be tied to ground and not be allowed to float.** Average power dissipation will be reduced by minimizing input rise times. As shown in the characteristic curves, average supply current is frequency dependent.

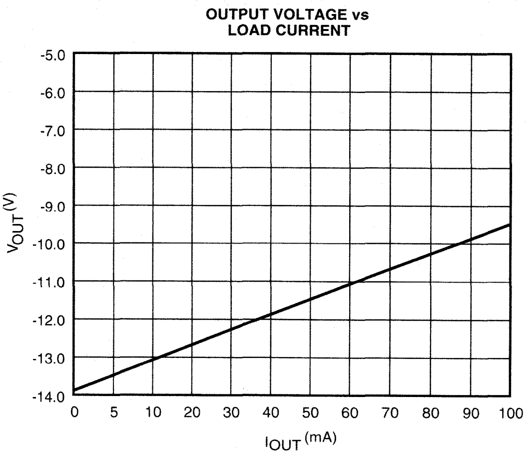
Voltage Doubler





Voltage Inverter





MIC1426/1427/1428

Dual 1.2A-Peak Low-Side MOSFET Driver

Bipolar/CMOS/DMOS Process

General Description

The MIC1426/27/28 are a family of 1.2A dual high-speed drivers. They are ideal for high-volume OEM manufacturers, with latch-up protection, and ESD protection. BiCMOS/DMOS fabrication is used for low power consumption and high efficiency.

These devices are fabricated using an epitaxial layer to effectively short out the intrinsic parasitic transistor responsible for CMOS latch-up. They incorporate a number of other design and process refinements to increase their long-term reliability.

The MIC1426 is compatible with the bipolar DS0026, but only draws 1/5 of the quiescent current. The MIC1426/27/28 are also compatible with the MIC426/27/28, but with 1.2A peak output current rather than the 1.5A of the MIC426/27/28 devices.

The high-input impedance MIC1426/27/28 drivers are CMOS/TTL input-compatible, do not require the speed-up needed by the bipolar devices, and can be directly driven by most PWM ICs.

This family of devices is available in inverting and non-inverting versions. Specifications have been optimized to achieve low-cost and high-performance devices, well-suited for the high-volume manufacturer.

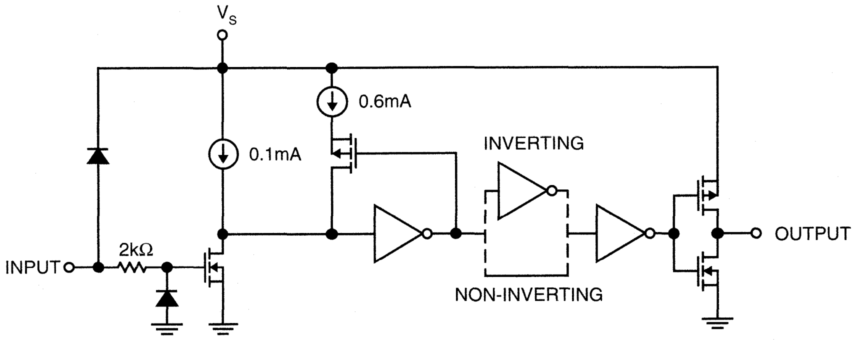
Features

- Low Cost
- Latch-Up Protected: Will Withstand 500mA Reverse Output Current
- ESD Protected .... ±2kV
- High Peak Output Current .... 1.2A Peak
- High Capacitive Load Drive Capability .... 1000pF in 35ns
- Wide Operating Range .... 4.75V to 16V
- Low Delay Time .... 75ns Max
- Low Equivalent Input Capacitance (typ) 6pF
- Logic Input Threshold Independent of Supply Voltage
- Output Voltage Swing to Within 25mV of Ground or V_S
- Low Output Impedance 8Ω

Applications

- Power MOSFET Drivers
- Switched Mode Power Supplies
- Pulse Transformer Drive
- Small Motor Controls
- Print Head Drive

Functional Diagram

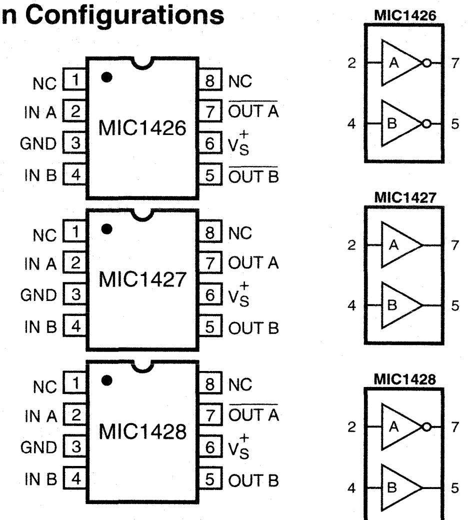


Functional Diagram for One Driver (Two Drivers per Package—Ground Unused Inputs)

Ordering Information

Part No.	Temperature Range	Package	Configuration
MIC1426CM	0°C to 70°C	8-Pin SO	Dual-Inverting
MIC1426CN	0°C to 70°C	8-Pin Plastic DIP	Dual-Inverting
MIC1427CM	0°C to 70°C	8-Pin SO	Dual Non-Inverting
MIC1427CN	0°C to 70°C	8-Pin Plastic DIP	Dual Non-Inverting
MIC1428CM	0°C to 70°C	8-Pin SO	Inverting and Non-Inverting
MIC1428CN	0°C to 70°C	8-Pin Plastic DIP	Inverting and Non-Inverting

Pin Configurations



NC = NO CONNECTION

Test Circuits

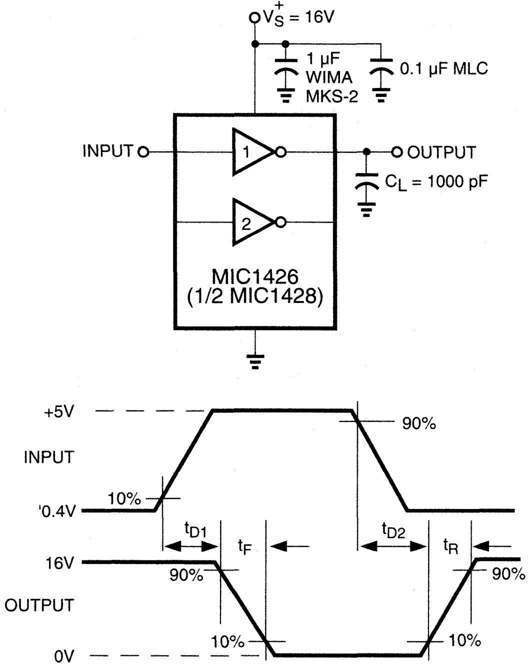


Figure 1. Inverting Driver Switching Time

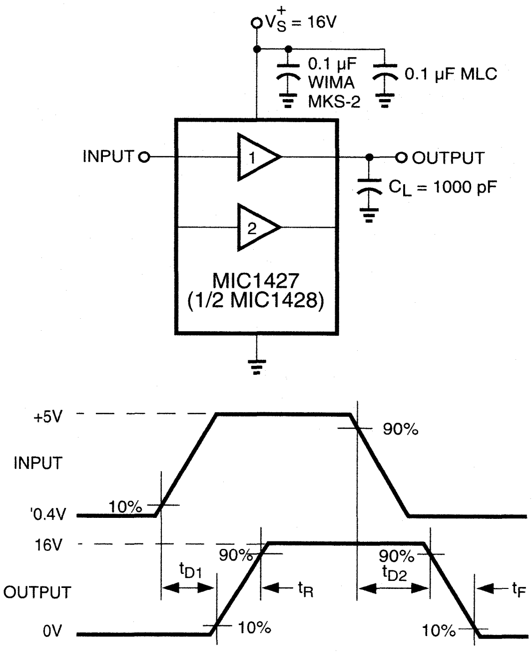


Figure 2. Non-Inverting Driver Switching Time

Absolute Maximum Ratings (Notes 1, 2 and 3)

Power Dissipation	
Plastic DIP	750mW
SOIC	830mW
Derating Factor	
Plastic DIP	7.7mW/°C
SOIC	8.3mW/°C
Supply Voltage	18V
Input Voltage, Any Terminal	V_S + 0.3V to GND – 0.3V
Operating Temperature: C Version	0°C to +70°C
Maximum Chip Temperature	+150°C
Storage Temperature	–55°C to +150°C
Lead Temperature (10 sec)	+300°C

NOTES: 1. Functional operation above the absolute maximum stress ratings is not implied.

2. Static-sensitive device (above 2kV). Unused devices must be stored in conductive material to protect devices from static discharge.

3. Switching times guaranteed by design.

Electrical Characteristics: $T_A = 25°C$ with $4.75V < V_S < 16V$ unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1, Input Voltage		3	1.4		V
V_{IL}	Logic 0, Input Voltage			1.1	0.8	V
I_{IN}	Input Current	$0V < V_{IN} < V_S$	–1		1	µA
OUTPUT						
V_{OH}	High Output Voltage	Test Figures 1 and 2	V_S–0.025			V
V_{OL}	Low Output Voltage	Test Figures 1 and 2			0.025	V
R_O	Output Resistance	$V_{IN} = 0.8V$ I_{OUT} = 10 mA, V_S = 16V		6	18	Ω
R_O	Output Resistance	$V_{IN} = 3V$ I_{OUT} = 10 mA, V_S = 16V		6	12	Ω
I_{PK}	Peak Output Current			1.5		A
I	Latch-Up Current	Withstand Reverse Current	>500			mA
SWITCHING TIME						
t_R	Rise Time	Test Figures 1 and 2		18	35	ns
t_F	Fall Time	Test Figures 1 and 2		15	25	ns
t_{D1}	Delay Time	Test Figures 1 and 2		17	75	ns
t_{D2}	Delay Time	Test Figures 1 and 2		23	75	ns
POWER SUPPLY						
I_S	Power Supply Current	V_{IN} = 3V (Both Inputs) V_{IN} = 0V (Both Inputs)		1.4 0.18	9 0.5	mA mA

Electrical Characteristics:

Over operating temperature range with 4.75V < V_S < 16V unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1, Input Voltage		3	1.5		V
V_{IL}	Logic 0, Input Voltage			1.0	0.8	V
I_{IN}	Input Current	0V < V_{IN} < V_S	–10		10	µA
OUTPUT						
V_{OH}	High Output Voltage	Test Figures 1 and 2	V_S–0.025			V
V_{OL}	Low Output Voltage	Test Figures 1 and 2			0.025	V
R_O	Output Resistance	V_{IN} = 0.8V I_{OUT} = 10 mA, V_S = 16V		8	23	Ω
R_O	Output Resistance	V_{IN} = 3V I_{OUT} = 10 mA, V_S = 16V		10	18	Ω
I	Latch-Up Current	Withstand Reverse Current	>500	1.5		mA
SWITCHING TIME						
t_R	Rise Time	Test Figures 1 and 2		20	60	ns
t_F	Fall Time	Test Figures 1 and 2		29	40	ns
t_{D1}	Delay Time	Test Figures 1 and 2		19	125	ns
t_{D2}	Delay Time	Test Figures 1 and 2		27	125	ns
POWER SUPPLY						
I_S	Power Supply Current	V_{IN} = 3V (Both Inputs)		1.5	13	mA
I_S	Power Supply Current	V_{IN} = 0V (Both Inputs)		0.19	0.7	mA

Supply Bypassing

Large currents are required to charge and discharge large capacitive loads quickly. For example, changing a 1000pF load 16V in 25ns, requires a 0.8A current from the device power supply.

To guarantee low supply impedance over a wide frequency range, a parallel capacitor combination is recommended for supply bypassing. Low-inductance ceramic MLC capacitors with short lead lengths (<0.5in.) should be used. A 1.0µF film capacitor in parallel with one or two 0.1µF ceramic MLC capacitors normally provides adequate bypassing.

Grounding

The MIC1426 and MIC1428 contain inverting drivers. Ground potential drops developed in common ground impedances from input to output will appear as negative feedback and degrade switching speed characteristics.

Individual ground returns for the input and output circuits or a ground plane should be used.

Input Stage

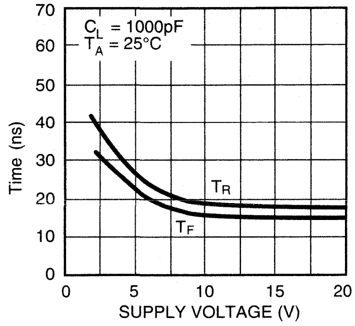
The input voltage level changes the no-load or quiescent supply current. The N-channel MOSFET input stage transistor drives a 2.5mA current source load. With a logic "1" input, the maximum quiescent supply current is 9mA. Logic "0" input level signals reduce quiescent current to 500µA maximum. **Unused driver inputs must be connected to V_S or GND**. Minimum power dissipation occurs for logic "0" inputs for the MIC1426/27/28.

The drivers are designed with 100mV of hysteresis. This provides clean transitions and minimizes output stage current spiking when changing states. Input voltage thresholds are approximately 1.5V, making logic "1" input any voltage greater than 1.5V up to V_S. Input current is less than 1µA over this range.

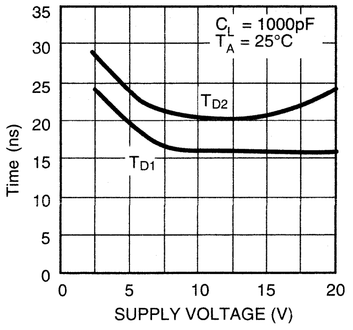
The MIC1426/27/28 may be directly driven by the TL494, SG1526/27, MIC38C42, TSC170 and similar switch-mode power supply integrated circuits.

MIC1426/7/8 Typical Characteristic Curves

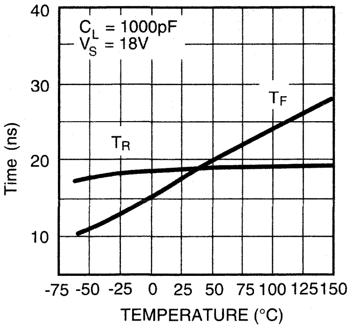
Rise and Fall Time vs. Supply Voltage



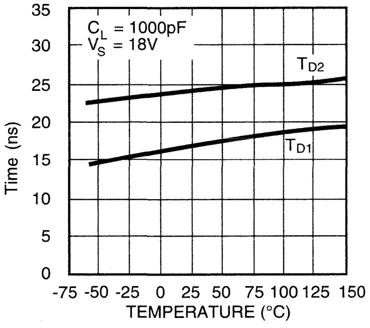
Delay Time vs. Supply Voltage



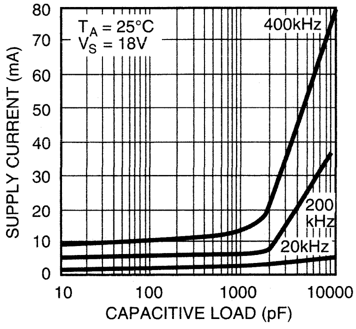
Rise and Fall Time vs. Temperature



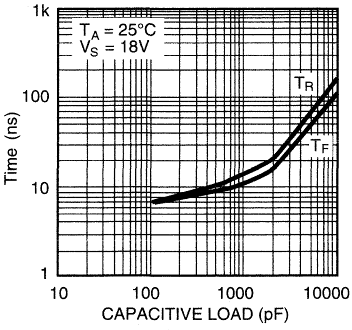
Delay Time vs. Temperature



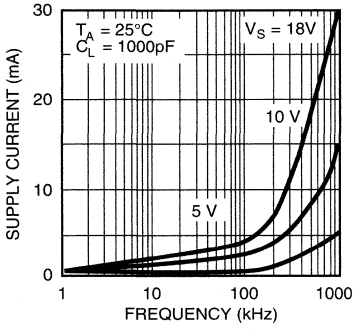
Supply Current vs. Capacitive Load



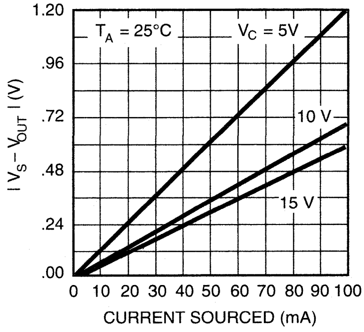
Rise and Fall Time vs. Capacitive Load



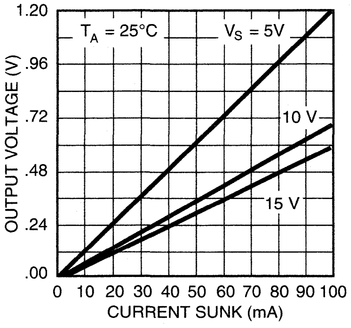
Supply Current vs. Frequency



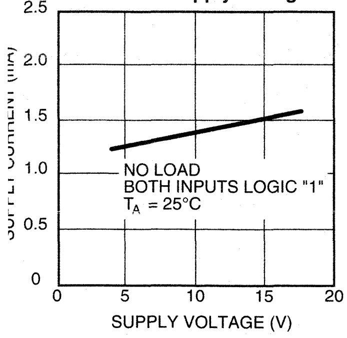
High Output vs. Current



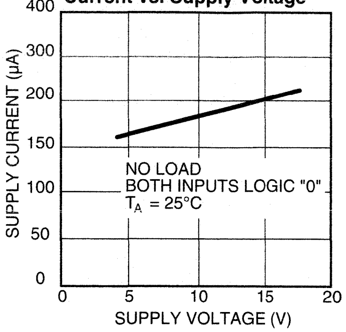
Low Output vs. Current



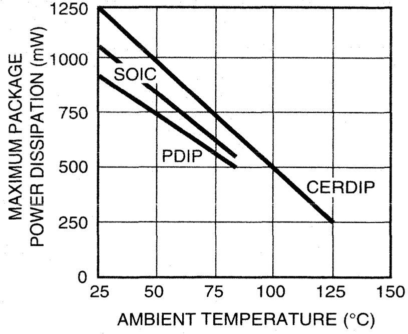
Quiescent Power Supply Current vs. Supply Voltage



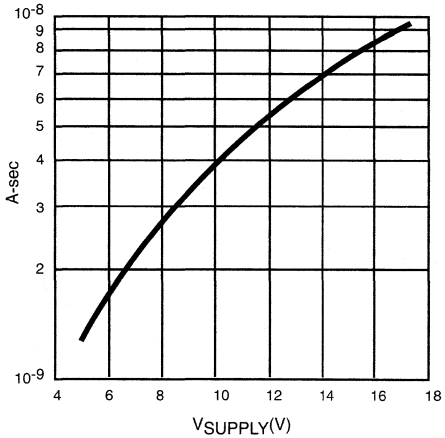
Quiescent Power Supply Current vs. Supply Voltage



Package Power Dissipation



Crossover Energy Loss



Note: The values on this graph represent the loss seen by a single transition of a single driver. For a complete cycle of a single driver multiply the stated value by 2.

MIC4416/4417

IttyBitty™ Low-Side MOSFET Driver

Preliminary Information

General Description

The MIC4416 and MIC4417 IttyBitty™ low-side MOSFET drivers are designed to switch an N-channel enhancement-type MOSFET from a TTL-compatible control signal in low-side switch applications. The MIC4416 is noninverting and the MIC4417 is inverting. These drivers feature short delays and high peak current to produce precise edges and rapid rise and fall times. Their tiny 4-lead SOT-143 package uses minimum space.

The MIC4416/7 is powered from a +4.5V to +18V supply voltage. The on-state gate drive output voltage is approximately equal to the supply voltage (no internal regulators or clamps). High supply voltages, such as 10V, are appropriate for use with standard N-channel MOSFETs. Low supply voltages, such as 5V, are appropriate for use with logic-level N-channel MOSFETs.

In a low-side configuration, the driver can control a MOSFET that switches any voltage up to the rating of the MOSFET.

The MIC4416 is available in the SOT-143 package and is rated for –40°C to +85°C ambient temperature range.

Features

- +4.5V to +18V operation
- Low steady-state supply current
  - 50µA typical, control input low
  - 370µA typical, control input high
- 1.2A nominal peak output
  - 3.5Ω typical output resistance at 15V supply
  - 7.8Ω typical output resistance at 5V supply
- 25mV maximum output offset from supply or ground
- Greater than 5MHz operation (unloaded)
- Operates in low-side switch circuits
- TTL-compatible input withstands –20V
- ESD protection
- Inverting and noninverting versions

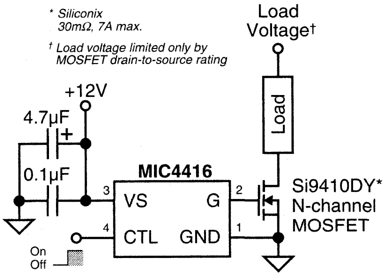
Applications

- Battery conservation
- Solenoid and motion control
- Lamp control
- Switch-mode power supplies

Ordering Information

Part Number	Temp. Range	Package	Marking
Noninverting			
MIC4416BM4	–40°C to +85°C	SOT-143	D10
Inverting			
MIC4417BM4	–40°C to +85°C	SOT-143	D11

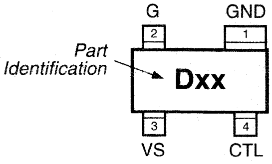
Typical Application


** Siliconix 30mΩ, 7A max.*

† Load voltage limited only by MOSFET drain-to-source rating

Low-Side Power Switch

in Configuration



SOT-143 (M4)

Part Number	Identification
MIC4416BM4	D10
MIC4417BM4	D11

Early production identification: ML10

in Description

Pin Number	Pin Name	Pin Function
1	GND	Ground: Power return.
2	G	Gate (Output) : Gate connection to external MOSFET.
3	VS	Supply (Input): +4.5V to +18V supply.
4	CTL	Control (Input): TTL-compatible on/off control input. *MIC4416 only:* Logic high forces the gate output to the supply voltage. Logic low forces the gate output to ground. *MIC4417 only:* Logic high forces the gate output to ground. Logic low forces the gate output to the supply voltage.

Absolute Maximum Ratings

Supply Voltage (V_S)	+20V
Control Voltage (V_{CTL})	–0.3V to +20V
Gate Voltage (V_G)	+20V
Lead Temperature, Soldering	260°C for 5 sec.

Operating Ratings

Supply Voltage (V_S)	+4.5 to +18V
Ambient Temperature Range (T_A)	–40°C to +85°C
Package Thermal Resistance (θ_{JA})	
SOT-143	220°C/W
(soldered to 0.25in^2 copper ground plane)	
Junction Temperature (T_J)	150°C max.

Electrical Characteristics

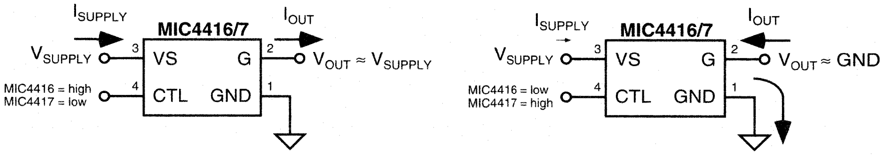
Parameter	Condition (Note 1)		Min	Typ	Max	Units
Supply Current	$4.5V \le V_S \le 18V$	$V_{CTL} = 0V$ $V_{CTL} = 5V$		50 370	200 1500	µA µA
Control Input Voltage	$4.5V \le V_S \le 18V$	V_{CTL} for logic 0 input V_{CTL} for logic 1 input	 2.4		0.8 	V V
Control Input Current	$0V \le V_{CTL} \le V_S$		10		10	µA
Delay Time, V_{CTL} Rising	$V_S = 5V$	$C_L = 1000pF$, **Note 2**		42		ns
	$V_S = 18V$	$C_L = 1000pF$, **Note 2**		23	40	ns
Delay Time, V_{CTL} Falling	$V_S = 5V$	$C_L = 1000pF$, **Note 2**		42		ns
	$V_S = 18V$	$C_L = 1000pF$, **Note 2**		33	60	ns
Output Rise Time	$V_S = 5V$	$C_L = 1000pF$, **Note 2**		24		ns
	$V_S = 18V$	$C_L = 1000pF$, **Note 2**		14	40	ns
Output Fall Time	$V_S = 5V$	$C_L = 1000pF$, **Note 2**		28		ns
	$V_S = 18V$	$C_L = 1000pF$, **Note 2**		16	40	ns
Gate Output Offset Voltage	$4.5V \le V_S \le 18V$	V_G = high V_G = low		–25 25		mV mV
Output Resistance	$V_S = 5V$, $I_{OUT} = 10mA$	P-channel (source) MOSFET N-channel (sink) MOSFET		7.6 7.8		Ω Ω
	$V_S = 18V$, $I_{OUT} = 10mA$	P-channel (source) MOSFET N-channel (sink) MOSFET		3.5 3.5	10 10	Ω Ω
Gate Output Reverse Current	No latch up		250			mA

General Note: Devices are ESD protected, however handling precautions are recommended.

Note 1: Typical values at $T_A = 25°C$. Minimum and maximum values indicate performance at $-40°C \ge T_A \ge +85°C$. Parts production tested at 25°C.

Note 2: Refer to "MIC4416 Timing Definitions" and "MIC4417 Timing Definitions" diagrams (see next page).

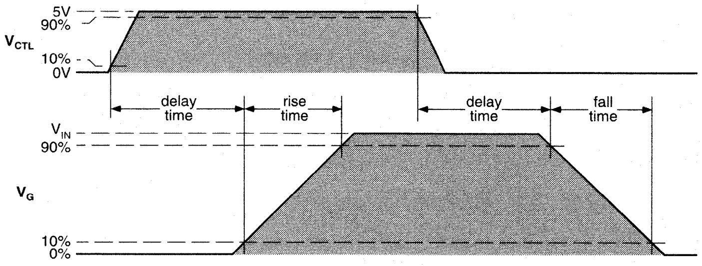
Definitions



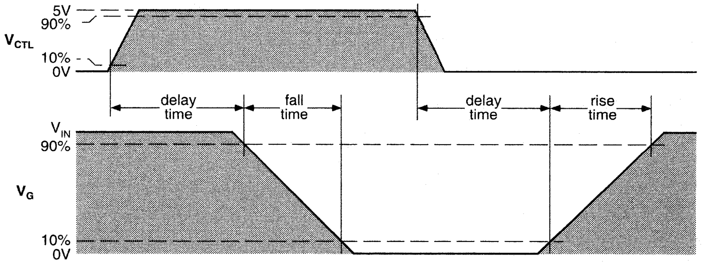
Source State
(P-channel on, N-channel off)

Sink State
(P-channel off, N-channel on)

MIC4416/MIC4417 Operating States

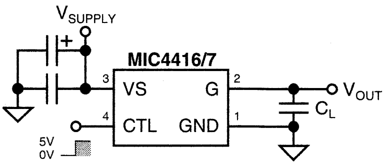


MIC4416 (Noninverting) Timing Definitions

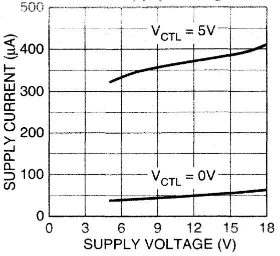


MIC4417 (Inverting) Timing Definitions

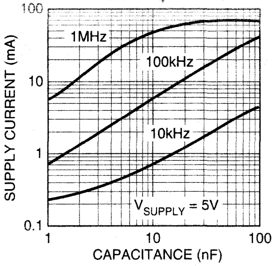
Test Circuit



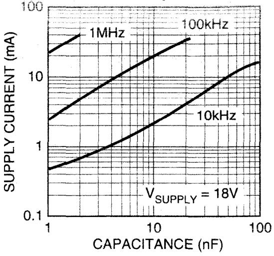
Typical Characteristics Note 3



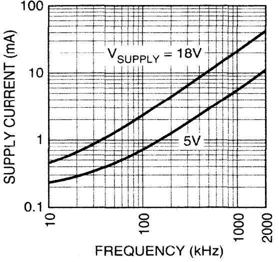
Quiescent Supply Current vs. Supply Voltage



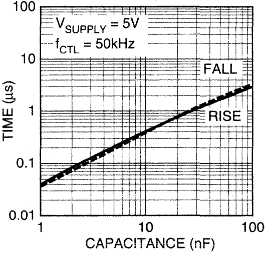
Supply Current vs. Load Capacitance



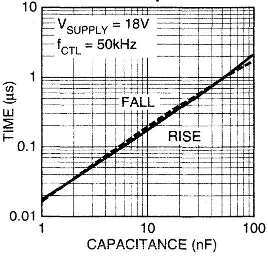
Supply Current vs. Load Capacitance



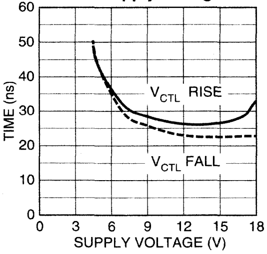
Supply Current vs. Frequency



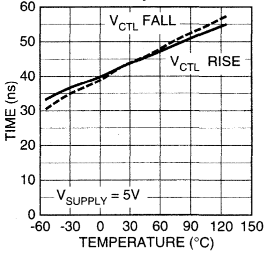
Output Rise and Fall Time vs. Load Capacitance



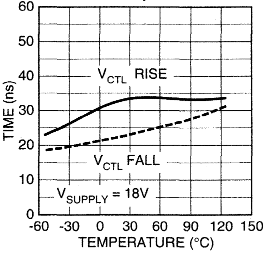
Output Rise and Fall Time vs. Load Capacitance



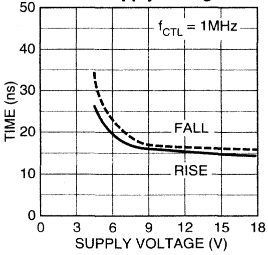
Delay Time vs. Supply Voltage



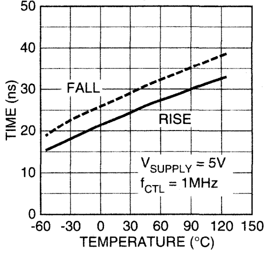
Delay Time vs. Temperature



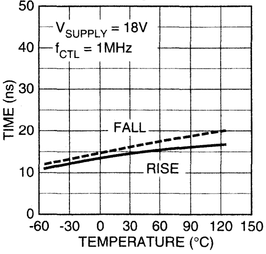
Delay Time vs. Temperature



Rise and Fall Time vs. Supply Voltage

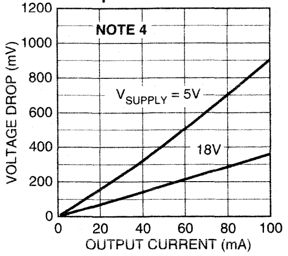


Rise and Fall Time vs. Temperature

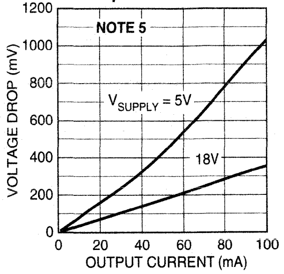


Rise and Fall Time vs. Temperature

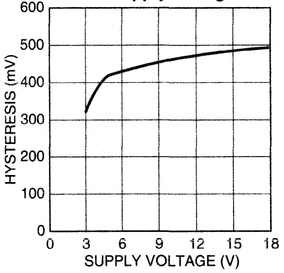
Output Voltage Drop vs. Output Source Current



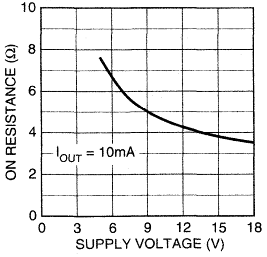
Output Voltage Drop vs. Output Sink Current



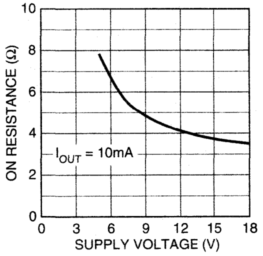
Control Input Hysteresis vs. Supply Voltage



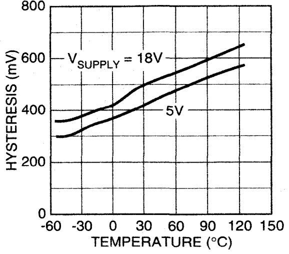
Output Source Resistance



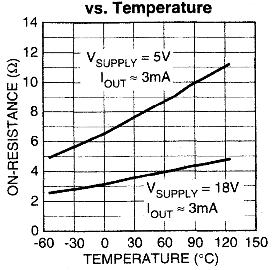
Output Sink Resistance



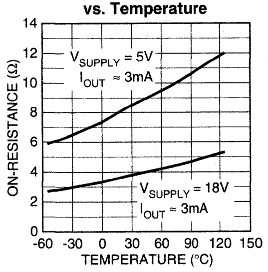
Control Input Hysteresis vs. Temperature



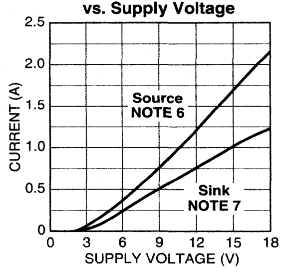
Output Source Resistance vs. Temperature



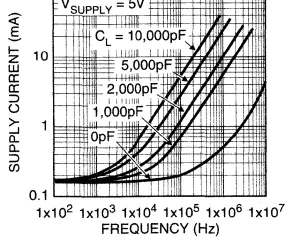
Output Sink Resistance vs. Temperature



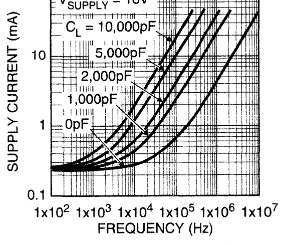
Peak Output Current vs. Supply Voltage



Supply Current vs. Frequency



Supply Current vs. Frequency



Note 3: Typical Characteristics at $T_A = 25°C$, $V_S = 5V$, $C_L = 1000pF$ unless noted.

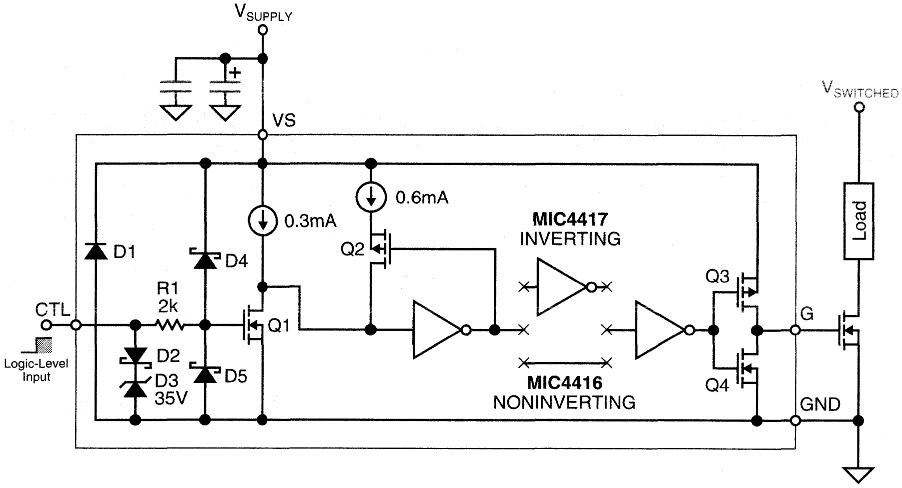
Note 4: Source-to-drain voltage drop across the internal P-channel MOSFET = $V_S - V_G$.

Note 5: Drain-to-source voltage drop across the internal N-channel MOSFET = $V_G - V_{GND}$. (Voltage applied to G.)

Note 6: 1µs pulse test, 50% duty cycle. OUT connected to GND. OUT sources current. (MIC4416, $V_{CTL} = 5V$; MIC4417, $V_{CTL} = 0V$)

Note 7: 1µs pulse test, 50% duty cycle. VS connected to OUT. OUT sinks current. (MIC4416, $V_{CTL} = 0V$; MIC4417, $V_{CTL} = 5V$)

Functional Diagram



Functional Diagram with External Components

Functional Description

Refer to the functional diagram.

The MIC4416 is a noninverting driver. A logic high on the CTL (control) input produces gate drive output. The MIC4417 is an inverting driver. A logic low on the CTL (control) input produces gate drive output. The G (gate) output is used to turn on an external N-channel MOSFET.

Supply

VS (supply) is rated for +4.5V to +18V. External capacitors are recommended to decouple noise.

Control

CTL (control) is a TTL-compatible input. CTL must be forced high or low by an external signal. A floating input will cause unpredictable operation.

A high input turns on Q1, which sinks the output of the 0.3mA and the 0.6mA current source, forcing the input of the first inverter low.

Hysteresis

The control threshold voltage, when CTL is rising, is slightly higher than the control threshold voltage when CTL is falling.

When CTL is low, Q2 is on, which applies the additional 0.6mA current source to Q1. Forcing CTL high turns on Q1 which must sink 0.9mA from the two current sources. The higher current through Q1 causes a larger drain-to-source voltage drop across Q1. A slightly higher control voltage is required to pull the input of the first inverter down to its threshold.

Q2 turns off after the first inverter output goes high. This reduces the current through Q1 to 0.3mA. The lower current reduces the drain-to-source voltage drop across Q1. A slightly lower control voltage will pull the input of the first inverter up to its threshold.

Drivers

The second (optional) inverter permits the driver to be manufactured in inverting and noninverting versions.

The last inverter functions as a driver for the output MOSFETs Q3 and Q4.

Gate Output

G (gate) is designed to drive a capacitive load. V_G (gate output voltage) is either approximately the supply voltage or approximately ground, depending on the logic state applied to CTL.

If CTL is high, and VS (supply) drops to zero, the gate output will be floating (unpredictable).

ESD Protection

D1 protects VS from negative ESD voltages. D2 and D3 clamp positive and negative ESD voltages applied to CTL. R1 isolates the gate of Q1 from sudden changes on the CTL input. D4 and D5 prevent Q1's gate voltage from exceeding the supply voltage or going below ground.

Application Information

The MIC4416/7 is designed to provide high peak current for charging and discharging capacitive loads. The 1.2A peak value is a nominal value determined under specific conditions. This nominal value is used to compare its relative size to other low-side MOSFET drivers. The MIC4416/7 is not designed to directly switch 1.2A continuous loads.

Supply Bypass

Capacitors from VS to GND are recommended to control switching and supply transients. Load current and supply lead length are some of the factors that affect capacitor size requirements.

A 4.7µF or 10µF tantalum capacitor is suitable for many applications. Low-ESR (equivalent series resistance) metalized film capacitors may also be suitable. An additional 0.1µF ceramic capacitor is suggested in parallel with the larger capacitor to control high-frequency transients.

The low ESR (equivalent series resistance) of tantalum capacitors makes them especially effective, but also makes them susceptible to uncontrolled inrush current from low impedance voltage sources (such as NiCd batteries or automatic test equipment). Avoid instantaneously applying voltage, capable of very high peak current, directly to or near tantalum capacitors without additional current limiting. Normal power supply turn-on (slow rise time) or printed circuit trace resistance is usually adequate for normal product usage.

Circuit Layout

Avoid long power supply and ground traces. They exhibit inductance that can cause voltage transients (inductive kick). Even with resistive loads, inductive transients can sometimes exceed the ratings of the MOSFET and the driver.

When a load is switched off, supply lead inductance forces current to continue flowing—resulting in a positive voltage spike. Inductance in the ground (return) lead to the supply has similar effects, except the voltage spike is negative.

Switching transitions momentarily draw current from VS to GND. This combines with supply lead inductance to create voltage transients at turn on and turnoff.

Transients can also result in slower apparent rise or fall times when driver's ground shifts with respect to the control input.

Minimize the length of supply and ground traces or use ground and power planes when possible. Bypass capacitors should be placed as close as practical to the driver.

MOSFET Selection

Standard MOSFET

A standard N-channel power MOSFET is fully enhanced with a gate-to-source voltage of approximately 10V and has an absolute maximum gate-to-source voltage of ±20V.

The MIC4416/7's on-state output is approximately equal to the supply voltage. The lowest usable voltage depends upon the behavior of the MOSFET.

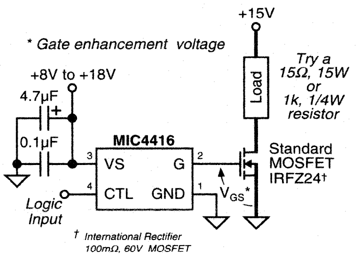


Figure 1. Using a Standard MOSFET

Logic-Level MOSFET

Logic-level N-channel power MOSFETs are fully enhanced with a gate-to-source voltage of approximately 5V and have an absolute maximum gate-to-source voltage of ±10V. They are less common and generally more expensive.

The MIC4416/7 can drive a logic-level MOSFET if the supply voltage, including transients, does not exceed the maximum MOSFET gate-to-source rating (10V).

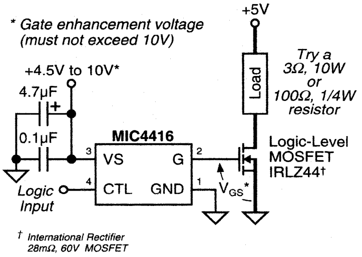


Figure 2. Using a Logic-Level MOSFET

At low voltages, the MIC4416/7's internal P- and N-channel MOSFET's on-resistance will increase and slow the output rise time. Refer to "Typical Characteristics" graphs.

Inductive Loads

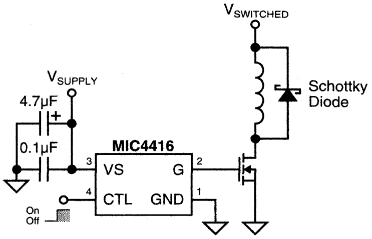


Figure 3. Switching an Inductive Load

Switching off an inductive load in a low-side application forces the MOSFET drain higher than the supply voltage (as the inductor resists changes to current). To prevent exceeding the MOSFET's drain-to-gate and drain-to-source ratings, a Schottky diode should be connected across the inductive load.

Power Dissipation

The maximum power dissipation must not be exceeded to prevent die meltdown or deterioration.

Power dissipation in on/off switch applications is negligible.

Fast repetitive switching applications, such as SMPS (switch-mode power supplies), cause a significant increase in power dissipation with frequency. Power is dissipated each time current passes through the internal output MOSFETs when charging or discharging the external MOSFET. Power is also dissipated during each transition when some current momentarily passes from VS to GND through both internal MOSFETs.

Power dissipation is the product of supply voltage and supply current:

1) $P_D = V_S \times I_S$

where:

P_D = power dissipation (W)

V_S = supply voltage (V)

I_S = supply current (A) [see paragraph below]

Supply current is a function of supply voltage, switching frequency, and load capacitance. Determine this value from the "Typical Characteristics: Supply Current vs. Frequency" graph or measure it in the actual application.

Do not allow P_D to exceed $P_{D\,(max)}$, below.

T_J (junction temperature) is the sum of T_A (ambient temperature) and the temperature rise across the thermal resistance of the package. In another form:

2) $$P_D \le \frac{150 - T_A}{220}$$

where:

$P_{D\,(max)}$ = maximum power dissipation (W)

150 = absolute maximum junction temperature (°C)

T_A = ambient temperature (°C) [68°F = 20°C]

220 = package thermal resistance (°C/W)

Maximum power dissipation at 20°C with the driver soldered to a 0.25in^2 ground plane is approximately 600mW.

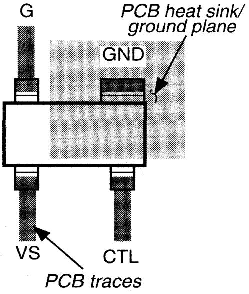


Figure 4. Heat-Sink Plane

The SOT-143 package θ_{JA} (junction-to-ambient thermal resistance) can be improved by using a heat sink larger than the specified 0.25in^2 ground plane. Significant heat transfer occurs through the large (GND) lead. This lead is an extension of the paddle to which the die is attached.

High-Frequency Operation

Although the MIC4416/7 driver will operate at frequencies greater than 1MHz, the MOSFET's capacitance and the load will affect the output waveform (at the MOSFET's drain).

For example, an MIC4416/IRL3103 test circuit using a 47Ω 5W load resistor will produce an output waveform that closely matches the input signal shape up to about 500kHz. The same test circuit with a 1kΩ load resistor operates only up to about 25kHz before the MOSFET source waveform shows significant change.

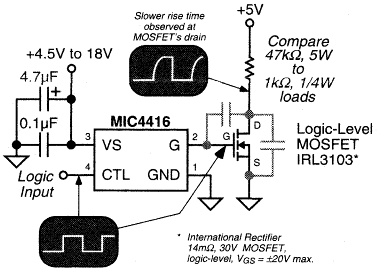


Figure 5. MOSFET Capacitance Effects at High Switching Frequency

When the MOSFET is driven off, the slower rise occurs because the MOSFET's output capacitance recharges through the load resistance (RC circuit). A lower load resistance allows the output to rise faster. For the fastest driver operation, choose the smallest power MOSFET that will safely handle the desired voltage, current, and safety margin. The smallest MOSFETs generally have the lowest capacitance.

MIC4420/4429

6A-Peak Low-Side MOSFET Driver

Bipolar/CMOS/DMOS Process

General Description

MIC4420 and MIC4429 MOSFET drivers are tough, efficient, and easy to use. The MIC4429 is an inverting driver, while the MIC4420 is a non-inverting driver.

Both versions are capable of 6A (peak) output and can drive the largest MOSFETs with an improved safe operating margin. The MIC4420/4429 accepts any logic input from 2.4V to V_S without external speed-up capacitors or resistor networks. Proprietary circuits allow the input to swing negative by as much as 5V without damaging the part. Additional circuits protect against damage from electrostatic discharge.

MIC4420/4429 drivers can replace three or more discrete components, reducing PCB area requirements, simplifying product design, and reducing assembly cost.

Modern BiCMOS/DMOS construction guarantees freedom from latch-up. The rail-to-rail swing capability insures adequate gate voltage to the MOSFET during power up/down sequencing.

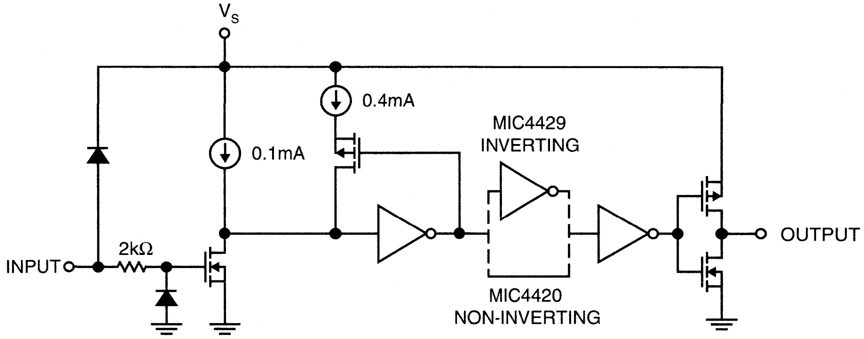
Features

- CMOS Construction
- Latch-Up Protected: Will Withstand >500mA Reverse Output Current
- Logic Input Will Withstand Negative Swing of Up to 5V
- Matched Rise and Fall Times 25ns
- High Peak Output Current .... 6A Peak
- Wide Operating Range .... 4.5V to 18V
- High Capacitive Load Drive 10,000pF
- Low Delay Time .... 55ns Typ
- Logic High Input for Any Voltage From 2.4V to V_S
- Low Equivalent Input Capacitance (typ) 6pF
- Low Supply Current .... 450µA With Logic 1 Input
- Low Output Impedance 2.5Ω
- Output Voltage Swing to Within 25mV of Ground or V_S
- MIL-STD-883 Method 5004/5005 version available

Applications

- Switch Mode Power Supplies
- Motor Controls
- Pulse Transformer Driver
- Class D Switching Amplifiers

Functional Diagram

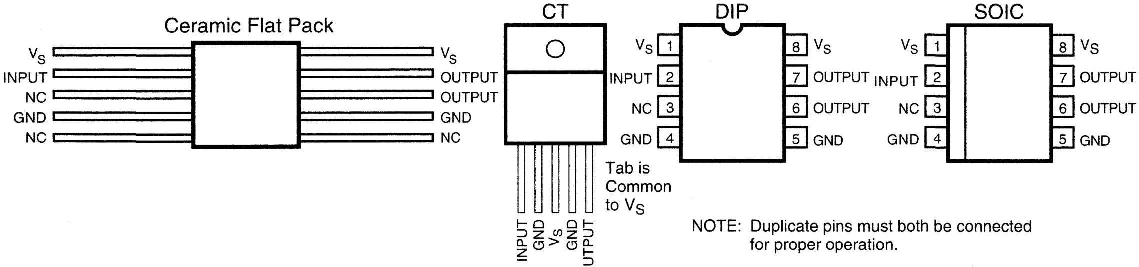


Ordering Information

Part No.	Temperature Range	Package	Configuration
5962-8877001PA[1]	–55°C to +125°C	8-Pin CerDIP	Inverting
5962-8877001HA[2]	–55°C to +125°C	10-Pin CerPak	Inverting
MIC4420CN	0°C to +70°C	8-Pin PDIP	Non-Inverting
MIC4420BN	–40°C to +85°C	8-Pin PDIP	Non-Inverting
MIC4420CM	0°C to +70°C	8-Pin SOIC	Non-Inverting
MIC4420BM	–40°C to +85°C	8-Pin SOIC	Non-Inverting
MIC4420AJ	–55°C to +125°C	8-Pin CerDIP	Non-Inverting
5962-8877003PA[3]	–55°C to +125°C	8-Pin CerDIP	Non-Inverting
5962-8877003HA[4]	–55°C to +125°C	10-Pin CerPak	Non-Inverting
MIC4420CT	0°C to +70°C	5-Pin TO-220	Non-Inverting
MIC4429CN	0°C to +70°C	8-Pin PDIP	Inverting
MIC4429BN	–40°C to +85°C	8-Pin PDIP	Inverting
MIC4429CM	0°C to +70°C	8-Pin SOIC	Inverting
MIC4429BM	–40°C to +85°C	8-Pin SOIC	Inverting
MIC4429AJ	–55°C to +125°C	8-Pin CerDIP	Inverting
5962-8877002PA[5]	–55°C to +125°C	8-Pin CerDIP	Inverting
5962-8877002HA[6]	–55°C to +125°C	10-Pin CerPak	Inverting
MIC4429CT	0°C to +70°C	5-Pin TO-220	Inverting

[1] Standard Military Drawing number for MIC429AJBQ
[2] Standard Military Drawing number for MIC429AWBQ
[3] Standard Military Drawing number for MIC4420AJBQ
[4] Standard Military Drawing number for MIC4420AWBQ
[5] Standard Military Drawing number for MIC4429AJBQ
[6] Standard Military Drawing number for MIC4429AWBQ

Pin Configurations



NOTE: Duplicate pins must both be connected for proper operation.

Absolute Maximum Ratings (Notes 1, 2 and 3)

Power Dissipation, $T_{AMBIENT} \leq 25°C$	
PDIP	960MW
SOIC	1040 mW
CerDIP	1250 mW
5-Pin TO-220	2W
Power Dissipation, $T_{CASE} \leq 25°C$	
5-Pin TO-220	12.5W
Derating Factors (To Ambient)	
PDIP	7.7 mW/°C
SOIC	8.3 mW/°C
CerDIP	10 mW/°C
5-Pin TO-220	17 mW/°C

Thermal Impedances (To Case)	
5-Pin TO-220 $R_{\theta J\text{-}C}$	10°C/W
Storage Temperature	–65°C to +150°C
Operating Temperature (Chip)	150°C
Operating Temperature (Ambient)	
C Version	0°C to +70°C
B Version	–40°C to +85°C
A Version	–55°C to +125°C
Lead Temperature (10 sec)	300°C
Supply Voltage	20V
Input Voltage	V_S + 0.3V to GND – 5V
Input Current ($V_{IN} > V_S$)	50 mA

If Military/Aerospace specified devices are required, contact Micrel for availability and specifications.

Electrical Characteristics: ($T_A = 25°C$ with $4.5V \le V_S \le 18V$ unless otherwise specified.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.4	1.4		V
V_{IL}	Logic 0 Input Voltage			1.1	0.8	V
V_{IN}	Input Voltage Range		–5		$V_S + 0.3$	V
I_{IN}	Input Current	$0 V \le V_{IN} \le V_S$	–10		10	µA
OUTPUT						
V_{OH}	High Output Voltage	See Figure 1	V_S–0.025			V
V_{OL}	Low Output Voltage	See Figure 1			0.025	V
R_O	Output Resistance, Output Low	$I_{OUT} = 10$ mA, $V_S = 18$ V		1.7	2.8	Ω
R_O	Output Resistance, Output High	$I_{OUT} = 10$ mA, $V_S = 18$ V		1.5	2.5	Ω
I_{PK}	Peak Output Current	$V_S = 18$ V (See Figure 5)		6		A
I_R	Latch-Up Protection Withstand Reverse Current		>500			mA
SWITCHING TIME (Note 3)						
t_R	Rise Time	Test Figure 1, $C_L = 2500$ pF		12	35	ns
t_F	Fall Time	Test Figure 1, $C_L = 2500$ pF		13	35	ns
t_{D1}	Delay Time	Test Figure 1		18	75	ns
t_{D2}	Delay Time	Test Figure 1		48	75	ns
Power Supply						
I_S	Power Supply Current	$V_{IN} = 3$ V $V_{IN} = 0$ V		0.45 90	1.5 150	mA µA
V_S	Operating Input Voltage		4.5		18	V

Electrical Characteristics: (T_A = –55°C to +125°C with 4.5V ≤ V_S ≤ 18V unless otherwise specified.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.4			V
V_{IL}	Logic 0 Input Voltage				0.8	V
V_{IN}	Input Voltage Range		–5		V_S + 0.3	V
I_{IN}	Input Current	0V ≤ V_{IN} ≤ V_S	–10		10	µA
OUTPUT						
V_{OH}	High Output Voltage	Figure 1	V_S–0.025			V
V_{OL}	Low Output Voltage	Figure 1			0.025	V
R_O	Output Resistance, Output Low	I_{OUT} = 10mA, V_S = 18V		3	5	Ω
R_O	Output Resistance, Output High	I_{OUT} = 10mA, V_S = 18V		2.3	5	Ω
SWITCHING TIME (Note 3)						
t_R	Rise Time	Figure 1, C_L = 2500pF		32	60	ns
t_F	Fall Time	Figure 1, C_L = 2500pF		34	60	ns
t_{D1}	Delay Time	Figure 1		50	100	ns
t_{D2}	Delay Time	Figure 1		65	100	ns
POWER SUPPLY						
I_S	Power Supply Current	V_{IN} = 3V V_{IN} = 0V		0.45 0.06	3.0 0.4	mA mA
V_S	Operating Input Voltage		4.5		18	V

NOTE 1: Functional operation above the absolute maximum stress ratings is not implied.

NOTE 2: Static-sensitive device. Store only in conductive containers. Handling personnel and equipment should be grounded to prevent damage from static discharge.

NOTE 3: Switching times guaranteed by design.

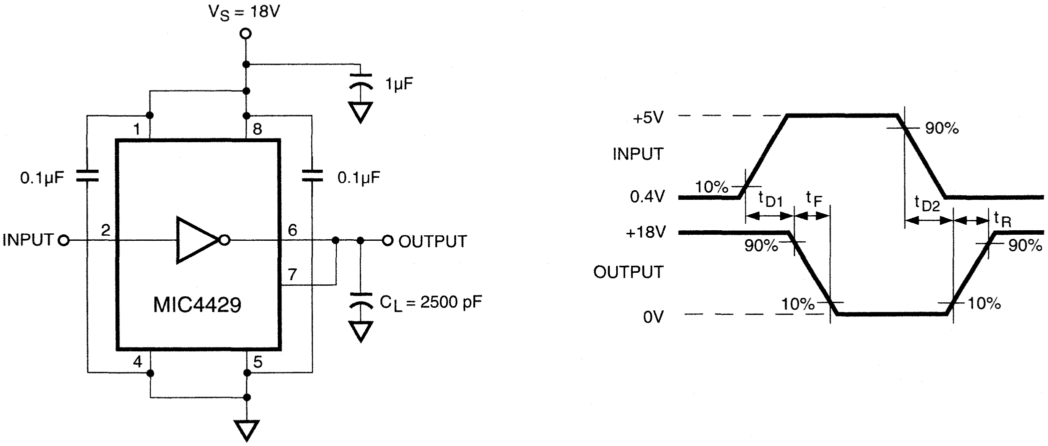
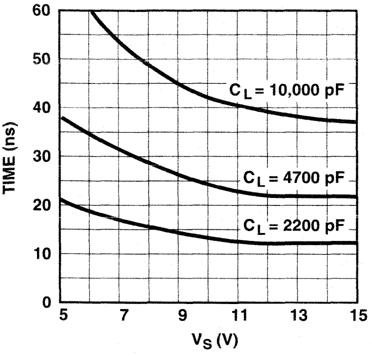


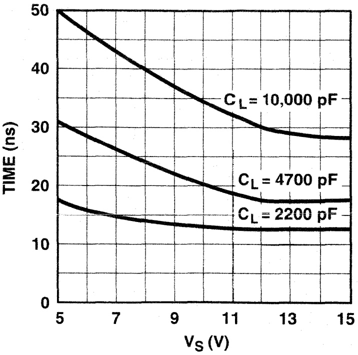
Figure 1. Switching Time Test Circuit

Typical Characteristic Curves

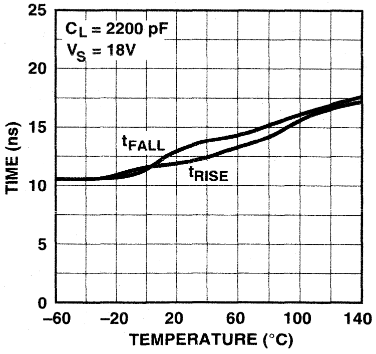
Rise Time vs. Supply Voltage



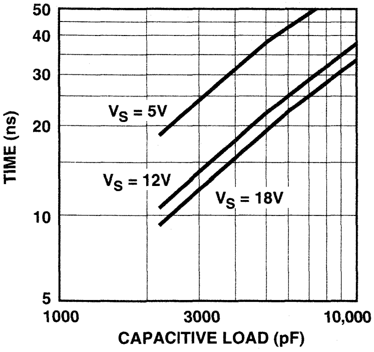
Fall Time vs. Supply Voltage



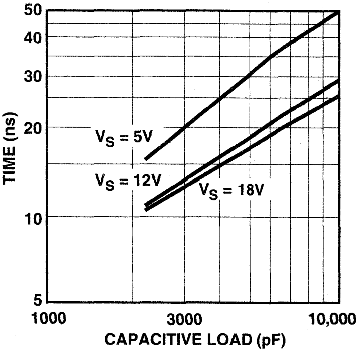
Rise and Fall Times vs. Temperature



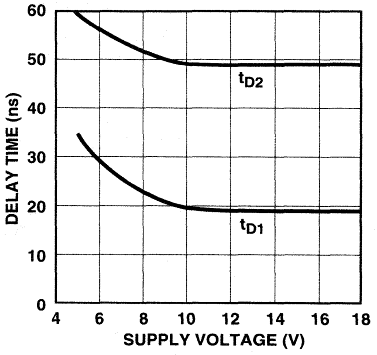
Rise Time vs. Capacitive Load



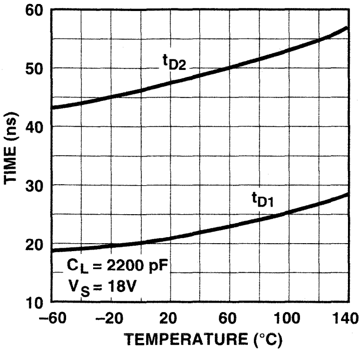
Fall Time vs. Capacitive Load



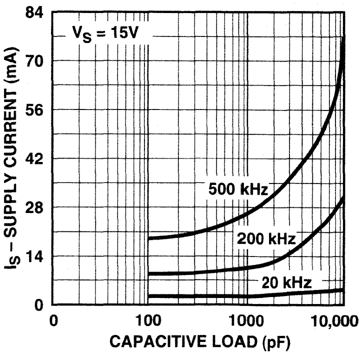
Delay Time vs. Supply Voltage



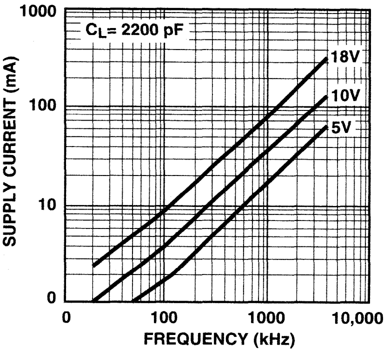
Propagation Delay Time vs. Temperature



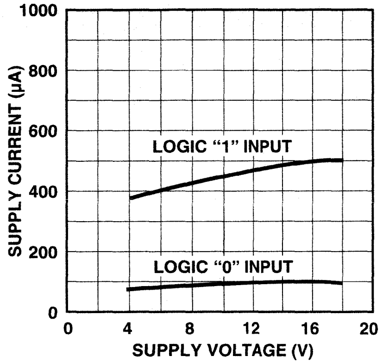
Supply Current vs. Capacitive Load

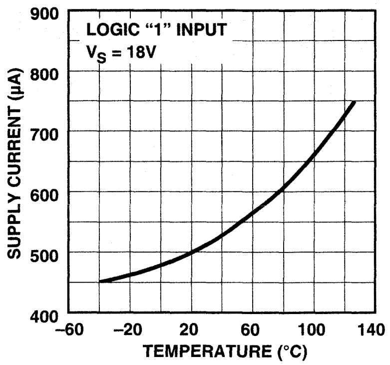


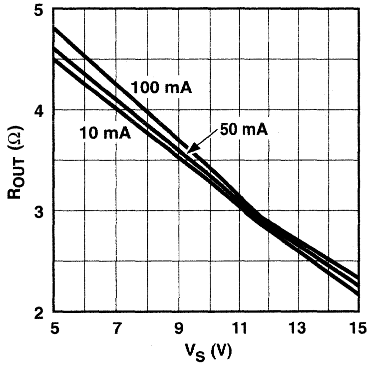
Supply Current vs. Frequency

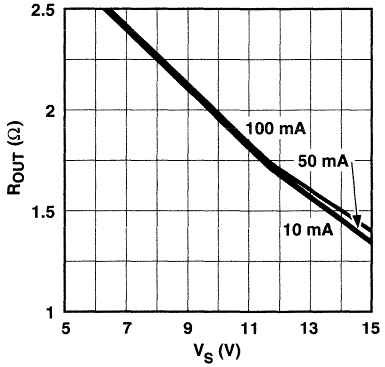


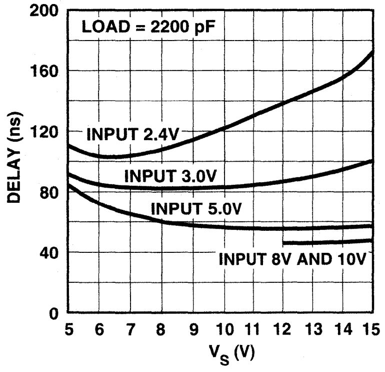
Typical Characteristic Curves (Cont.)

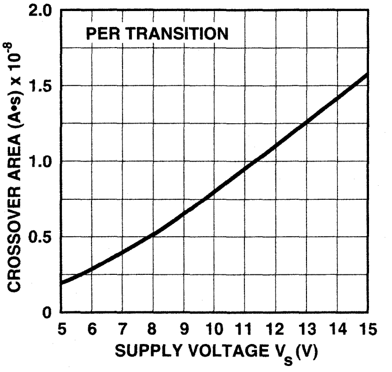

Quiescent Power Supply Voltage vs. Supply Current


Quiescent Power Supply Current vs. Temperature


High-State Output Resistance


Low-State Output Resistance


Effect of Input Amplitude on Propagation Delay


Crossover Area vs. Supply Voltage

Applications Information

Supply Bypassing

Charging and discharging large capacitive loads quickly requires large currents. For example, charging a 2500pF load to 18V in 25ns requires a 1.8 A current from the device power supply.

The MIC4420/4429 has double bonding on the supply pins, the ground pins and output pins This reduces parasitic lead inductance. Low inductance enables large currents to be switched rapidly. It also reduces internal ringing that can cause voltage breakdown when the driver is operated at or near the maximum rated voltage.

Internal ringing can also cause output oscillation due to feedback. This feedback is added to the input signal since it is referenced to the same ground.

To guarantee low supply impedance over a wide frequency range, a parallel capacitor combination is recommended for supply bypassing. Low inductance ceramic disk capacitors with short lead lengths (< 0.5 inch) should be used. A 1µF low ESR film capacitor in parallel with two 0.1 µF low ESR ceramic capacitors, (such as AVX RAM GUARD®), provides adequate bypassing. Connect one ceramic capacitor directly between pins 1 and 4. Connect the second ceramic capacitor directly between pins 8 and 5.

Grounding

The high current capability of the MIC4420/4429 demands careful PC board layout for best performance Since the MIC4429 is an inverting driver, any ground lead impedance will appear as negative feedback which can degrade switching speed. Feedback is especially noticeable with slow-rise time inputs. The MIC4429 input structure includes 300mV of hysteresis to ensure clean transitions and freedom from oscillation, but attention to layout is still recommended.

Figure 3 shows the feedback effect in detail. As the MIC4429 input begins to go positive, the output goes negative and several amperes of current flow in the ground lead. As little as 0.05Ω of PC trace resistance can produce hundreds of millivolts at the MIC4429 ground pins. If the driving logic is referenced to power ground, the effective logic input level is reduced and oscillation may result.

To insure optimum performance, separate ground traces should be provided for the logic and power connections. Connecting the logic ground directly to the MIC4429 GND pins will ensure full logic drive to the input and ensure fast output switching. Both of the MIC4429 GND pins should, however, still be connected to power ground.

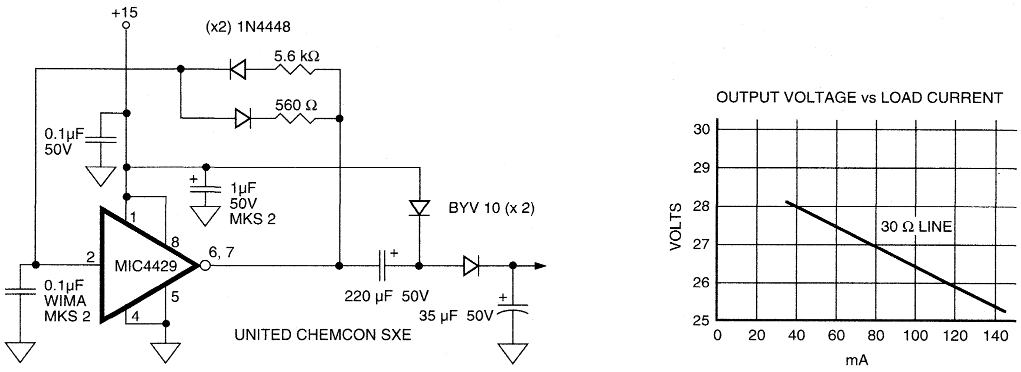


Figure 2. Self Contained Voltage Doubler

Input Stage

The input voltage level of the 4429 changes the quiescent supply current. The N channel MOSFET input stage transistor drives a 450μA current source load. With a logic "1" input, the maximum quiescent supply current is 450μA. Logic "0" input level signals reduce quiescent current to 55μA maximum.

The MIC4420/4429 input is designed to provide 300mV of hysteresis. This provides clean transitions, reduces noise sensitivity, and minimizes output stage current spiking when changing states. Input voltage threshold level is approximately 1.5V, making the device TTL compatible over the 4 .5V to 18V operating supply voltage range. Input current is less than 10μA over this range.

The MIC4429 can be directly driven by the TL494, SG1526/1527, SG1524, TSC170, MIC38HC42 and similar switch mode power supply integrated circuits. By offloading the power-driving duties to the MIC4420/4429, the power supply controller can operate at lower dissipation. This can improve performance and reliability.

The input can be greater than the ^+V_S supply, however, current will flow into the input lead. The propagation delay for T_{D2} will increase to as much as 400ns at room temperature. The input currents can be as high as 30mA p-p (6.4mA_{RMS}) with the input, 6 V greater than the supply voltage. No damage will occur to MIC4420/4429 however, and it will not latch.

The input appears as a 38pF capacitance, and does not change even if the input is driven from an AC source. Care should be taken so that the input does not go more than 5 volts below the negative rail.

Power Dissipation

CMOS circuits usually permit the user to ignore power dissipation. Logic families such as 4000 and 74C have outputs which can only supply a few milliamperes of current, and even shorting outputs to ground will not force enough current to destroy the device. The MIC4420/4429 on the other hand, can source or sink several amperes and drive large capacitive loads at high frequency. The package power dissipation limit can easily be exceeded. Therefore, some attention should be given to power dissipation when driving low impedance loads and/or operating at high frequency.

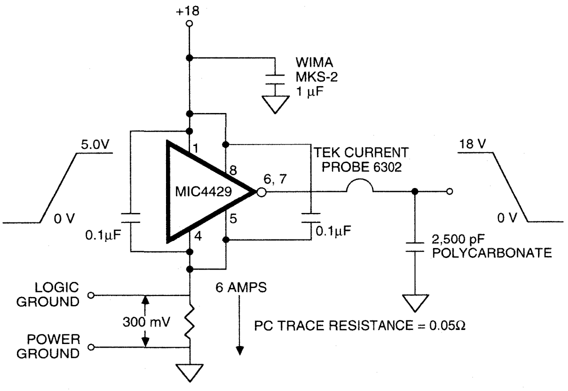


Figure 3. Switching Time Degradation Due to Negative Feedback

The supply current vs frequency and supply current vs capacitive load characteristic curves aid in determining power dissipation calculations. Table 1 lists the maximum safe operating frequency for several power supply voltages when driving a 2500pF load. More accurate power dissipation figures can be obtained by summing the three dissipation sources.

Given the power dissipation in the device, and the thermal resistance of the package, junction operating temperature for any ambient is easy to calculate. For example, the thermal resistance of the 8-pin CerDIP package, from the data sheet, is 150°C/W. In a 25°C ambient, then, using a maximum junction temperature of 150°C, this package will dissipate 800mW.

Accurate power dissipation numbers can be obtained by summing the three sources of power dissipation in the device:

- Load Power Dissipation (P_L)
- Quiescent power dissipation (P_Q)
- Transition power dissipation (P_T)

Calculation of load power dissipation differs depending on whether the load is capacitive, resistive or inductive.

Resistive Load Power Dissipation

Dissipation caused by a resistive load can be calculated as:

$$P_L = I^2 R_O D$$

where:

I = the current drawn by the load
R_O = the output resistance of the driver when the output is high, at the power supply voltage used. (See data sheet)
D = fraction of time the load is conducting (duty cycle)

Table 1: MIC4429 Maximum Operating Frequency

V_S	Max Frequency
18V	500kHz
15V	700kHz
10V	1.6MHz

Conditions: 1. DIP Package (θ_{JA} = 130°C/W)
2. T_A = 25°C
3. C_L = 2500pF

Capacitive Load Power Dissipation

Dissipation caused by a capacitive load is simply the energy placed in, or removed from, the load capacitance by the driver. The energy stored in a capacitor is described by the equation:

$$E = 1/2\ C\ V^2$$

As this energy is lost in the driver each time the load is charged or discharged, for power dissipation calculations the 1/2 is removed. This equation also shows that it is good practice not to place more voltage on the capacitor than is necessary, as dissipation increases as the square of the voltage applied to the capacitor. For a driver with a capacitive load:

$$P_L = F\ C\ (V_S)^2$$

where:

F = Operating Frequency
C = Load Capacitance
V_S = Driver Supply Voltage

Inductive Load Power Dissipation

For inductive loads the situation is more complicated. For the part of the cycle in which the driver is actively forcing current into the inductor, the situation is the same as it is in the resistive case:

$$P_{L1} = I^2\ R_O\ D$$

However, in this instance the R_O required may be either the on resistance of the driver when its output is in the high state, or its on resistance when the driver is in the low state, depending on how the inductor is connected, and this is still only half the story. For the part of the cycle when the inductor is forcing current through the driver, dissipation is best described as

$$P_{L2} = I\ V_D\ (1\text{-}D)$$

where V_D is the forward drop of the clamp diode in the driver (generally around 0.7V). The two parts of the load dissipation must be summed in to produce P_L

$$P_L = P_{L1} + P_{L2}$$

Quiescent Power Dissipation

Quiescent power dissipation (P_Q, as described in the input section) depends on whether the input is high or low. A low input will result in a maximum current drain (per driver) of ≤0.2mA; a logic high will result in a current drain of ≤2.0mA. Quiescent power can therefore be found from:

$$P_Q = V_S\ [D\ I_H + (1\text{-}D)\ I_L]$$

where:

I_H = quiescent current with input high
I_L = quiescent current with input low
D = fraction of time input is high (duty cycle)
V_S = power supply voltage

Transition Power Dissipation

Transition power is dissipated in the driver each time its output changes state, because during the transition, for a very brief interval, both the N- and P-channel MOSFETs in the output totem-pole are ON simultaneously, and a current is conducted through them from V^+_S to ground. The transition power dissipation is approximately:

$$P_T = 2\ F\ V_S\ (A{\bullet}s)$$

where (A•s) is a time-current factor derived from the typical characteristic curves.

Total power (P_D) then, as previously described is:

$$P_D = P_L + P_Q + P_T$$

Definitions

C_L = Load Capacitance in Farads.

D = Duty Cycle expressed as the fraction of time the input to the driver is high.

F = Operating Frequency of the driver in Hertz

I_H = Power supply current drawn by a driver when both inputs are high and neither output is loaded.

I_L = Power supply current drawn by a driver when both inputs are low and neither output is loaded.

I_D = Output current from a driver in Amps.

P_D = Total power dissipated in a driver in Watts.

P_L = Power dissipated in the driver due to the driver's load in Watts.

P_Q = Power dissipated in a quiescent driver in Watts.

P_T = Power dissipated in a driver when the output changes states ("shoot-through current") in Watts. NOTE: The "shoot-through" current from a dual transition (once up, once down) for both drivers is shown by the "Typical Characteristic Curve : Crossover Area vs. Supply Voltage and is in ampere-seconds. This figure must be multiplied by the number of repetitions per second (frequency) to find Watts.

R_O = Output resistance of a driver in Ohms.

V_S = Power supply voltage to the IC in Volts.

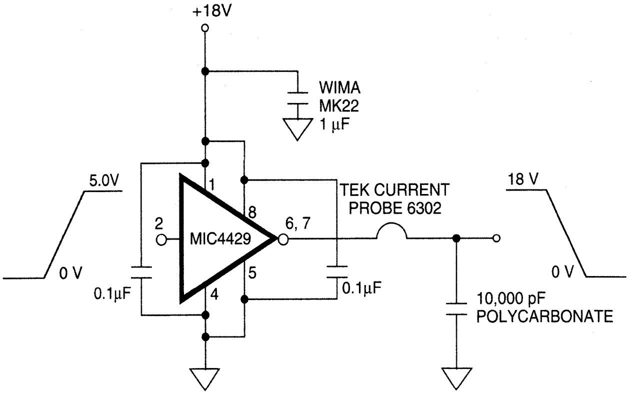


Figure 6. Peak Output Current Test Circuit

MIC4421/4422

9A-Peak Low-Side MOSFET Driver

Bipolar/CMOS/DMOS Process

General Description

MIC4421 and MIC4422 MOSFET drivers are rugged, efficient, and easy to use. The MIC4421 is an inverting driver, while the MIC4422 is a non-inverting driver.

Both versions are capable of 9A (peak) output and can drive the largest MOSFETs with an improved safe operating margin. The MIC4421/4422 accepts any logic input from 2.4V to V_S without external speed-up capacitors or resistor networks. Proprietary circuits allow the input to swing negative by as much as 5V without damaging the part. Additional circuits protect against damage from electrostatic discharge.

MIC4421/4422 drivers can replace three or more discrete components, reducing PCB area requirements, simplifying product design, and reducing assembly cost.

Modern Bipolar/CMOS/DMOS construction guarantees freedom from latch-up. The rail-to-rail swing capability of CMOS/DMOS insures adequate gate voltage to the MOSFET during power up/down sequencing. Since these devices are fabricated on a self-aligned process, they have very low crossover current, run cool, use little power, and are easy to drive.

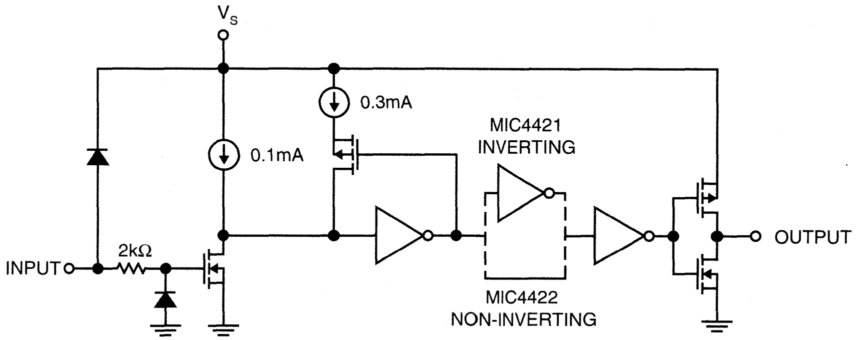
Features

- BiCMOS/DMOS Construction
- Latch-Up Proof: Fully Isolated Process is Inherently Immune to Any Latch-up.
- Input Will Withstand Negative Swing of Up to 5V
- Matched Rise and Fall Times 25ns
- High Peak Output Current .... 9A Peak
- Wide Operating Range .... 4.5V to 18V
- High Capacitive Load Drive 47,000pF
- Low Delay Time .... 30ns Typ.
- Logic High Input for Any Voltage from 2.4V to V_S
- Low Equivalent Input Capacitance (typ) 7pF
- Low Supply Current .... 450µA With Logic 1 Input
- Low Output Impedance 1.5Ω
- Output Voltage Swing to Within 25mV of GND or V_S
- MIL-STD-883 Method 5004/5005 Version Available

Applications

- Switch Mode Power Supplies
- Motor Controls
- Pulse Transformer Driver
- Class D Switching Amplifiers
- Line Drivers
- Driving MOSFET or IGBT Parallel Chip Modules
- Local Power ON/OFF Switch
- Pulse Generators

Functional Diagram

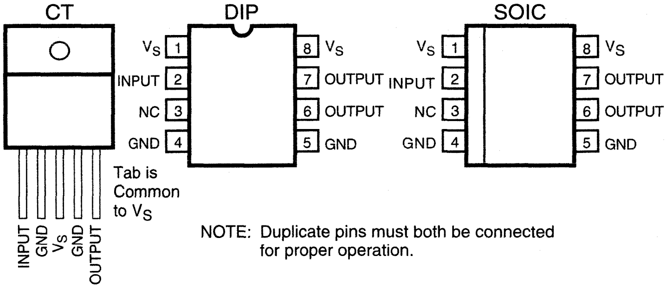


Ordering Information

Part No.	Temperature Range	Package	Configuration
MIC4421CN	0°C to +70°C	8-Pin PDIP	Inverting
MIC4421BN	–40°C to +85°C	8-Pin PDIP	Inverting
MIC4421CM	0°C to +70°C	8-Pin SOIC	Inverting
MIC4421BM	–40°C to +85°C	8-Pin SOIC	Inverting
MIC4421AJ	–55°C to +125°C	8-Pin CerDIP	Inverting
MIC4421CT	0°C to +70°C	5-Pin TO-220	Inverting
MIC4422CN	0°C to +70°C	8-Pin PDIP	Non-Inverting
MIC4422BN	–40°C to +85°C	8-Pin PDIP	Non-Inverting
MIC4422CM	0°C to +70°C	8-Pin SOIC	Non-Inverting
MIC4422BM	–40°C to +85°C	8-Pin SOIC	Non-Inverting
MIC4422AJ	–55°C to +125°C	8-Pin CerDIP	Non-Inverting
MIC4422CT	0°C to +70°C	5-Pin TO-220	Non-Inverting

For Standard Military Drawing equivalent drivers, see the MIC4451/4452 data sheet.

Pin Configurations



NOTE: Duplicate pins must both be connected for proper operation.

Absolute Maximum Ratings (Notes 1, 2 and 3)

Power Dissipation, $T_{AMBIENT} \leq 25°C$	
PDIP	960mW
SOIC	1040mW
CerDIP	1250mW
5-Pin TO-220	2W
Power Dissipation, $T_{CASE} \leq 25°C$	
5-Pin TO-220	12.5W
Derating Factors (To Ambient)	
PDIP	7.7mW/°C
SOIC	8.3mW/°C
CerDIP	10mW/°C
5-Pin TO-220	17mW/°C

Thermal Impedances (To Case)	
5-Pin TO-220 $R_{\theta J\text{-}C}$	10°C/W
Storage Temperature	–65°C to +150°C
Operating Temperature (Chip)	150°C
Operating Temperature (Ambient)	
C Version	0°C to +70°C
B Version	–40°C to +85°C
A Version	–55°C to +125°C
Lead Temperature (10 sec)	300°C
Supply Voltage	20V
Input Voltage	V_S + 0.3V to GND – 5V
Input Current ($V_{IN} > V_S$)	50 mA

Electrical Characteristics: (T_A = 25°C with 4.5 V ≤ V_S ≤ 18 V unless otherwise specified.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.4	1.3		V
V_{IL}	Logic 0 Input Voltage			1.1	0.8	V
V_{IN}	Input Voltage Range		–5		V_S + 0.3	V
I_{IN}	Input Current	0 V ≤ V_{IN} ≤ V_S	–10		10	µA
OUTPUT						
V_{OH}	High Output Voltage	See Figure 1	V_S–0.025			V
V_{OL}	Low Output Voltage	See Figure 1			0.025	V
R_O	Output Resistance, Output High	I_{OUT} = 10 mA, V_S = 18 V		0.6		Ω
R_O	Output Resistance, Output Low	I_{OUT} = 10 mA, V_S = 18 V		0.8	1.7	Ω
I_{PK}	Peak Output Current	V_S = 18 V (See Figure 5)		9		A
I_{DC}	Continuous Output Current		2			A
I_R	Latch-Up Protection Withstand Reverse Current	Duty Cycle ≤ 2% t ≤ 300 µs	>1500			mA
SWITCHING TIME (Note 3)						
t_R	Rise Time	Test Figure 1, C_L = 10,000 pF		20	75	ns
t_F	Fall Time	Test Figure 1, C_L = 10,000 pF		24	75	ns
t_{D1}	Delay Time	Test Figure 1		15	60	ns
t_{D2}	Delay Time	Test Figure 1		35	60	ns
Power Supply						
I_S	Power Supply Current	V_{IN} = 3 V V_{IN} = 0 V		0.4 80	1.5 150	mA µA
V_S	Operating Input Voltage		4.5		18	V

Electrical Characteristics:

(Over operating temperature range with 4.5V ≤ V_S ≤ 18V unless otherwise specified.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.4	1.4		V
V_{IL}	Logic 0 Input Voltage			1.0	0.8	V
V_{IN}	Input Voltage Range		–5		V_S + 0.3	V
I_{IN}	Input Current	0V ≤ V_{IN} ≤ V_S	–10		10	μA
OUTPUT						
V_{OH}	High Output Voltage	Figure 1	V_S–0.025			V
V_{OL}	Low Output Voltage	Figure 1			0.025	V
R_O	Output Resistance, Output High	I_{OUT} = 10mA, V_S = 18V		0.8	3.6	Ω
R_O	Output Resistance, Output Low	I_{OUT} = 10mA, V_S = 18V		1.3	2.7	Ω
SWITCHING TIME (Note 3)						
t_R	Rise Time	Figure 1, C_L = 10,000pF		23	120	ns
t_F	Fall Time	Figure 1, C_L = 10,000pF		30	120	ns
t_{D1}	Delay Time	Figure 1		20	80	ns
t_{D2}	Delay Time	Figure 1		40	80	ns
POWER SUPPLY						
I_S	Power Supply Current	V_{IN} = 3V V_{IN} = 0V		0.6 0.1	3 0.2	mA
V_S	Operating Input Voltage		4.5		18	V

NOTE 1: Functional operation above the absolute maximum stress ratings is not implied.
NOTE 2: Static-sensitive device. Store only in conductive containers. Handling personnel and equipment should be grounded to prevent damage from static discharge.
NOTE 3: Switching times guaranteed by design.

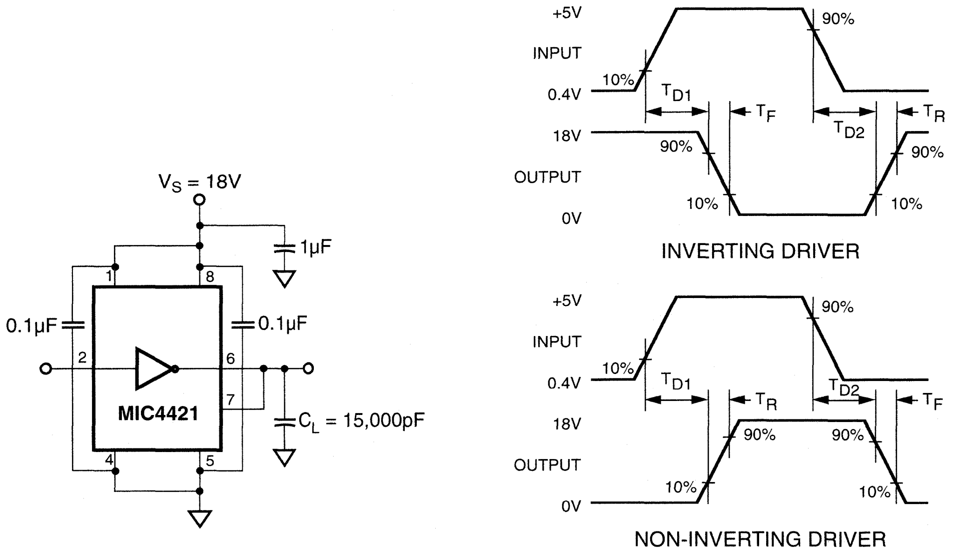
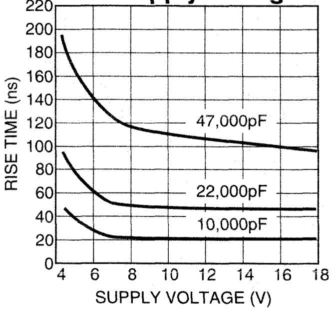


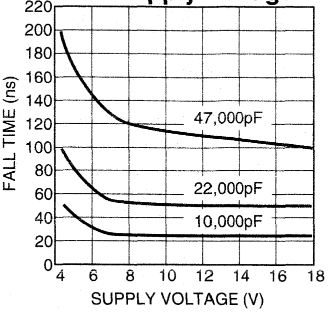
Figure 1. Switching Time Test Circuit

Typical Characteristic Curves

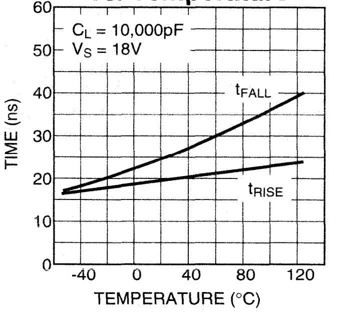
Rise Time vs. Supply Voltage



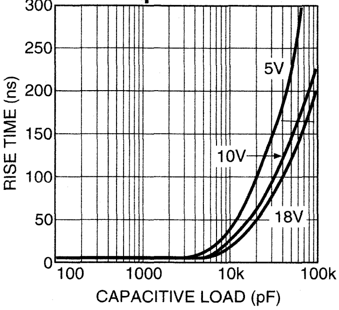
Fall Time vs. Supply Voltage



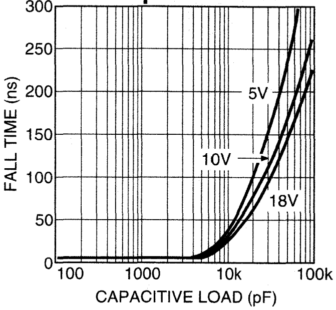
Rise and Fall Times vs. Temperature



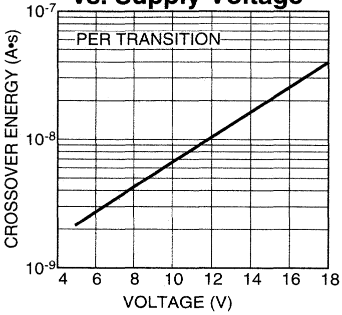
Rise Time vs. Capacitive Load



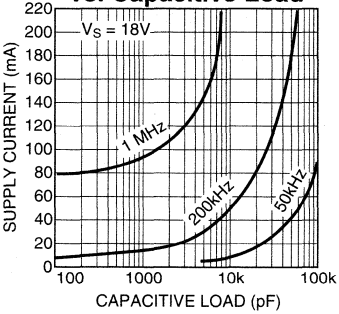
Fall Time vs. Capacitive Load



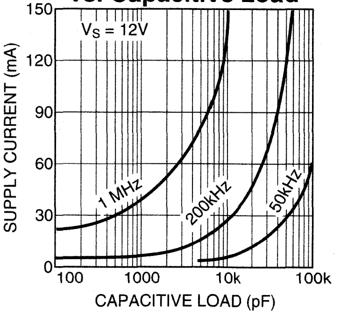
Crossover Energy vs. Supply Voltage



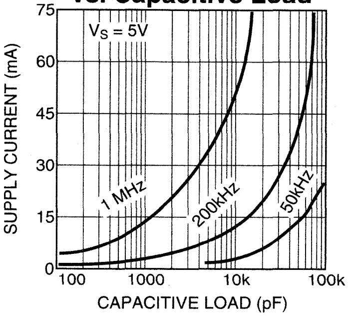
Supply Current vs. Capacitive Load



Supply Current vs. Capacitive Load

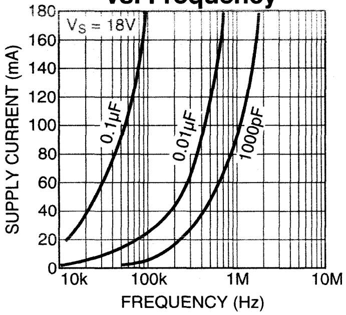


Supply Current vs. Capacitive Load

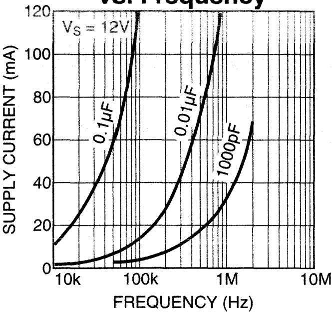


Typical Characteristic Curves (Cont.)

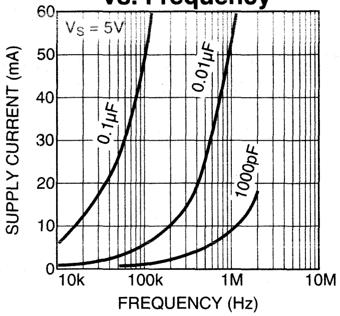
Supply Current vs. Frequency



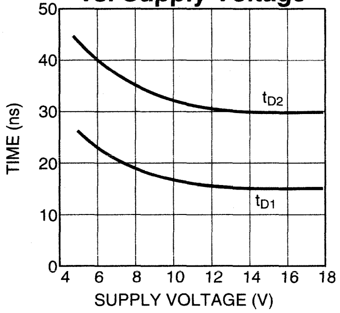
Supply Current vs. Frequency



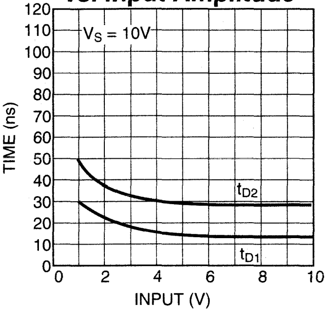
Supply Current vs. Frequency



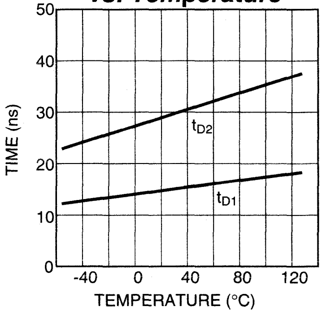
Propagation Delay vs. Supply Voltage



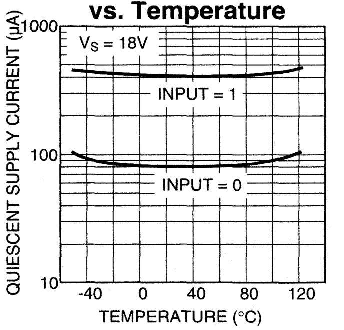
Propagation Delay vs. Input Amplitude



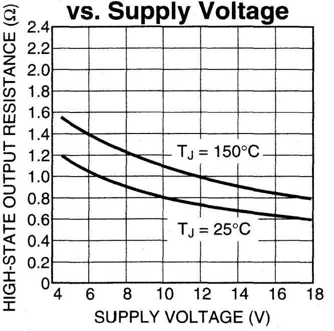
Propagation Delay vs. Temperature



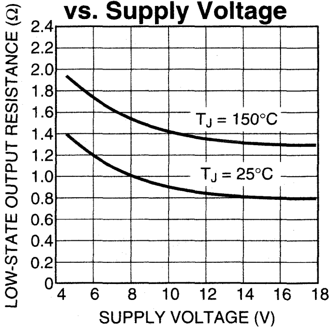
Quiescent Supply Current vs. Temperature



High-State Output Resist. vs. Supply Voltage



Low-State Output Resist. vs. Supply Voltage



Applications Information

Supply Bypassing

Charging and discharging large capacitive loads quickly requires large currents. For example, charging a 10,000pF load to 18V in 50ns requires 3.6A.

The MIC4421/4422 has double bonding on the supply pins, the ground pins and output pins. This reduces parasitic lead inductance. Low inductance enables large currents to be switched rapidly. It also reduces internal ringing that can cause voltage breakdown when the driver is operated at or near the maximum rated voltage.

Internal ringing can also cause output oscillation due to feedback. This feedback is added to the input signal since it is referenced to the same ground.

To guarantee low supply impedance over a wide frequency range, a parallel capacitor combination is recommended for supply bypassing. Low inductance ceramic disk capacitors with short lead lengths (< 0.5 inch) should be used. A 1µF low ESR film capacitor in parallel with two 0.1µF low ESR ceramic capacitors, (such as AVX RAM Guard®), provides adequate bypassing. Connect one ceramic capacitor directly between pins 1 and 4. Connect the second ceramic capacitor directly between pins 8 and 5.

Grounding

The high current capability of the MIC4421/4422 demands careful PC board layout for best performance. Since the MIC4421 is an inverting driver, any ground lead impedance will appear as negative feedback which can degrade switching speed. Feedback is especially noticeable with slow-rise time inputs. The MIC4421 input structure includes about 200mV of hysteresis to ensure clean transitions and freedom from oscillation, but attention to layout is still recommended.

Figure 5 shows the feedback effect in detail. As the MIC4421 input begins to go positive, the output goes negative and several amperes of current flow in the ground lead. As little as 0.05Ω of PC trace resistance can produce hundreds of millivolts at the MIC4421 ground pins. If the driving logic is referenced to power ground, the effective logic input level is reduced and oscillation may result.

To insure optimum performance, separate ground traces should be provided for the logic and power connections. Connecting the logic ground directly to the MIC4421 GND pins will ensure full logic drive to the input and ensure fast output switching. Both of the MIC4421 GND pins should, however, still be connected to power ground.

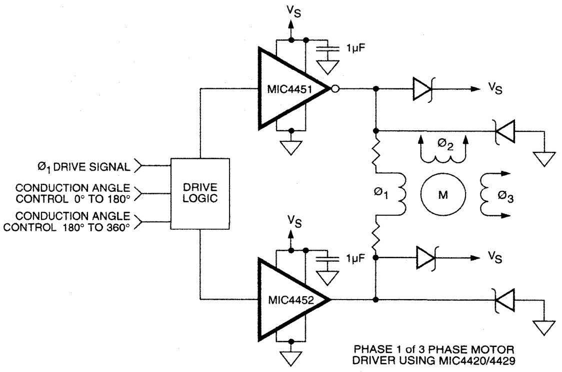


Figure 3. Direct Motor Drive

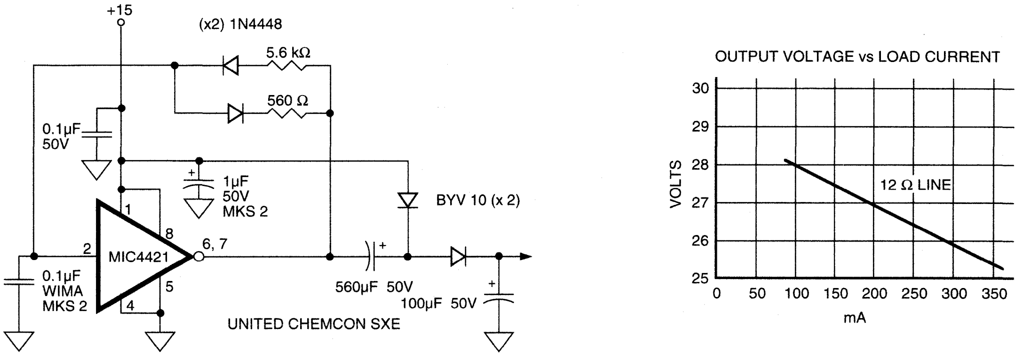


Figure 4. Self Contained Voltage Doubler

Input Stage

The input voltage level of the MIC4421 changes the quiescent supply current. The N channel MOSFET input stage transistor drives a 320µA current source load. With a logic "1" input, the maximum quiescent supply current is 400µA. Logic "0" input level signals reduce quiescent current to 80µA typical.

The MIC4421/4422 input is designed to provide 300mV of hysteresis. This provides clean transitions, reduces noise sensitivity, and minimizes output stage current spiking when changing states. Input voltage threshold level is approximately 1.5V, making the device TTL compatible over the full temperature and operating supply voltage ranges. Input current is less than ±10µA.

The MIC4421 can be directly driven by the TL494, SG1526/1527, SG1524, TSC170, MIC38C42, and similar switch mode power supply integrated circuits. By offloading the power-driving duties to the MIC4421/4422, the power supply controller can operate at lower dissipation. This can improve performance and reliability.

The input can be greater than the V_S supply, however, current will flow into the input lead. The input currents can be as high as 30mA p-p (6.4mA$_{RMS}$) with the input. No damage will occur to MIC4421/4422 however, and it will not latch.

The input appears as a 7pF capacitance and does not change even if the input is driven from an AC source. While the device will operate and no damage will occur up to 25V below the negative rail, input current will increase up to 1mA/V due to the clamping action of the input, ESD diode, and 1kΩ resistor.

Power Dissipation

CMOS circuits usually permit the user to ignore power dissipation. Logic families such as 4000 and 74C have outputs which can only supply a few milliamperes of current, and even shorting outputs to ground will not force enough current to destroy the device. The MIC4421/4422 on the other hand, can source or sink several amperes and drive large capacitive loads at high frequency. The package power dissipation limit can easily be exceeded. Therefore, some attention should be given to power dissipation when driving low impedance loads and/or operating at high frequency.

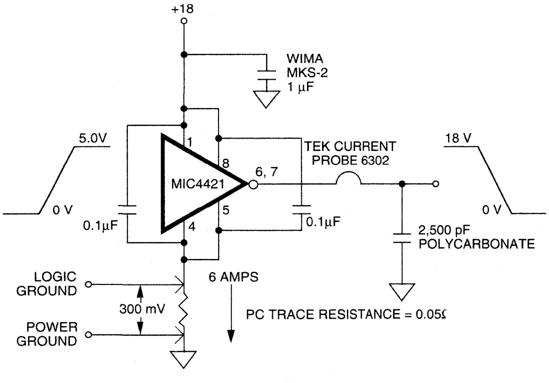


Figure 5. Switching Time Degradation Due to Negative Feedback

The supply current vs. frequency and supply current vs capacitive load characteristic curves aid in determining power dissipation calculations. Table 1 lists the maximum safe operating frequency for several power supply voltages when driving a 10,000pF load. More accurate power dissipation figures can be obtained by summing the three dissipation sources.

Given the power dissipation in the device, and the thermal resistance of the package, junction operating temperature for any ambient is easy to calculate. For example, the thermal resistance of the 8-pin CerDIP package, from the data sheet, is 150°C/W. In a 25°C ambient, then, using a maximum junction temperature of 150°C, this package will dissipate 800mW.

Accurate power dissipation numbers can be obtained by summing the three sources of power dissipation in the device:

- Load Power Dissipation (P_L)
- Quiescent power dissipation (P_Q)
- Transition power dissipation (P_T)

Calculation of load power dissipation differs depending on whether the load is capacitive, resistive or inductive.

Resistive Load Power Dissipation

Dissipation caused by a resistive load can be calculated as:

$$P_L = I^2 R_O D$$

where:

I = the current drawn by the load

R_O = the output resistance of the driver when the output is high, at the power supply voltage used. (See data sheet)

D = fraction of time the load is conducting (duty cycle)

Table 1: MIC4421 Maximum Operating Frequency

V_S	Max Frequency
18V	220kHz
15V	300kHz
10V	640kHz
5V	2MHz

Conditions: 1. CerDIP Package (θ_{JA} = 150°C/W)
2. T_A = 25°C
3. C_L = 10,000pF

Capacitive Load Power Dissipation

Dissipation caused by a capacitive load is simply the energy placed in, or removed from, the load capacitance by the driver. The energy stored in a capacitor is described by the equation:

$$E = 1/2\ C\ V^2$$

As this energy is lost in the driver each time the load is charged or discharged, for power dissipation calculations the 1/2 is removed. This equation also shows that it is good practice not to place more voltage in the capacitor than is necessary, as dissipation increases as the square of the voltage applied to the capacitor. For a driver with a capacitive load:

$$P_L = F\ C\ (V_S)^2$$

where:

F = Operating Frequency
C = Load Capacitance
V_S = Driver Supply Voltage

Inductive Load Power Dissipation

For inductive loads the situation is more complicated. For the part of the cycle in which the driver is actively forcing current into the inductor, the situation is the same as it is in the resistive case:

$$P_{L1} = I^2\ R_O\ D$$

However, in this instance the R_O required may be either the on resistance of the driver when its output is in the high state, or its on resistance when the driver is in the low state, depending on how the inductor is connected, and this is still only half the story. For the part of the cycle when the inductor is forcing current through the driver, dissipation is best described as

$$P_{L2} = I\ V_D\ (1 - D)$$

where V_D is the forward drop of the clamp diode in the driver (generally around 0.7V). The two parts of the load dissipation must be summed in to produce P_L

$$P_L = P_{L1} + P_{L2}$$

Quiescent Power Dissipation

Quiescent power dissipation (P_Q, as described in the input section) depends on whether the input is high or low. A low input will result in a maximum current drain (per driver) of ≤ 0.2mA; a logic high will result in a current drain of ≤ 3.0mA. Quiescent power can therefore be found from:

$$P_Q = V_S\ [D\ I_H + (1 - D)\ I_L]$$

where:

I_H = quiescent current with input high
I_L = quiescent current with input low
D = fraction of time input is high (duty cycle)
V_S = power supply voltage

Transition Power Dissipation

Transition power is dissipated in the driver each time its output changes state, because during the transition, for a very brief interval, both the N- and P-channel MOSFETs in the output totem-pole are ON simultaneously, and a current is conducted through them from V_S to ground. The transition power dissipation is approximately:

$$P_T = 2\ F\ V_S\ (A{\bullet}s)$$

where (A•s) is a time-current factor derived from the typical characteristic curve “Crossover Energy vs. Supply Voltage.”

Total power (P_D) then, as previously described is just

$$P_D = P_L + P_Q + P_T$$

Definitions

C_L = Load Capacitance in Farads.

D = Duty Cycle expressed as the fraction of time the input to the driver is high.

F = Operating Frequency of the driver in Hertz

I_H = Power supply current drawn by a driver when both inputs are high and neither output is loaded.

I_L = Power supply current drawn by a driver when both inputs are low and neither output is loaded.

I_D = Output current from a driver in Amps.

P_D = Total power dissipated in a driver in Watts.

P_L = Power dissipated in the driver due to the driver's load in Watts.

P_Q = Power dissipated in a quiescent driver in Watts.

P_T = Power dissipated in a driver when the output changes states (“shoot-through current”) in Watts. NOTE: The “shoot-through” current from a dual transition (once up, once down) for both drivers is stated in Figure 7 in ampere-nanoseconds. This figure must be multiplied by the number of repetitions per second (frequency) to find Watts.

R_O = Output resistance of a driver in Ohms.

V_S = Power supply voltage to the IC in Volts.

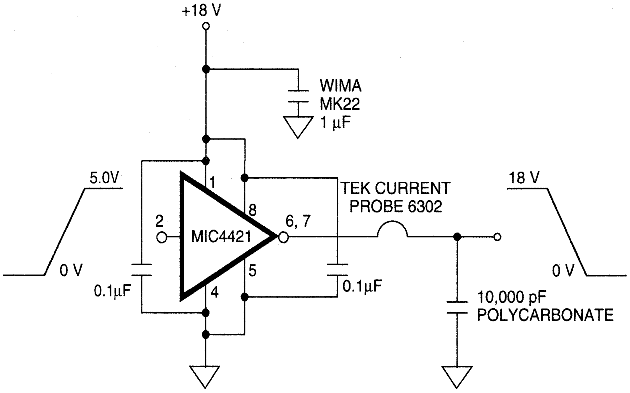


Figure 6. Peak Output Current Test Circuit

MIC4423/4424/4425

Dual 3A-Peak Low-Side MOSFET Driver

Bipolar/CMOS/DMOS Process

General Description

The MIC4423/4424/4425 family of parts are CMOS buffer/drivers built using a highly reliable BCD process. They are higher output current versions of the new MIC4426 family of buffer/drivers, which, in turn, are improved versions of the MIC426/427/428 family. All three families are pin-compatible. The MIC4423/24/25 drivers are capable of giving reliable service in far more demanding electrical environments than their antecedents. They will not latch under any conditions within their power and voltage ratings. They are not subject to damage when up to 5V of noise spiking, of either polarity, occurs on the ground pin. They can accept, without either damage or logic upset, up to half an amp of reverse current (of either polarity) being forced back into their outputs.

As a result, the MIC4423/24/25 series drivers are much easier to use, more flexible in operation, and much more forgiving than any other driver, CMOS or bipolar, currently available. Because they are fabricated in BiCMOS/DMOS, they dissipate a minimum of power, and provide rail-to-rail voltage swings to better insure the logic state of any load they drive.

Although primarily intended for driving power MOSFETs, the 4423/4424/4425 series drivers are equally well suited to driving any other load (capacitive, resistive, or inductive) which requires a low-impedance driver capable of high peak currents and fast switching times. For example, heavily loaded clock lines, coaxial cables, or piezoelectric transducers all can be driven from the MIC4423/24/25. The only known limitation on loading is that total power dissipated in the driver must be kept within the maximum power dissipation limits of the package.

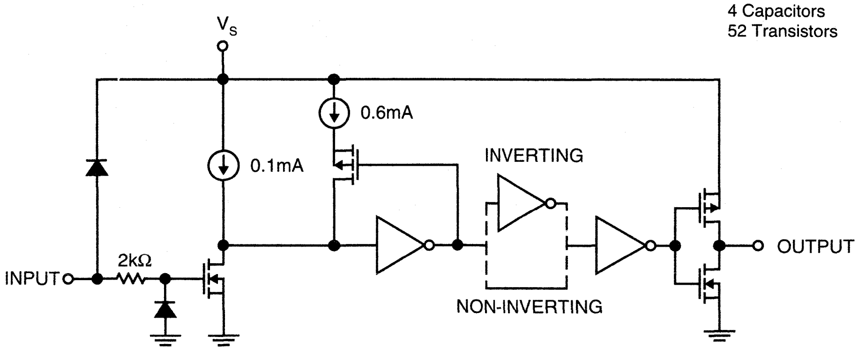
Features

- Built using reliable, low power Bipolar/CMOS/DMOS process
- Latch-Up Protected: Withstands >500mA Reverse Current
- Logic Input Will Withstand Negative Swing to –5V
- High Peak Output Current .... 3A Peak
- Wide Operating Range .... 4.5V to 18V
- High Capacitive Load
  Drive Capability .... 1800pF in 25ns
- Short Delay Times .... <40ns typ.
- Consistent Delay Times with Changes in Supply Voltage
- Matched Rise and Fall Times
- Logic High Input for Any Voltage From 2.4V to V_S
- Logic Input Threshold Independent of Supply Voltage
- Low Equivalent Input Capacitance (typ) 6pF
- Low Supply Current
  3.5mA with Logic 1 Inputs
  350µA with Logic 0 Inputs
- Low Output Impedance .... 3.5Ω typ.
- Output Voltage Swing to Within 25mV of Ground or V_S
- Pin-Out Same as MIC426/427/428
- Available in Inverting, Non-Inverting, and Differential Configurations
- ESD Protected
- MIL-STD-883 Method 5004/5005 version available

As MOSFET drivers, the MIC4423/24/25 can easily switch 1800pF gate capacitances in 25ns, and provide low enough impedances in both the ON and OFF states to assure that a MOSFET's intended state will not be affected even by large transients.

Functional Diagram

Integrated Component Count:
4 Resistors
4 Capacitors
52 Transistors



Functional Diagram for One Driver (Two Drivers per Package—Ground Unused Inputs)

Ordering Information

Part Number	Temperature Range	Package	Configuration
MIC4423CWM MIC4423BWM	0°C to +70°C –40°C to +85°C	16-Pin SO Wide	Dual Inverting
MIC4423CN MIC4423BN	0°C to +70°C –40°C to +85°C	8-Pin Plastic DIP	Dual Inverting
MIC4423AJ 5962-8850304PA[1]	–55°C to +125°C –55°C to +125°C	8-Pin CerDIP	Dual Inverting
MIC4424CWM MIC4424BWM	0°C to +70°C –40°C to +85°C	16-Pin SO Wide	Dual Non-Inverting
MIC4424CN MIC4424BN	0°C to +70°C –40°C to +85°C	8-Pin Plastic DIP	Dual Non-Inverting
MIC4424AJ 5962-8850305PA[2]	–55°C to +125°C –55°C to +125°C	8-Pin CerDIP	Dual Non-Inverting
MIC4425CWM MIC4425BWM	0°C to +70°C –40°C to +85°C	16-Pin SO Wide	Inverting + Non Inverting
MIC4425CN MIC4425BN	0°C to +70°C –40°C to +85°C	8-Pin Plastic DIP	Inverting + Non Inverting
MIC4425AJ 5962-8850306PA[3]	–55°C to +125°C –55°C to +125°C	8-Pin CerDIP	Inverting + Non Inverting

[1] Standard Military Drawing number for MIC4423AJBQ

[2] Standard Military Drawing number for MIC4424AJBQ

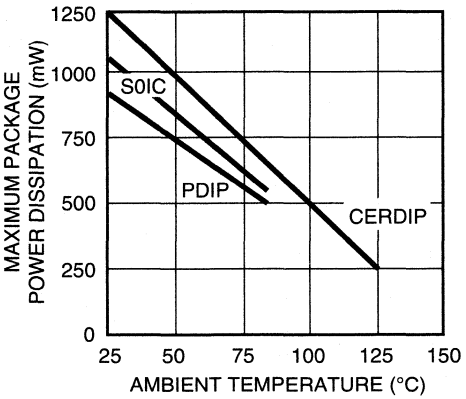
[3] Standard Military Drawing number for MIC4425AJBQ

Absolute Maximum Ratings (Notes 1, 2, and 3)

If Military/Aerospace specified devices are required, contact Micrel for availability and specifications.

Supply Voltage	22V
Input Voltage	V_S + 0.3V to GND – 5V
Maximum Chip Temperature	150°C
Storage Temperature Range	-65°C to 150°C
Lead Temperature (10 sec.)	300°C
Package Thermal Resistance	
CERDIP $R_{\theta J\text{-}A}$	100°C/W
CERDIP $R_{\theta J\text{-}C}$	50°C/W
PDIP $R_{\theta J\text{-}A}$	130°C/W
PDIP $R_{\theta J\text{-}C}$	42°C/W
SOIC $R_{\theta J\text{-}A}$	120°C/W
SOIC $R_{\theta J\text{-}C}$	75°C/W
Operating Temperature Range	
C Version	0°C to +70°C
B Version	–40°C to +85°C
A Version	–55°C to +125°C

Package Power Dissipation



MIC4423/4424/4425 Electrical Characteristics:

Specifications measured at T_A = 25°C with 4.5V ≤ V_S ≤ 18V unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.4			V
V_{IL}	Logic 0 Input Voltage				0.8	V
I_{IN}	Input Current	0V ≤ V_{IN} ≤ V_S	–1		1	μA
OUTPUT						
V_{OH}	High Output Voltage		V_S–0.025			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance HI State	I_{OUT} = 10mA, V_S = 18V		2.8	5	Ω
R_O	Output Resistance LO State	I_{OUT} = 10mA, V_S = 18V		3.5	5	Ω
I_{PK}	Peak Output Current			3		A
I	Latch-Up Protection Withstand Reverse Current		>500			mA
SWITCHING TIME						
T_R	Rise Time	Test Figure 1, C_L = 1800pF		23	35	ns
T_F	Fall Time	Test Figure 1, C_L = 1800pF		25	35	ns
T_{D1}	Delay TIme	Test Figure 1, C_L = 1800pF		33	75	ns
T_{D2}	Delay Time	Test Figure 1, C_L = 1800pF		38	75	ns
POWER SUPPLY						
I_S	Power Supply Current	V_{IN} = 3.0V (Both Inputs)		1.5	2.5	mA
I_S	Power Supply Current	V_{IN} = 0.0V (Both Inputs)		0.15	0.25	mA

MIC4423/4424/4425 Electrical Characteristics:

Specifications measured over operating temperature range with 4.5V ≤ V_S ≤ 18V unless otherwise specified.

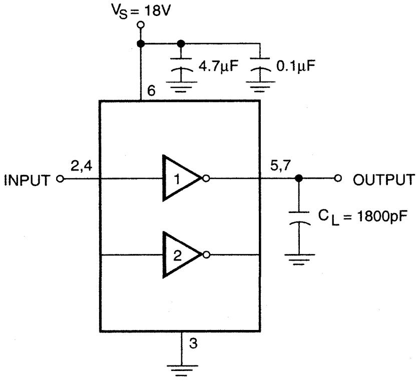
Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.4			V
V_{IL}	Logic 0 Input Voltage				0.8	V
I_{IN}	Input Current	0 ≤ V_{IN} ≤ V_S	–10		10	μA
OUTPUT						
V_{OH}	High Output Voltage		V_S–0.025			V
V_{OL}	Low Output Voltage				0.025	V

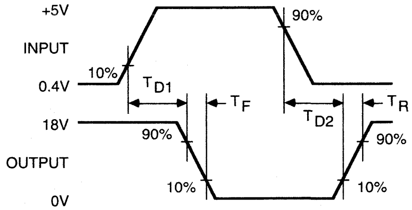
MIC4423/4424/4425 Electrical Characteristics:

Specifications measured over operating temperature range with 4.5V ≤ V_S ≤ 18V unless otherwise specified.

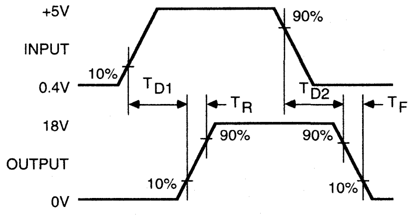
Symbol	Parameter	Conditions	Min	Typ	Max	Units
OUTPUT						
R_O	Output Resistance, Output High	V_{IN} = 0.8V I_{OUT} = 10mA, V_S = 18V		3.7	8	Ω
R_O	Output Resistance, Output Low	V_{IN} = 2.4V I_{OUT} = 10mA, V_S = 18V		4.3	8	Ω
SWITCHING TIME						
T_R	Rise Time	Test Figure 1, C_L = 1800pF		28	60	ns
T_F	Fall Time	Test Figure 1, C_L = 1800pF		32	60	ns
T_{D1}	Delay TIme	Test Figure 1, C_L = 1800pF		32	100	ns
T_{D2}	Delay Time	Test Figure 1, C_L = 1800pF		38	100	ns
POWER SUPPLY						
I_S	Power Supply Current	V_{IN} = 3.0V (Both Inputs)		2	3.5	mA
I_S	Power Supply Current	V_{IN} = 0.0V (Both Inputs)		0.20	0.3	mA

Note 1: Functional operation above the absolute maximum stress ratings is not implied.
Note 2: Static Sensitive device. Unused devices must be stored in conductive material to protect devices from static discharge and static fields.
Note 3: Switching times guaranteed by design.





INVERTING DRIVER

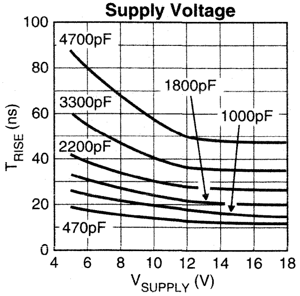


NON-INVERTING DRIVER

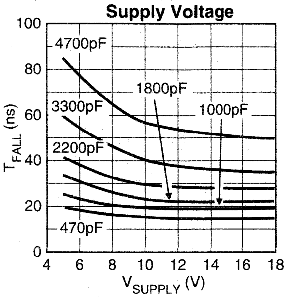
Figure 1. Switching Time Test Circuit

Typical Characteristic Curves

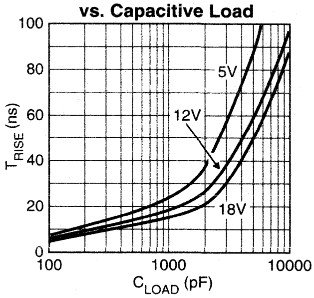
Rise Time vs. Supply Voltage



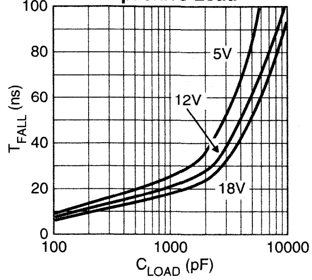
Fall Time vs. Supply Voltage



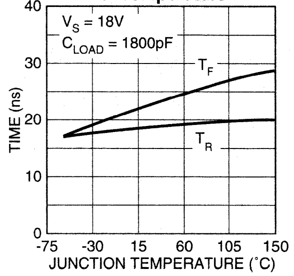
Rise Time vs. Capacitive Load



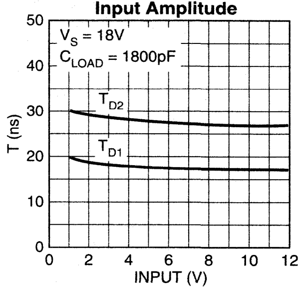
Fall Time vs. Capacitive Load



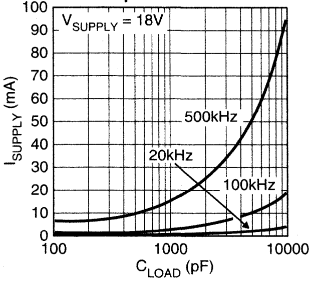
Rise and Fall Time vs. Temperature



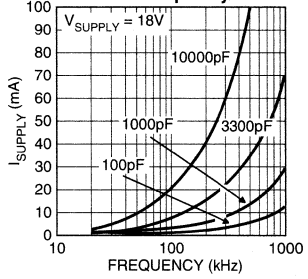
Propagation Delay vs. Input Amplitude



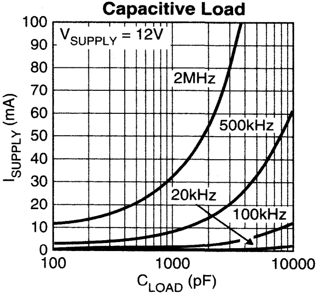
Supply Current vs. Capacitive Load



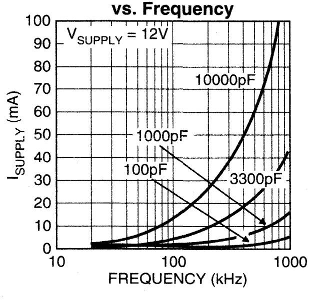
Supply Current vs. Frequency



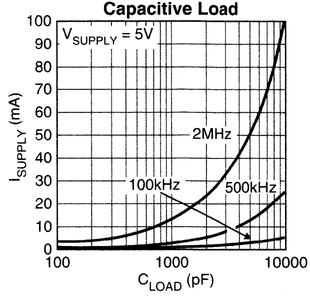
Supply Current vs. Capacitive Load



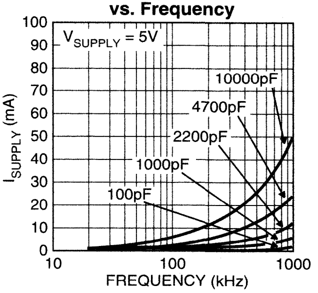
Supply Current vs. Frequency



Supply Current vs. Capacitive Load

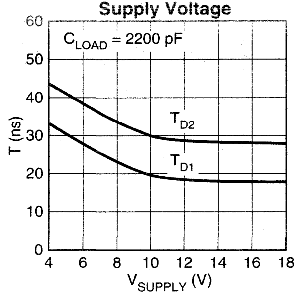


Supply Current vs. Frequency

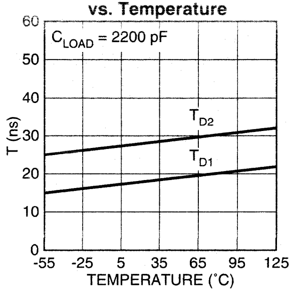


Typical Characteristic Curves (Continued)

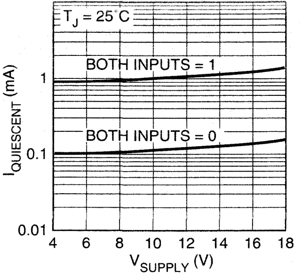
Delay Time vs. Supply Voltage



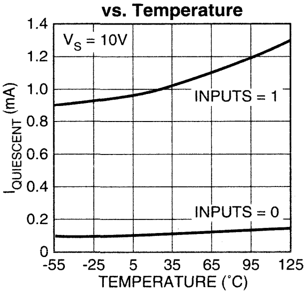
Delay Time vs. Temperature



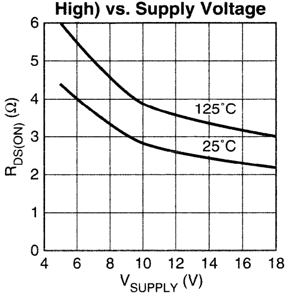
Quiescent Supply Current vs. Voltage



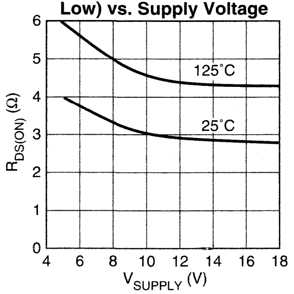
Quiescent Current vs. Temperature



Output Resistance (Output High) vs. Supply Voltage



Output Resistance (Output Low) vs. Supply Voltage



Application Information

Although the MIC4423/24/25 drivers have been specifically constructed to operate reliably under any practical circumstances, there are nonetheless details of usage which will provide better operation of the device.

Supply Bypassing

Charging and discharging large capacitive loads quickly requires large currents. For example, charging 2000pF from 0 to 15 volts in 20ns requires a constant current of 1.5A. In practice, the charging current is not constant, and will usually peak at around 3A. In order to charge the capacitor, the driver must be capable of drawing this much current, this quickly, from the system power supply. In turn, this means that as far as the driver is concerned, the system power supply, as seen by the driver, must have a **VERY** low impedance.

As a practical matter, this means that the power supply bus must be capacitively bypassed at the driver with at least 100X the load capacitance in order to achieve optimum driving speed. It also implies that the bypassing capacitor must have very low internal inductance and resistance at all frequencies of interest. Generally, this means using two capacitors, one a high-performance low ESR film, the other a low internal resistance ceramic, as together the valleys in their two impedance curves allow adequate performance over a broad enough band to get the job done. PLEASE NOTE that many film capacitors can be sufficiently inductive as to be useless for this service. Likewise, many multilayer ceramic capacitors have unacceptably high internal resistance. Use capacitors intended for high pulse current service (in-house we use WIMA™ film capacitors and AVX Ramguard™ ceramics; several other manufacturers of equivalent devices also exist). The high pulse current demands of capacitive drivers also mean that the bypass capacitors must be mounted very close to the driver in order to prevent the effects of lead inductance or PCB land inductance from nullifying what you are trying to accomplish. For optimum results the sum of the lengths of the leads and the lands from the capacitor body to the driver body should total 2.5cm or less.

Bypass capacitance, and its close mounting to the driver serves two purposes. Not only does it allow optimum performance from the driver, it minimizes the amount of lead length radiating at high frequency during switching, (due to the large Δ I) thus minimizing the amount of EMI later available for system disruption and subsequent cleanup. It should also be noted that the actual frequency of the EMI produced by a driver is not the clock frequency at which it is driven, but is related to the highest rate of change of current produced during switching, a frequency generally one or two orders of magnitude higher, and thus more difficult to filter if you let it permeate your system. ***Good bypassing practice is essential to proper operation of high speed driver ICs.***

Grounding

Both proper bypassing and proper grounding are necessary for optimum driver operation. Bypassing capacitance only allows a driver to turn the load ON. Eventually (except in rare circumstances) it is also necessary to turn the load OFF. This requires attention to the ground path. Two things other than the driver affect the rate at which it is possible to turn a load off: The adequacy of the grounding available for the driver, and the inductance of the leads from the driver to the load. The latter will be discussed in a separate section.

Best practice for a ground path is obviously a well laid out ground plane. However, this is not always practical, and a poorly-laid out ground plane can be worse than none. Attention to the paths taken by return currents even in a ground plane is essential. In general, the leads from the driver to its load, the driver to the power supply, and the driver to whatever is driving it should all be as low in resistance and inductance as possible. Of the three paths, the ground lead from the driver to the logic driving it is most sensitive to resistance or inductance, and ground current from the load are what is most likely to cause disruption. Thus, these ground paths should be arranged so that they never share a land, or do so for as short a distance as is practical.

To illustrate what can happen, consider the following: The inductance of a 2cm long land, 1.59mm (0.062") wide on a PCB with no ground plane is approximately 45nH. Assuming a dI/dt of 0.3A/ns (which will allow a current of 3A to flow after 10ns, and is thus slightly slow for our purposes) a voltage of 13.5 Volts will develop along this land in response to our postulated ΔI. For a 1cm land, (approximately 15nH) 4.5 Volts is developed. Either way, anyone using TTL-level input signals to the driver will find that the response of their driver has been seriously degraded by a common ground path for input to and output from the driver of the given dimensions. Note that this is before accounting for any resistive drops in the circuit. The resistive drop in a 1.59mm (0.062") land of 2oz. Copper carrying 3A will be about 4mV/cm (10mV/in) at DC, and the resistance will increase with frequency as skin effect comes into play.

The problem is most obvious in inverting drivers where the input and output currents are in phase so that any attempt to raise the driver's input voltage (in order to turn the driver's load off) is countered by the voltage developed on the common ground path as the driver attempts to do what it was supposed to. It takes very little common ground path, under these circumstances, to alter circuit operation drastically.

Output Lead Inductance

The same descriptions just given for PCB land inductance apply equally well for the output leads from a driver to its load, except that commonly the load is located much further away from the driver than the driver's ground bus.

Generally, the best way to treat the output lead inductance problem, when distances greater than 4cm (2") are involved, requires treating the output leads as a transmission line. Unfortunately, as both the output impedance of the driver and the input impedance of the MOSFET gate are at least an order of magnitude lower than the impedance of common coax, using coax is seldom a cost-effective solution. A twisted pair works about as well, is generally lower in cost, and allows use of a wider variety of connectors. The second wire of the twisted pair should carry common from as close as possible to the ground pin of the driver directly to the ground terminal of the load. Do not use a twisted pair where the second wire in the pair is the output of the other driver, as this will not provide a complete current path for either driver. Likewise, do not use a twisted triad with two outputs and a common return unless both of the loads to be driver are mounted extremely close to each other, and you can guarantee that they will never be switching at the same time.

For output leads on a printed circuit, the general rule is to make them as short and as wide as possible. The lands should also be treated as transmission lines: i.e. minimize sharp bends, or narrowings in the land, as these will cause ringing. For a rough estimate, on a 1.59mm (0.062") thick G-10 PCB a pair of opposing lands each 2.36mm (0.093") wide translates to a characteristic impedance of about 50Ω. Half that width suffices on a 0.787mm (0.031") thick board. For accurate impedance matching with a MIC4423/24/25 driver, on a 1.59mm (0.062") board a land width of 42.75mm (1.683") would be required, due to the low impedance of the driver and (usually) its load. This is obviously impractical under most circumstances. Generally the tradeoff point between lands and wires comes when lands narrower than 3.18mm (0.125") would be required on a 1.59mm (0.062") board.

To obtain minimum delay between the driver and the load, it is considered best to locate the driver as close as possible to the load (using adequate bypassing). Using matching transformers at both ends of a piece of coax, or several matched lengths of coax between the driver and the load, works in theory, but is not optimum.

Driving At Controlled Rates

Occasionally there are situations where a controlled rise or fall time (which may be considerably longer than the normal rise or fall time of the driver's output) is desired for a load. In such cases it is still prudent to employ best possible practice in terms of bypassing, grounding and PCB layout, and then reduce the switching speed of the load (NOT the driver) by adding a noninductive series resistor of appropriate value between the output of the driver and the load. For situations where only rise or only fall should be slowed, the resistor can be paralleled with a fast diode so that switching in the other direction remains fast. Due to the Schmitt-trigger action of the driver's input it is not possible to slow the rate of rise (or fall) of the driver's input signal to achieve slowing of the output.

Input Stage

The input stage of the MIC4423/24/25 consists of a single-MOSFET class A stage with an input capacitance of ≤38pF. This capacitance represents the maximum load from the driver that will be seen by its controlling logic. The drain load on the input MOSFET is a –2mA current source. Thus, the quiescent current drawn by the driver varies, depending on the logic state of the input.

Following the input stage is a buffer stage which provides ~400mV of hysteresis for the input, to prevent oscillations when slowly-changing input signals are used or when noise is present on the input. Input voltage switching threshold is approximately 1.5V which makes the driver directly compatible with TTL signals, or with CMOS powered from any supply voltage between 3V and 15V.

The MIC4423/24/25 drivers can also be driven directly by the SG1524/25/26/27, TL494/95, TL594/95, NE5560/61/62/68, TSC170, MIC38C42, and similar switch mode power supply ICs. By relocating the main switch drive function into the driver rather than using the somewhat limited drive capabilities of a PWM IC. The PWM IC runs cooler, which generally improves its performance and longevity, and the main switches switch faster, which reduces switching losses and increase system efficiency.

The input protection circuitry of the MIC4423/24/25, in addition to providing 2kV or more of ESD protection, also works to prevent latchup or logic upset due to ringing or voltage spiking on the logic input terminal. In most CMOS devices when the logic input rises above the power supply terminal, or descends below the ground terminal, the device can be destroyed or rendered inoperable until the power supply is cycled OFF and ON. The MIC4423/24/25 drivers have been designed to prevent this. Input voltages excursions as great as 5V below ground will not alter the operation of the device. Input excursions above the power supply voltage will result in the excess voltage being conducted to the power supply terminal of the IC. Because the excess voltage is simply conducted to the power terminal, if the input to the driver is left in a high state when the power supply to the driver is turned off, currents as high as 30mA can be conducted through the driver from the input terminal to its power supply terminal. This may overload the output of whatever is driving the driver, and may cause other devices that share the driver's power supply, as well as the driver, to operate when they are assumed to be off, but it will not harm the driver itself. Excessive input voltage will also slow the driver down, and result in much longer internal propagation delays within the drivers. T_{D2}, for example, may increase to several hundred nanoseconds. In general, while the driver will accept this sort of misuse without damage, proper termination of the line feeding the driver so that line spiking and ringing are minimized, will always result in faster and more reliable operation of the device, leave less EMI to be filtered elsewhere, be less stressful to other components in the circuit, and leave less chance of unintended modes of operation.

Power Dissipation

CMOS circuits usually permit the user to ignore power dissipation. Logic families such as 4000 series and 74Cxxx have outputs which can only source or sink a few milliamps of current, and even shorting the output of the device to ground or V_{CC} may not damage the device. CMOS drivers, on the other hand, are intended to source or sink several Amps of current. This is necessary in order to drive large capacitive loads at frequencies into the megahertz range. Package power dissipation of driver ICs can easily be exceeded when driving large loads at high frequencies. Care must therefore be paid to device dissipation when operating in this domain.

The Supply Current vs Frequency and Supply Current vs Load characteristic curves furnished with this data sheet aid in estimating power dissipation in the driver. Operating frequency, power supply voltage, and load all affect power dissipation.

Given the power dissipation in the device, and the thermal resistance of the package, junction operating temperature for any ambient is easy to calculate. For example, the thermal resistance of the 8-pin CerDIP package, from the datasheet, is 150°C/W. In a 25°C ambient, then, using a maximum junction temperature of 150°C, this package will dissipate 800mW.

Accurate power dissipation numbers can be obtained by summing the three sources of power dissipation in the device:

- Load power dissipation (P_L)
- Quiescent power dissipation (P_Q)
- Transition power dissipation (P_T)

Calculation of load power dissipation differs depending on whether the load is capacitive, resistive or inductive.

Resistive Load Power Dissipation

Dissipation caused by a resistive load can be calculated as:

$$P_L = I^2 R_O D$$

where:

I = the current drawn by the load
R_O = the output resistance of the driver when the output is high, at the power supply voltage used (See characteristic curves)
D = fraction of time the load is conducting (duty cycle)

Capacitive Load Power Dissipation

Dissipation caused by a capacitive load is simply the energy placed in, or removed from, the load capacitance by the driver. The energy stored in a capacitor is described by the equation:

$$E = 1/2\ C\ V^2$$

As this energy is lost in the driver each time the load is charged or discharged, for power dissipation calculations the 1/2 is removed. This equation also shows that it is good practice not to place more voltage in the capacitor than is necessary, as dissipation increases as the square of the voltage applied to the capacitor. For a driver with a capacitive load:

$$P_L = F\ C\ (V_S)^2$$

where:

F = Operating Frequency
C = Load Capacitance
V_S = Driver Supply Voltage

Inductive Load Power Dissipation

For inductive loads the situation is more complicated. For the part of the cycle in which the driver is actively forcing current into the inductor, the situation is the same as it is in the resistive case:

$$P_{L1} = I^2 R_O D$$

However, in this instance the R_O required may be either the on resistance of the driver when its output is in the high state, or its on resistance when the driver is in the low state, depending on how the inductor is connected, and this is still only half the story. For the part of the cycle when the inductor is forcing current through the driver, dissipation is best described as

$$P_{L2} = I\ V_D\ (1 - D)$$

where V_D is the forward drop of the clamp diode in the driver (generally around 0.7V). The two parts of the load dissipation must be summed in to produce P_L

$$P_L = P_{L1} + P_{L2}$$

Quiescent Power Dissipation

Quiescent power dissipation (P_Q, as described in the input section) depends on whether the input is high or low. A low input will result in a maximum current drain (per driver) of ≤0.2mA; a logic high will result in a current drain of ≤2.0mA. Quiescent power can therefore be found from:

$$P_Q = V_S\ [D\ I_H + (1 - D)\ I_L]$$

where:

I_H = quiescent current with input high
I_L = quiescent current with input low
D = fraction of time input is high (duty cycle)
V_S = power supply voltage

Transition Power Dissipation

Transition power is dissipated in the driver each time its output changes state, because during the transition, for a very brief interval, both the N- and P-channel MOSFETs in the output totem-pole are ON simultaneously, and a current is conducted through them from V_S to ground. The transition power dissipation is approximately:

$$P_T = F\ V_S\ (A•s)$$

where (A•s) is a time-current factor derived from Figure 2.

Total power (P_D) then, as previously described is just

$$P_D = P_L + P_Q + P_T$$

Examples show the relative magnitude for each term.

EXAMPLE 1: A MIC4423 operating on a 12V supply driving two capacitive loads of 3000pF each, operating at 250kHz, with a duty cycle of 50%, in a maximum ambient of 60°C.

First calculate load power loss:

$$P_L = F \times C \times (V_S)^2$$
$$P_L = 250{,}000 \times (3 \times 10^{-9} + 3 \times 10^{-9}) \times 12^2 = 0.2160\text{W}$$

Then transition power loss:

$$P_T = F \times V_S \times (A•s)$$
$$= 250{,}000 • 12 • 2.2 \times 10^{-9} = 6.6\text{mW}$$

Then quiescent power loss:

$$\begin{aligned} P_Q &= V_S \times [D \times I_H + (1 - D) \times I_L] \\ &= 12 \times [(0.5 \times 0.0035) + (0.5 \times 0.0003)] \\ &= 0.0228\text{W} \end{aligned}$$

Total power dissipation, then, is:

$$\begin{aligned} P_D &= 0.2160 + 0.0066 + 0.0228 \\ &= 0.2454\text{W} \end{aligned}$$

Assuming an SOIC package, with an $R_{\theta J\text{-}A}$ of 120°C/W, this will result in the junction running at:

$$0.2454 \times 120 = 29.4°\text{C}$$

above ambient, which, given a maximum ambient temperature of 60°C, will result in a maximum junction temperature of 89.4°C.

EXAMPLE 2: A MIC4424 operating on a 15V input, with one driver driving a 50Ω resistive load at 1MHz, with a duty cycle of 67%, and the other driver quiescent, in a maximum ambient temperature of 40°C:

$$P_L = I^2 \times R_O \times D$$

First, I_O must be determined.

$$I_O = V_S / (R_O + R_{LOAD})$$

Given R_O from the characteristic curves then,

$$I_O = 15 / (3.3 + 50)$$

$$I_O = 0.281\text{A}$$

and:

$$\begin{aligned} P_L &= (0.281)^2 \times 3.3 \times 0.67 \\ &= 0.174\text{W} \\ P_T &= F \times V_S \times (A{\bullet}s)/2 \end{aligned}$$

(because only one side is operating)

$$\begin{aligned} &= (1{,}000{,}000 \times 15 \times 3.3 \times 10^{-9}) / 2 \\ &= 0.025\text{ W} \end{aligned}$$

and:

$$\begin{aligned} P_Q = 15 \times [&(0.67 \times 0.00125) + (0.33 \times 0.000125) + \\ &(1 \times 0.000125)] \end{aligned}$$

(this assumes that the unused side of the driver has its input grounded, which is more efficient)

$$= 0.015\text{W}$$

then:

$$\begin{aligned} P_D &= 0.174 + 0.025 + 0.0150 \\ &= 0.213\text{W} \end{aligned}$$

In a ceramic package with an $R_{\theta J\text{-}A}$ of 100°C/W, this amount of power results in a junction temperature given the maximum 40°C ambient of:

$$(0.213 \times 100) + 40 = 61.4°\text{C}$$

The actual junction temperature will be lower than calculated both because duty cycle is less than 100% and because the graph lists $R_{DS(on)}$ at a T_J of 125°C and the $R_{DS(on)}$ at 61°C T_J will be somewhat lower.

Definitions

C_L = Load Capacitance in Farads.

D = Duty Cycle expressed as the fraction of time the input to the driver is high.

F = Operating Frequency of the driver in Hertz

I_H = Power supply current drawn by a driver when both inputs are high and neither output is loaded.

I_L = Power supply current drawn by a driver when both inputs are low and neither output is loaded.

I_D = Output current from a driver in Amps.

P_D = Total power dissipated in a driver in Watts.

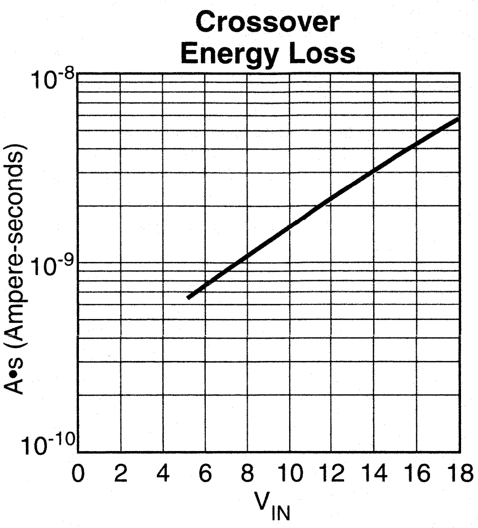
P_L = Power dissipated in the driver due to the driver's load in Watts.

P_Q = Power dissipated in a quiescent driver in Watts.

P_T = Power dissipated in a driver when the output changes states ("shoot-through current") in Watts. NOTE: The "shoot-through" current from a dual transition (once up, once down) for both drivers is stated in the graph on the following page in ampere-nanoseconds. This figure must be multiplied by the number of repetitions per second (frequency to find Watts).

R_O= Output resistance of a driver in Ohms.

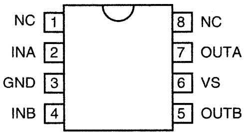
V_S= Power supply voltage to the IC in Volts.



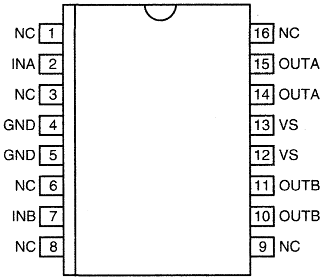
NOTE: THE VALUES ON THIS GRAPH REPRESENT THE LOSS SEEN BY BOTH DRIVERS IN A PACKAGE DURING ONE COMPLETE CYCLE. FOR A SINGLE DRIVER DIVIDE THE STATED VALUES BY 2. FOR A SINGLE TRANSITION OF A SINGLE DRIVER, DIVIDE THE STATED VALUE BY 4.

Figure 2.

Pin Configuration



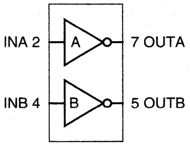
8-pin DIP (N,J)



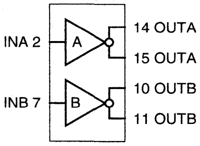
16-lead Wide SOIC (WM)

Driver Configuration

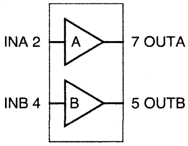
MIC4423xN/J



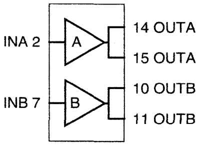
MIC4423xWM



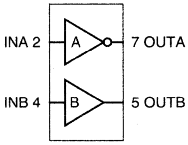
MIC4424xN/J



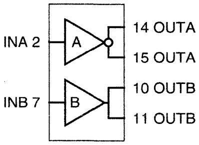
MIC4424xWM



MIC4425xN/J



MIC4425xWM



WM Package Note

Duplicate GND, VS, OUTA, *and* OUTB *pins must be externally connected together.*

MIC4426/4427/4428

Dual 1.5A-Peak Low-Side MOSFET Driver

Bipolar/CMOS/DMOS Process

General Description

The MIC4426/4427/4428 family of buffer/drivers are built using a new, highly reliable BiCMOS/DMOS process. They are improved versions of the MIC426/427/428 family of buffer/drivers (with which they are pin compatible) and are capable of giving reliable service in far more demanding electrical environments: they will not latch under any conditions within their power and voltage ratings. They are not subject to damage when up to 5V of noise spiking, of either polarity, occurs on the ground pin. They can accept, without either damage or logic upset, up to half an amp of reverse current (of either polarity) being forced back into their outputs.

As a result, the MIC4426/27/28 series drivers are much easier to use, more flexible in operation, and much more forgiving than any other driver, CMOS or bipolar, currently available. Because they are fabricated in BiCMOS/DMOS, they dissipate a minimum of power, and provide rail-to-rail voltage swings to better insure the logic state of any load they are driving.

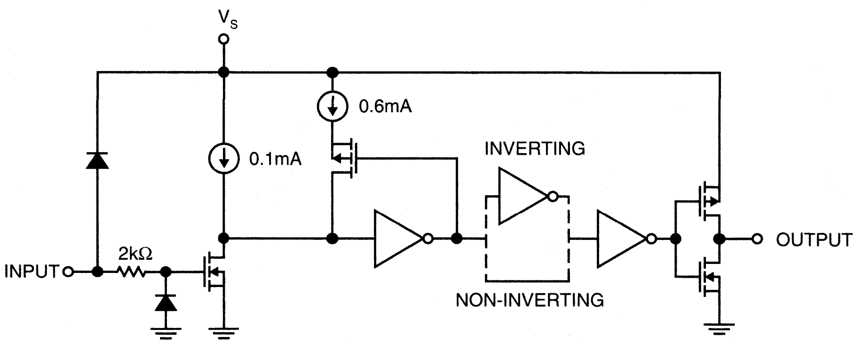
Although primarily intended for driving power MOSFETs, the 4426/4427/4428 series drivers are equally well suited to driving any other load (capacitive, resistive, or inductive) which requires a low-impedance driver capable of high peak currents and fast switching times. For example, heavily loaded clock lines, coaxial cables, or piezoelectric transducers all can be driven from the MIC4426/27/28. The only known limitation on loading is that total power dissipated in the driver must be kept within the maximum power dissipation limits of the package.

Features

- Built using reliable, low power Bipolar/CMOS/DMOS processes
- Latch-Up Protected: Withstands >500mA Reverse Current
- Logic Input Will Withstand Negative Swing Up to 5V
- High Peak Output Current .... 1.5A Peak
- Wide Operating Range .... 4.5V to 18V
- High Capacitive Load
  Drive Capability .... 1000pF in 25ns
- Short Delay Times .... <40ns typ.
- Consistent Delay Times with Changes in Supply Voltage
- Matched Rise and Fall Times
- Logic High Input for Any Voltage From 2.4V to V_S
- Logic Input Threshold Independent of Supply Voltage
- Low Equivalent Input Capacitance (typ) 6pF
- Low Supply Current
  - 4 mA with Logic 1 Inputs
  - 400 µA with Logic 0 Inputs
- Low Output Impedance 7Ω
- Output Voltage Swing to Within 25mV of Ground or V_S
- Pin-Out Same as MIC426/427/428
- Available in Inverting, Non-Inverting, and Differential Configurations
- ESD Protected
- MIL-STD-883 Method 5004/5005 version available

As MOSFET drivers, the MIC4426/27/28 can easily switch 1000pF gate capacitances in under 30ns, and provide low enough impedances in both the ON and OFF states to assure that a MOSFET's intended state will not be affected even by large transients.

Functional Diagram



Functional Diagram for One Driver (Two Drivers per Package—Ground Unused Inputs)

Ordering Information

Part Number	Temperature Range	Package	Configuration
MIC4426CM MIC4426BM	0°C to +70°C –40°C to+85°C	8-Pin SOIC	Dual Inverting
MIC4426CN MIC4426BN	0°C to +70°C –40°C to +85°C	8-Pin Plastic DIP	Dual Inverting
MIC4426AJ 5962-8850307PA[1]	–55°C to +125°C –55°C to +125°C	8-Pin CerDIP	Dual Inverting
MIC4427CM MIC4427BM	0°C to +70°C –40°C to +85°C	8-Pin SOIC	Dual Non-Inverting
MIC4427CN MIC4427BN	0°C to +70°C –40°C to +85°C	8-Pin Plastic DIP	Dual Non-Inverting
MIC4427AJ 5962-8850308PA[2]	–55°C to +125°C –55°C to +125°C	8-Pin CerDIP	Dual Non-Inverting
MIC4428CM MIC4428BM	0°C to +70°C –40°C to +85°C	8-Pin SOIC	Inverting + Non-Inverting
MIC4428CN MIC4428BN	0°C to +70°C –40°C to +85°C	8-Pin Plastic DIP	Inverting + Non-Inverting
MIC4428AJ 5962-8850309PA[3]	–55°C to +125°C –55°C to +125°C	8-Pin CerDIP	Inverting + Non-Inverting

[1] Standard Military Drawing number for MIC4426AJBQ
[2] Standard Military Drawing number for MIC4427AJBQ
[3] Standard Military Drawing number for MIC4428AJBQ

Absolute Maximum Ratings (Notes 1 and 2)

If Military/Aerospace specified devices are required, contact Micrel for availability and specifications.

Supply Voltage	22 V
Input Voltage	V_S + 0.3V to GND – 5V
Maximum Chip Temperature	150°C
Storage Temperature Range	–65°C to 150°C
Lead Temperature (10 sec.)	300°C
Package Thermal Resistance	
CERDIP $R_{\theta J\text{-}A}$	100°C/W
CERDIP $R_{\theta J\text{-}C}$	50°C/W
PDIP $R_{\theta J\text{-}A}$	130°C/W
PDIP $R_{\theta J\text{-}C}$	42°C/W
SOIC $R_{\theta J\text{-}A}$	120°C/W
SOIC $R_{\theta J\text{-}C}$	75°C/W
Operating Temperature Range	
C Version	0°C to +70°C
B Version	–40°C to +85°C
A Version	–55°C to +125°C

MIC4426/4427/4428 Electrical Characteristics:

Specifications measured at $T_A = 25°C$ with $4.5V \le V_S \le 18V$ unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.4	1.4		V
V_{IL}	Logic 0 Input Voltage			1.1	0.8	V
I_{IN}	Input Current	$0 \le V_{IN} \le V_S$	–1		1	µA
OUTPUT						
V_{OH}	High Output Voltage		V_S–0.025			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance	I_{OUT} = 10mA, V_S = 18V		6	10	Ω
I_{PK}	Peak Output Current			1.5		A
I	Latch-Up Protection Withstand Reverse Current		>500			mA
SWITCHING TIME						
T_R	Rise Time	Test Figure 1		18	30	ns
T_F	Fall Time	Test Figure 1		23	30	ns
T_{D1}	Delay TIme	Test FIgure 1		17	30	ns
T_{D2}	Delay Time	Test Figure 1		23	50	ns
POWER SUPPLY						
I_S	Power Supply Current	V_{IN} = 3.0V (Both Inputs)		1.4	4.5	mA
I_S	Power Supply Current	V_{IN} = 0.0V (Both Inputs)		0.18	0.4	mA

MIC4426/4427/4428 Electrical Characteristics:

Specifications measured over operating temperature range with $4.5V \le V_S \le 18V$ unless otherwise specified.

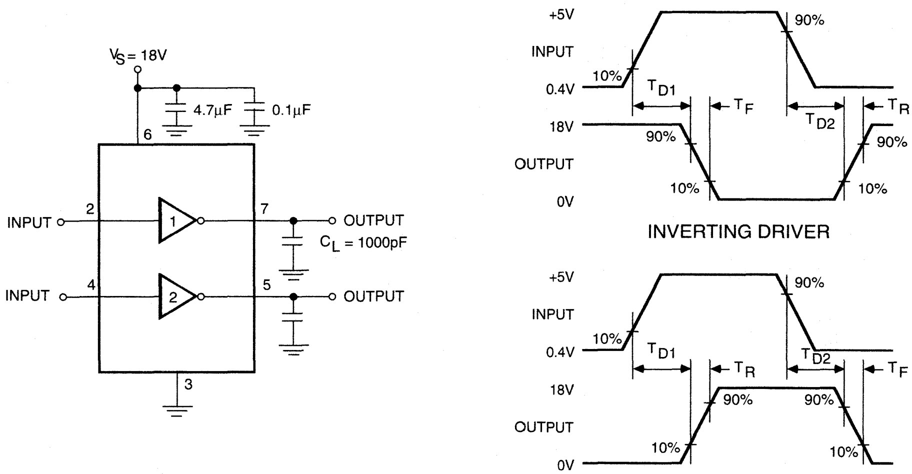
Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.4	1.5		V
V_{IL}	Logic 0 Input Voltage			1.0	0.8	V
I_{IN}	Input Current	$0 \le V_{IN} \le V_S$	–1		1	µA
OUTPUT						
V_{OH}	High Output Voltage		V_S–0.025			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance	I_{OUT} = 10mA, V_S = 18V		8	12	Ω

MIC4426/4427/4428 Electrical Characteristics:

Specifications measured over operating temperature range with 4.5 V ≤ V_S ≤ 18 V unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
OUTPUT						
I_{PK}	Peak Output Current			1.5		A
I	Latch-Up Protection Withstand Reverse Current		>500			mA
SWITCHING TIME						
T_R	Rise Time	Test Figure 1		20	40	ns
T_F	Fall Time	Test Figure 1		29	40	ns
T_{D1}	Delay TIme	Test FIgure 1		19	40	ns
T_{D2}	Delay Time	Test Figure 1		27	60	ns
POWER SUPPLY						
I_S	Power Supply Current	V_{IN} = 3.0 V (Both Inputs)		1.5	8	mA
I_S	Power Supply Current	V_{IN} = 0.0 V (Both Inputs)		0.19	0.6	mA

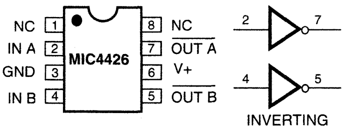
Note 1: Functional operation above the absolute maximum stress ratings is not implied.
Note 2: Static Sensitive device. Store only in conductive containers. Handling personnel and equipment should be grounded to prevent static damage.

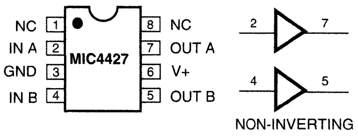


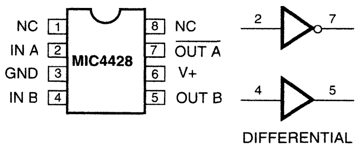
NON-INVERTING DRIVER

Figure 1. Switching Time Test Circuit

Pin Configuration

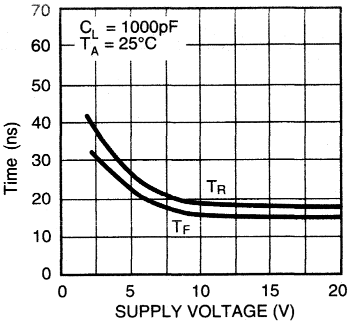




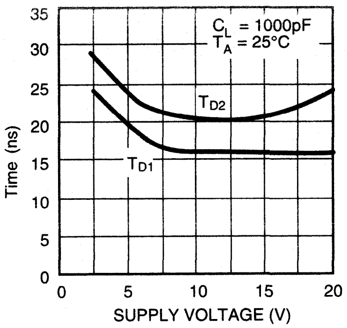


Typical Characteristic Curves

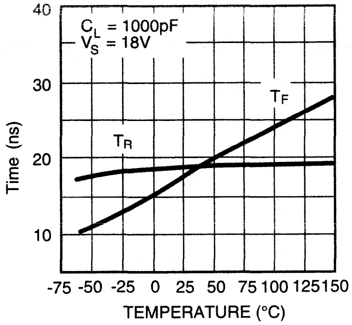
Rise and Fall Time vs. Supply Voltage



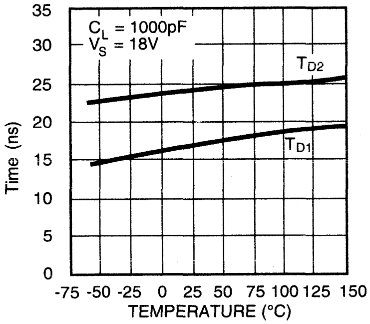
Delay Time vs. Supply Voltage



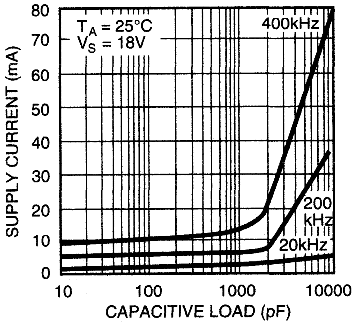
Rise and Fall Time vs. Temperature



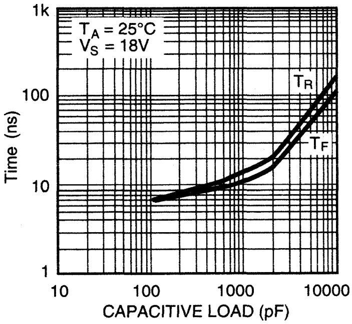
Delay Time vs. Temperature



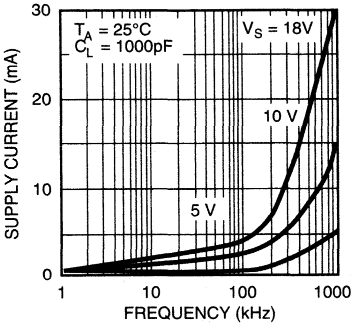
Supply Current vs. Capacitive Load



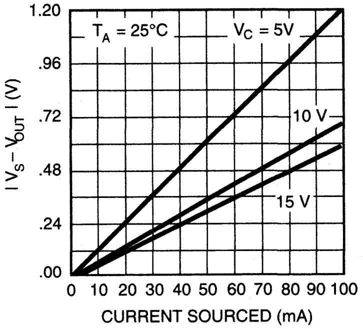
Rise and Fall Time vs. Capacitive Load



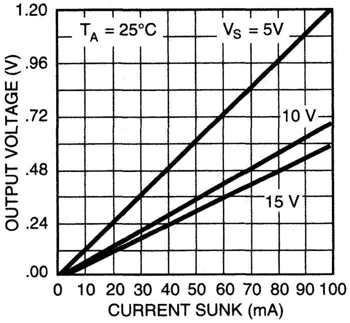
Supply Current vs. Frequency



High Output vs. Current

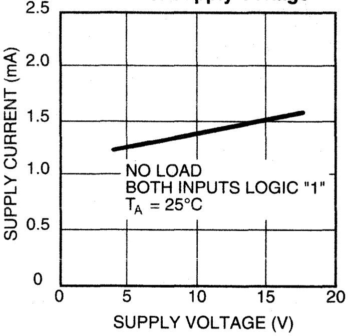


Low Output vs. Current

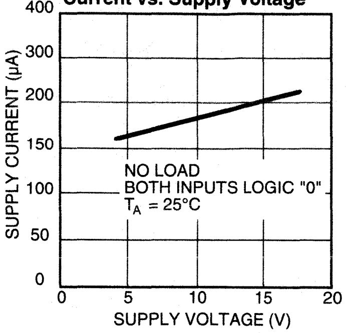


Typical Characteristic Curves (Continued)

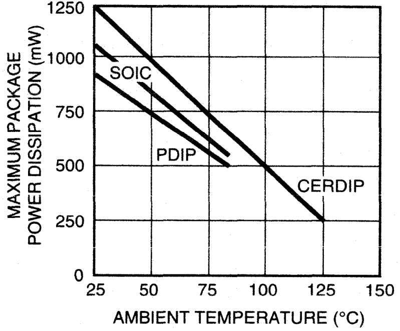
Quiescent Power Supply Current vs. Supply Voltage



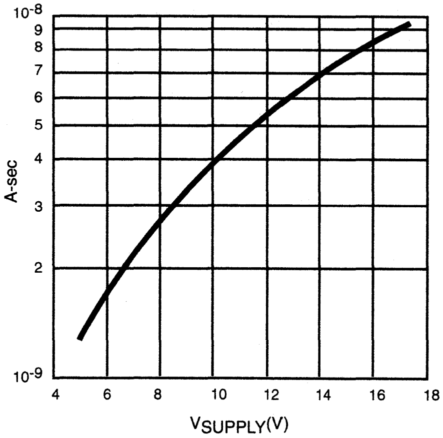
Quiescent Power Supply Current vs. Supply Voltage



Package Power Dissipation



Crossover Energy Loss



Note: The values on this graph represent the loss seen by a single transition of a single driver. For a complete cycle of a single driver multiply the stated value by 2.

MIC4451/4452

12A-Peak Low-Side MOSFET Driver

Bipolar/CMOS/DMOS Process

General Description

MIC4451 and MIC4452 CMOS MOSFET drivers are tough, efficient, and easy to use. The MIC4451 is an inverting driver, while the MIC4452 is a non-inverting driver.

Both versions are capable of 12A (peak) output and can drive the largest MOSFETs with an improved safe operating margin. The MIC4451/4452 accepts any logic input from 2.4V to V_S without external speed-up capacitors or resistor networks. Proprietary circuits allow the input to swing negative by as much as 5V without damaging the part. Additional circuits protect against damage from electrostatic discharge.

MIC4451/4452 drivers can replace three or more discrete components, reducing PCB area requirements, simplifying product design, and reducing assembly cost.

Modern Bipolar/CMOS/DMOS construction guarantees freedom from latch-up. The rail-to-rail swing capability of CMOS/DMOS insures adequate gate voltage to the MOSFET during power up/down sequencing. Since these devices are fabricated on a self-aligned process, they have very low crossover current, run cool, use little power, and are easy to drive.

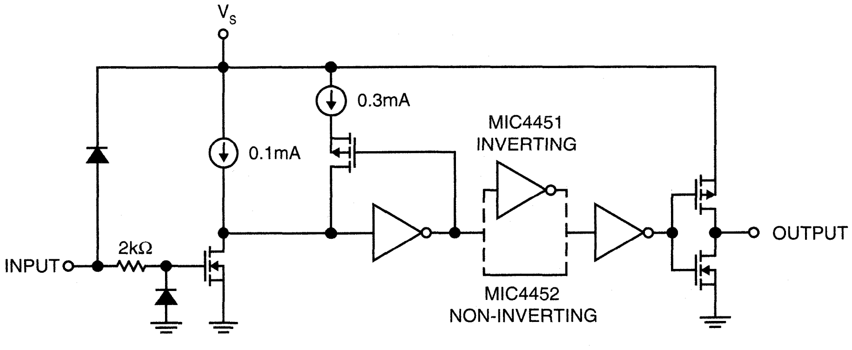
Features

- BiCMOS/DMOS Construction
- Latch-Up Proof: Fully Isolated Process is Inherently Immune to Any Latch-up.
- Input Will Withstand Negative Swing of Up to 5V
- Matched Rise and Fall Times 25ns
- High Peak Output Current .... 12A Peak
- Wide Operating Range .... 4.5V to 18V
- High Capacitive Load Drive 62,000pF
- Low Delay Time .... 30ns Typ.
- Logic High Input for Any Voltage from 2.4V to V_S
- Low Supply Current .... 450μA With Logic 1 Input
- Low Output Impedance 1.0Ω
- Output Voltage Swing to Within 25mV of GND or V_S
- MIL-STD-883 Method 5004/5005 Version Available
- Low Equivalent Input Capacitance (typ) 7pF

Applications

- Switch Mode Power Supplies
- Motor Controls
- Pulse Transformer Driver
- Class D Switching Amplifiers
- Line Drivers
- Driving MOSFET or IGBT Parallel Chip Modules
- Local Power ON/OFF Switch
- Pulse Generators

Functional Diagram

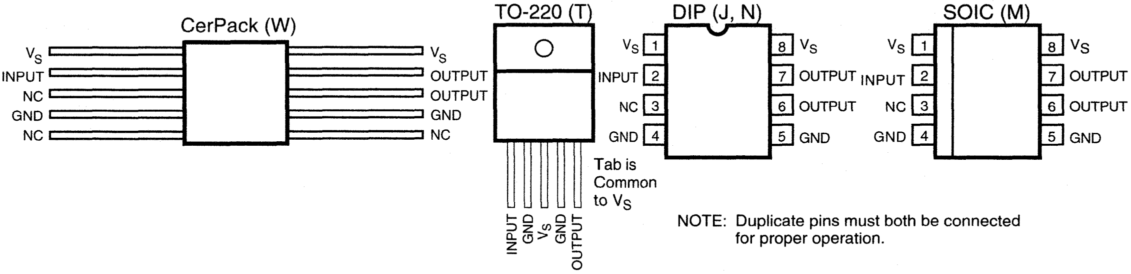


Ordering Information

Part No.	Temperature Range	Package	Configuration
MIC4451BN	–40°C to +85°C	8-Pin PDIP	Inverting
MIC4451BM	–40°C to +85°C	8-Pin SOIC	Inverting
MIC4451AJ	–55°C to +125°C	8-Pin CerDIP	Inverting
5962-8877004PA[1]	–55°C to +125°C	8-Pin CerDIP	Inverting
5962-8877004HA[2]	–55°C to +125°C	10-Pin CerPak	Inverting
MIC4451CT	0°C to +70°C	5-Pin TO-220	Inverting
MIC4452BN	–40°C to +85°C	8-Pin PDIP	Non-Inverting
MIC4452BM	–40°C to +85°C	8-Pin SOIC	Non-Inverting
MIC4452AJ	–55°C to +125°C	8-Pin CerDIP	Non-Inverting
5962-8877005PA[3]	–55°C to +125°C	8-Pin CerDIP	Non-Inverting
5962-8877005HA[4]	–55°C to +125°C	10-Pin CerPak	Non-Inverting
MIC4452CT	0°C to +70°C	5-Pin TO-220	Non-Inverting

[1] Standard Military Drawing number for MIC4451AJBQ
[2] Standard Military Drawing number for MIC4451AWBQ
[3] Standard Military Drawing number for MIC4452AJBQ
[4] Standard Military Drawing number for MIC4452AWBQ

Pin Configurations



NOTE: Duplicate pins must both be connected for proper operation.

5

Absolute Maximum Ratings (Notes 1, 2 and 3)

Power Dissipation, $T_{AMBIENT} \leq 25°C$	
PDIP	960mW
SOIC	1040mW
CerDIP	1250 mW
5-Pin TO-220	2W
Power Dissipation, $T_{CASE} \leq 25°C$	
5-Pin TO-220	12.5W
Derating Factors (To Ambient)	
PDIP	7.7mW/°C
SOIC	8.3 mW/°C
CerDIP	10 mW/°C
5-Pin TO-220	17mW/°C

Thermal Impedances (To Case)	
5-Pin TO-220 $R_{\theta J\text{-}C}$	10°C/W
Storage Temperature	–65°C to +150°C
Operating Temperature (Chip)	150°C
Operating Temperature (Ambient)	
C Version	0°C to +70°C
B Version	–40°C to +85°C
A Version	–55°C to +125°C
Lead Temperature (10 sec)	300°C
Supply Voltage	20V
Input Voltage	V_S + 0.3V to GND – 5V
Input Current ($V_{IN} > V_S$)	50 mA

Electrical Characteristics: (T_A = 25°C with 4.5 V ≤ V_S ≤ 18 V unless otherwise specified.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.4	1.3		V
V_{IL}	Logic 0 Input Voltage			1.1	0.8	V
V_{IN}	Input Voltage Range		–5		$V_S + 0.3$	V
I_{IN}	Input Current	0 V ≤ V_{IN} ≤ V_S	–10		10	µA
OUTPUT						
V_{OH}	High Output Voltage	See Figure 1	V_S–0.025			V
V_{OL}	Low Output Voltage	See Figure 1			0.025	V
R_O	Output Resistance, Output High	I_{OUT} = 10 mA, V_S = 18 V		0.6	1.5	Ω
R_O	Output Resistance, Output Low	I_{OUT} = 10 mA, V_S = 18 V		0.8	1.5	Ω
I_{PK}	Peak Output Current	V_S = 18 V (See Figure 5)		12		A
I_{DC}	Continuous Output Current		2			A
I_R	Latch-Up Protection Withstand Reverse Current	Duty Cycle ≤ 2% t ≤ 300 µs	>1500			mA
SWITCHING TIME (Note 3)						
t_R	Rise Time	Test Figure 1, C_L = 15,000 pF		20	40	ns
t_F	Fall Time	Test Figure 1, C_L = 15,000 pF		24	50	ns
t_{D1}	Delay Time	Test Figure 1		15	30	ns
t_{D2}	Delay Time	Test Figure 1		35	60	ns
Power Supply						
I_S	Power Supply Current	V_{IN} = 3 V V_{IN} = 0 V		0.4 80	1.5 150	mA µA
V_S	Operating Input Voltage		4.5		18	V

Electrical Characteristics: (Over operating temperature range with 4.5V < V_S < 18V unless otherwise specified.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.4	1.4		V
V_{IL}	Logic 0 Input Voltage			1.0	0.8	V
V_{IN}	Input Voltage Range		–5		$V_S + 0.3$	V
I_{IN}	Input Current	$0V \leq V_{IN} \leq V_S$	–10		10	µA
OUTPUT						
V_{OH}	High Output Voltage	Figure 1	V_S–0.025			V
V_{OL}	Low Output Voltage	Figure 1			0.025	V
R_O	Output Resistance, Output High	I_{OUT} = 10mA, V_S = 18V		0.8	2.2	Ω
R_O	Output Resistance, Output Low	I_{OUT} = 10mA, V_S = 18V		1.3	2.2	Ω
SWITCHING TIME (Note 3)						
t_R	Rise Time	Figure 1, C_L = 15,000pF		23	50	ns
t_F	Fall Time	Figure 1, C_L = 15,000pF		30	60	ns
t_{D1}	Delay Time	Figure 1		20	40	ns
t_{D2}	Delay Time	Figure 1		40	80	ns
POWER SUPPLY						
I_S	Power Supply Current	V_{IN} = 3V V_{IN} = 0V		0.6 0.1	3 0.4	mA
V_S	Operating Input Voltage		4.5		18	V

NOTE 1: Functional operation above the absolute maximum stress ratings is not implied.
NOTE 2: Static-sensitive device. Store only in conductive containers. Handling personnel and equipment should be grounded to prevent damage from static discharge.
NOTE 3: Switching times guaranteed by design.

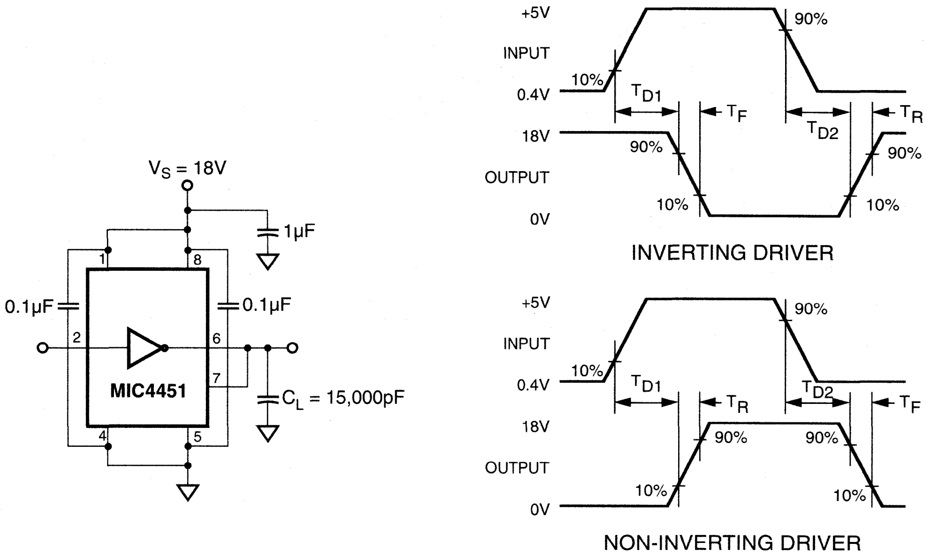
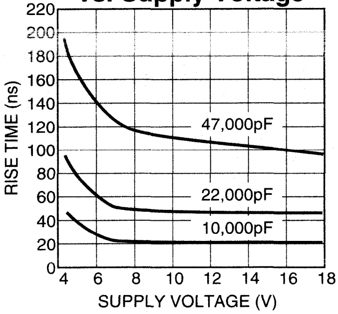


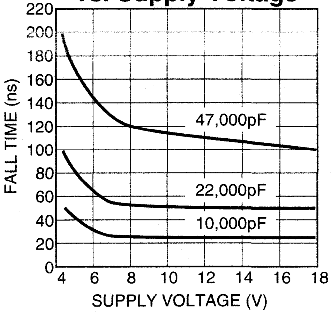
Figure 1. Switching Time Test Circuit

Typical Characteristic Curves

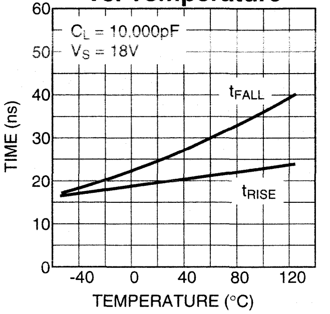
Rise Time vs. Supply Voltage



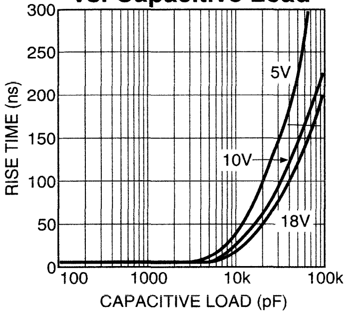
Fall Time vs. Supply Voltage



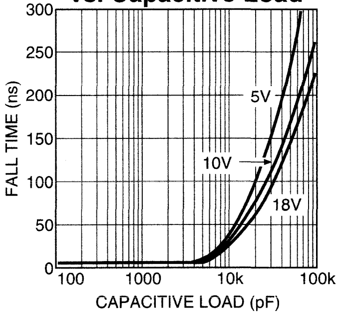
Rise and Fall Times vs. Temperature



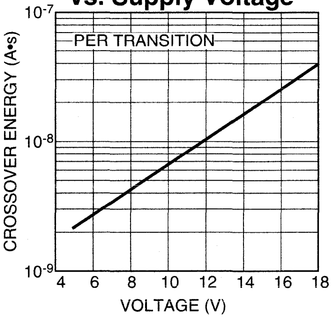
Rise Time vs. Capacitive Load



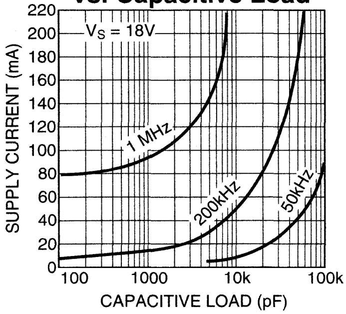
Fall Time vs. Capacitive Load



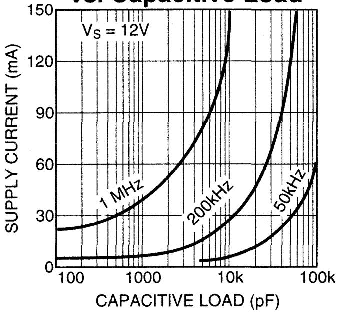
Crossover Energy vs. Supply Voltage



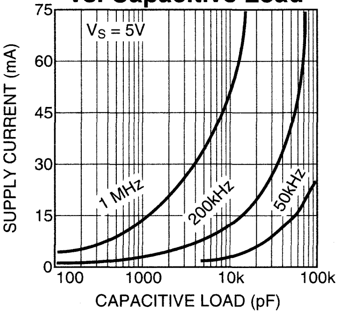
Supply Current vs. Capacitive Load



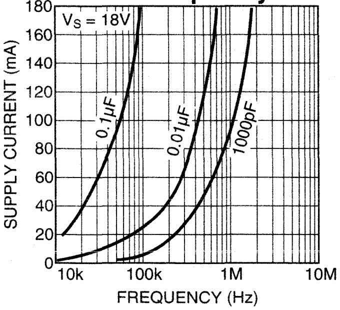
Supply Current vs. Capacitive Load

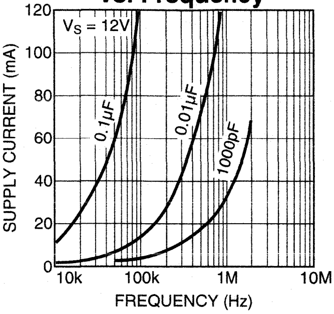


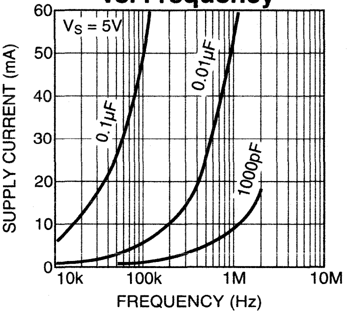
Supply Current vs. Capacitive Load

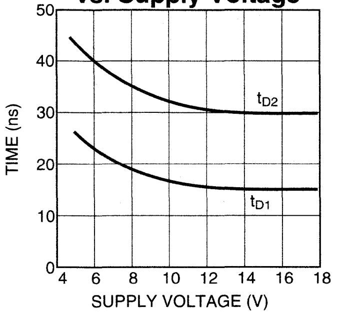


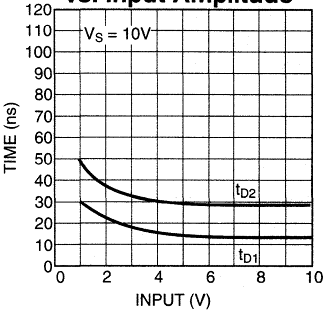
Typical Characteristic Curves (Cont.)

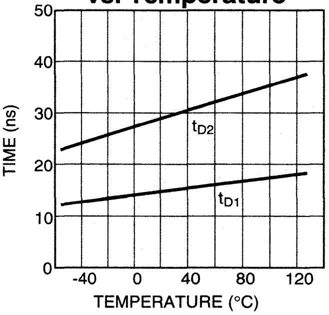

Supply Current vs. Frequency

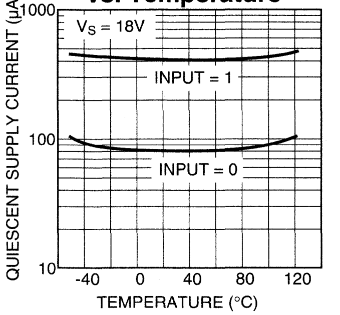

Supply Current vs. Frequency

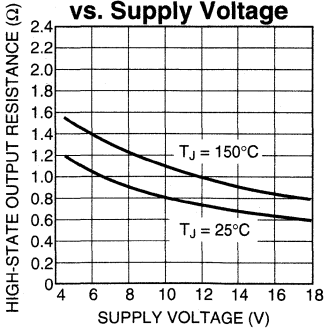

Supply Current vs. Frequency

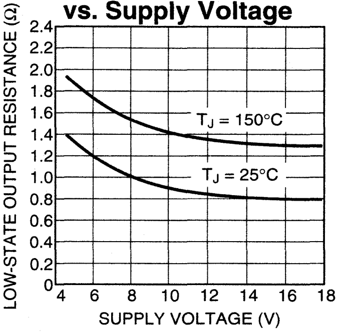

Propagation Delay vs. Supply Voltage


Propagation Delay vs. Input Amplitude


Propagation Delay vs. Temperature


Quiescent Supply Current vs. Temperature


High-State Output Resist. vs. Supply Voltage


Low-State Output Resist. vs. Supply Voltage

Applications Information

Supply Bypassing

Charging and discharging large capacitive loads quickly requires large currents. For example, changing a 10,000pF load to 18V in 50ns requires 3.6A.

The MIC4451/4452 has double bonding on the supply pins, the ground pins and output pins. This reduces parasitic lead inductance. Low inductance enables large currents to be switched rapidly. It also reduces internal ringing that can cause voltage breakdown when the driver is operated at or near the maximum rated voltage.

Internal ringing can also cause output oscillation due to feedback. This feedback is added to the input signal since it is referenced to the same ground.

To guarantee low supply impedance over a wide frequency range, a parallel capacitor combination is recommended for supply bypassing. Low inductance ceramic disk capacitors with short lead lengths (< 0.5 inch) should be used. A 1µF low ESR film capacitor in parallel with two 0.1µF low ESR ceramic capacitors, (such as AVX RAM GUARD®), provides adequate bypassing. Connect one ceramic capacitor directly between pins 1 and 4. Connect the second ceramic capacitor directly between pins 8 and 5.

Grounding

The high current capability of the MIC4451/4452 demands careful PC board layout for best performance. Since the MIC4451 is an inverting driver, any ground lead impedance will appear as negative feedback which can degrade switching speed. Feedback is especially noticeable with slow-rise time inputs. The MIC4451 input structure includes 200mV of hysteresis to ensure clean transitions and freedom from oscillation, but attention to layout is still recommended.

Figure 5 shows the feedback effect in detail. As the MIC4451 input begins to go positive, the output goes negative and several amperes of current flow in the ground lead. As little as 0.05Ω of PC trace resistance can produce hundreds of millivolts at the MIC4451 ground pins. If the driving logic is referenced to power ground, the effective logic input level is reduced and oscillation may result.

To insure optimum performance, separate ground traces should be provided for the logic and power connections. Connecting the logic ground directly to the MIC4451 GND pins will ensure full logic drive to the input and ensure fast output switching. Both of the MIC4451 GND pins should, however, still be connected to power ground.

Input Stage

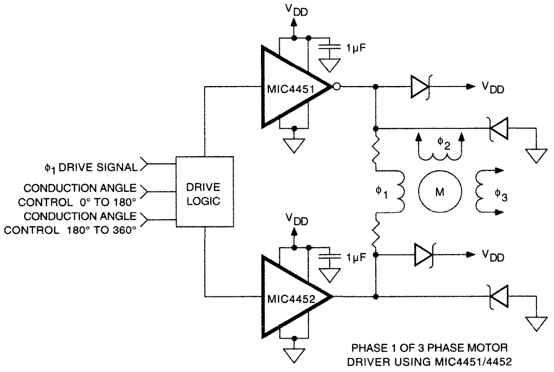


Figure 3. Direct Motor Drive

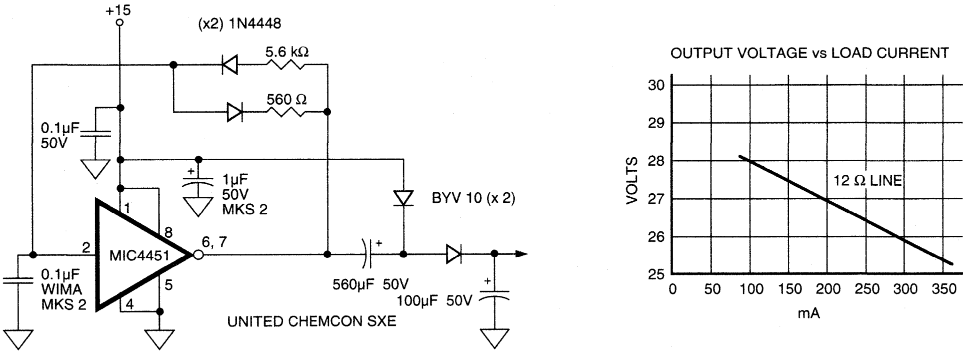


Figure 4. Self Contained Voltage Doubler

The input voltage level of the MIC4451 changes the quiescent supply current. The N channel MOSFET input stage transistor drives a 320µA current source load. With a logic "1" input, the maximum quiescent supply current is 400µA. Logic "0" input level signals reduce quiescent current to 80µA typical.

The MIC4451/4452 input is designed to provide 200mV of hysteresis. This provides clean transitions, reduces noise sensitivity, and minimizes output stage current spiking when changing states. Input voltage threshold level is approximately 1.5V, making the device TTL compatible over the full temperature and operating supply voltage ranges. Input current is less than ±10µA.

The MIC4451 can be directly driven by the TL494, SG1526/1527, SG1524, TSC170, MIC38C42, and similar switch mode power supply integrated circuits. By offloading the power-driving duties to the MIC4451/4452, the power supply controller can operate at lower dissipation. This can improve performance and reliability.

The input can be greater than the V_S supply, however, current will flow into the input lead. The input currents can be as high as 30mA p-p (6.4mA_{RMS}) with the input. No damage will occur to MIC4451/4452 however, and it will not latch.

The input appears as a 7pF capacitance and does not change even if the input is driven from an AC source. While the device will operate and no damage will occur up to 25V below the negative rail, input current will increase up to 1mA/V due to the clamping action of the input, ESD diode, and 1kΩ resistor.

Power Dissipation

CMOS circuits usually permit the user to ignore power dissipation. Logic families such as 4000 and 74C have outputs which can only supply a few milliamperes of current, and even shorting outputs to ground will not force enough current to destroy the device. The MIC4451/4452 on the other hand, can source or sink several amperes and drive large capacitive loads at high frequency. The package power dissipation limit can easily be exceeded. Therefore, some attention should be given to power dissipation when driving low impedance loads and/or operating at high frequency.

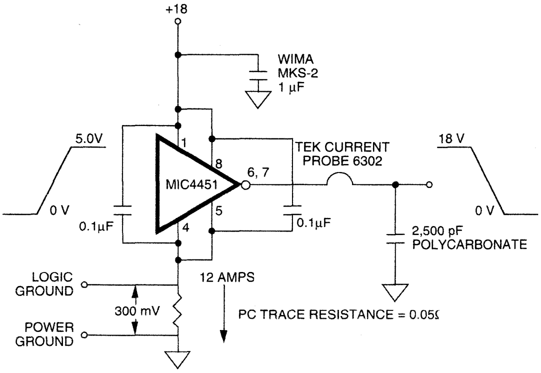


Figure 5. Switching Time Degradation Due to Negative Feedback

The supply current vs. frequency and supply current vs capacitive load characteristic curves aid in determining power dissipation calculations. Table 1 lists the maximum safe operating frequency for several power supply voltages when driving a 10,000pF load. More accurate power dissipation figures can be obtained by summing the three dissipation sources.

Given the power dissipation in the device, and the thermal resistance of the package, junction operating temperature for any ambient is easy to calculate. For example, the thermal resistance of the 8-pin CerDIP package, from the data sheet, is 100°C/W. In a 25°C ambient, then, using a maximum junction temperature of 125°C, this package will dissipate 1W.

Accurate power dissipation numbers can be obtained by summing the three sources of power dissipation in the device:

- Load Power Dissipation (P_L)
- Quiescent power dissipation (P_Q)
- Transition power dissipation (P_T)

Calculation of load power dissipation differs depending on whether the load is capacitive, resistive or inductive.

Resistive Load Power Dissipation

Dissipation caused by a resistive load can be calculated as:

$$P_L = I^2 R_O D$$

where:

I = the current drawn by the load
R_O = the output resistance of the driver when the output is high, at the power supply voltage used. (See data sheet)
D = fraction of time the load is conducting (duty cycle)

Capacitive Load Power Dissipation

Table 1: MIC4451 Maximum Operating Frequency

V_S	Max Frequency
18V	220kHz
15V	300kHz
10V	640kHz
5V	2MHz

Conditions: 1. CerDIP Package (θ_{JA} = 150°C/W)
2. T_A = 25°C
3. C_L = 10,000pF

Dissipation caused by a capacitive load is simply the energy placed in, or removed from, the load capacitance by the driver. The energy stored in a capacitor is described by the equation:

$$E = 1/2\ C\ V^2$$

As this energy is lost in the driver each time the load is charged or discharged, for power dissipation calculations the 1/2 is removed. This equation also shows that it is good practice not to place more voltage on the capacitor than is necessary, as dissipation increases as the square of the voltage applied to the capacitor. For a driver with a capacitive load:

$$P_L = F\ C\ (V_S)^2$$

where:

F = Operating Frequency
C = Load Capacitance
V_S = Driver Supply Voltage

Inductive Load Power Dissipation

For inductive loads the situation is more complicated. For the part of the cycle in which the driver is actively forcing current into the inductor, the situation is the same as it is in the resistive case:

$$P_{L1} = I^2\ R_O\ D$$

However, in this instance the R_O required may be either the on resistance of the driver when its output is in the high state, or its on resistance when the driver is in the low state, depending on how the inductor is connected, and this is still only half the story. For the part of the cycle when the inductor is forcing current through the driver, dissipation is best described as

$$P_{L2} = I\ V_D\ (1 - D)$$

where V_D is the forward drop of the clamp diode in the driver (generally around 0.7V). The two parts of the load dissipation must be summed in to produce P_L

$$P_L = P_{L1} + P_{L2}$$

Quiescent Power Dissipation

Quiescent power dissipation (P_Q, as described in the input section) depends on whether the input is high or low. A low input will result in a maximum current drain (per driver) of $\leq$ 0.2mA; a logic high will result in a current drain of $\leq$ 3.0mA. Quiescent power can therefore be found from:

$$P_Q = V_S\ [D\ I_H + (1 - D)\ I_L]$$

where:

I_H = quiescent current with input high
I_L = quiescent current with input low
D = fraction of time input is high (duty cycle)
V_S = power supply voltage

Transition Power Dissipation

Transition power is dissipated in the driver each time its output changes state, because during the transition, for a very brief interval, both the N- and P-channel MOSFETs in the output totem-pole are ON simultaneously, and a current is conducted through them from V_S to ground. The transition power dissipation is approximately:

$$P_T = 2\ F\ V_S\ (A\bullet S)$$

where (A•S) is a time-current factor derived from the typical characteristic curve "Crossover Energy vs. Supply Voltage."

Total power (P_D) then, as previously described is:

$$P_D = P_L + P_Q + P_T$$

Definitions

C_L = Load Capacitance in Farads.

D = Duty Cycle expressed as the fraction of time the input to the driver is high.

F = Operating Frequency of the driver in Hertz

I_H = Power supply current drawn by a driver when both inputs are high and neither output is loaded.

I_L = Power supply current drawn by a driver when both inputs are low and neither output is loaded.

I_D = Output current from a driver in Amps.

P_D = Total power dissipated in a driver in Watts.

P_L = Power dissipated in the driver due to the driver's load in Watts.

P_Q = Power dissipated in a quiescent driver in Watts.

P_T = Power dissipated in a driver when the output changes states ("shoot-through current") in Watts. NOTE: The "shoot-through" current from a dual transition (once up, once down) for both drivers is stated in Figure 7 in ampere-nanoseconds. This figure must be multiplied by the number of repetitions per second (frequency) to find Watts.

R_O = Output resistance of a driver in Ohms.

V_S = Power supply voltage to the IC in Volts.

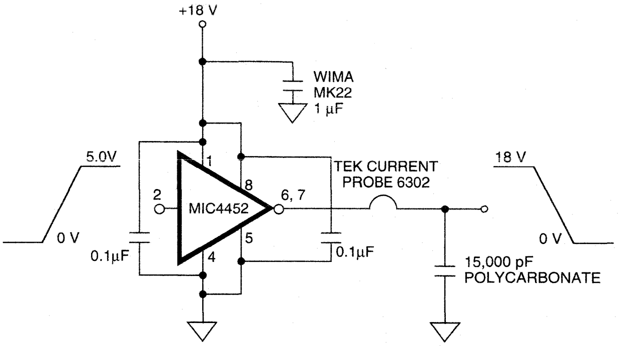


Figure 6. Peak Output Current Test Circuit

MIC4467/4468/4469

Quad 1.2A Low-Side MOSFET Driver

Bipolar/CMOS/DMOS

General Description

The MIC4467/8/9 family of 4-output CMOS buffer/drivers is an expansion from the earlier single- and dual-output drivers, to which they are functionally closely related. Because package pin count permitted it, each driver has been equipped with a 2-input logic gate for added flexibility. Placing four high-power drivers in a single package also improves system reliability and reduces total system cost. In some applications, one of these drivers can replace not only two packages of single-input drivers, but some of the associated logic as well.

Although primarily intended for driving power MOSFETs, and similar highly capacitive loads, these drivers are equally well suited to driving any other load (capacitive, resistive, or inductive), which requires a high-efficiency, low-impedance driver capable of high peak currents, rail-to-rail voltage swings, and fast switching times. For example, heavily loaded clock lines, coaxial cables, and piezoelectric transducers can all be

Features

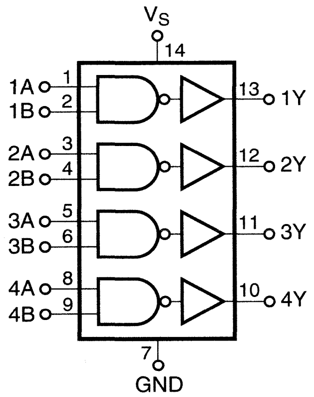
- Built using reliable, low power CMOS processes
- Latchproof. Withstands 500mA Inductive Kickback
- 3 Input Logic Choices
- Symmetrical Rise and Fall Times 25ns
- Short, Equal Delay Times 75ns
- High Peak Output Current 1.2A
- Wide Operating Range .... 4.5 to 18V
- Low Equivalent Input Capacitance (typ) 6pF
- Inputs = Logic 1 for Any Input From 2.4V to V_S
- ESD Protected

Applications

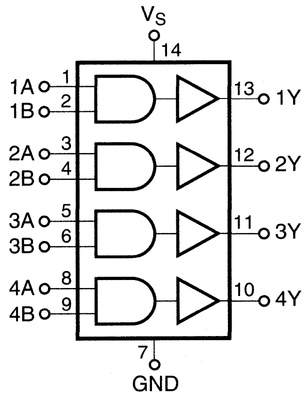
- General-Purpose CMOS Logic Buffer
- Driving All 4 MOSFETs in an H-Bridge
- Direct Small-Motor Driver
- Relay or Peripheral Drivers
- Dual Differential Output Power Drivers
- CCD Driver
- Pin-Switching Network Driver

Logic Diagrams

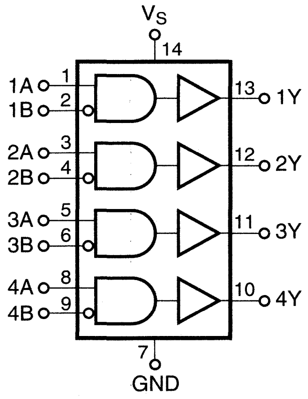
MIC4467



MIC4468



MIC4469



driven easily with MIC446X series drivers. The only limitation on loading is that total power dissipation in the IC must be kept within the power dissipation limits of the package.

The MIC446X series drivers are built using a BCD process. They will not latch under any conditions within their power and voltage ratings. They are not subject to damage when up to 5V of noise spiking (either polarity) occurs on the ground line. They can accept up to half an amp of inductive kickback current (either polarity) into their outputs without damage or logic upset.

Ordering Information

Part No.	Package	Temp. Range
MIC44xxCN*	14-Pin Plastic DIP	0° to +70°C
MIC44xxCWM*	16-Pin Wide SOIC	0° to +70°C
MIC44xxBN*	14-Pin Plastic DIP	–40° to +85°C
MIC44xxBWM*	16-Pin Wide SOIC	–40° to +85°C
MIC44xxAJ*	14-Pin CerDIP	–40° to +85°C
SMD see below	14-Pin CerDIP	–55° to +125°C
MIC44xxAL*	20-Pin LCC	–55° to +125°C

* xx identifies input logic:
67 — NAND
68 — AND
69 — AND with one inverting input

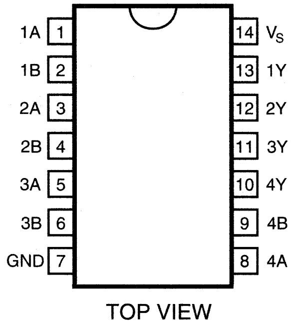
SMD number 5962-9459401MCA for MIC4467AJBQ
SMD number 5962-9459402MCA for MIC4468AJBQ
SMD number 5962-9459403MCA for MIC4469AJBQ

Truth Table

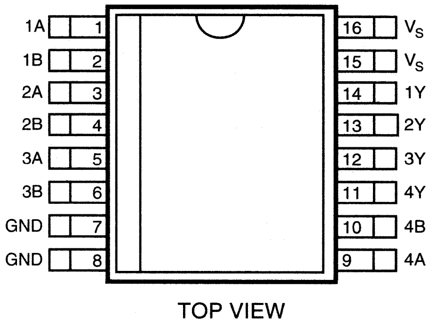
	Inputs		Output
Part No.	**A**	**B**	**Y**
MIC4467 (Each Driver)	L	X	H
	X	L	H
	H	H	L
MIC4468 (Each Driver)	H	H	H
	L	X	L
	X	L	L
MIC4469 (Each Driver)	L	X	L
	X	H	L
	H	L	H

Pin Configurations

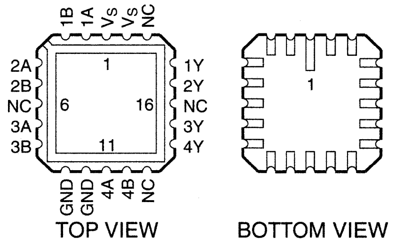
14-Pin Dual-In-Line Package - N, J



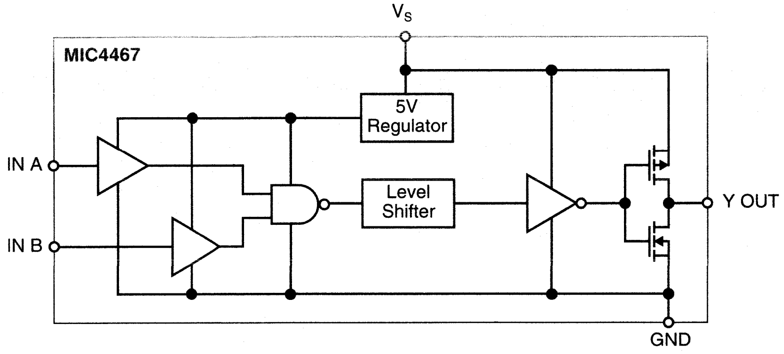
16-Pin Wide SOIC - WM



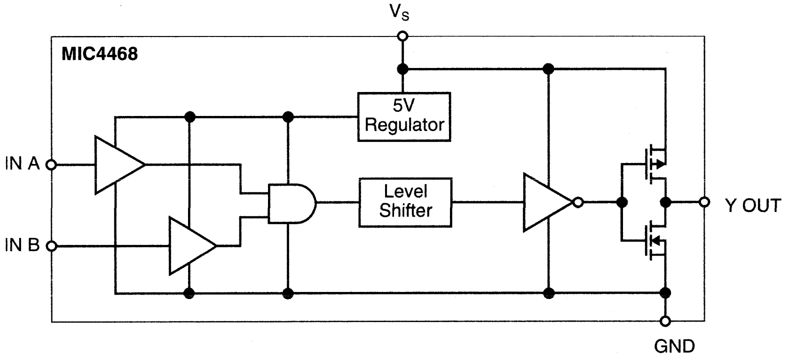
20-Pin LCC - L



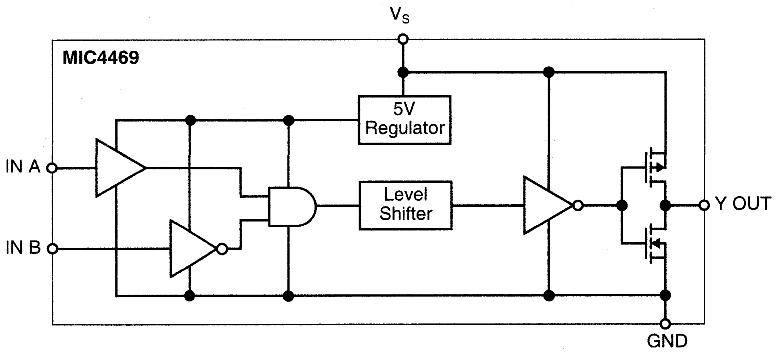
Block Diagrams



Functional Diagram for One Driver (Four Drivers per Package–Ground Unused Inputs)



Functional Diagram for One Driver (Four Drivers per Package–Ground Unused Inputs)



Functional Diagram for One Driver (Four Drivers per Package–Ground Unused Inputs)

Absolute Maximum Ratings (Notes 1 and 2)

Supply Voltage	22V
Input Voltage	(GND – 5V) to (V_S + 0.3V)
Maximum Chip Temperature	
Operating	150°C
Storage	–65° to +150°C
Maximum Load Temperature (10 sec, for soldering)	300°C
Operating Ambient Temperature	
C Version	0° to +70°C
B Version	–40° to +85°C
A Version	–55° to +125°C

Power Dissipation	
P Package (14-Pin Plastic DIP)	1.5W
WM Package (16-Pin Wide SOIC)	1W
J Package (14-Pin CerDIP)	1.25W
L Package (20-Pin LCC)	1W
Package Thermal Resistance	
P Package (14-Pin Plastic DIP) $R_{\theta J-A}$	80°C/W
WM Package (16-Pin Wide SOIC) $R_{\theta J-A}$	120°C/W
J Package (14-Pin CerDIP) $R_{\theta J-A}$	100°C/W
L Package (20-Pin LCC) $R_{\theta J-A}$	120°C/W

Electrical Characteristics: Measured at T_A = 25°C with 4.5V ≤ V_S ≤ 18V unless otherwise specified.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.4	1.3		V
V_{IL}	Logic 0 Input Voltage			1.2	0.8	V
I_{IN}	Input Current	$0 \le V_{IN} \le V_S$	–1		1	µA
OUTPUT						
V_{OH}	High Output Voltage	I_{LOAD} = 10mA	V_S-0.15			V
V_{OL}	Low Output Voltage	I_{LOAD} = 10mA			0.15	V
R_O	Output Resistance	I_{OUT} = 10mA, V_S = 18V		5	15	Ω
I_{PK}	Peak Output Current			1.2		A
I	Latch-Up Protection Withstand Reverse Current		>500			mA
SWITCHING TIME						
t_R	Rise Time	Test Figure 1		14	25	ns
t_F	Fall Time	Test Figure 1		13	25	ns
t_{D1}	Delay Time	Test Figure 1		30	75	ns
t_{D2}	Delay Time	Test Figure 1		45	75	ns
POWER SUPPLY						
I_S	Power Supply Current Supply			0.2	4	mA

Electrical Characteristics:

Measured over operating temperature range with 4.5V ≤ V_S ≤ 18V unless otherwise specified.

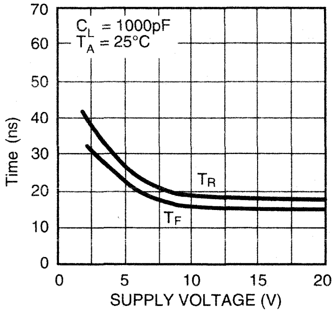
Symbol	Parameter	Conditions	Min	Typ	Max	Units
INPUT						
V_{IH}	Logic 1 Input Voltage		2.4	1.4		V
V_{IL}	Logic 0 Input Voltage			1.0	0.8	V
I_{IN}	Input Current	$0 \le V_{IN} \le V_S$	–1		1	µA
OUTPUT						
V_{OH}	High Output Voltage	I_{LOAD} = 10 mA	V_S-0.3			V
V_{OL}	Low Output Voltage	I_{LOAD} = 10 mA			0.3	V
R_O	Output Resistance	I_{OUT} = 10 mA, V_S = 18V		7	30	Ω
I_{PK}	Peak Output Current			1.2		A
I	Latch-Up Protection Withstand Reverse Current		500			mA
SWITCHING TIME						
t_R	Rise Time	Test Figure 1		17	50	ns
t_F	Fall Time	Test Figure 1		16	50	ns
t_{D1}	Delay Time	Test Figure 1		35	100	ns
t_{D2}	Delay Time	Test Figure 1		55	100	ns
POWER SUPPLY						
I_S	Power Supply Current Supply			0.4	8	mA

NOTE 1: Functional operation above the absolute maximum stress ratings is not implied.

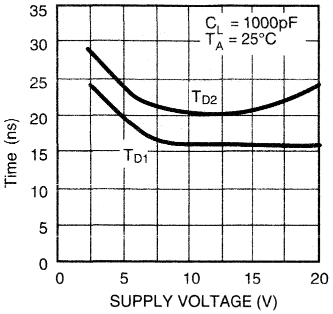
NOTE 2: Static sensitive device. Store only in conductive containers. Handling personnel and equipment should be grounded to prevent static damage.

Typical Characteristics

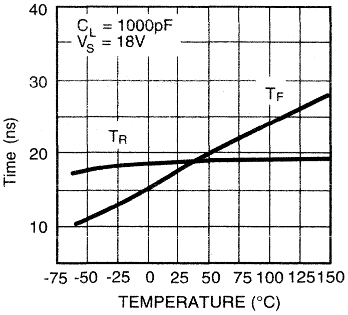
Rise and Fall Time vs. Supply Voltage



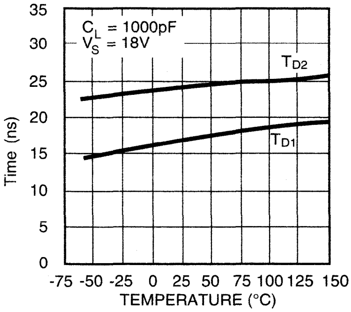
Delay Time vs. Supply Voltage



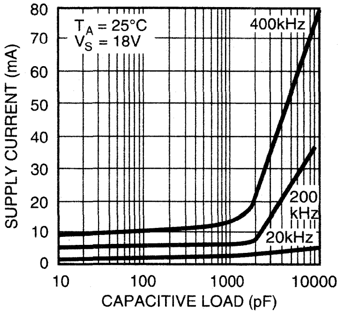
Rise and Fall Time vs. Temperature



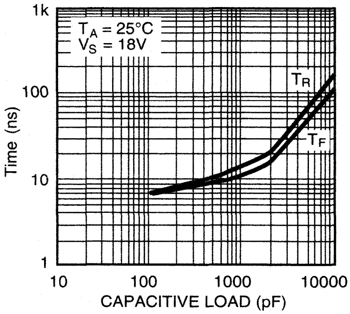
Delay Time vs. Temperature



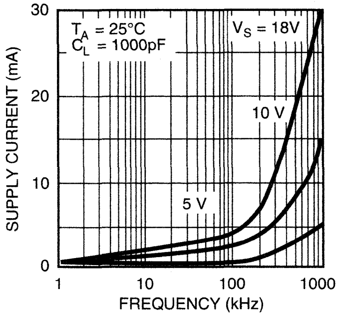
Supply Current vs. Capacitive Load



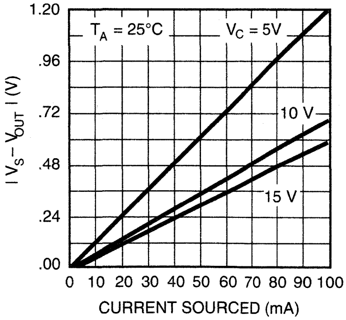
Rise and Fall Time vs. Capacitive Load



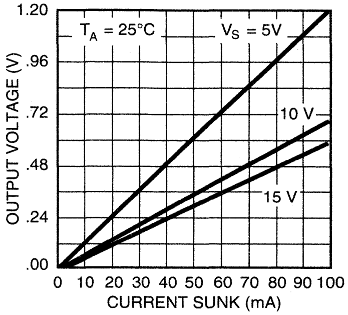
Supply Current vs. Frequency



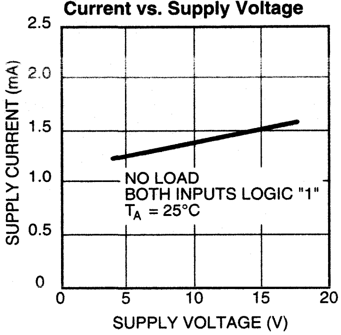
High Output vs. Current



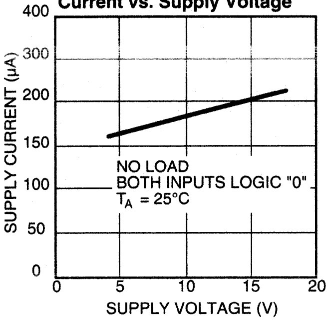
Low Output vs. Current



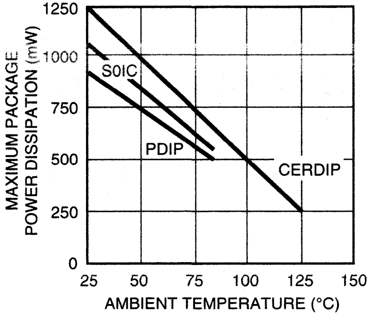
Quiescent Power Supply Current vs. Supply Voltage



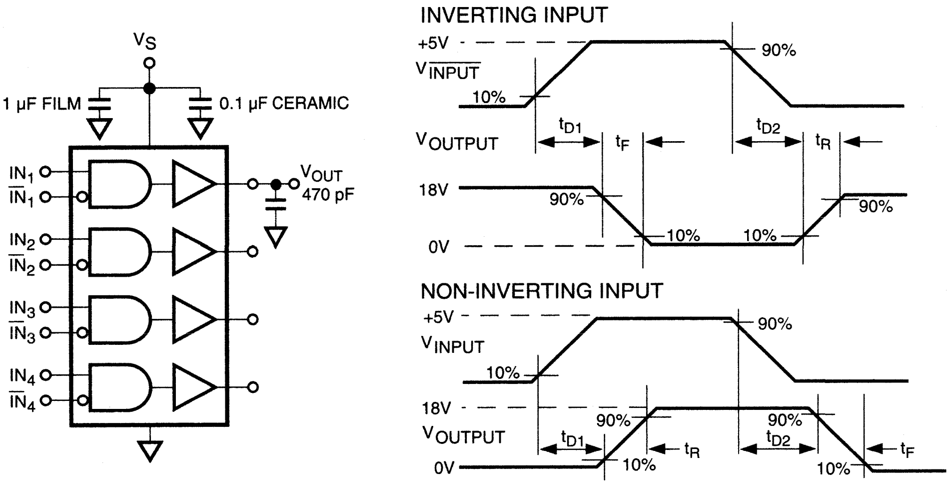
Quiescent Power Supply Current vs. Supply Voltage



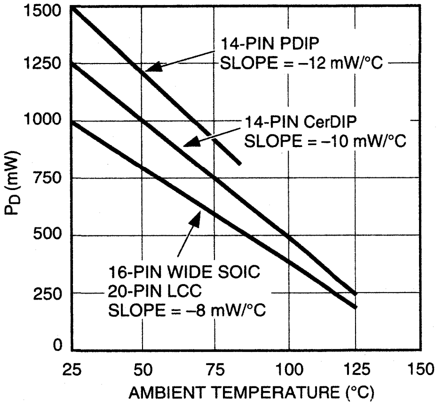
Package Power Dissipation



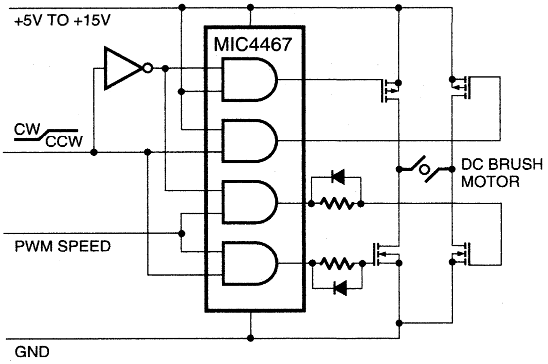
Test Figure 1



Package Power Dissipation



Quad Driver Drives H Bridge to Control Motor Speed and Direction



MIC5010

Full-Featured High- or Low-Side MOSFET Driver

General Description

The MIC5010 is the full-featured member of the Micrel MIC501X driver family. These ICs are designed to drive the gate of an N-channel power MOSFET above the supply rail in high-side power switch applications. The MIC5010 is compatible with standard or current-sensing power FETs in both high- and low-side driver topologies.

The MIC5010 charges a 1nF load in 60µs typical and protects the MOSFET from over-current conditions. Faster switching is achieved by adding two 1nF charge pump capacitors. The current sense trip point is fully programmable and a dynamic threshold allows high in-rush current loads to be started. A fault pin indicates when the MIC5010 has turned off the FET due to excessive current.

Other members of the Micrel driver family include the MIC5011 minimum parts count 8 pin driver, MIC5012 dual driver, and MIC5013 protected 8 pin driver.

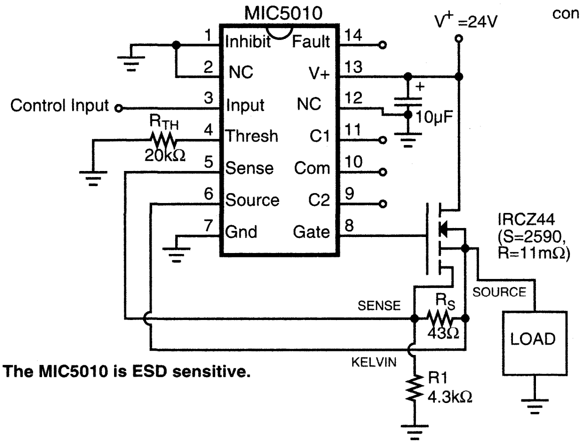
Features

- 7V to 32V operation
- Less than 1µA standby current in the "OFF" state
- Internal charge pump to drive the gate of an N-channel power FET above supply
- MIL-STD-883 Method 5004/5005 version available
- Available in small outline SOIC packages
- Internal zener clamp for gate protection
- 25µs typical turn-on time to 50% gate overdrive
- Programmable over-current sensing
- Dynamic current threshold for high in-rush loads
- Fault output pin indicates current faults
- Implements high- or low-side switches

Applications

- Lamp drivers
- Relay and solenoid drivers
- Heater switching
- Power bus switching
- Motion control
- Half or full H-bridge drivers

Typical Application



Note: The MIC5010 is ESD sensitive.

$$R_S = \frac{SR(V_{TRIP} + 100mV)}{R\,I_L - (V_{TRIP} + 100mV)}$$

$$R1 = \frac{V^+SRR_S}{100mV\,(SR + R_S)}$$

$$R_{TH} = \frac{2200}{V_{TRIP}} - 1000$$

For this example:
I_L =30A (trip current)
V_{TRIP} =100mV

Figure 1. High-Side Driver with Current-Sensing MOSFET

Ordering Information

Part Number	Temperature Range	Package
MIC5010BN	–40°C to +85°C	14-pin Plastic DIP
MIC5010BM	–40°C to +85°C	14-pin SOIC
MIC5010AJB*	–55°C to +125°C	14-pin Ceramic DIP

* AJB indicates units screened to MIL-STD 883, Method 5004, condition B, and burned-in for 1-week.

Protected under one or more of the following Micrel patents:
patent #4,951,101; patent #4,914,546

Absolute Maximum Ratings (Note 1, 2)

Inhibit Voltage, Pin 1	–1V to V+
Input Voltage, Pin 3	–10V to V+
Threshold Voltage, Pin 4	– 0.5 to +5V
Sense Voltage, Pin 5	–10V to V+
Source Voltage, Pin 6	–10V to V+
Current into Pin 6	50 mA
Gate Voltage, Pin 8	–1V to 50V
Supply Voltage (V^+), Pin 13	–0.5V to 36V
Fault Output Current, Pin 14	–1mA to +1mA
Junction Temperature	150°C

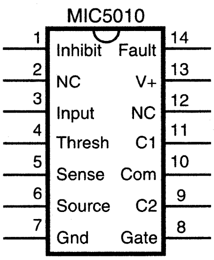
Operating Ratings (Notes 1, 2)

Power Dissipation	1.56W
θ_{JA} (Plastic DIP)	80 °C/W
θ_{JA} (Ceramic DIP)	105°C/W
θ_{JA} (SOIC)	115°C/W
Ambient Temperature: B version	–40°C to +85°C
Ambient Temperature: A version	–55°C to +125°C
Storage Temperature	–65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	260°C
Supply Voltage (V^+), Pin 13	7V to 32V high side 7V to 15V low side

Pin Description (Refer to Figures 1 and 2)

Pin Number	Pin Name	Pin Function
1	Inhibit	Inhibits current sense function when connected to supply. Normally grounded.
3	Input	Resets current sense latch and turns on power MOSFET when taken above threshold (3.5V typical). Pin 3 requires <1µA to switch.
4	Threshold	Sets current sense trip voltage according to: $V_{TRIP} = \frac{2200}{R_{TH}+1000}$ where R_{TH} to ground is 3.3k to 20kΩ. Adding capacitor C_{TH} increases the trip voltage at turn-on to 2V. Use C_{TH} =10µF for a 10mS turn-on time constant.
5	Sense	The sense pin causes the current sense to trip when V_{SENSE} is V_{TRIP} above V_{SOURCE}. Pin 5 is used in conjunction with a current shunt in the source of a 3 lead FET or a resistor R_S in the sense lead of a current sensing FET.
6	Source	Reference for the current sense voltage on pin 5 and return for the gate clamp zener. Connect to the load side of current shunt or kelvin lead of current sensing FET. Pins 5 and 6 can safely swing to –10V when turning off inductive loads.
7	Ground	
8	Gate	Drives and clamps the gate of the power FET. Pin 8 will be clamped to approximately –0.7V by an internal diode when turning off inductive loads.
9, 10, 11	C2, Com, C1	Optional 1nF capacitors reduce gate turn-on time; C2 has dominant effect.
13	V^+	Supply pin; must be decoupled to isolate from large transients caused by the power FET drain. 10µF is recommended close to pins 13 and 7.
14	Fault	Outputs status of protection circuit when pin 3 is high. Fault low indicates normal operation; fault high indicates current sense tripped.

Pin Configuration



Electrical Characteristics (Note 3) Test circuit. $T_A = -55°C$ to $+125°C$, $V^+ = 15V$, $V_1 = 0$ V, $I_4 = I_5 = I_{14} = 0$, all switches open, unless otherwise specified.

Parameter	Conditions			Min	Typical	Max	Units
Supply Current, I_{13}	$V^+ = 32V$	$V_{IN} = 0V$, S4 closed			0.1	10	µA
		$V_{IN} = V_S = 32V$, $I_4 = 200µA$			8	20	mA
Logic Input Voltage, V_{IN}	$V^+ = 4.75V$	Adjust V_{IN} for V_{GATE} low				2	V
		Adjust V_{IN} for V_{GATE} high		4.5			V
	$V^+ = 15V$	Adjust V_{IN} for V_{GATE} high		5.0			V
Logic Input Current, I_3	$V+ = 32V$	$V_{IN} = 0V$		–1			µA
		$V_{IN} = 32V$				1	µA
Input Capacitance	Pin 3				5		pF
Gate Drive, V_{GATE}	S1, S2 closed,	$V^+ = 7V$, $I_8 = 0$		13	15		V
	$V_S = V+$, $V_{IN} = 5V$	$V^+ = 15V$, $I_8 = 100$ µA		24	27		V
Zener Clamp,	S2 closed, $V_{IN} = 5V$	$V+ = 15V$, $V_S = 15V$		11	12.5	15	V
$V_{GATE} - V_{SOURCE}$		$V^+ = 32V$, $V_S = 32V$		11	13	16	V
Gate Turn-on Time, t_{ON} (Note 4)	V_{IN} switched from 0 to 5V; measure time for V_{GATE} to reach 20V				25	50	µs
Gate Turn-off Time, t_{OFF}	V_{IN} switched from 5 to 0V; measure time for V_{GATE} to reach 1V				4	10	µs
Threshold Bias Voltage, V_4	$I_4 = 200$ µA			1.7	2	2.2	V
Current Sense Trip Voltage,	S2 closed, $V_{IN} = 5V$,	$V^+ = 7V$,	S4 closed	75	105	135	mV
$V_{SENSE} - V_{SOURCE}$	Increase I_5	$I_4 = 100$ µA	$V_S = 4.9V$	70	100	130	mV
		$V^+ = 15V$	S4 closed	150	210	270	mV
		$I_4 = 200$ µA	$V_S = 11.8V$	140	200	260	mV
		$V^+ = 32V$	$V_S = 0V$	360	520	680	mV
		$I_4 = 500$ µA	$V_S = 25.5V$	350	500	650	mV
Peak Current Trip Voltage, $V_{SENSE} - V_{SOURCE}$	S3, S4 closed, $V^+ = 15V$, $V_{IN} = 5V$				1.6	2.1	V
Fault Output Voltage, V_{14}	$V_{IN} = 0V$, $I_{14} = -100$ µA				0.4	1	V
	$V_{IN} = 5V$, $I_{14} = 100$ µA, current sense tripped			14	14.6		V
Current Sense Inhibit, V_1	V_1 above which current sense is disabled				7.5	13	V
	Minimum possible V_1				1		V

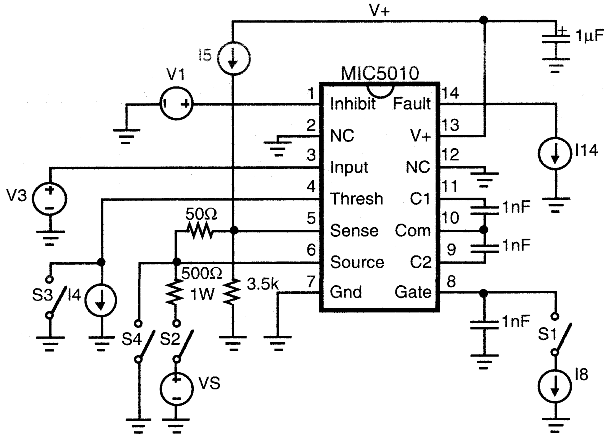
Note 1 **Absolute Maximum Ratings** indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its specified **Operating Ratings**.

Note 2 The MIC5010 is ESD sensitive.

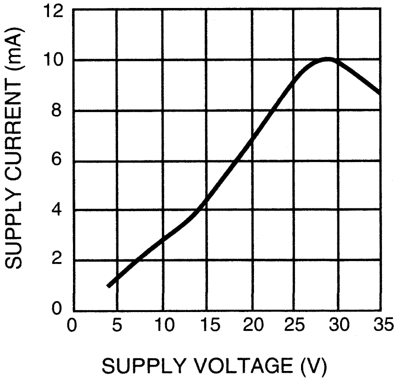
Note 3 Minimum and maximum **Electrical Characteristics** are 100% tested at $T_A = 25°C$ and $T_A = 85°C$, and 100% guaranteed over the entire range. Typicals are characterized at 25°C and represent the most likely parametric norm.

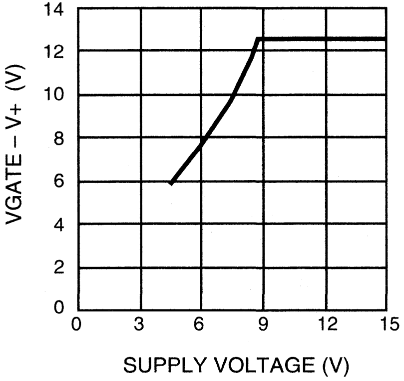
Note 4 Test conditions reflect worst case high-side driver performance. Low-side and bootstrapped topologies are significantly faster—see **Applications Information**.

Test Circuit



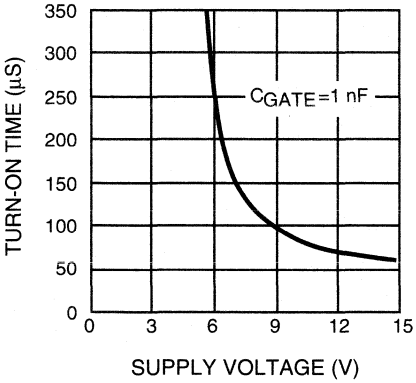
Typical Characteristics


Supply Current

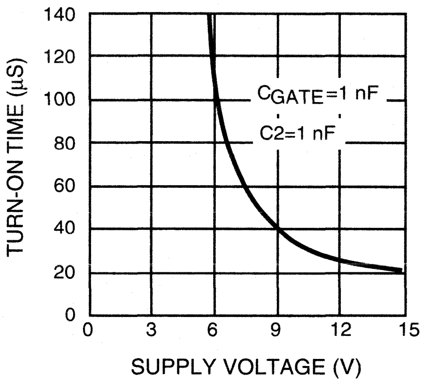

DC Gate Voltage above Supply

Typical Characteristics (Continued)

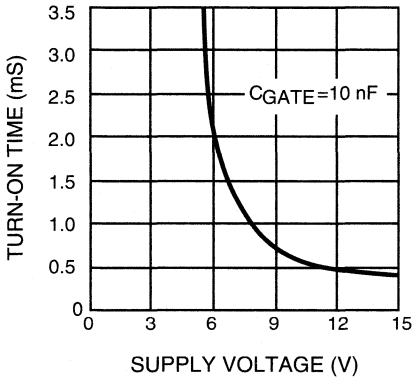
High-side Turn-on Time*



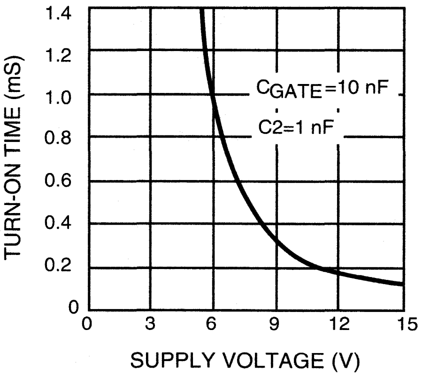
High-side Turn-on Time*



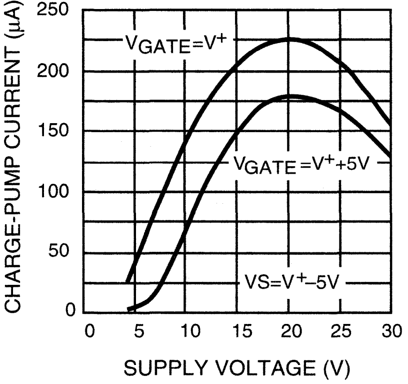
High-side Turn-on Time*



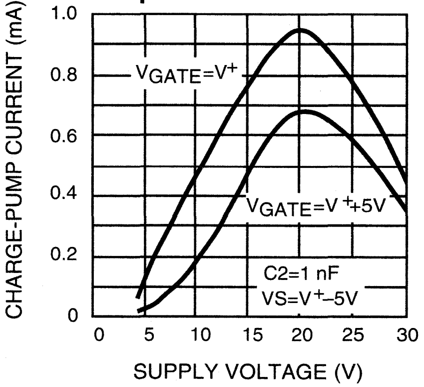
High-side Turn-on Time*



Charge Pump Output Current



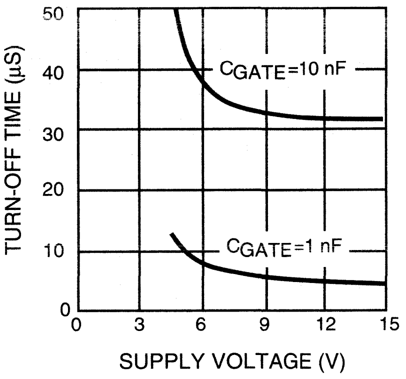
Charge Pump Output Current



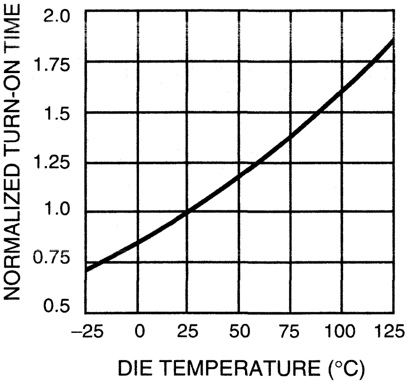
* Time for gate to reach V^+ + 5V in test circuit with VS = V^+ – 5V (prevents gate clamp from interfering with measurement).

Typical Characteristics (Continued)

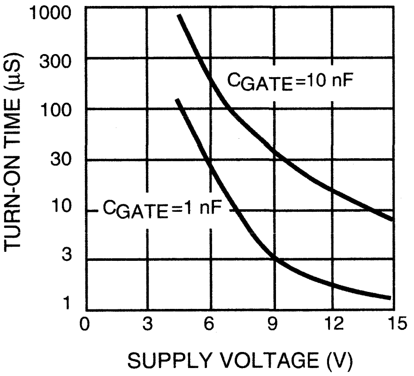
Turn-off Time



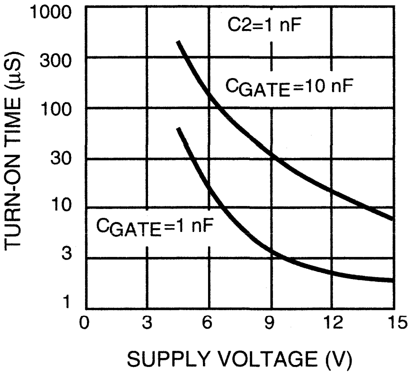
Turn-on Time



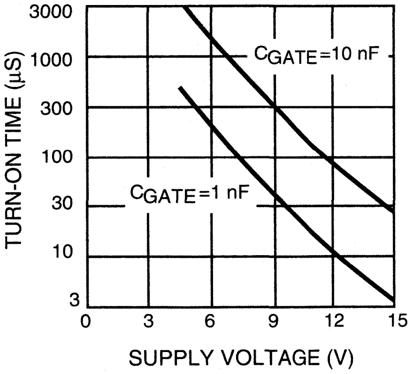
Low-side Turn-on Time for Gate = 5V



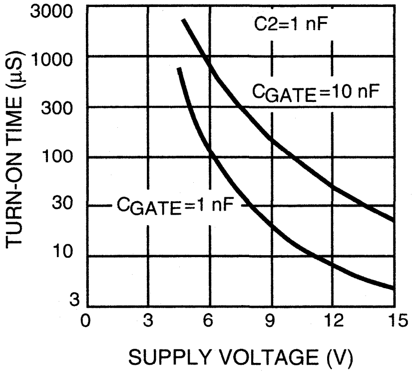
Low-side Turn-on Time for Gate = 5V



Low-side Turn-on Time for Gate = 10V



Low-side Turn-on Time for Gate = 10V



Applications Information

Functional Description (Refer to Block Diagram)

The various MIC5010 functions are controlled via a logic block connected to the input pin 3. When the input is low all functions are turned off for low standby current, and the gate of the power MOSFET is also held low through 500Ω to an N-channel switch. When the input is taken above the turn-on threshold (3.5V typical), the N-channel switch turns off and the charge pump is turned on to charge the gate of the power FET. A bandgap type voltage regulator is also turned on which biases the current sense circuitry.

The charge pump incorporates a 100kHz oscillator and on-chip pump capacitors capable of charging 1 nF to 5V above supply in 60µS typical. With the addition of 1nF capacitors at C1 and C2, the turn-on time is reduced to 25µS typical. The charge pump is capable of pumping thegate up to over twice the supply voltage. For this reason a zener clamp (12.5V typical) is provided between the gate pin 8 and the source pin 6 to prevent exceeding the V_{GS} rating of the MOSFET at high supplies.

The current sense operates by comparing the sense voltage at pin 5 to an offset version of the source voltage at pin 6. Current I4 flowing in threshold pin 4 is mirrored and returned to the source via a 1kΩ resistor to set the offset or trip voltage. When ($V_{SENSE} - V_{SOURCE}$) exceeds V_{TRIP}, the current sense trips and sets the current sense latch to turn off the power FET. An integrating comparator is used to reduce sensitivity to spikes on pin 5. The latch is reset to turn the FET back on by "recycling" the input pin 3 low and then high again.

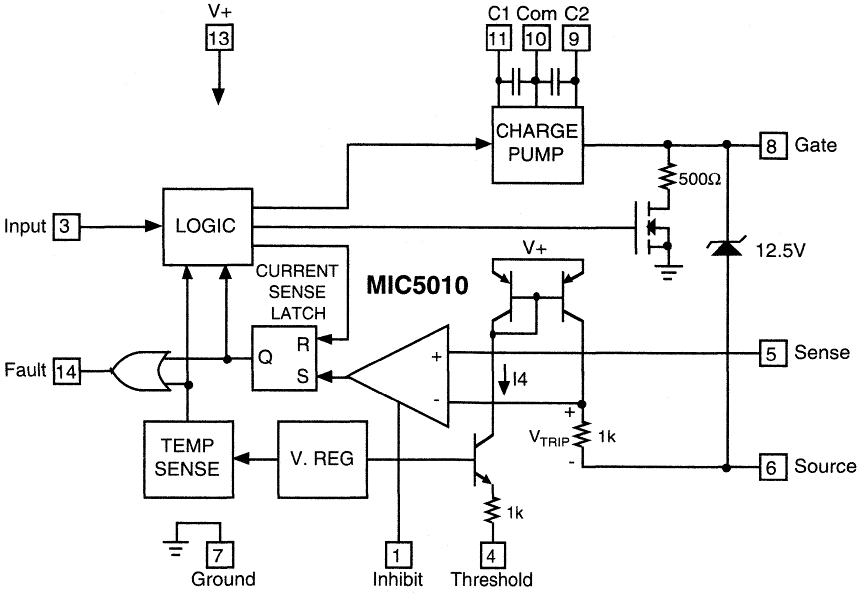
A resistor R_{TH} from pin 4 to ground sets I4, and hence V_{TRIP}. An additional capacitor C_{TH} from pin 4 to ground creates a higher trip voltage at turn-on, which is necessary to prevent high in-rush current loads such as lamps or capacitors from false-tripping the current sense.

When the current sense has tripped, the fault pin 14 will be high as long as the input pin 3 remains high. However, when the input is low the fault pin will also be low.

Construction Hints

High current pulse circuits demand equipment and assembly techniques that are more stringent than normal, low current lab practices. The following are the sources of common pitfalls encountered while prototyping:Supplies: many bench power supplies have poor transient response. Circuits that are being pulse tested, or those that operate by pulse-width modulation will produce strange results when used with a supply that has poor ripple rejection, or a peaked transient response. Monitor the power supply voltage that appears at the drain of a high-side driver (or the supply side of the load in a low-side driver) with an oscilloscope. It is not uncommon to find bench power supplies in the 1kW class that overshoot or undershoot by as much as 50% when pulse loaded. Not only will the load current and voltage measurements be affected, but it is possible to over-stress various components—especially electrolytic capacitors—with possibly catastrophic results. A 10µF supply bypass capacitor at the chip is recommended.

Block Diagram



Applications Information (Continued)

Residual Resistances: Resistances in circuit connections may also cause confusing results. For example, a circuit may employ a 50mΩ power MOSFET for low drop, but careless construction techniques could easily add 50 to 100 mΩ resistance. Do not use a socket for the MOSFET. If the MOSFET is a TO-220 type package, make high-current drain connections to the tab. Wiring losses have a profound effect on high-current circuits. A floating millivoltmeter can identify connections that are contributing excess drop under load.

Circuit Topologies

The MIC5010 is suited for use in high- or low-side driver applications with over-current protection for both current-sensing and standard MOSFETs. In addition, the MIC5010 works well in applications where, for faster switching times, the supply is bootstrapped from the MOSFET source output. Low voltage, high-side drivers (such as shown in the Test Circuit) are the slowest; their speed is reflected in the gate turn-on time specifications. The fastest drivers are the low-side and bootstrapped high-side types. Load current switching times are often much faster than the time to full gate enhancement, depending on the circuit type, the MOSFET, and the load. Turn-off times are essentially the same for all circuits (less than 10µs to $V_{GS} = 1V$). The choice of one topology over another is based on a combination of considerations including speed, voltage, and desired system characteristics. Each topology is described in this section. Note that I_L, as used in the design equations, is the load current that just trips the over-current comparator.

Low-Side Driver with Current Shunt (Figure 2). The over-current comparator monitors R_S and trips if $I_L \times R_S$ exceeds V_{TRIP}. R_{TH} is selected to produce the desired trip voltage. As a guideline, keep V_{TRIP} within the limits of 100mV and 500mV (R_{TH} = 3.3kΩ to 20kΩ). Thresholds at the high end offer the best noise immunity, but also compromise switch drop (especially in low voltage applications) and power dissipation.

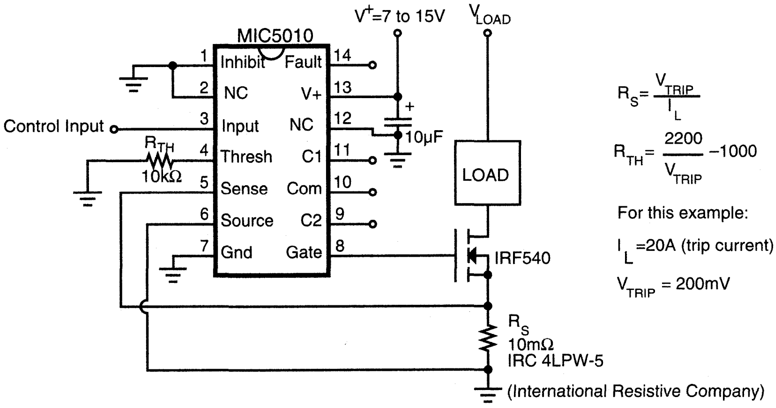
The trip current is set higher than the maximum expected load current--typically twice that value. Trip point accuracy is a function of resistor tolerances, comparator offset (only a few millivolts), and threshold bias voltage (V_4). The values shown in Figure 2 are designed for a trip current of 20 amperes. It is important to ground pin 6 at the current shunt R_S, to eliminate the effects of ground resistance.

A key advantage of the low-side topology is that the load supply is limited only by the MOSFET BV_{DSS} rating. Clamping may be required to protect the MOSFET drain terminal from inductive switching transients. The MIC5010 supply should be limited to 15V in low-side topologies; otherwise, a large current will be forced through the gate clamp zener.

Low-side drivers constructed with the MIC501X family are also fast; the MOSFET gate is driven to near supply immediately when commanded ON. Typical circuits achieve 10V enhancement in 10µs or less on a 12 to 15V supply.

High-Side Driver with Current Shunt (Figure 3). The comparator input pins (source and sense) float with the current sensing resistor (R_S) on top of the load. R1 and R2 add a small, additional potential to V_{TRIP} to prevent false-triggering of the over-current shutdown circuit with open or inductive loads. R1 is sized for a current flow of 1mA, while R2 contributes a drop of 100mV. The shunt voltage should be 200 to 500mV at the trip point. The example of Figure 3 gives a 10A trip current when the output is near supply. The trip point is somewhat reduced when the output is at ground as the voltage drop across R1 (and therefore R2) is zero.

High-side drivers implemented with MIC501X drivers are



$$R_S = \frac{V_{TRIP}}{I_L}$$

$$R_{TH} = \frac{2200}{V_{TRIP}} - 1000$$

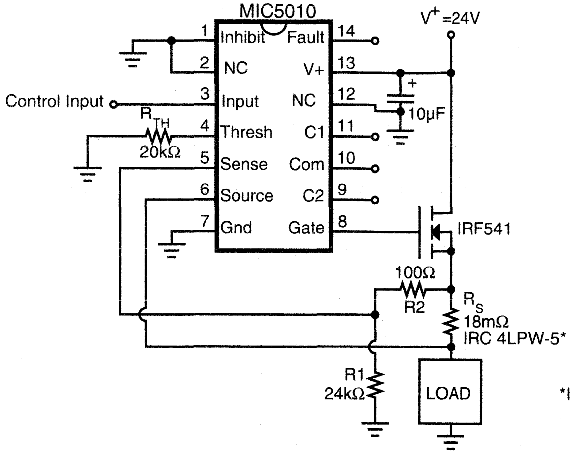
For this example:

I_L =20A (trip current)

V_{TRIP} = 200mV

Figure 2. Low-Side Driver with Current Shunt

Applications Information (Continued)



$$R1 = \frac{V^+}{1\text{mA}}$$

$$R2 = 100\Omega$$

$$R_S = \frac{100\text{mV} + V_{TRIP}}{I_L}$$

$$R_{TH} = \frac{2200}{V_{TRIP}} - 1000$$

For this example:
I_L =10A (trip current)
V_{TRIP} =100mV

*International Resistive Company

Figure 3. High-Side Driver with Current Shunt

self-protected against inductive switching transients. During turn-off an inductive load will force the MOSFET source 5V or more below ground, while the driver holds the gate at ground potential. The MOSFET is forced into conduction, and it dissipates the energy stored in the load inductance. The MIC5010 source and sense pins (5 and 6) are designed to withstand this negative excursion without damage. External clamp diodes are unnecessary, but may be added to reduce power dissipation in the MOSFET.

Current Shunts (R_S). Low-valued resistors are necessary for use at R_S.Values for R_S range from 5 to 50mΩ, at 2 to 10W. Worthy of special mention are Kelvin-sensed, "four-terminal" units supplied by a number of manufacturers[†]. Kelvin-sensed resistors eliminate errors that are caused by lead and terminal resistances, and simplify product assembly. 10% tolerance is normally adequate, and with shunt potentials of 200mV thermocouple effects are insignificant. Temperature coefficient is important; a linear, 500ppm/°C change will contribute as much as 10% shift in the over-current trip point. Most power resistors designed for current shunt service drift less than 100ppm/°C.

Low-Side Driver with Current Sensing MOSFET (Figure 4). Several manufacturers now supply power MOSFETs in which a small sampling of the total load current is diverted to a "sense" pin. One additional pin, called "Kelvin source," is included to eliminate the effects of resistance in the source bond wires. Current-sensing MOSFETs are specified with a sensing ratio "S" which describes the relationship between the on-resistance of the sense connection and the body resistance "R" of the main source pin. Current sensing MOSFETs eliminate the current shunt required by standard MOSFETs.

The design equations for a low-side driver using a current sensing MOSFET are shown in Figure 4. "S" is specified on the MOSFET's datasheet, and "R" must be measured or estimated. V_{TRIP} must be less than R × I_L, or else R_S will become negative. Substituting a MOSFET with higher on-resistance, or reducing V_{TRIP} fixes this problem. V_{TRIP} = 100 to 200mV is suggested. Although the load supply is limited only by MOSFET ratings, the MIC5010 supply should be limited to 15V to prevent damage to the gate clamp zener. Output clamping is necessary for inductive loads.

"R" is the body resistance of the MOSFET, excluding bond resistances. $R_{DS(ON)}$ as specified on MOSFET data sheets includes bond resistances. A Kelvin-connected ohmmeter (using TAB and SOURCE for forcing, and SENSE and KELVIN for sensing) is the best method of evaluating "R." Alternatively, "R" can be estimated for large MOSFETs ($R_{DS(ON)} \leq 100\text{m}\Omega$) by simply halving the stated $R_{DS(ON)}$, or by subtracting 20 to 50mΩ from the stated $R_{DS(ON)}$ for smaller MOSFETs.

High-Side Driver with Current Sensing MOSFET (Figure 1). The design starts by determining the value of "S" and "R" for the MOSFET (use the guidelines described for the low-side version). Let V_{TRIP} = 100 mV, and calculate R_S for a desired trip current. Next calculate R_{TH} and R1. The trip

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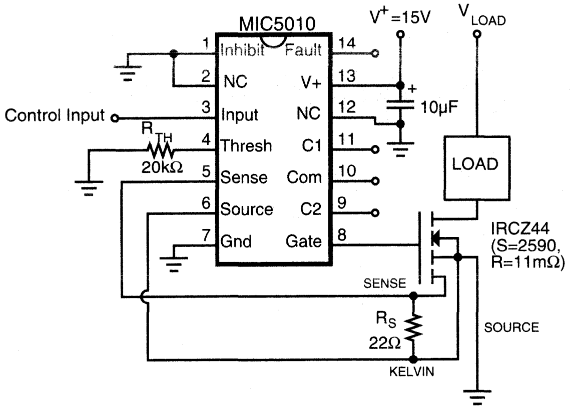
[†] Suppliers of Kelvin-sensed power resistors:
Dale Electronics, Inc., 2064 12th Ave., Columbus, NE 68601. Tel: (402) 564-3131
International Resistive Co., P.O. Box 1860, Boone, NC 28607-1860. Tel: (704) 264-8861
Kelvin, 14724 Ventura Blvd., Ste. 1003, Sherman Oaks, CA 91403-3501. Tel: (818) 990-1192
RCD Components, Inc., 520 E. Industrial Pk. Dr., Manchester, NH 03103. Tel: (603) 669-0054
Ultronix, Inc., P.O. Box 1090, Grand Junction, CO 81502. Tel: (303) 242-0810

Applications Information (Continued)



$$R_S = \frac{S\,R\,V_{TRIP}}{R\,I_L - V_{TRIP}}$$

$$R_{TH} = \frac{2200}{V_{TRIP}} - 1000$$

For this example:

I_L =20A (trip current)

V_{TRIP} =100mV

Figure 4. Low-Side Driver with Current-Sensing MOSFET

point is somewhat reduced when the output is at ground as the voltage drop across R1 is zero. No clamping is required for inductive loads.

Typical Applications

Start-up into a Dead Short. If the MIC5010 attempts to turn on a MOSFET when the load is shorted, a very high current flows. The over-current shutdown will protect the MOSFET, but only after a time delay of 5 to 10µs. The MOSFET must be capable of handling the overload; consult the device's SOA curve. If a short circuit causes the MOSFET to exceed its 10µs SOA, a small inductance in series with the source can help limit di/dt to control the peak current during the 5 to 10µs delay.

When testing short-circuit behavior, use a current probe rated for both the peak current and the high di/dt.

The over-current shutdown delay varies with comparator overdrive, owing to noise filtering in the comparator. A delay of up to 100µs can be observed at the threshold of shutdown. A 20% overdrive reduces the delay to near minimum.

Incandescent Lamps. The cold filament of an incandescent lamp exhibits less than one-tenth as much resistance as when the filament is hot. The initial turn-on current of a #6014 lamp is about 70A, tapering to 4.4A after a few hundred milliseconds. It is unwise to set the over-current trip point to 70A to accommodate such a load. A "resistive" short that draws less than 70A could destroy the MOSFET by allowing sustained, excessive dissipation. If the over-current trip point is set to less than 70A, the MIC5010 will not start a cold filament. The solution is to start the lamp with a high trip point, but reduce this to a reasonable value after the lamp is hot.

The MIC5010 over-current shutdown circuit is designed to handle this situation by varying the trip point with time (see Figure 5). R_{TH1} functions in the conventional manner, providing a current limit of approximately twice that required by the lamp. R_{TH2} acts to increase the current limit at turn-on to approximately 10 times the steady-state lamp current. The high initial trip point decays away according to a 20ms time constant contributed by C_{TH}. R_{TH2} could be eliminated with C_{TH} working against the internal 1kΩ resistor, but this results in a very high over-current threshold. As a rule of thumb design the over-current circuitry in the conventional manner, then add the R_{TH2}/C_{TH} network to allow for lamp start-up. Let $R_{TH2} = (R_{TH1} \div 10) - 1k\Omega$, and choose a capacitor that provides the desired time constant working against R_{TH2} and the internal 1kΩ resistor.

When the MIC5010 is turned off, the threshold pin (4) appears as an open circuit, and C_{TH} is discharged through R_{TH1} and R_{TH2}. This is much slower than the turn-on time

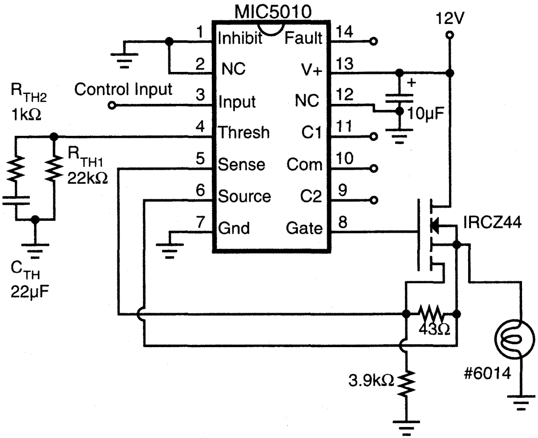


Figure 5. Time-Variable Trip Threshold

Applications Information (Continued)

constant, and it simulates the thermal response of the filament. If the lamp is pulse-width modulated, the current limit will be reduced by the residual charge left in C_{TH}.

Modifying Switching Times. Do not add external capacitors to the gate to slow down the switching time. Add a resistor (1kΩ to 51kΩ) in series with the gate of the MOSFET to achieve this result.

External capacitors can be added at C1 and C2 for faster switching times (see Block Diagram). Values of 100pF to 1nF produce useful speed increases. If component count is critical, C2 (pins 9 to 10) can be used alone with only a small loss of speed compared to using both capacitors.

Bootstrapped High-Side Driver (Figure 6). The speed of a high-side driver can be increased to better than 10µs by bootstrapping the supply off of the MOSFET source. This topology can be used where the load is pulse-width modulated (100Hz to 20kHz), or where it is energized for only a short period of time (≤25ms). If the load is left energized for a long period of time (>25ms), the bootstrap capacitor will discharge and the MIC5010 supply pin will fall to $V^+ = V_{DD} - 1.4$. Under this condition pins 5 and 6 will be held above V^+ and may false trigger the over-current circuit. A larger capacitor will lengthen the maximum "on" time; 1000µF will hold the circuit up for 2.5 seconds, but requires more charge time when the circuit is turned off. The optional Schottky barrier diode improves turn-on time on supplies of less than 10V.

Since the supply current in the "off" state is only a small leakage, the 100nF bypass capacitor tends to remain charged for several seconds after the MIC5010 is turned off. In a PWM application the chip supply is actually much higher than the system supply, which improves switching time.

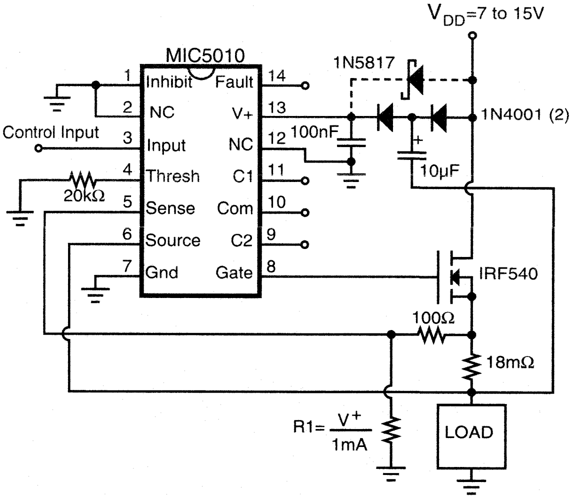


Figure 6. Bootstrapped High-Side Driver

Electronic Circuit Breaker (Figure 7). The MIC5010 forms the basis of a high-performance, fast-acting circuit breaker. By adding feedback from FAULT to INPUT the breaker can be made to automatically reset. If an over-current condition

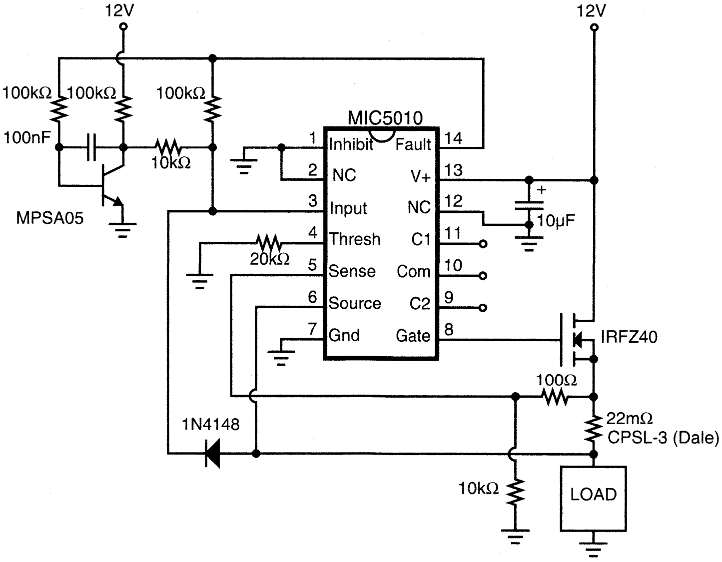


Figure 7. 10-Ampere Electronic Circuit Breaker

Applications Information (Continued)

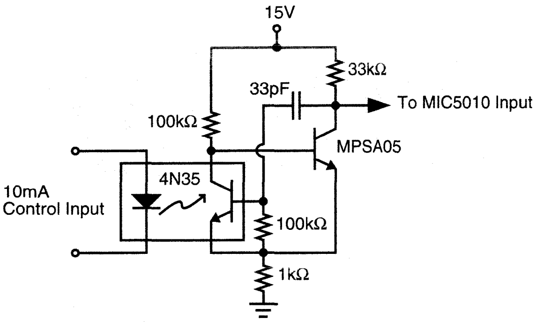


Figure 8. Improved Opto-Isolator Performance

occurs, the circuit breaker shuts off. The breaker tests the load every 18ms until the short is removed, at which time the circuit latches ON. No reset button is necessary.

Opto-Isolated Interface (Figure 8). Although the MIC5010 has no special input slew rate requirement, the lethargic transitions provided by an opto-isolator may cause oscillations on the rise and fall of the output. The circuit shown accelerates the input transitions from a 4N35 opto-isolator by adding hysteresis. Opto-isolators are used where the control circuitry cannot share a common ground with the MIC5010 and high-current power supply, or where the control circuitry is located remotely. This implementation is intrinsically safe; if the control line is severed the MIC5010 will turn OFF.

Fault-Protected Industrial Switch (Figure 9). The most common manual control for industrial loads is a push button on/off switch. The "on" button is physically arranged in a recess so that in a panic situation the "off" button, which extends out from the control box, is more easily pressed. This circuit is compatible with control boxes such as the CR2943 series (GE). The circuit is configured so that if both switches close simultaneously, the "off" button has precedence. If there is a fault condition the circuit will latch off, and it can be reset by pushing the "on" button.

This application also illustrates how two (or more) MOSFETs can be paralleled. This reduces the switch drop, and distributes the switch dissipation into multiple packages.

High-Voltage Bootstrap (Figure 10). Although the MIC5010 is limited to operation on 7 to 32V supplies, a floating bootstrap arrangement can be used to build a high-side switch that operates on much higher voltages. The MIC5010 and MOSFET are configured as a low-side driver, but the load is connected in series with ground. The high speed normally associated with low-side drivers is retained in this circuit.

Power for the MIC5010 is supplied by a charge pump. A 20kHz square wave (15Vp-p) drives the pump capacitor and delivers current to a 100µF storage capacitor. A zener diode limits the supply to 18V. When the MIC5010 is off, power is supplied by a diode connected to a 15V supply. The circuit of Figure 8 is put to good use as a barrier between low voltage control circuitry and the 90V motor supply.

Half-Bridge Motor Driver (Figure 11). Closed loop control of motor speed requires a half-bridge driver. This topology presents an extra challenge since the two output devices should not cross conduct (shoot-through) when switching. Cross conduction increases output device power dissipation and, in the case of the MIC5010, could trip the over-current comparator. Speed is also important, since PWM control requires the outputs to switch in the 2 to 20kHz range.

The circuit of Figure 11 utilizes fast configurations for both the top- and bottom-side drivers. Delay networks at each input provide a 2 to 3µs dead time effectively eliminating

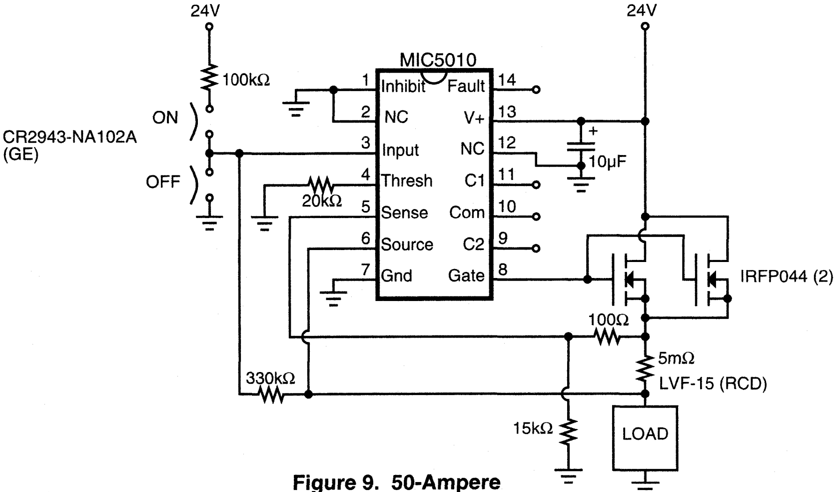


Figure 9. 50-Ampere Industrial Switch

Applications Information (Continued)

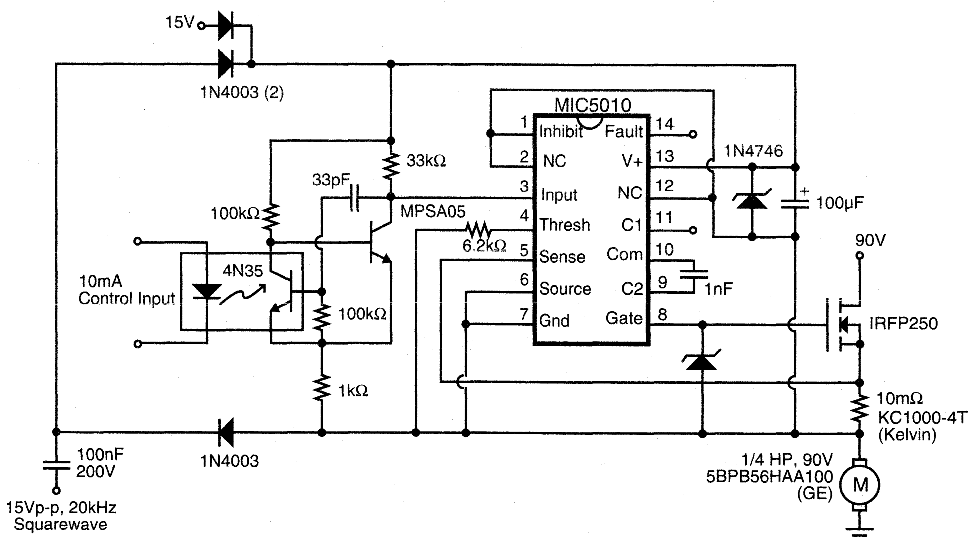


Figure 10. High-Voltage Bootstrapped Driver

cross conduction. Both the top- and bottom-side drivers are protected, so the output can be shorted to either rail without damage.

The top-side driver is based on the bootstrapped circuit of Figure 6, and cannot be switched on indefinitely. The bootstrap capacitor (1µF) relies on being pulled to ground by the bottom-side output to recharge. This limits the maximum duty cycle to slightly less than 100%.

Two of these circuits can be connected together to form an H-bridge. If the H-bridge is used for locked antiphase control, no special considerations are necessary. In the case of sign/magnitude control, the "sign" leg of the H-bridge should be held low (PWM input held low) while the other leg is driven by the magnitude signal.

If current feedback is required for torque control, it is available in chopped form at the bottom-side driver's 22mΩ current-sensing resistor.

Time-Delay Relay (Figure 12). The MIC5010 forms the basis of a simple time-delay relay. As shown, the delay commences when power is applied, but the 100kΩ/1N4148 could be independently driven from an external source such as a switch or another high-side driver to give a delay relative to some other event in the system.

Hysteresis has been added to guarantee clean switching at turn-on. Note that an over-current condition latches the relay in a safe, OFF condition. Operation is restored by either cycling power or by momentarily shorting pin 3 to ground.

Motor Driver with Stall Shutdown (Figure 13). Tachometer feedback can be used to shut down a motor driver circuit when a stall condition occurs. The control switch is a 3-way type; the "START" position is momentary and forces the driver ON. When released, the switch returns to the "RUN" position, and the tachometer's output is used to hold the MIC5010 input ON. If the motor slows down, the tach output is reduced, and the MIC5010 switches OFF. Resistor "R" sets the shutdown threshold. If the output current exceeds 30A, the MIC5010 shuts down and remains in that condition until the momentary "RESET" button is pushed. Control is then returned to the START/RUN/STOP switch.

Applications Information (Continued)

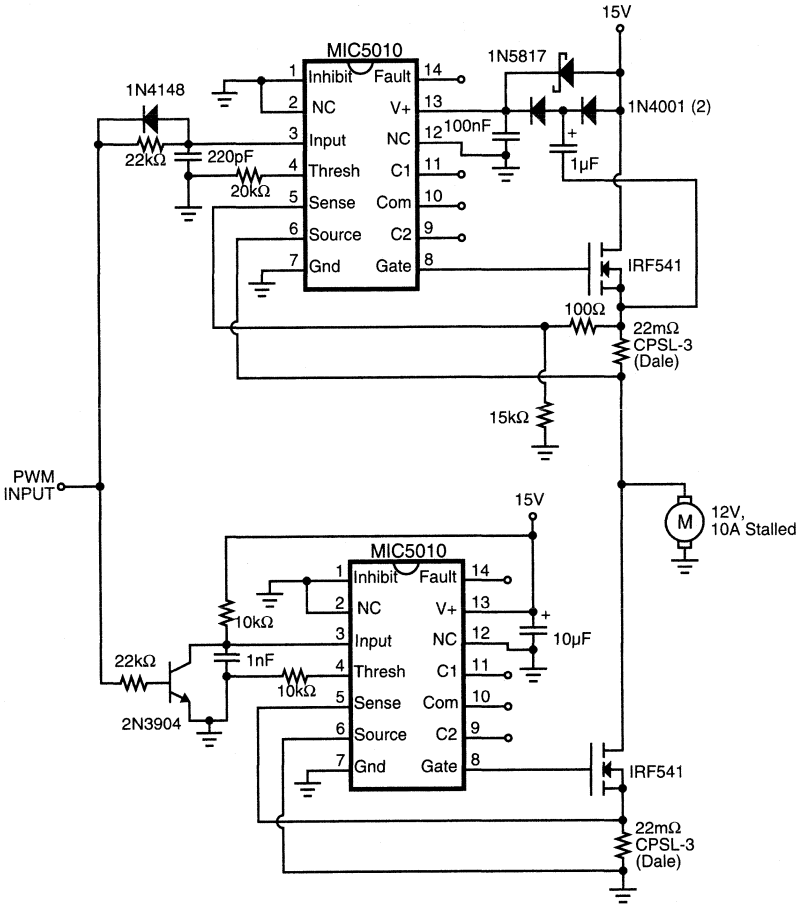


Figure 11. Half-Bridge Motor Driver

Applications Information (Continued)

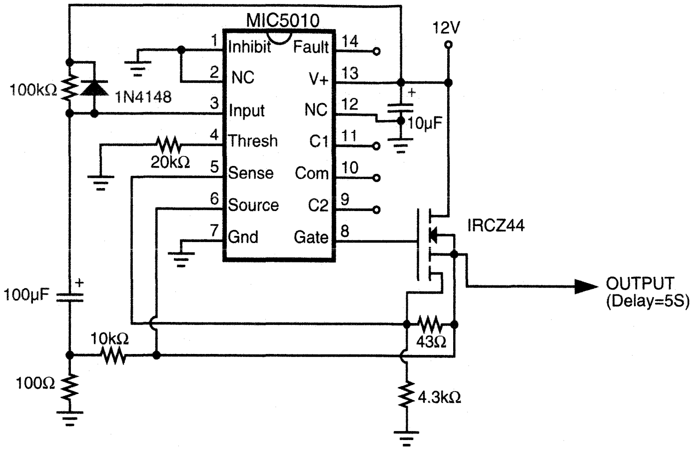


Figure 12. Time-Delay Relay with 30A Over-Current Protection

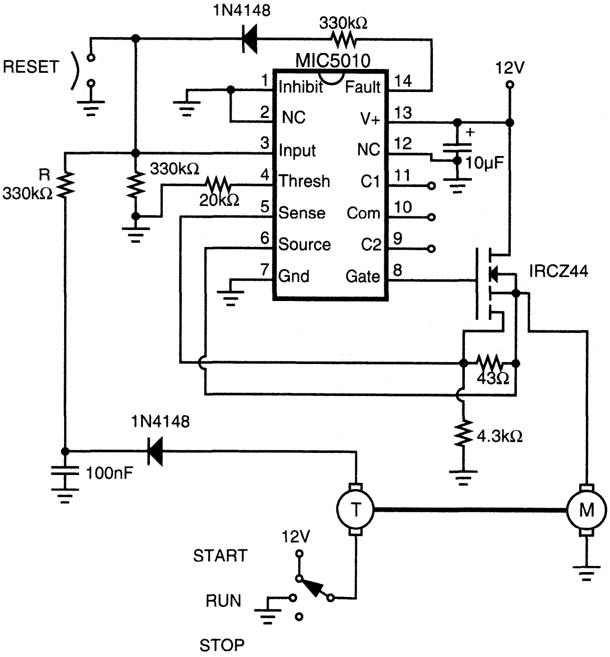


Figure 13. Motor Stall Shutdown

Applications Information (Continued)

Gate Control Circuit

When applying the MIC5010, it is helpful to understand the operation of the gate control circuitry (see Figure 14). The gate circuitry can be divided into two sections: 1) charge pump (oscillator, Q1-Q5, and the capacitors) and 2) gate turn-off switch (Q6).

When the MIC5010 is in the OFF state, the oscillator is turned off, thereby disabling the charge pump. Q5 is also turned off, and Q6 is turned on. Q6 holds the gate pin (G) at ground potential which effectively turns the external MOSFET off.

Q6 is turned off when the MIC5010 is commanded on. Q5 pulls the gate up to supply (through 2 diodes). Next, the charge pump begins supplying current to the gate. The gate accepts charge until the gate-source voltage reaches 12.5V and is clamped by the zener diode.

A 2-output, three-phase clock switches Q1-Q4, providing a quasi-tripling action. During the initial phase Q4 and Q2 are ON. C1 is discharged, and C2 is charged to supply through Q5. For the second phase Q4 turns off and Q3 turns on, pushing pin C2 above supply (charge is dumped into the gate). Q3 also charges C1. On the third phase Q2 turns off and Q1 turns on, pushing the common point of the two capacitors above supply. Some of the charge in C1 makes its way to the gate. The sequence is repeated by turning Q2 and Q4 back on, and Q1 and Q3 off.

In a low-side application operating on a 12 to 15V supply, the MOSFET is fully enhanced by the action of Q5 alone. On supplies of more than approximately 14V, current flows directly from Q5 through the zener diode to ground. To prevent excessive current flow, the MIC5010 supply should be limited to 15V in low-side applications.

The action of Q5 makes the MIC5010 operate quickly in low-side applications. In high-side applications Q5 precharges the MOSFET gate to supply, leaving the charge pump to carry the gate up to full enhancement 10V above supply. Bootstrapped high-side drivers are as fast as low-side drivers since the chip supply is boosted well above the drain at turn-on.

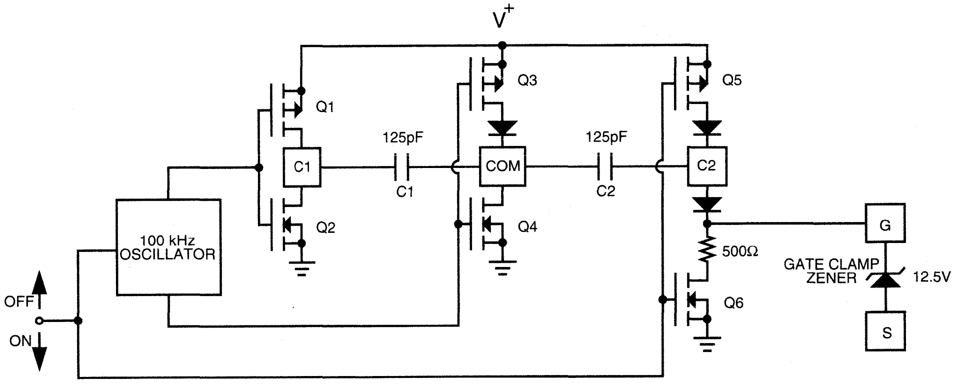


Figure 14. Gate Control Circuit Detail

MIC5011

Minimum Parts High- or Low-Side MOSFET Driver

General Description

The MIC5011 is the "minimum parts count" member of the Micrel MIC501X driver family. These ICs are designed to drive the gate of an N-channel power MOSFET above the supply rail in high-side power switch applications. The 8-pin MIC5011 is extremely easy to use, requiring only a power FET and nominal supply decoupling to implement either a high- or low-side switch.

The MIC5011 charges a 1nF load in 60µs typical with no external components. Faster switching is achieved by adding two 1nF charge pump capacitors. Operation down to 4.75V allows the MIC5011 to drive standard MOSFETs in 5V low-side applications by boosting the gate voltage above the logic supply. In addition, multiple paralleled MOSFETs can be driven by a single MIC5011 for ultra-high current applications.

Other members of the Micrel driver family include the MIC5010 full-featured driver, MIC5012 dual driver, and MIC5013 protected 8-pin driver.

For new designs, Micrel recommends the pin-compatible MIC5014 MOSFET driver.

Features

- 4.75V to 32V operation
- Less than 1µA standby current in the "off" state
- Internal charge pump to drive the gate of an N-channel power FET above supply
- MIL-STD-883 Method 5004/5005 version available
- Available in small outline SOIC packages
- Internal zener clamp for gate protection
- Minimum external parts count
- Can be used to boost drive to low-side power FETs operating on logic supplies
- 25µs typical turn-on time with optional external capacitors
- Implements high- or low-side drivers

Applications

- Lamp drivers
- Relay and solenoid drivers
- Heater switching
- Power bus switching

Typical Applications

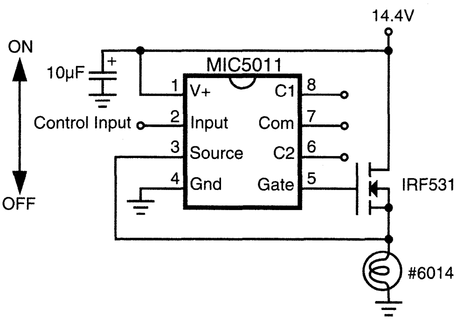


Figure 1. High Side Driver

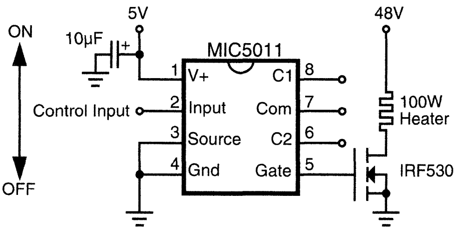


Figure 2. Low Side Driver

Ordering Information

Part Number	Temp. Range	Package
MIC5011BN	–40°C to +85°C	8-pin Plastic DIP
MIC5011BM	–40°C to +85°C	8-pin SOIC
5962-9313901MPA*	–55°C to +125°C	8-pin Ceramic DIP

* Standard Military Drawing number for MIC5011AJBQ

Note: The MIC5011 is ESD sensitive.

Protected under one or more of the following Micrel patents:
patent #4,951,101; patent #4,914,546

Absolute Maximum Ratings (Note 1, 2)

Supply Voltage (V^+), Pin 1	–0.5V to 36V
Input Voltage, Pin 2	–10V to V^+
Source Voltage, Pin 3	–10V to V^+
Current into Pin 3	50mA
Gate Voltage, Pin 5	–1V to 50V
Junction Temperature	150°C

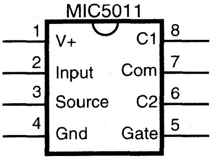
Operating Ratings (Notes 1, 2)

Power Dissipation	1.25W
θ_{JA} (Plastic DIP)	100°C/W
θ_{JA} (Ceramic DIP)	125°C/W
θ_{JA} (SOIC)	170°C/W
Ambient Temperature: B version	–40°C to +85°C
Ambient Temperature: A version	–55°C to +125°C
Storage Temperature	–65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	260°C
Supply Voltage (V^+), Pin 1	4.75V to 32V high side 4.75V to 15V low side

Pin Description (Refer to **Typical Applications**)

Pin Number	Pin Name	Pin Function
1	V^+	Supply; must be decoupled to isolate from large transients caused by the power FET drain. 10µF is recommended close to pins 1 and 4.
2	Input	Turns on power MOSFET when taken above threshold (3.5V typical). Requires <1 µA to switch.
3	Source	Connects to source lead of power FET and is the return for the gate clamp zener. Can safely swing to –10V when turning off inductive loads.
4	Ground	
5	Gate	Drives and clamps the gate of the power FET. Will be clamped to approximately –0.7V by an internal diode when turning off inductive loads.
6, 7, 8	C2, Com, C1	Optional 1nF capacitors reduce gate turn-on time; C2 has dominant effect.

Pin Configuration



Electrical Characteristics (Note 3) Test circuit. $T_A = -55°C$ to $+125°C$, $V^+ = 15V$, all switches open, unless otherwise specified.

Parameter	**Conditions**		**Min**	**Typical**	**Max**	**Units**
Supply Current, I_1	$V^+ = 32V$	$V_{IN} = 0V$, S2 closed		0.1	10	µA
		$V_{IN} = V^+ = 32V$		8	20	mA
	$V^+ = 5V$	$V_{IN} = 5V$, S2 closed		1.6	4	mA
Logic Input Voltage	$V^+ = 4.75V$	Adjust V_{IN} for V_{GATE} low			2	V
		Adjust V_{IN} for V_{GATE} high	4.5			V
	$V^+ = 15V$	Adjust V_{IN} for V_{GATE} high	5.0			V
Logic Input Current, I_2	$V^+ = 32V$	$V_{IN} = 0V$	–1			µA
		$V_{IN} = 32V$			1	µA
Input Capacitance	Pin 2			5		pF
Gate Drive, V_{GATE}	S1, S2 closed,	$V^+ = 4.75V$, $I_{GATE} = 0$, $V_{IN} = 4.5V$	7	10		V
	$V_S = V+$, $V_{IN} = 5V$	$V^+ = 15V$, $I_{GATE} = 100µA$, $V_{IN} = 5V$	24	27		V
Zener Clamp,	S2 closed, $V_{IN} = 5V$	$V^+ = 15V$, $V_S = 15V$	11	12.5	15	V
$V_{GATE} - V_{SOURCE}$		$V^+ = 32V$, $V_S = 32V$	11	13	16	V
Gate Turn-on Time, t_{ON} (Note 4)	V_{IN} switched from 0 to 5V; measure time for V_{GATE} to reach 20V			25	50	µs
Gate Turn-off Time, t_{OFF}	V_{IN} switched from 5 to 0V; measure time for V_{GATE} to reach 1V			4	10	µs

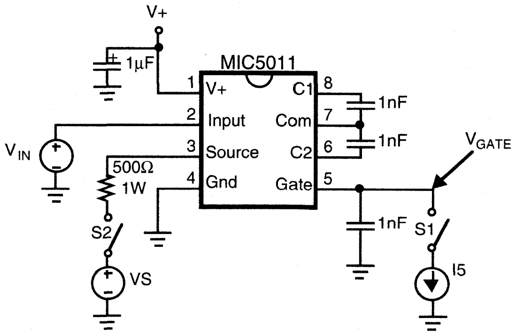
Note 1 **Absolute Maximum Ratings** indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its specified **Operating Ratings**.

Note 2 The MIC5011 is ESD sensitive.

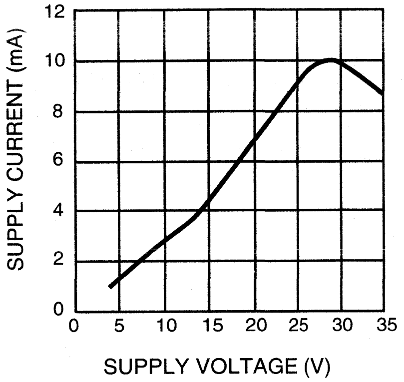
Note 3 Minimum and maximum **Electrical Characteristics** are 100% tested at $T_A = 25°C$ and $T_A = 85°C$, and 100% guaranteed over the entire range. Typicals are characterized at 25°C and represent the most likely parametric norm.

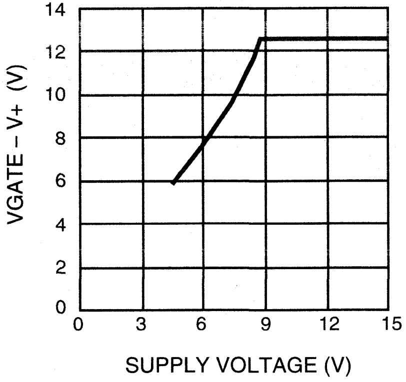
Note 4 Test conditions reflect worst case high-side driver performance. Low-side and bootstrapped topologies are significantly faster—see **Applications Information**. Maximum value of switching speed seen at 125°C, units operated at room temperature will reflect the typical values shown.

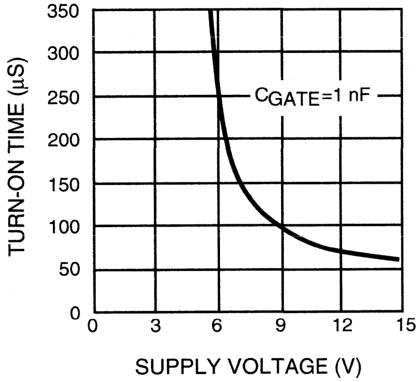
Test Circuit

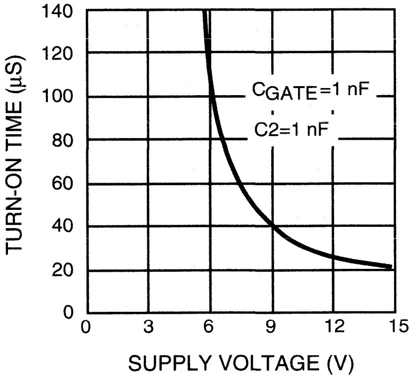


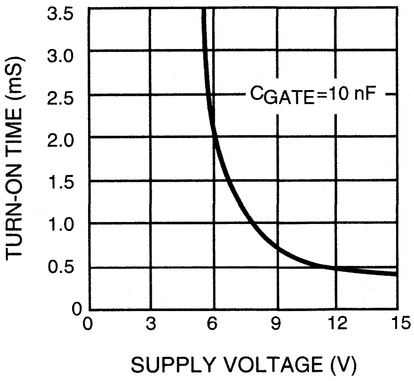
Typical Characteristics (Continued)

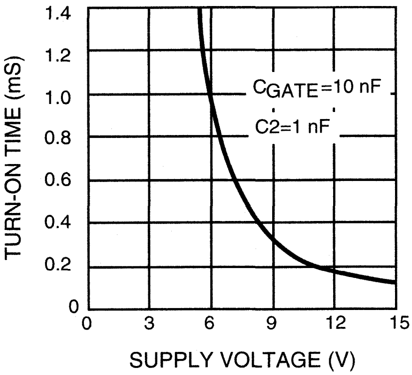

Supply Current


DC Gate Voltage above Supply


High-side Turn-on Time*


High-side Turn-on Time*

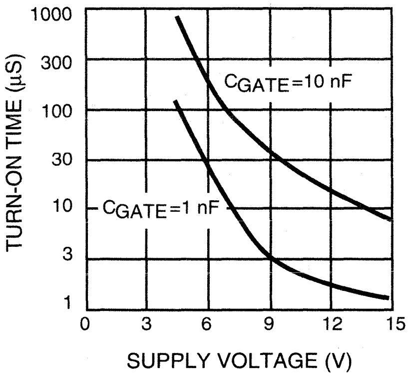

High-side Turn-on Time*


High-side Turn-on Time*

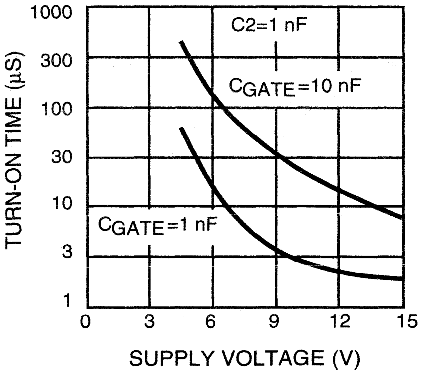
* Time for gate to reach $V^+ + 5V$ in test circuit with $VS = V^+ - 5V$.

Typical Characteristics (Continued)

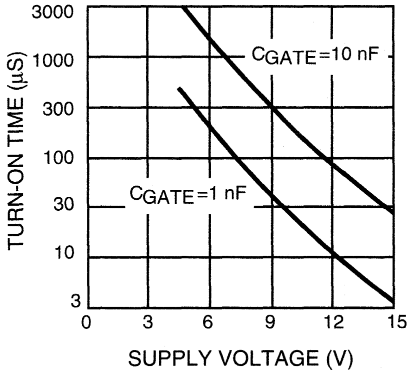
Low-side Turn-on Time for Gate = 5V



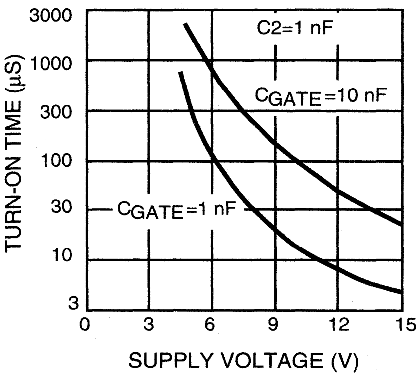
Low-side Turn-on Time for Gate = 5V



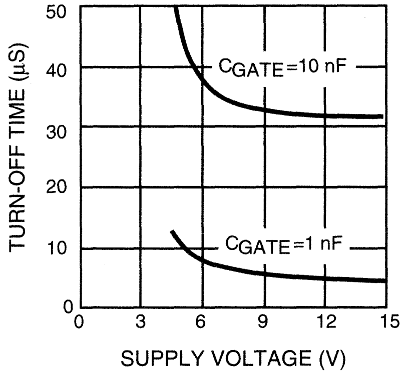
Low-side Turn-on Time for Gate = 10V



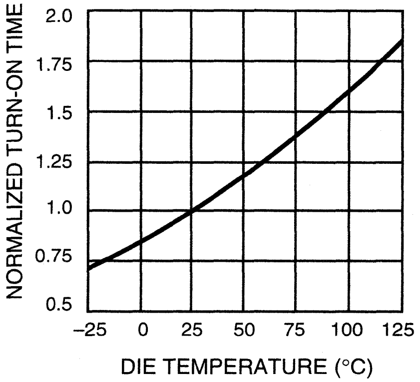
Low-side Turn-on Time for Gate = 10V

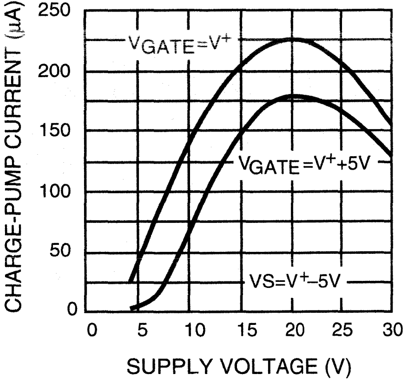


Turn-off Time

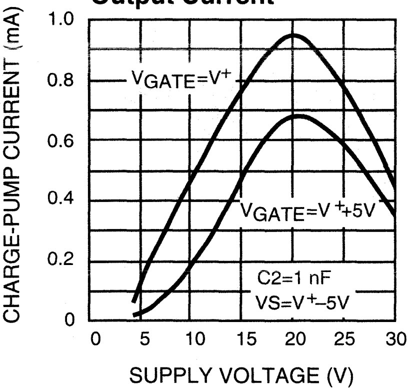


Turn-on Time



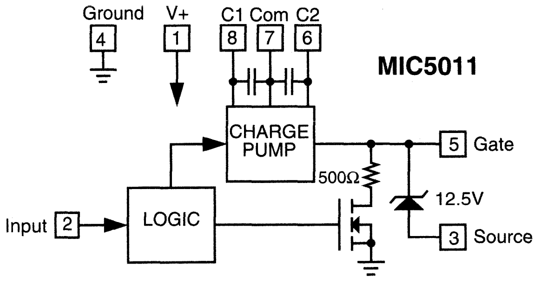


Charge Pump Output Current



Charge Pump Output Current

Block Diagram



Applications Information

Functional Description (Refer to Block Diagram)

The MIC5011 functions are controlled via a logic block connected to the input pin 2. When the input is low, all functions are turned off for low standby current and the gate of the power MOSFET is also held low through 500Ω to an N-channel switch. When the input is taken above the turn-on threshold (3.5V typical), the N-channel switch turns off and the charge pump is turned on to charge the gate of the power FET.

The charge pump incorporates a 100kHz oscillator and on-chip pump capacitors capable of charging 1nF to 5V above supply in 60μs typical. With the addition of 1nF capacitors at C1 and C2, the turn-on time is reduced to 25μs typical (see Figure 3). The charge pump is capable of pumping the gate up to over twice the supply voltage. For this reason, a zener clamp (12.5V typical) is provided between the gate pin 5 and source pin 3 to prevent exceeding the V_{GS} rating of the MOSFET at high supplies.

Applications Information (Continued)

Construction Hints

High current pulse circuits demand equipment and assembly techniques that are more stringent than normal, low current lab practices. The following are the sources of pitfalls most often encountered during prototyping. *Supplies*: many bench power supplies have poor transient response. Circuits that are being pulse tested, or those that operate by pulse-width modulation will produce strange results when used with a supply that has poor ripple rejection, or a peaked transient response. Always monitor the power supply voltage that appears at the drain of a high-side driver (or the supply side of the load in a low-side driver) with an oscilloscope. It is not uncommon to find bench power supplies in the 1 kW class that overshoot or undershoot by as much as 50% when pulse loaded. Not only will the load current and voltage measurements be affected, but it is possible to over-stress various components—especially electrolytic capacitors—with possibly catastrophic results. A 10µF supply bypass capacitor at the chip is recommended.

Residual Resistances: Resistances in circuit connections may also cause confusing results. For example, a circuit may employ a 50mΩ power MOSFET for low drop, but careless construction techniques could easily add 50 to 100mΩ resistance. Do not use a socket for the MOSFET. If the MOSFET is a TO-220 type package, make high-current drain connections to the tab. Wiring losses have a profound effect on high-current circuits. A floating millivoltmeter can identify connections that are contributing excess drop under load.

Circuit Topologies

The MIC5011 is suited for use with standard MOSFETs in high- or low-side driver applications. In addition, the MIC5011 works well in applications where, for faster switching times, the supply is bootstrapped from the MOSFET source output. Low voltage, high-side drivers (such as shown in Figure 1) are the slowest; their speed is reflected in the gate turn-on time specifications. The fastest drivers are the low-side and bootstrapped high-side types (Figures 2 and 4). Load current switching times are often much faster than the time to full gate enhancement, depending on the circuit type, the MOSFET, and the load. Turn-off times are essentially the same for all circuits (less than 10µs to $V_{GS} = 1V$). The choice of one topology over another is based on a combination of considerations including speed, voltage, and desired system characteristics.

High-Side Driver (Figure 1). The high-side topology works well down to $V^+ = 7V$ with standard MOSFETs. From 4.75 to 7V supply, a logic-level MOSFET can be substituted since the MIC5011 will not reach 10V gate enhancement (10V is the maximum rating for logic-compatible MOSFETs).

High-side drivers implemented with MIC501X drivers are self-protected against inductive switching transients. During turn-off an inductive load will force the MOSFET source 5V or more below ground, while the MIC5011 holds the gate at ground potential. The MOSFET is forced into conduction, and it dissipates the energy stored in the load inductance. The MIC5011 source pin (3) is designed to withstand this negative excursion without damage. External clamp diodes are unnecessary.

Low-Side Driver (Figure 2). A key advantage of the low-side topology is that the load supply is limited only by the MOSFET BVDSS rating. Clamping may be required to protect the MOSFET drain terminal from inductive switching transients. The MIC5011 supply should be limited to 15V in low-side topologies, otherwise a large current will be forced through the gate clamp zener.

Low-side drivers constructed with the MIC501X family are also fast; the MOSFET gate is driven to near supply immediately when commanded ON. Typical circuits achieve 10V enhancement in 10µs or less on a 12 to 15V supply.

Modifying Switching Times (Figure 3). High-side switching times can be improved by a factor of 2 or more by adding external charge pump capacitors of 1nF each. In cost-sensitive applications, omit C1 (C2 has a dominant effect on speed).

Do not add external capacitors to the MOSFET gate. Add a resistor (1kΩ to 51kΩ) in series with the gate to slow down the switching time.

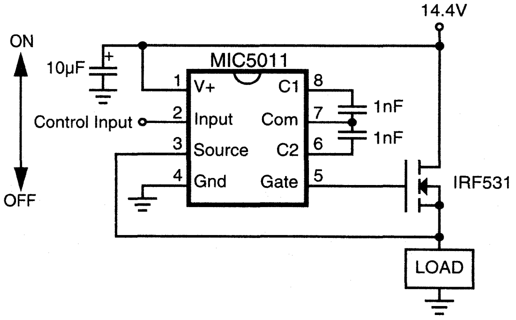


Figure 3. High Side Driver with External Charge Pump Capacitors

Bootstrapped High-Side Driver (Figure 4). The speed of a high-side driver can be increased to better than 10µs by bootstrapping the supply off of the MOSFET source. This topology can be used where the load is pulse-width modulated (100Hz to 20kHz), or where it is energized continuously. The Schottky barrier diode prevents the MIC5011 supply pin from dropping more than 200mV below the drain supply, and it also improves turn-on time on supplies of less than 10V. Since the supply current in the "off" state is only a small leakage, the 100nF bypass capacitor tends to remain charged for several seconds after the MIC5011 is turned off. In a PWM application the chip supply is sustained at a higher potential than the system supply, which improves switching time.

Applications Information (Continued)

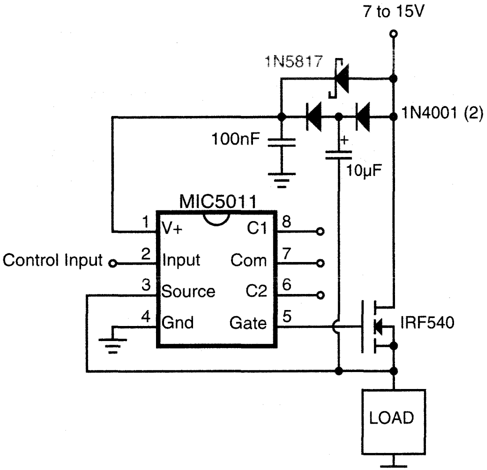


Figure 4. Bootstrapped High-Side Driver

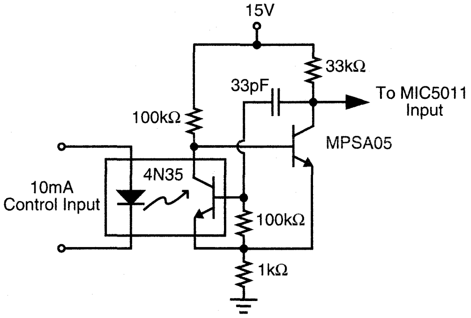


Figure 5. Improved Opto-Isolator Performance

Opto-Isolated Interface (Figure 5). Although the MIC5011 has no special input slew rate requirement, the lethargic transitions provided by an opto-isolator may cause oscillations on the rise and fall of the output. The circuit shown accelerates the input transitions from a 4N35 opto-isolator by adding hysteresis. Opto-isolators are used where the control circuitry cannot share a common ground with the MIC5011 and high-current power supply, or where the control circuitry is located remotely. This implementation is intrinsically safe; if the control line is severed the MIC5011 will turn OFF.

Industrial Switch (Figure 6). The most common manual control for industrial loads is a push button on/off switch. The "on" button is physically arranged in a recess so that in a panic situation the "off" button, which extends out from the control box, is more easily pressed. This circuit is compatible with control boxes such as the CR2943 series (GE). The circuit is configured so that if both switches close simultaneously, the "off" button has precedence.

This application also illustrates how two (or more) MOSFETs can be paralleled. This reduces the switch drop, and distributes the switch dissipation into multiple packages.

High-Voltage Bootstrap (Figure 7). Although the MIC5011 is limited to operation on 4.75 to 32V supplies, a floating bootstrap arrangement can be used to build a high-side switch that operates on much higher voltages. The MIC5011 and MOSFET are configured as a low-side driver, but the load is connected in series with ground.

Power for the MIC5011 is supplied by a charge pump. A 20kHz square wave (15Vp-p) drives the pump capacitor and delivers current to a 100µF storage capacitor. A zener

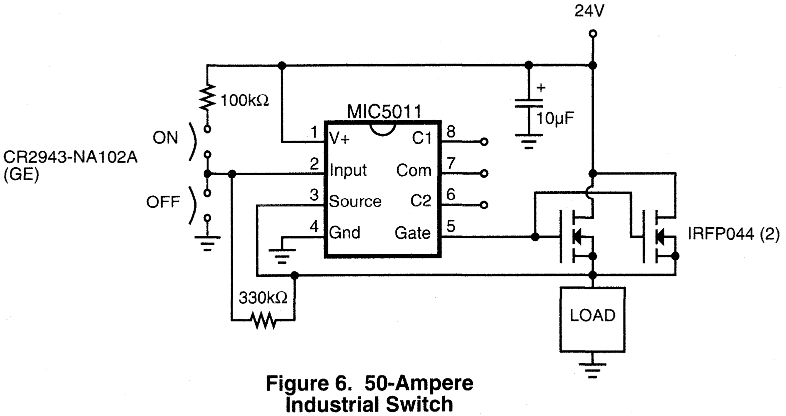


Figure 6. 50-Ampere Industrial Switch

Applications Information (Continued)

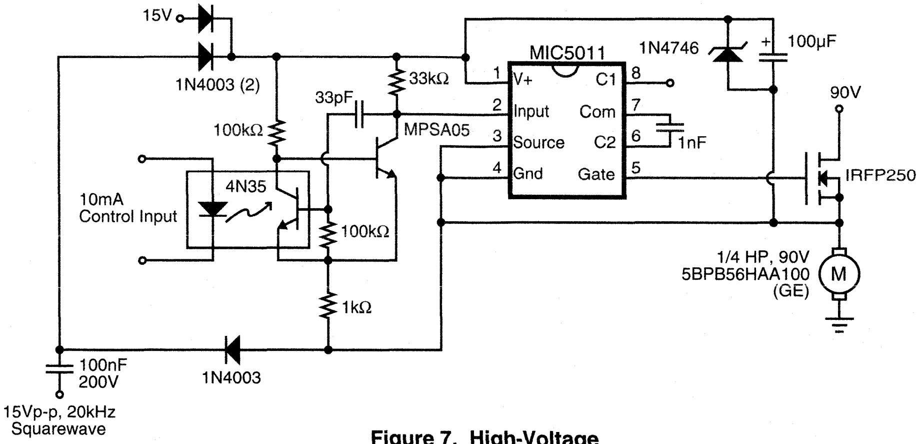


Figure 7. High-Voltage Bootstrapped Driver

diode limits the supply to 18V. When the MIC5011 is off, power is supplied by a diode connected to a 15V supply. The circuit of Figure 5 is put to good use as a barrier between low voltage control circuitry and the 90V motor supply.

Half-Bridge Motor Driver (Figure 8). Closed loop control of motor speed requires a half-bridge driver. This topology presents an extra challenge since the two output devices should not cross conduct (shoot-through) when switching. Cross conduction increases output device power dissipation. Speed is also important, since PWM control requires the outputs to switch in the 2 to 20kHz range.

The circuit of Figure 8 utilizes fast configurations for both the top- and bottom-side drivers. Delay networks at each input provide a 2 to 3µs dead time effectively eliminating cross conduction. Two of these circuits can be connected together to form an H-bridge for locked antiphase or sign/magnitude control.

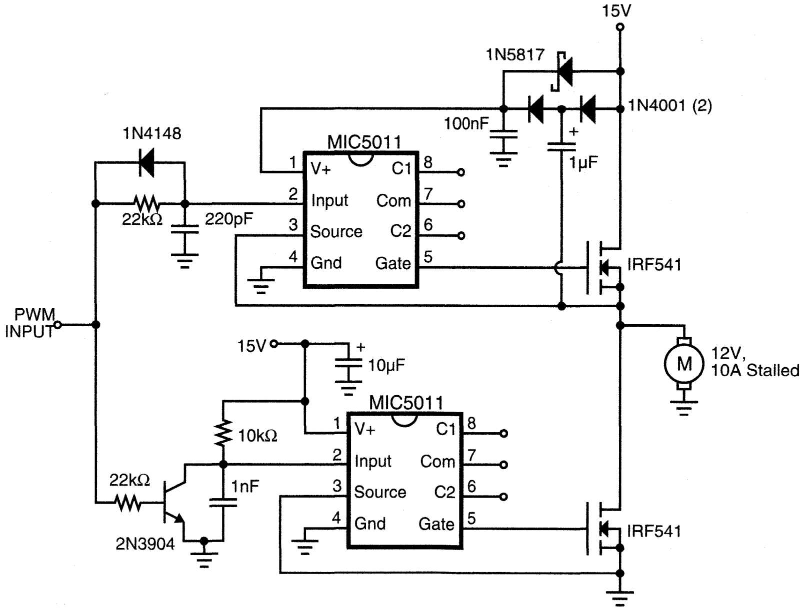


Figure 8. Half-Bridge Motor Driver

Applications Information (Continued)

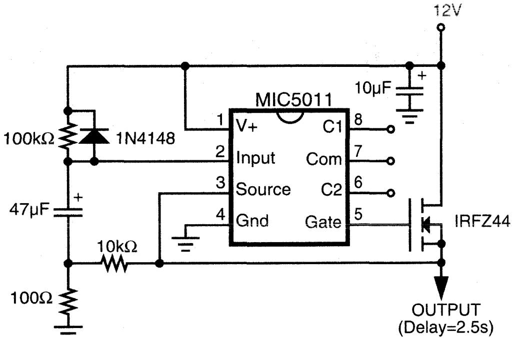


Figure 9. 30 Ampere Time-Delay Relay

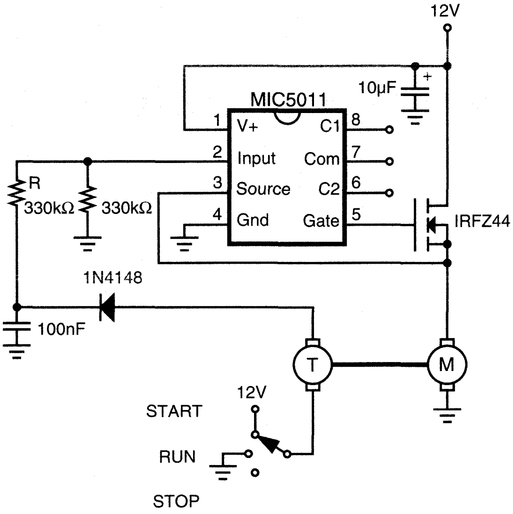


Figure 10. Motor Stall Shutdown

Time-Delay Relay (Figure 9). The MIC5011 forms the basis of a simple time-delay relay. As shown, the delay commences when power is applied, but the 100kΩ/1N4148 could be independently driven from an external source such as a switch or another high-side driver to give a delay relative to some other event in the system. Hysteresis has been added to guarantee clean switching at turn-on.

Motor Driver with Stall Shutdown (Figure 10). Tachometer feedback can be used to shut down a motor driver circuit when a stall condition occurs. The control switch is a 3-way type; the "START" position is momentary and forces the driver ON. When released, the switch returns to the "RUN" position, and the tachometer's output is used to hold the MIC5011 input ON. If the motor slows down, the tach output is reduced, and the MIC5011 switches OFF. Resistor "R" sets the shutdown threshold.

Electronic Governor (Figure 11). The output of an ac tachometer can be used to form a PWM loop to maintain the speed of a motor. The tachometer output is rectified, partially filtered, and fed back to the input of the MIC5011. When the motor is stalled there is no tachometer output, and MIC5011 input is pulled high delivering full power to the motor. If the motor spins fast enough, the tachometer output is sufficient to pull the MIC5011 input low, shutting the output off. Since the rectified waveform is only partially filtered, the input oscillates around its threshold causing the MIC5011 to switch on and off at the frequency of the tachometer signal. A PWM action results since the average dc voltage at the input decreases as the motor spins faster. The 1kΩ potentiometer is used to set the running speed of the motor. Loop gain (and speed regulation) is increased by increasing the value of the 100nF filter capacitor.

The performance of such a loop is imprecise, but stable and inexpensive. A more elaborate loop would consist of a PWM controller and a half-bridge.

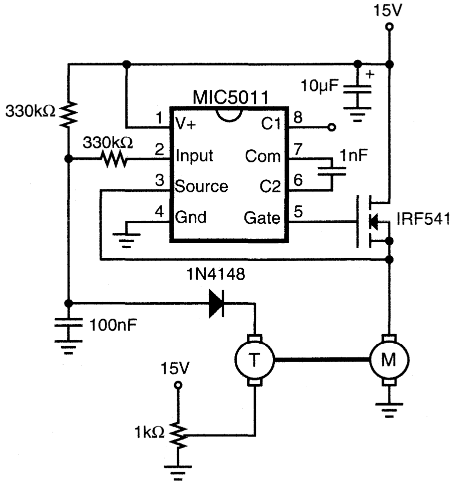


Figure 11. Electronic Governor

Applications Information (Continued)

Gate Control Circuit

When applying the MIC5011, it is helpful to understand the operation of the gate control circuitry (see Figure 12). The gate circuitry can be divided into two sections: 1) charge pump (oscillator, Q1-Q5, and the capacitors) and 2) gate turn-off switch (Q6).

When the MIC5011 is in the OFF state, the oscillator is turned off, thereby disabling the charge pump. Q5 is also turned off, and Q6 is turned on. Q6 holds the gate pin (G) at ground potential which effectively turns the external MOSFET off.

Q6 is turned off when the MIC5011 is commanded on, and Q5 pulls the gate up to supply (through 2 diodes). Next, the charge pump begins supplying current to the gate. The gate accepts charge until the gate-source voltage reaches 12.5V and is clamped by the zener diode.

A 2-output, three-phase clock switches Q1-Q4, providing a quasi-tripling action. During the initial phase Q4 and Q2 are ON. C1 is discharged, and C2 is charged to supply through Q5. For the second phase Q4 turns off and Q3 turns on, pushing pin C2 above supply (charge is dumped into the gate). Q3 also charges C1. On the third phase Q2 turns off and Q1 turns on, pushing the common point of the two capacitors above supply. Some of the charge in C1 makes its way to the gate. The sequence is repeated by turning Q2 and Q4 back on, and Q1 and Q3 off.

In a low-side application operating on a 12 to 15V supply, the MOSFET is fully enhanced by the action of Q5 alone. On supplies of more than approximately 14V, current flows directly from Q5 through the zener diode to ground. To prevent excessive current flow, the MIC5011 supply should be limited to 15V in low-side applications.

The action of Q5 makes the MIC5011 operate quickly in low-side applications. In high-side applications Q5 precharges the MOSFET gate to supply, leaving the charge pump to carry the gate up to full enhancement 10V above supply. Bootstrapped high-side drivers are as fast as low-side drivers since the chip supply is boosted well above the drain at turn-on.

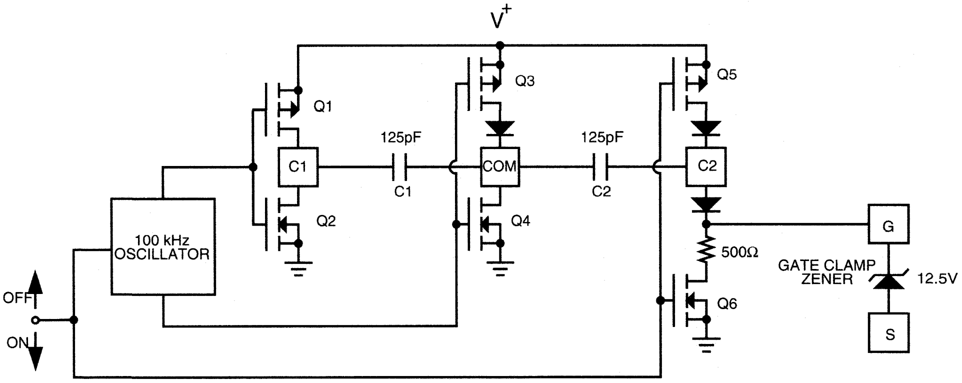


Figure 12. Gate Control Circuit Detail

MIC5012

Dual High- or Low-Side MOSFET Driver

General Description

The MIC5012 is the dual member of the Micrel MIC501X driver family. These ICs are designed to drive the gate of an N-channel power MOSFET above the supply rail in high-side power switch applications. The 14-pin MIC5012 is extremely easy to use, requiring only a power FET and nominal supply decoupling to implement either a high- or low-side switch.

The MIC5012 charges a 1nF load in 60µs typical. Operation down to 4.75V allows the MIC5012 to drive standard MOSFETs in 5V low-side applications by boosting the gate voltage above the logic supply. In addition, multiple, paralleled MOSFETs can be driven by a single MIC5012 for ultra-high current applications.

Other members of the Micrel driver family include the MIC5010 full-featured driver, MIC5011 minimum parts count driver, and MIC5013 protected 8-pin driver.

For new designs, Micrel recommends the pin-compatible MIC5016 dual MOSFET driver.

Features

- 4.75V to 32V operation
- 2 independent drivers; implements high and low side drivers
- Less than 1µA standby current in the “off” state per channel
- MIL-STD-883 Method 5004/5005 version available
- Available in small outline SOIC packages
- Internal charge pump to drive the gate of an N-channel power FET above supply
- Internal zener clamp for gate protection
- Minimum external parts count
- Can be used to boost drive to low-side power FETs operating on logic supplies
- Independent supply pins for half-bridge applications

Applications

- Lamp drivers
- Motion Control
- Heater switching
- Power bus switching
- Half or full H-bridge drivers

Typical Applications

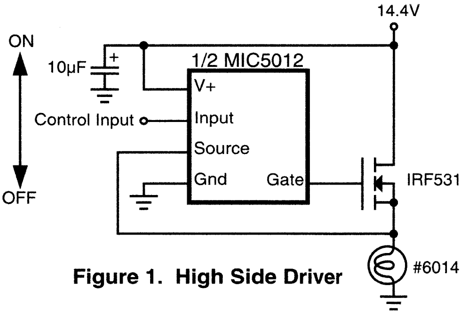


Figure 1. High Side Driver

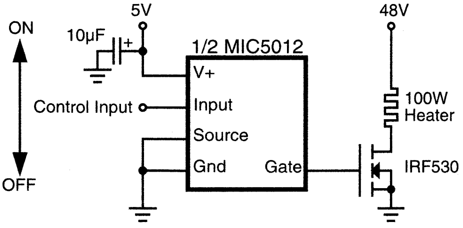


Figure 2. Low Side Driver

Ordering Information

Part Number	Temp. Range	Package
MIC5012BN	–40°C to +85°C	14-pin Plastic DIP
MIC5012BWM	–40°C to +85°C	16-pin Wide SOIC
5962-9313902MPA*	–55°C to +125°C	14-pin Ceramic DIP

* Standard Military Drawing number for MIC5012AJBQ

Note: The MIC5012 is ESD sensitive.

Protected under one or more of the following Micrel patents:
patent #4,951,101; patent #4,914,546

Absolute Maximum Ratings (Note 1, 2)

Supply Voltage (V^+), Pins 10, 12	–0.5V to 36V
Input Voltage, Pins 11, 14	–10V to V^+
Source Voltage, Pins 2, 5	–10V to V^+
Current into Pins 2, 5	50mA
Gate Voltage, Pins 4, 6	–1V to 50V
Junction Temperature	150°C

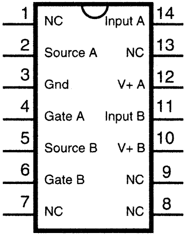
Operating Ratings (Notes 1, 2)

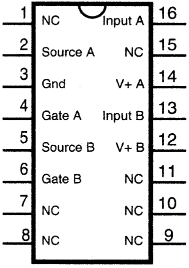
Power Dissipation	1.56W
θ_{JA} (Plastic DIP)	80 °C/W
θ_{JA} (Ceramic DIP)	105°C/W
θ_{JA} (SOIC)	105°C/W
Ambient Temperature: B version	–40°C to +85°C
Ambient Temperature: A version	–55°C to +125°C
Storage Temperature	–65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	260°C
Supply Voltage (V^+), Pin 1	4.75V to 32V high side 4.75V to 15V low side

Pin Description (Refer to **Typical Applications**)

DIP Pin Number	Pin Name	Pin Function
12, 10	V^+	Supply; must be decoupled to isolate from large transients caused by the power FET drain. 10µF is recommended close to pins 1 and 4.
14, 11	Input	Turns on power MOSFET when taken above threshold (3.5V typical). Requires <1 µA to switch.
2, 5	Source	Connects to source lead of power FET and is the return for the gate clamp zener. Can safely swing to –10V when turning off inductive loads.
3	Ground	
4, 6	Gate	Drives and clamps the gate of the power FET. Clamped to approximately –0.7V by an internal diode when turning off inductive loads.

Pin Configuration


MIC5012 (N, J)


MIC5012 (WM)

Electrical Characteristics (Note 3) Test circuit. $T_A = -55°C$ to $+125°C$, $V^+ = 15V$, all switches open, unless otherwise specified.

Parameter	Conditions		Min	Typical	Max	Units
Supply Current (per section)	$V^+ = 32V$	$V_{IN} = 0V$, S2 closed		0.1	10	µA
		$V_{IN} = V_S = 32V$		8	20	mA
	$V^+ = 5V$	$V_{IN} = 5V$, S2 closed		1.6	4	mA
Logic Input Voltage	$V^+ = 4.75V$	Adjust V_{IN} for V_{GATE} low			2	V
		Adjust V_{IN} for V_{GATE} high	4.5			V
	$V^+ = 15V$	Adjust V_{IN} for V_{GATE} high	5.0			V
Logic Input Current, I_2	$V^+ = 32V$	$V_{IN} = 0V$	−1			µA
		$V_{IN} = 32V$			1	µA
Input Capacitance	Pins 11, 14			5		pF
Gate Drive, V_{GATE}	S1, S2 closed, $V_S = V+$, $V_{IN} = 5V$	$V^+ = 4.75V$, $I_{GATE} = 0$, $V_{IN} = 4.5V$	7	10		V
		$V^+ = 15V$, $I_{GATE} = 100\mu A$, $V_{IN} = 5V$	24	27		V
Zener Clamp, $V_{GATE} - V_{SOURCE}$	S2 closed, $V_{IN} = 5V$	$V^+ = 15V$, $V_S = 15V$	11	12.5	15	V
		$V^+ = 32V$, $V_S = 32V$	11	13	16	V
Gate Turn-on Time, t_{ON} (Note 4)	V_{IN} switched from 0 to 5V; measure time for V_{GATE} to reach 20V			60	200	µs
Gate Turn-off Time, t_{OFF}	V_{IN} switched from 5 to 0V; measure time for V_{GATE} to reach 1V			4	10	µs

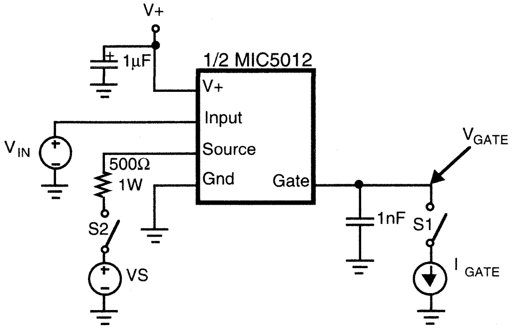
Note 1 **Absolute Maximum Ratings** indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its specified **Operating Ratings**.

Note 2 The MIC5012 is ESD sensitive.

Note 3 Minimum and maximum **Electrical Characteristics** are 100% tested at $T_A = 25°C$ and $T_A = 85°C$, and 100% guaranteed over the entire range. Typicals are characterized at 25°C and represent the most likely parametric norm.

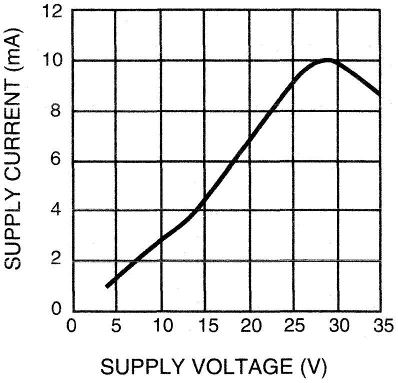
Note 4 Test conditions reflect worst case high-side driver performance. Low-side and bootstrapped topologies are significantly faster—see **Applications Information**. Maximum value of switching speed seen at 125°C, units operated at room temperature will reflect the typical values shown.

Test Circuit

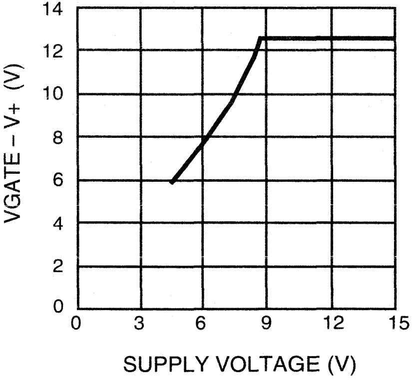


Typical Characteristics (Continued)

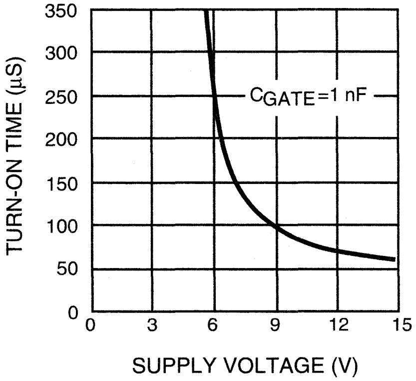
Supply Current



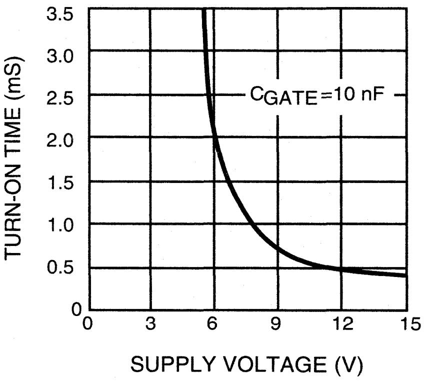
DC Gate Voltage above Supply



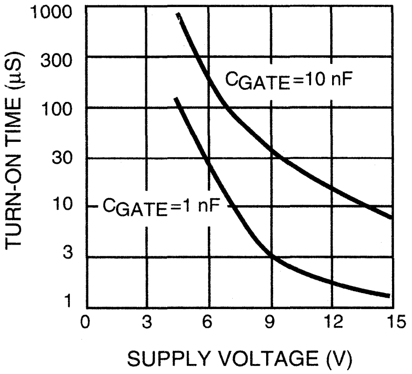
High-side Turn-on Time*



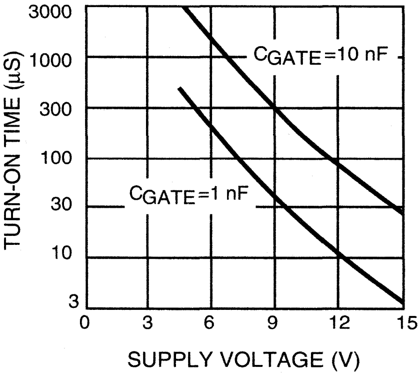
High-side Turn-on Time*



Low-side Turn-on Time for Gate = 5V

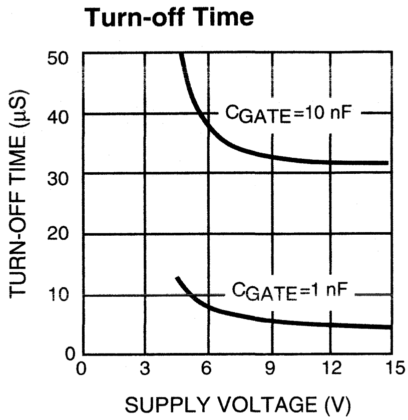


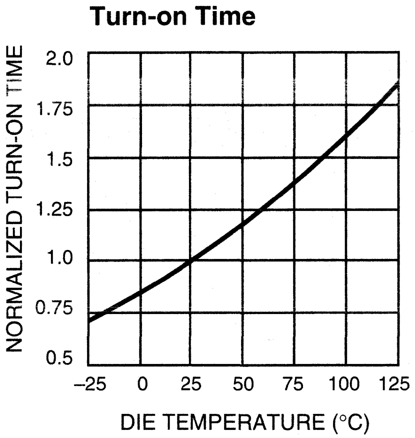
Low-side Turn-on Time for Gate = 10V

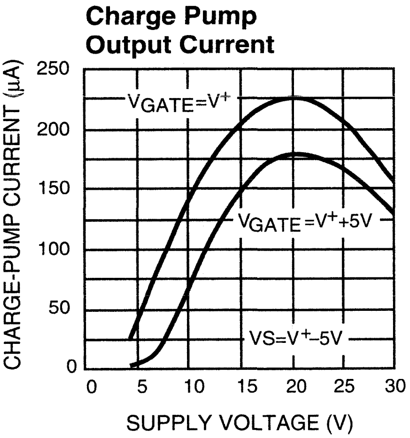


* Time for gate to reach V^+ + 5V in test circuit with VS = V^+ – 5V.

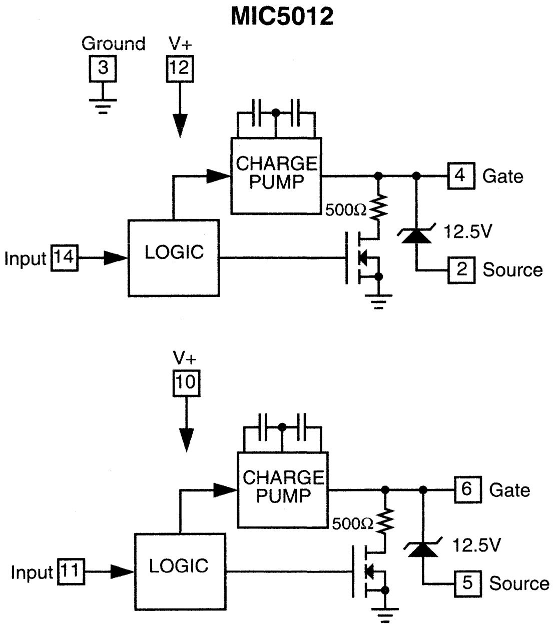
Typical Characteristics (Continued)


Turn-off Time


Turn-on Time


Charge Pump Output Current

Block Diagram



Applications Information

Functional Description (Refer to **Block Diagram**)

The MIC5012 consists of two independent drivers sharing a common ground. The functions are controlled via a logic block connected to the logic input. When the input is low, all functions are turned off for low standby current and the gate of the power MOSFET is also held low through 500Ω to an N-channel switch. When the input is taken above the turn-on threshold (3.5V typical), the N-channel switch turns off and the charge pump is turned on to charge the gate of the power FET.

The charge pump incorporates a 100kHz oscillator and on-chip pump capacitors capable of charging 1nF to 5V above supply in 60µs typical. The charge pump is capable of pumping the gate up to over twice the supply voltage. For this reason, a zener clamp (12.5V typical) is provided between the gate pin and source pin to prevent exceeding the V_{GS} rating of the MOSFET at high supplies.

Since the supply pins are independent, the two drivers contained in the MIC5012 can be operated from separate supplies of different values (see Figure 6).

Construction Hints

High current pulse circuits demand equipment and assembly techniques that are more stringent than normal, low current lab practices. The following are the sources of

Applications Information (Continued)

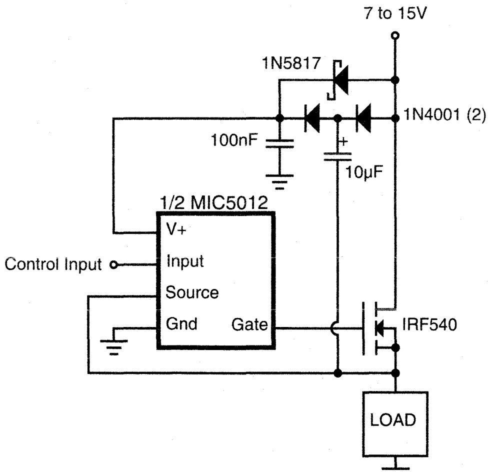


Figure 3. Bootstrapped High-Side Driver

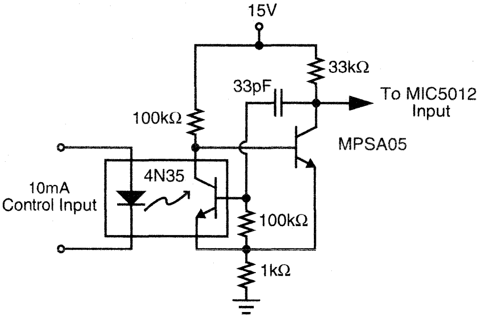


Figure 4. Improved Opto-Isolator Performance

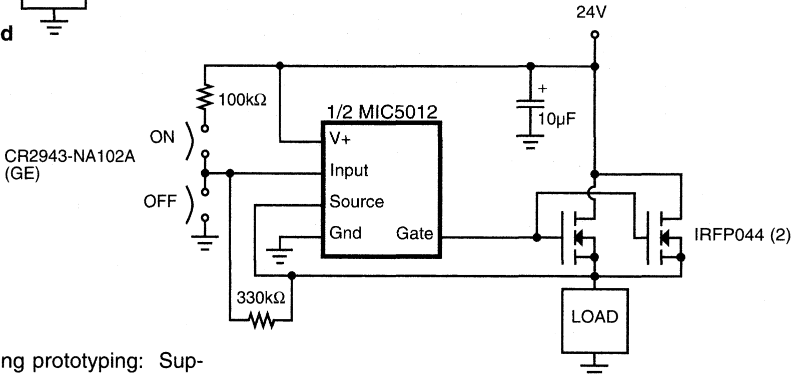


Figure 5. 50-Ampere Industrial Switch

pitfalls most often encountered during prototyping: Supplies: many bench power supplies have poor transient response. Circuits that are being pulse tested, or those that operate by pulse-width modulation will produce strange results when used with a supply that has poor ripple rejection, or a peaked transient response. Always monitor the power supply voltage that appears at the drain of a high-side driver (or the supply side of the load in a low-side driver) with an oscilloscope. It is not uncommon to find bench power supplies in the 1kW class that overshoot or undershoot by as much as 50% when pulse loaded. Not only will the load current and voltage measurements be affected, but it is possible to over-stress various components—especially electrolytic capacitors—with possibly catastrophic results. A 10µF supply bypass capacitor at the chip is recommended.

Residual Resistances: Resistances in circuit connections may also cause confusing results. For example, a circuit may employ a 50mΩ power MOSFET for low drop, but careless construction techniques could easily add 50 to 100mΩ resistance. Do not use a socket for the MOSFET. If the MOSFET is a TO-220 type package, make high-current drain connections to the tab. Wiring losses have a profound effect on high-current circuits. A floating millivoltmeter can identify connections that are contributing excess drop under load.

Circuit Topologies

The MIC5012 is suited for use with standard MOSFETs in high- or low-side driver applications. In addition, the MIC5012 works well in applications where, for faster switching times, the supply is bootstrapped from the MOSFET source output. Low voltage, high-side drivers (such as shown in Figure 1) are the slowest; their speed is reflected in the gate turn-on time specifications. The fastest drivers are the low-side and bootstrapped high-side types (Figures 2 and 4). Load current switching times are often much faster than the time to full gate enhancement, depending on the circuit type, the MOSFET, and the load. Turn-off times are essentially the same for all circuits (less than 10µs to V_{GS} = 1V). The choice of one topology over another is based on a combination of considerations including speed, voltage, and desired system characteristics.

High-Side Driver (Figure 1). The high-side topology works well down to V^+ = 7V with standard MOSFETs. From 4.75 to 7V supply, a logic-level MOSFET can be substituted since the MIC5012 will not reach 10V gate enhancement (10V is the maximum rating for logic-compatible MOSFETs).

Applications Information (Continued)

High-side drivers implemented with MIC501X drivers are self-protected against inductive switching transients. During turn-off an inductive load will force the MOSFET source 5V or more below ground, while the MIC5012 holds the gate at ground potential. The MOSFET is forced into conduction, and it dissipates the energy stored in the load inductance. The MIC5012 source pin is designed to withstand this negative excursion without damage. External clamp diodes are unnecessary.

Low-Side Driver (Figure 2). A key advantage of the low-side topology is that the load supply is limited only by the MOSFET BV_{DSS} rating. Clamping may be required to protect the MOSFET drain terminal from inductive switching transients. The MIC5012 supply should be limited to 15V in low-side topologies; otherwise, a large current will be forced through the gate clamp zener. The switching speed to 10V enhancement is 300µs driving 1nF on a 5V supply. On a 15V supply the turn-on time is less than 2µs to 10V

Low-side drivers constructed with the MIC501X family are also fast; the MOSFET gate is driven to near supply immediately when commanded ON. Typical circuits achieve 10V enhancement in 10µs or less on a 12 to 15V supply.

Modifying Switching Times. Do not add external capacitors to the MOSFET gate. Add a resistor (1kΩ to 51kΩ) in series with the gate to slow down the switching time.

Bootstrapped High-Side Driver (Figure 3). The speed of a high-side driver can be increased to better than 10µs by bootstrapping the supply off of the MOSFET source. This topology can be used where the load is pulse-width modulated (100Hz to 20kHz), or where it is energized continuously. The Schottky barrier diode prevents the MIC5012 supply pin from dropping more than 200mV below the drain supply, and it also improves turn-on time on supplies of less than 10V. Since the supply current in the "off" state is only a small leakage, the 100nF bypass capacitor tends to remain charged for several seconds after the MIC5012 is turned off. In a PWM application the chip supply is sustained at a higher potential than the system supply, which improves switching time.

Opto-Isolated Interface (Figure 4). Although the MIC5012 has no special input slew rate requirement, the lethargic transitions provided by an opto-isolator may cause oscillations on the rise and fall of the output. The circuit shown accelerates the input transitions from a 4N35 opto-isolator by adding hysteresis. Opto-isolators are used where the control circuitry cannot share a common ground with the MIC5012 and high-current power supply, or where the control circuitry is located remotely. This implementation is intrinsically safe; if the control line is severed the MIC5012 will turn OFF.

Industrial Switch (Figure 5). The most common manual control for industrial loads is a push button on/off switch. The "on" button is physically arranged in a recess so that in a panic situation the "off" button, which extends out from the control box, is more easily pressed. This circuit is compatible with control boxes such as the CR2943 series (GE). The circuit is configured so that if both switches close simultaneously, the "off" button has precedence.

This application also illustrates how two (or more) MOSFETs

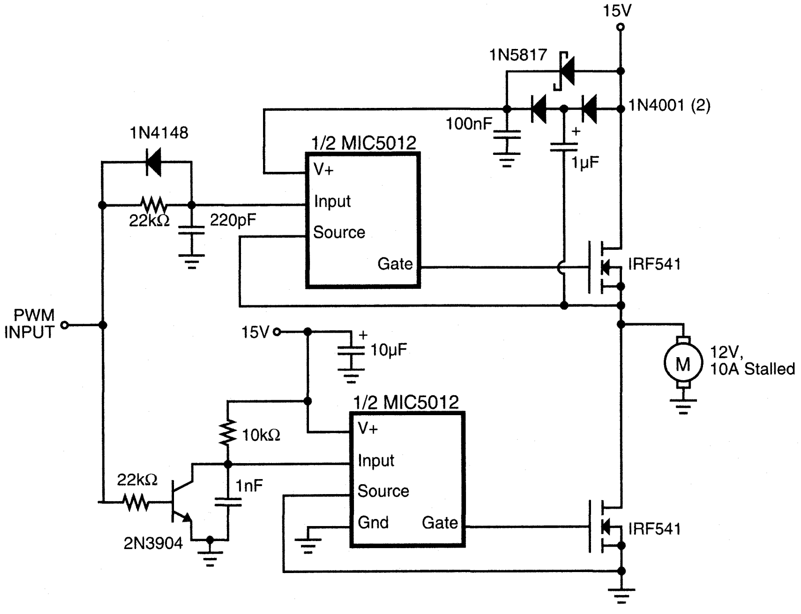


Figure 6. Half-Bridge Motor Driver

Applications Information (Continued)

can be paralleled. This reduces the switch drop, and distributes the switch dissipation into multiple packages.

Half-Bridge Motor Driver (Figure 6). Closed loop control of motor speed requires a half-bridge driver. This topology presents an extra challenge since the two output devices should not cross conduct (shoot-through) when switching. Cross conduction increases output device power dissipation. Speed is also important, since PWM control requires the outputs to switch in the 2 to 20kHz range.

The circuit of Figure 6 utilizes fast configurations for both the top- and bottom-side drivers. Delay networks at each input provide a 2 to 3μs dead time effectively eliminating cross conduction. Two of these circuits can be connected together to form an H-bridge for locked antiphase or sign/magnitude control.

Time-Delay Relay (Figure 7). The MIC5012 forms the basis of a simple time-delay relay. As shown, the delay commences when power is applied, but the 100kΩ/1N4148 could be independently driven from an external source such as a switch or another high-side driver to give a delay relative to some other event in the system. Hysteresis has been added to guarantee clean switching at turn-on.

Motor Driver with Stall Shutdown (Figure 8). Tachometer feedback can be used to shut down a motor driver circuit when a stall condition occurs. The control switch is a 3-way type; the "START" position is momentary and forces the driver ON. When released, the switch returns to the "RUN" position, and the tachometer's output is used to hold the MIC5012 input ON. If the motor slows down, the tach output is reduced, and the MIC5012 switches OFF. Resistor "R" sets the shutdown threshold.

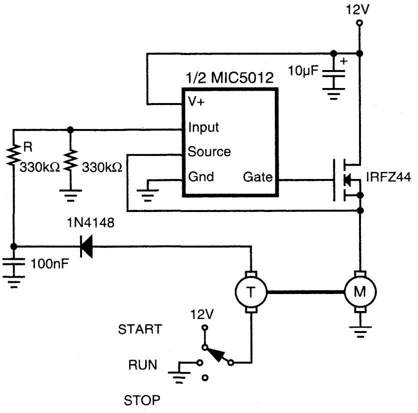


Figure 8. Motor Stall Shutdown

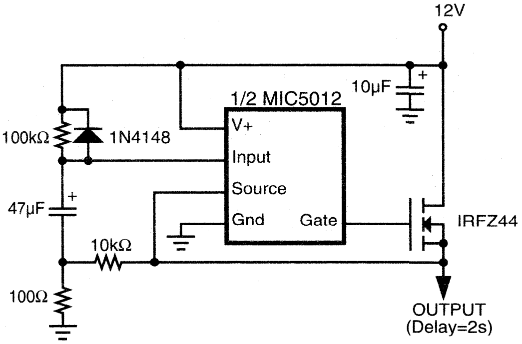


Figure 7. 30 Ampere Time-Delay Relay

Electronic Governor (Figure 9). The output of an ac tachometer can be used to form a PWM loop to maintain the speed of a motor. The tachometer output is rectified, partially filtered, and fed back to the input of the MIC5012. When the motor is stalled there is no tachometer output, and MIC5012 input is pulled high delivering full power to the motor. If the motor spins fast enough, the tachometer output is sufficient to pull the MIC5012 input low, shutting the output off. Since the rectified waveform is only partially filtered, the input oscillates around its threshold causing the MIC5012 to switch on and off at the frequency of the tachometer signal. A PWM action results since the average dc voltage at the input decreases as the motor spins faster. The 1kΩ potentiometer is used to set the running speed of the motor. Loop gain (and speed regulation) is increased by increasing the value of the 100nF filter capacitor.

The performance of such a loop is imprecise, but stable and inexpensive. A more elaborate loop would consist of a PWM controller and a half-bridge.

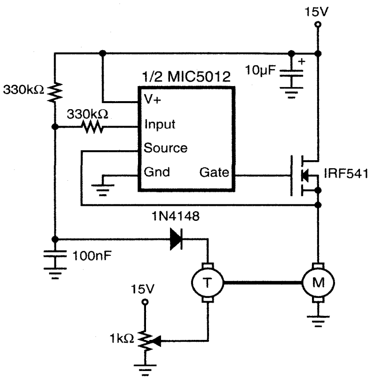


Figure 9. Electronic Governor

Applications Information (Continued)

Gate Control Circuit

When applying the MIC5012, it is helpful to understand the operation of the gate control circuitry (see Figure 12). The gate circuitry can be divided into two sections: 1) charge pump (oscillator, Q1-Q5, and the capacitors) and 2) gate turn-off switch (Q6).

When the MIC5012 is in the OFF state, the oscillator is turned off, thereby disabling the charge pump. Q5 is also turned off, and Q6 is turned on. Q6 holds the gate pin (G) at ground potential which effectively turns the external MOSFET off.

Q6 is turned off when the MIC5012 is commanded on, and Q5 pulls the gate up to supply (through 2 diodes). Next, the charge pump begins supplying current to the gate. The gate accepts charge until the gate-source voltage reaches 12.5V and is clamped by the zener diode.

A 2-output, three-phase clock switches Q1-Q4, providing a quasi-tripling action. During the initial phase Q4 and Q2 are ON. C1 is discharged, and C2 is charged to supply through Q5. For the second phase Q4 turns off and Q3 turns on, pushing C2 above supply (charge is dumped into the gate). Q3 also charges C1. On the third phase Q2 turns off and Q1 turns on, pushing the common point of the two capacitors above supply. Some of the charge in C1 makes its way to the gate. The sequence is repeated by turning Q2 and Q4 back on, and Q1 and Q3 off.

In a low-side application operating on a 12 to 15V supply, the MOSFET is fully enhanced by the action of Q5 alone. On supplies of more than approximately 14V, current flows directly from Q5 through the zener diode to ground. To prevent excessive current flow, the MIC5012 supply should be limited to 15V in low-side applications.

The action of Q5 makes the MIC5012 operate quickly in low-side applications. In high-side applications Q5 precharges the MOSFET gate to supply, leaving the charge pump to carry the gate up to full enhancement 10V above supply. Bootstrapped high-side drivers are as fast as low-side drivers since the chip supply is boosted well above the drain at turn-on.

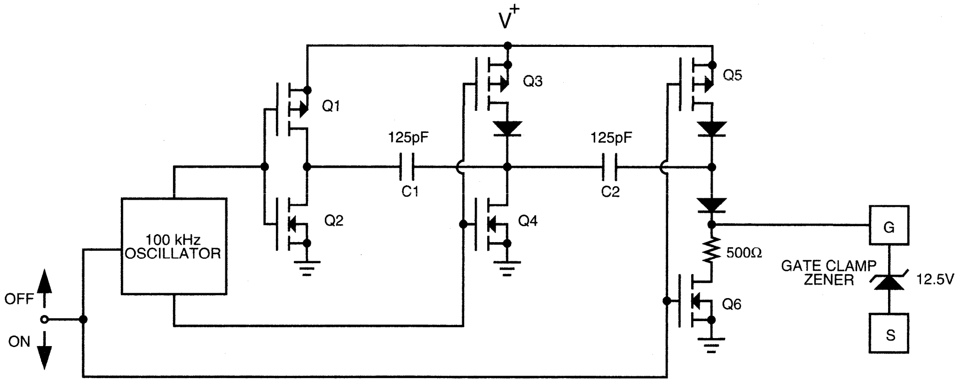


Figure 10. Gate Control Circuit Detail

MIC5013

Protected High- or Low-Side MOSFET Driver

General Description

The MIC5013 is an 8-pin MOSFET driver with over-current shutdown and a fault flag. It is designed to drive the gate of an N-channel power MOSFET above the supply rail high-side power switch applications. The MIC5013 is compatible with standard or current-sensing power MOSFETs in both high- and low-side driver topologies.

The MIC5013 charges a 1nF load in 60µs typical and protects the MOSFET from over-current conditions. The current sense trip point is fully programmable and a dynamic threshold allows high in-rush current loads to be started. A fault pin indicates when the MIC5013 has turned off the FET due to excessive current.

Other members of the Micrel driver family include the MIC5010 full-featured driver, MIC5011 minimum parts count driver, and MIC5012 dual driver.

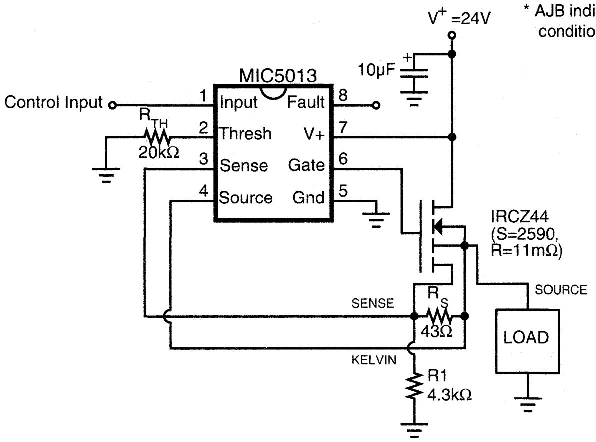
Features

- 7V to 32V operation
- Less than 1µA standby current in the "OFF" state
- MIL-STD-883 Method 5004/5005 version available
- Available in small outline SOIC packages
- Internal charge pump to drive the gate of an N-channel power FET above supply
- Internal zener clamp for gate protection
- 60µs typical turn-on time to 50% gate overdrive
- Programmable over-current sensing
- Dynamic current threshold for high in-rush loads
- Fault output pin indicates current faults
- Implements high- or low-side switches

Applications

- Lamp drivers
- Relay and solenoid drivers
- Heater switching
- Power bus switching
- Motion control

Typical Application



$$R_S = \frac{SR(V_{TRIP} + 100mV)}{R\,I_L - (V_{TRIP} + 100mV)}$$

$$R1 = \frac{V^+SRR_S}{100mV\,(SR+R_S)}$$

$$R_{TH} = \frac{2200}{V_{TRIP}} - 1000$$

For this example:

I_L =30A (trip current)

V_{TRIP} =100mV

Figure 1. High-Side Driver with Current-Sensing MOSFET

Note: The MIC5013 is ESD sensitive.

Ordering Information

Part Number	Temperature Range	Package
MIC5013BN	–40°C to +85°C	8-pin Plastic DIP
MIC5013BM	–40°C to +85°C	8-pin SOIC
MIC5013AJB*	–55°C to +125°C	8-pin Ceramic DIP

* AJB indicates units screened to MIL-STD 883, Method 5004, condition B, and burned-in for 1-week.

Protected under one or more of the following Micrel patents:
patent #4,951,101; patent #4,914,546

Absolute Maximum Ratings (Note 1, 2)

Input Voltage, Pin 1	–10 to V+
Threshold Voltage, Pin 2	–0.5 to +5V
Sense Voltage, Pin 3	–10V to V+
Source Voltage, Pin 4	–10V to V+
Current into Pin 4	50mA
Gate Voltage, Pin 6	–1V to 50V
Supply Voltage (V+), Pin 7	–0.5V to 36V
Fault Output Current, Pin 8	–1mA to +1mA
Junction Temperature	150°C

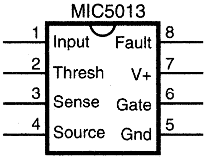
Operating Ratings (Notes 1, 2)

Power Dissipation	1.25W
θ_{JA} (Plastic DIP)	100°C/W
θ_{JA} (Ceramic DIP)	125°C/W
θ_{JA} (SOIC)	170°C/W
Ambient Temperature: B version	–40°C to +85°C
Ambient Temperature: A version	–55°C to +125°C
Storage Temperature	–65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	260°C
Supply Voltage (V+), Pin 7	7V to 32V high side 7V to 15V low side

Pin Description (Refer to Figures 1 and 2)

Pin Number	Pin Name	Pin Function
1	Input	Resets current sense latch and turns on power MOSFET when taken above threshold (3.5V typical). Pin 1 requires <1μA to switch.
2	Threshold	Sets current sense trip voltage according to: $$V_{TRIP} = \frac{2200}{R_{TH}+1000}$$ where R_{TH} to ground is 3.3k to 20kΩ. Adding capacitor C_{TH} increases the trip voltage at turn-on to 2V. Use C_{TH} =10μF for a 10ms turn-on time constant.
3	Sense	The sense pin causes the current sense to trip when V_{SENSE} is V_{TRIP} above V_{SOURCE}. Pin 3 is used in conjunction with a current shunt in the source of a 3 lead FET or a resistor R_S in the sense lead of a current sensing FET.
4	Source	Reference for the current sense voltage on pin 3 and return for the gate clamp zener. Connect to the load side of current shunt or kelvin lead of current sensing FET. Pins 3 and 4 can safely swing to –10V when turning off inductive loads.
5	Ground	
6	Gate	Drives and clamps the gate of the power FET. Pin 6 will be clamped to approximately –0.7V by an internal diode when turning off inductive loads.
7	V+	Supply pin; must be decoupled to isolate from large transients caused by the power FET drain. 10μF is recommended close to pins 7 and 5.
8	Fault	Outputs status of protection circuit when pin 1 is high. Fault low indicates normal operation; fault high indicates current sense tripped.

Pin Configuration



Electrical Characteristics (Note 3) Test circuit. $T_A = -55°C$ to $+125°C$, $V^+ = 15V$, all switches open, unless otherwise specified.

Parameter	Conditions			Min	Typical	Max	Units
Supply Current, I_7	$V^+ = 32V$	$V_{IN} = 0V$, S4 closed			0.1	10	µA
		$V_{IN} = V_S = 32V$			8	20	mA
Logic Input Voltage, V_{IN}	$V^+ = 4.75V$	Adjust V_{IN} for V_{GATE} low				2	V
		Adjust V_{IN} for V_{GATE} high		4.5			V
	$V^+ = 15V$	Adjust V_{IN} for V_{GATE} high		5.0			V
Logic Input Current, I_1	$V+ = 32V$	$V_{IN} = 0V$		–1			µA
		$V_{IN} = 32V$				1	µA
Input Capacitance	Pin 1				5		pF
Gate Drive, V_{GATE}	S1, S2 closed,	$V^+ = 7V$, $I_6 = 0$		13	15		V
	$V_S = V+$, $V_{IN} = 5V$	$V^+ = 15V$, $I_6 = 100\ \mu A$		24	27		V
Zener Clamp, $V_{GATE} - V_{SOURCE}$	S2 closed, $V_{IN} = 5V$	$V+ = 15V$, $V_S = 15V$		11	12.5	15	V
		$V^+ = 32V$, $V_S = 32V$		11	13	16	V
Gate Turn-on Time, t_{ON} (Note 4)	V_{IN} switched from 0 to 5V; measure time for V_{GATE} to reach 20V				60	200	µs
Gate Turn-off Time, t_{OFF}	V_{IN} switched from 5 to 0V; measure time for V_{GATE} to reach 1V				4	10	µs
Threshold Bias Voltage, V_2	$I_2 = 200\ \mu A$			1.7	2	2.2	V
Current Sense Trip Voltage, $V_{SENSE} - V_{SOURCE}$	S2 closed, $V_{IN} = 5V$, Increase I_3	$V^+ = 7V$,	S4 closed	75	105	135	mV
		$I_2 = 100\ \mu A$	$V_S = 4.9V$	70	100	130	mV
		$V^+ = 15V$	S4 closed	150	210	270	mV
		$I_2 = 200\ \mu A$	$V_S = 11.8V$	140	200	260	mV
		$V^+ = 32V$	$V_S = 0V$	360	520	680	mV
		$I_2 = 500\ \mu A$	$V_S = 25.5V$	350	500	650	mV
Peak Current Trip Voltage, $V_{SENSE} - V_{SOURCE}$	S3, S4 closed, $V^+ = 15V$, $V_{IN} = 5V$			1.6	2.1		V
Fault Output Voltage, V_{14}	$V_{IN} = 0V$, $I_8 = -100\ \mu A$				0.4	1	V
	$V_{IN} = 5V$, $I_8 = 100\ \mu A$, current sense tripped			14	14.6		V

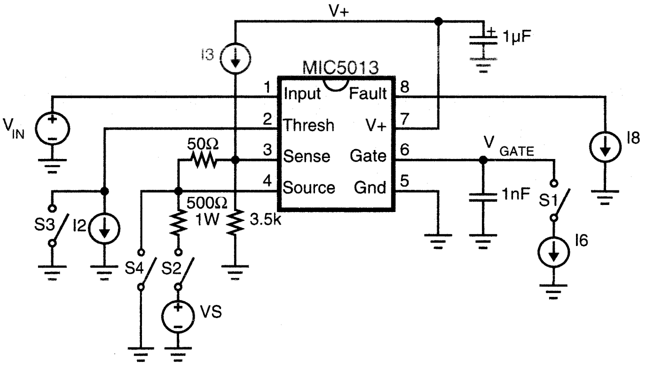
Note 1 **Absolute Maximum Ratings** indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its specified **Operating Ratings**.

Note 2 The MIC5010 is ESD sensitive.

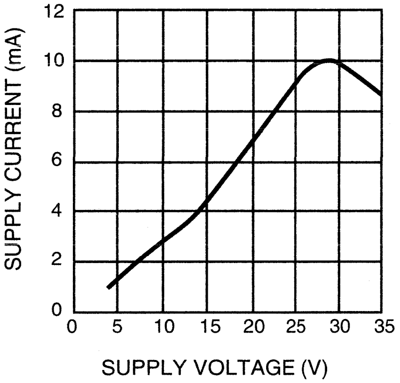
Note 3 Minimum and maximum **Electrical Characteristics** are 100% tested at $T_A = 25°C$ and $T_A = 85°C$, and 100% guaranteed over the entire range. Typicals are characterized at 25°C and represent the most likely parametric norm.

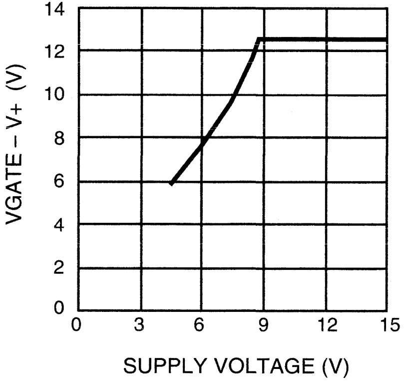
Note 4 Test conditions reflect worst case high-side driver performance. Low-side and bootstrapped topologies are significantly faster—see **Applications Information**.

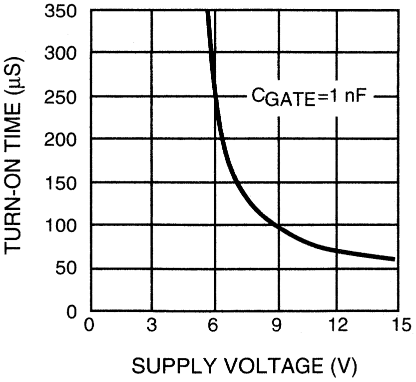
Test Circuit

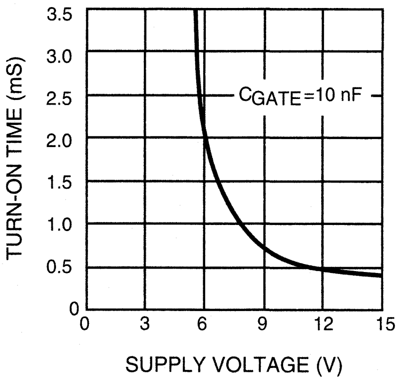


Typical Characteristics


Supply Current

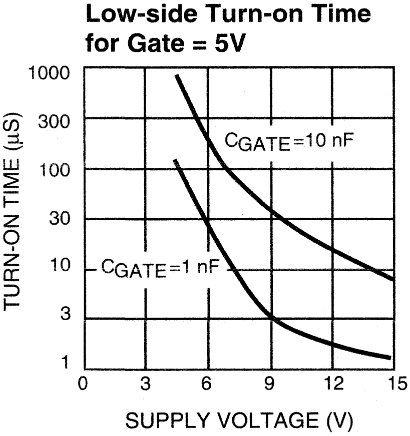

DC Gate Voltage above Supply

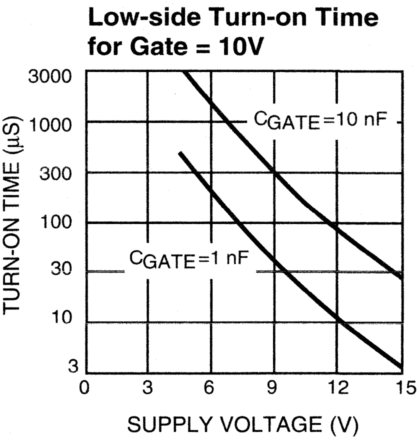

High-side Turn-on Time*

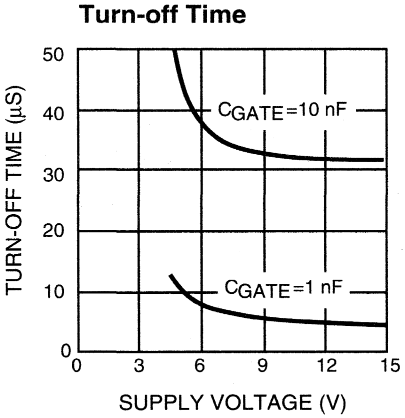

High-side Turn-on Time*

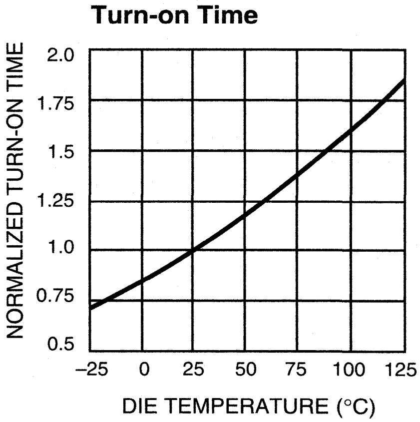
* Time for gate to reach $V^+ + 5V$ in test circuit with $VS = V^+ - 5V$ (prevents gate clamp from interfering with measurement).

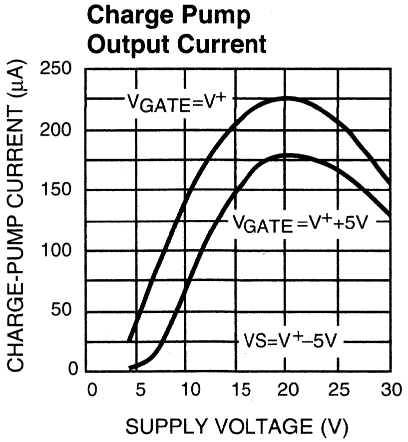
Typical Characteristics (Continued)



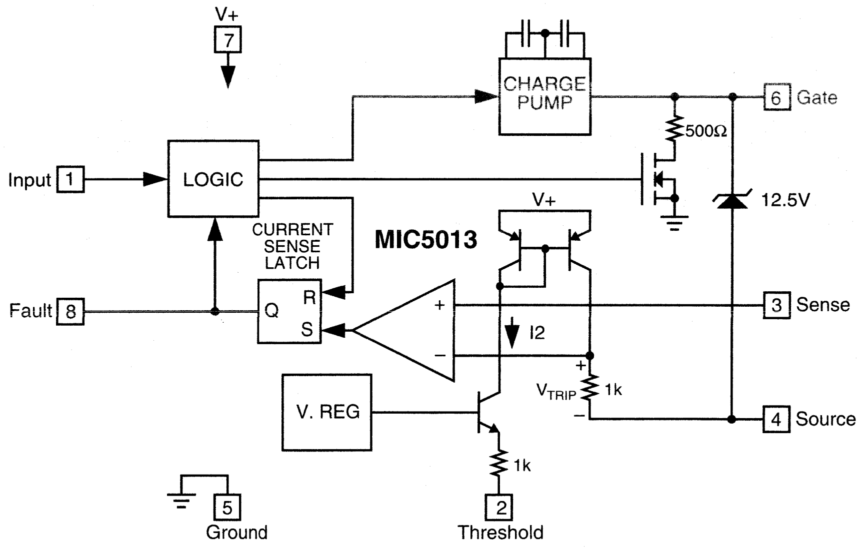








Block Diagram



Applications Information

Functional Description (refer to block diagram)

The various MIC5013 functions are controlled via a logic block connected to the input pin 1. When the input is low, all functions are turned off for low standby current and the gate of the power MOSFET is also held low through 500Ω to an N-channel switch. When the input is taken above the turn-on threshold (3.5V typical), the N-channel switch turns off and the charge pump is turned on to charge the gate of the power FET. A bandgap type voltage regulator is also turned on which biases the current sense circuitry.

The charge pump incorporates a 100kHz oscillator and on-chip pump capacitors capable of charging 1nF to 5V above supply in 60µs typical. The charge pump is capable of pumping the gate up to over twice the supply voltage. For this reason, a zener clamp (12.5V typical) is provided between the gate pin 6 and source pin 4 to prevent exceeding the V_{GS} rating of the MOSFET at high supplies.

The current sense operates by comparing the sense voltage at pin 3 to an offset version of the source voltage at pin 4. Current I2 flowing in threshold pin 2 is mirrored and returned to the source via a 1kΩ resistor to set the offset, or trip voltage. When ($V_{SENSE} - V_{SOURCE}$) exceeds V_{TRIP}, the current sense trips and sets the current sense latch to turn off the power FET. An integrating comparator is used to reduce sensitivity to spikes on pin 3. The latch is reset to turn the FET back on by "recycling" the input pin 1 low and then high again.

A resistor R_{TH} from pin 2 to ground sets I2, and hence V_{TRIP}. An additional capacitor C_{TH} from pin 2 to ground creates a higher trip voltage at turn-on, which is necessary to prevent high in-rush current loads such as lamps or capacitors from false-tripping the current sense.

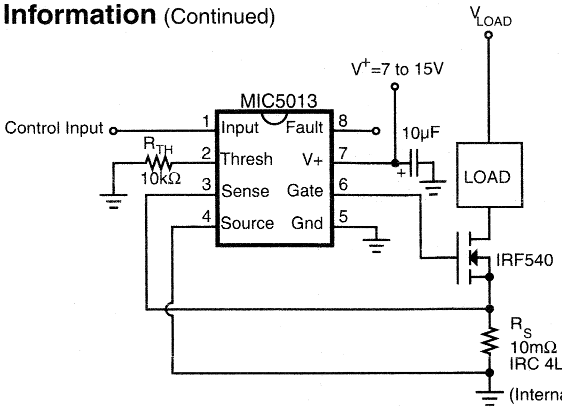
When the current sense has tripped, the fault pin 8 will be high as long as the input pin 1 remains high. However, when the input is low the fault pin will also be low.

Construction Hints

High current pulse circuits demand equipment and assembly techniques that are more stringent than normal low current lab practices. The following are the sources of pitfalls most often encountered during prototyping: Supplies: many bench power supplies have poor transient response. Circuits that are being pulse tested, or those that operate by pulse-width modulation will produce strange results when used with a supply that has poor ripple rejection, or a peaked transient response. Monitor the power supply voltage that appears at the drain of a high-side driver (or the supply side of the load in a low-side driver) with an oscilloscope. It is not uncommon to find bench power supplies in the 1kW class that overshoot or undershoot by as much as 50% when pulse loaded. Not only will the load current and voltage measurements be affected, but it is possible to over-stress various components—especially electrolytic capacitors—with possibly catastrophic results. A 10µF supply bypass capacitor at the chip is recommended.

Residual Resistances: Resistances in circuit connections may also cause confusing results. For example, a circuit may employ a 50mΩ power MOSFET for low drop, but careless construction techniques could easily add 50 to 100mΩ resistance. Do not use a socket for the MOSFET. If the MOSFET is a TO-220 type package, make high-current drain connections to the tab. Wiring losses have a profound effect on high-current circuits. A floating millivoltmeter can identify connections that are contributing excess drop under load.

Applications Information (Continued)



$$R_S = \frac{V_{TRIP}}{I_L}$$

$$R_{TH} = \frac{2200}{V_{TRIP}} - 1000$$

For this example:

I_L =20A (trip current)

V_{TRIP} = 200mV

Figure 2. Low-Side Driver with Current Shunt

Circuit Topologies

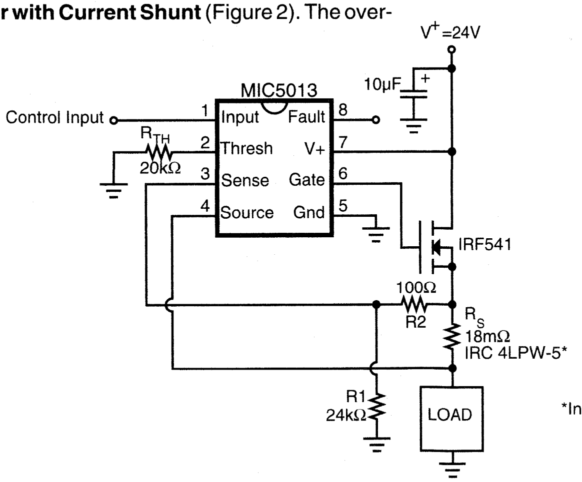
The MIC5013 is suited for use in high- or low-side driver applications with over-current protection for both current-sensing and standard MOSFETs. In addition, the MIC5013 works well in applications where, for faster switching times, the supply is bootstrapped from the MOSFET source output. Low voltage, high-side drivers (such as shown in the Test Circuit) are the slowest; their speed is reflected in the gate turn-on time specifications. The fastest drivers are the low-side and bootstrapped high-side types. Load current switching times are often much faster than the time to full gate enhancement, depending on the circuit type, the MOSFET, and the load. Turn-off times are essentially the same for all circuits (less than 10µs to V_{GS} = 1V). The choice of one topology over another is based on a combination of considerations including speed, voltage, and desired system characteristics. Each topology is described in this section. Note that I_L, as used in the design equations, is the load current that just trips the over-current comparator.

Low-Side Driver with Current Shunt (Figure 2). The over-current comparator monitors RS and trips if $I_L \times R_S$ exceeds V_{TRIP}. R is selected to produce the desired trip voltage.

As a guideline, keep V_{TRIP} within the limits of 100mV and 500mV (R_{TH} = 3.3kΩ to 20kΩ). Thresholds at the high end offer the best noise immunity, but also compromise switch drop (especially in low voltage applications) and power dissipation.

The trip current is set higher than the maximum expected load current—typically twice that value. Trip point accuracy is a function of resistor tolerances, comparator offset (only a few millivolts), and threshold bias voltage (V2). The values shown in Figure 2 are designed for a trip current of 20 amperes. It is important to ground pin 4 at the current shunt R_S, to eliminate the effects of ground resistance.

A key advantage of the low-side topology is that the load supply is limited only by the MOSFET BVDSS rating. Clamping may be required to protect the MOSFET drain terminal from inductive switching transients. The MIC5013



$$R1 = \frac{V^+}{1mA}$$

R2=100Ω

$$R_S = \frac{100mV + V_{TRIP}}{I_L}$$

$$R_{TH} = \frac{2200}{V_{TRIP}} - 1000$$

For this example:

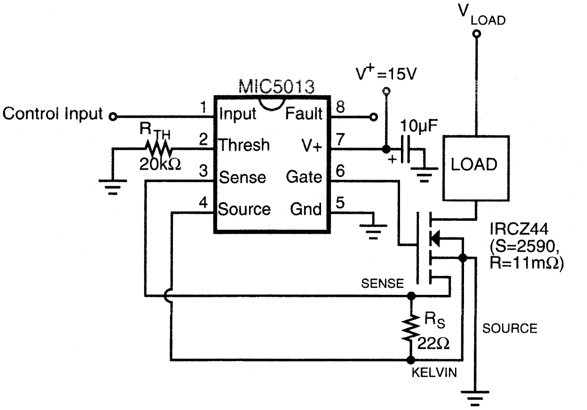
I_L =10A (trip current)

V_{TRIP}=100mV

*International Resistive Company

Figure 3. High-Side Driver with Current Shunt

Applications Information (Continued)



$$R_S = \frac{SR\ V_{TRIP}}{R\ I_L - V_{TRIP}}$$

$$R_{TH} = \frac{2200}{V_{TRIP}} - 1000$$

For this example:
I_L =20A (trip current)
V_{TRIP} =100mV

Figure 4. Low-Side Driver with Current-Sensing MOSFET

supply should be limited to 15V in low-side topologies; otherwise, a large current will be forced through the gate clamp zener.

Low-side drivers constructed with the MIC501X family are also fast; the MOSFET gate is driven to near supply immediately when commanded ON. Typical circuits achieve 10V enhancement in 10µs or less on a 12 to 15V supply.

High-Side Driver with Current Shunt (Figure 3). The comparator input pins (source and sense) float with the current sensing resistor (R_S) on top of the load. R1 and R2 add a small, additional potential to V_{TRIP} to prevent false-triggering of the over-current shutdown circuit with open or inductive loads. R1 is sized for a current flow of 1mA, while R2 contributes a drop of 100mV. The shunt voltage should be 200 to 500mV at the trip point. The example of Figure 3 gives a 10A trip current when the output is near supply. The trip point is somewhat reduced when the output is at ground as the voltage drop across R1 (and therefore R2) is zero.

High-side drivers implemented with MIC5013 drivers are self-protected against inductive switching transients. During turn-off an inductive load will force the MOSFET source 5V or more below ground, while the driver holds the gate at ground potential. The MOSFET is forced into conduction, and it dissipates the energy stored in the load inductance. The MIC5013 source and sense pins (3 and 4) are designed to withstand this negative excursion without damage. External clamp diodes are unnecessary.

Current Shunts (R_S). Low-valued resistors are necessary for use at R_S.Values for R_S range from 5 to 50mΩ, at 2 to 10W. Worthy of special mention are Kelvin-sensed, "four-terminal" units supplied by a number of manufacturers† (see next page). Kelvin-sensed resistors eliminate errors caused by lead and terminal resistances, and simplify product assembly. 10% tolerance is normally adequate, and with shunt potentials of 200mV thermocouple effects are insignificant. Temperature coefficient is important; a linear, 500 ppm/°C change will contribute as much as 10% shift in the over-current trip point. Most power resistors designed for current shunt service drift less than 100 ppm/°C.

Low-Side Driver with Current Sensing MOSFET (Figure 4). Several manufacturers now supply power MOSFETs in which a small sampling of the total load current is diverted to a "sense" pin. One additional pin, called "Kelvin source," is included to eliminate the effects of resistance in the source bond wires. Current-sensing MOSFETs are specified with a sensing ratio "S" which describes the relationship between the on-resistance of the sense connection and the body resistance "R" of the main source pin. Current sensing MOSFETs eliminate the current shunt required by standard MOSFETs.

The design equations for a low-side driver using a current sensing MOSFET are shown in Figure 4. "S" is specified on the MOSFET's datasheet, and "R" must be measured or estimated. V_{TRIP} must be less than $R \times I_L$, or else R_S will become negative. Substituting a MOSFET with higher on-resistance, or reducing V_{TRIP} fixes this problem. V_{TRIP} = 100 to 200mV is suggested. Although the load supply is limited only by MOSFET ratings, the MIC5013 supply should be limited to 15V to prevent damage to the gate clamp zener. Output clamping is necessary for inductive loads.

"R" is the body resistance of the MOSFET, excluding bond resistances. $R_{DS(ON)}$ as specified on MOSFET data sheets

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† Suppliers of Kelvin-sensed power resistors:
Dale Electronics, Inc., 2064 12th Ave., Columbus, NE 68601. Tel: (402) 564-3131
International Resistive Co., P.O. Box 1860, Boone, NC 28607-1860. Tel: (704) 264-8861
Kelvin, 14724 Ventura Blvd., Ste. 1003, Sherman Oaks, CA 91403-3501. Tel: (818) 990-1192
RCD Components, Inc., 520 E. Industrial Pk. Dr., Manchester, NH 03103. Tel: (603) 669-0054
Ultronix, Inc., P.O. Box 1090, Grand Junction, CO 81502. Tel: (303) 242-0810

Applications Information (Continued)

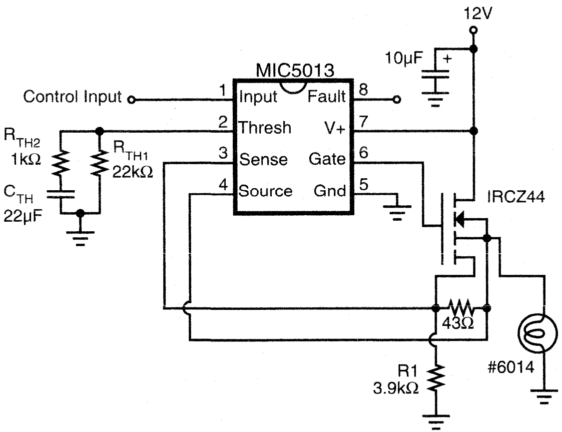


Figure 5. Time-Variable Trip Threshold

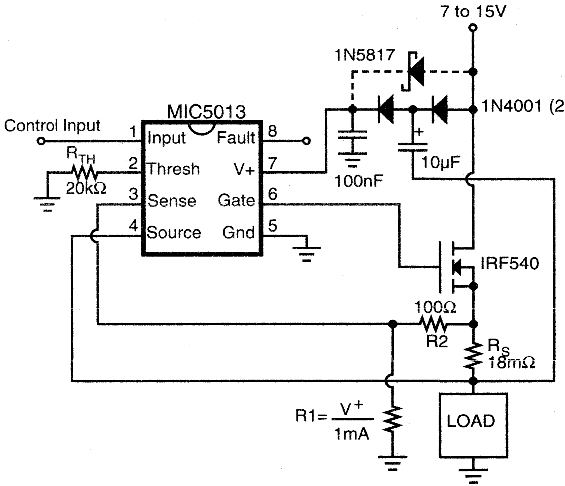


Figure 6. Bootstrapped High-Side Driver

includes bond resistances. A Kelvin-connected ohmmeter (using TAB and SOURCE for forcing, and SENSE and KELVIN for sensing) is the best method of evaluating "R." Alternatively, "R" can be estimated for large MOSFETs ($R_{DS(ON)} \leq 100m\Omega$) by simply halving the stated $R_{DS(ON)}$, or by subtracting 20 to 50mΩ from the stated $R_{DS(ON)}$ for smaller MOSFETs.

High-Side Driver with Current Sensing MOSFET (Figure 5). The design starts by determining the value of "S" and "R" for the MOSFET (use the guidelines described for the low-side version). Let V_{TRIP} = 100mV, and calculate R_S for a desired trip current. Next calculate R_{TH} and R1. The trip point is somewhat reduced when the output is at ground as the voltage drop across R1 is zero. No clamping is required for inductive loads, but may be added to reduce power dissipation in the MOSFET.

Typical Applications

Start-up into a Dead Short. If the MIC5013 attempts to turn on a MOSFET when the load is shorted, a very high current flows. The over-current shutdown will protect the MOSFET, but only after a time delay of 5 to 10µs. The MOSFET must be capable of handling the overload; consult the device's SOA curve. If a short circuit causes the MOSFET to exceed its 10µs SOA, a small inductance in series with the source can help limit di/dt to control the peak current during the 5 to 10µs delay.

When testing short-circuit behavior, use a current probe rated for both the peak current and the high di/dt.

The over-current shutdown delay varies with comparator overdrive, owing to noise filtering in the comparator. A delay of up to 100µs can be observed at the threshold of shutdown. A 20% overdrive reduces the delay to near minimum.

Incandescent Lamps. The cold filament of an incandescent lamp exhibits less than one-tenth as much resistance as when the filament is hot. The initial turn-on current of a #6014 lamp is about 70A, tapering to 4.4A after a few hundred milliseconds. It is unwise to set the over-current trip point to 70A to accommodate such a load. A "resistive" short that draws less than 70A could destroy the MOSFET by allowing sustained, excessive dissipation. If the over-current trip point is set to less than 70A, the MIC5013 will not start a cold filament. The solution is to start the lamp with a high trip point, but reduce this to a reasonable value after the lamp is hot.

The MIC5013 over-current shutdown circuit is designed to handle this situation by varying the trip point with time (see Figure 5). R_{TH1} functions in the conventional manner, providing a current limit of approximately twice that required by the lamp. R_{TH2} acts to increase the current limit at turn-on to approximately 10 times the steady-state lamp current. The high initial trip point decays away according to a 20ms time constant contributed by C_{TH}. R_{TH2} could be eliminated with C_{TH} working against the internal 1kΩ resistor, but this results in a very high over-current threshold. As a rule of thumb design the over-current circuitry in the conventional manner, then add the R_{TH2}/C_{TH} network to allow for lamp start-up. Let $R_{TH2} = (R_{TH1} \div 10) - 1k\Omega$, and choose a capacitor that provides the desired time constant working against R_{TH2} and the internal 1kΩ resistor.

When the MIC5013 is turned off, the threshold pin (2) appears as an open circuit, and C_{TH} is discharged through R_{TH1} and R_{TH2}. This is much slower than the turn-on time constant, and it simulates the thermal response of the filament. If the lamp is pulse-width modulated, the current limit will be reduced by the residual charge left in C_{TH}.

Modifying Switching Times. Do not add external capacitors to the gate to slow down the switching time. Add a resistor (1kΩ to 51kΩ) in series with the gate of the MOSFET to achieve this result.

Bootstrapped High-Side Driver (Figure 6). The speed of a high-side driver can be increased to better than 10µs by bootstrapping the supply off of the MOSFET source. This topology can be used where the load is pulse-width modu-

Applications Information (Continued)

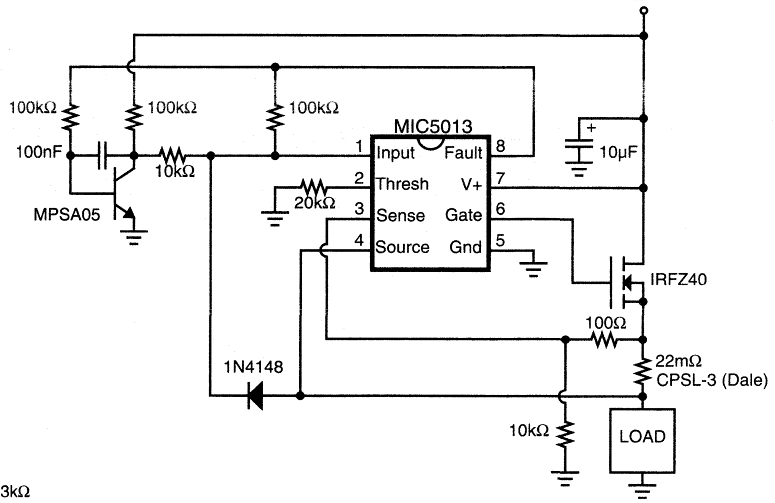


Figure 7. 10-Ampere Electronic Circuit Breaker

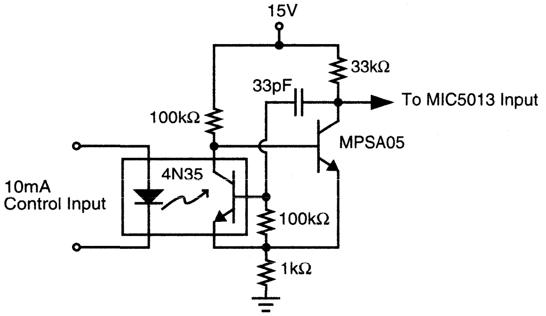


Figure 8. Improved Opto-Isolator Performance

lated (100Hz to 20kHz), or where it is energized for only a short period of time (≤25ms). If the load is left energized for a long period of time (>25ms), the bootstrap capacitor will discharge and the MIC5013 supply pin will fall to $V+ = V_{DD} -1.4$. Under this condition pins 3 and 4 will be held above V+ and may false trigger the over-current circuit. A larger capacitor will lengthen the maximum "on" time; 1000µF will hold the circuit up for 2.5 seconds, but requires more charge time when the circuit is turned off. The optional Schottky barrier diode improves turn-on time on supplies of less than 10V.

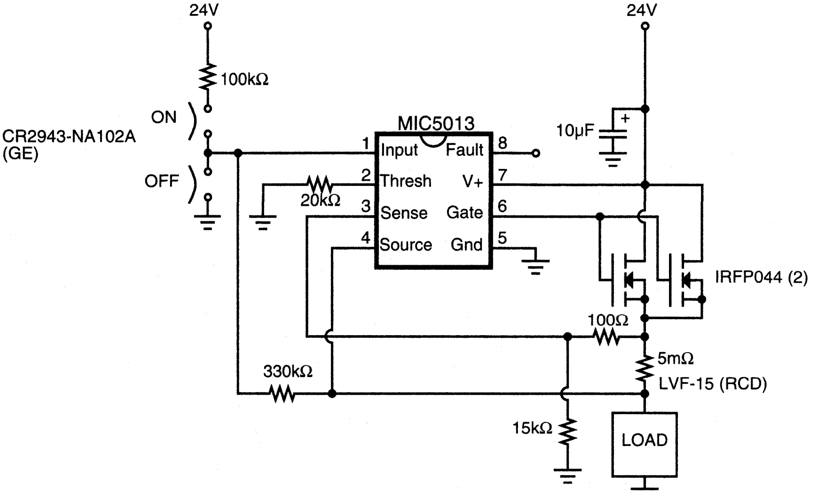


Figure 9. 50-Ampere Industrial Switch

Applications Information (Continued)

Since the supply current in the "OFF" state is only a small leakage, the 100nF bypass capacitor tends to remain charged for several seconds after the MIC5013 is turned off. In a PWM application the chip supply is actually much higher than the system supply, which improves switching time.

Electronic Circuit Breaker (Figure 7). The MIC5013 forms the basis of a high-performance, fast-acting circuit breaker. By adding feedback from FAULT to INPUT the breaker can be made to automatically reset. If an over-current condition occurs, the circuit breaker shuts off. The breaker tests the load every 18ms until the short is removed, at which time the circuit latches ON. No reset button is necessary.

Opto-Isolated Interface (Figure 8). Although the MIC5013 has no special input slew rate requirement, the lethargic transitions provided by an opto-isolator may cause oscillations on the rise and fall of the output. The circuit shown accelerates the input transitions from a 4N35 opto-isolator by adding hysteresis. Opto-isolators are used where the control circuitry cannot share a common ground with the MIC5013 and high-current power supply, or where the control circuitry is located remotely. This implementation is intrinsically safe; if the control line is severed the MIC5013 will turn OFF.

Fault-Protected Industrial Switch (Figure 9). The most common manual control for industrial loads is a push button on/off switch. The "on" button is physically arranged in a recess so that in a panic situation the "off" button, which extends out from the control box, is more easily pressed. This circuit is compatible with control boxes such as the CR2943 series (GE). The circuit is configured so that if both switches close simultaneously, the "off" button has precedence. If there is a fault condition the circuit will latch off, and it can be reset by pushing the "ON" button.

This application also illustrates how two (or more) MOSFETs can be paralleled. This reduces the switch drop, and distributes the switch dissipation into multiple packages.

High-Voltage Bootstrap (Figure 10). Although the MIC5013 is limited to operation on 7 to 32V supplies, a floating bootstrap arrangement can be used to build a high-side switch that operates on much higher voltages. The MIC5013 and MOSFET are configured as a low-side driver, but the load is connected in series with ground. The high speed normally associated with low-side drivers is retained in this circuit.

Power for the MIC5013 is supplied by a charge pump. A 20kHz square wave (15Vp-p) drives the pump capacitor and delivers current to a 100µF storage capacitor. A zener diode limits the supply to 18V. When the MIC5013 is off, power is supplied by a diode connected to a 15V supply. The circuit of Figure 8 is put to good use as a barrier between low voltage control circuitry and the 90V motor supply.

Half-Bridge Motor Driver (Figure 11). Closed loop control of motor speed requires a half-bridge driver. This topology presents an extra challenge since the two output devices should not cross conduct (shoot-through) when switching. Cross conduction increases output device power dissipation and, in the case of the MIC5013, could trip the over-current comparator. Speed is also important, since PWM control requires the outputs to switch in the 2 to 20kHz range.

The circuit of Figure 11 utilizes fast configurations for both the top- and bottom-side drivers. Delay networks at each input provide a 2 to 3µs dead time effectively eliminating cross conduction. Both the top- and bottom-side drivers are protected, so the output can be shorted to either rail without damage.

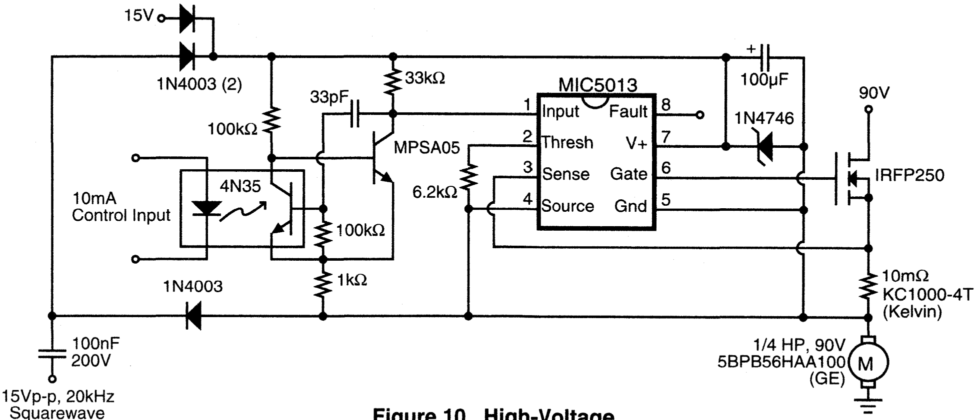


Figure 10. High-Voltage Bootstrapped Driver

Applications Information (Continued)

The top-side driver is based on the bootstrapped circuit of Figure 6, and cannot be switched on indefinitely. The bootstrap capacitor (1µF) relies on being pulled to ground by the bottom-side output to recharge. This limits the maximum duty cycle to slightly less than 100%.

Two of these circuits can be connected together to form an H-bridge. If the H-bridge is used for locked antiphase control, no special considerations are necessary. In the case of sign/magnitude control, the "sign" leg of the H-bridge should be held low (PWM input held low) while the other leg is driven by the magnitude signal.

If current feedback is required for torque control, it is available in chopped form at the bottom-side driver's 22 mΩ current-sensing resistor.

Time-Delay Relay (Figure 12). The MIC5013 forms the basis of a simple time-delay relay. As shown, the delay commences when power is applied, but the 100 kΩ/1N4148 could be independently driven from an external source such as a switch or another high-side driver to give a delay relative to some other event in the system.

Hysteresis has been added to guarantee clean switching at turn-on. Note that an over-current condition latches the relay in a safe, OFF condition. Operation is restored by either cycling power or by momentarily shorting pin 1 to ground.

Motor Driver with Stall Shutdown (Figure 13). Tachometer feedback can be used to shut down a motor driver circuit when a stall condition occurs. The control switch is a 3-way type; the "START" position is momentary and forces the driver ON. When released, the switch returns to the "RUN" position, and the tachometer's output is used to hold the MIC5013 input ON. If the motor slows down, the tach output is reduced, and the MIC5013 switches OFF. Resistor "R" sets the shutdown threshold. If the output current exceeds 30A, the MIC5013 shuts down and remains in that condition until the momentary "RESET" button is pushed. Control is then returned to the START/RUN/STOP switch.

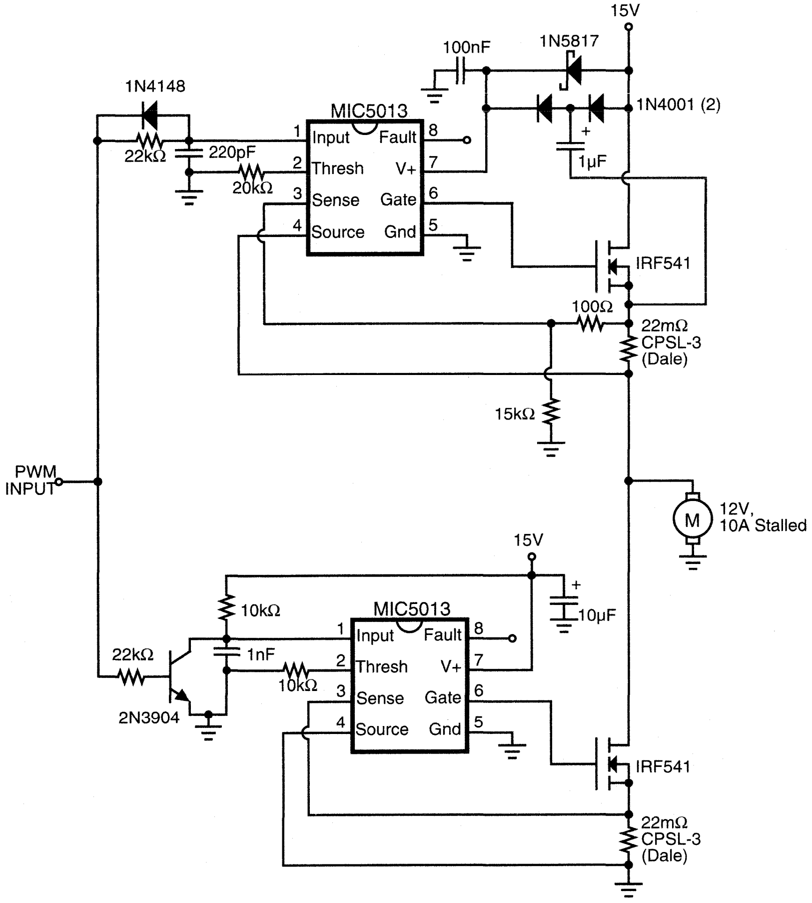


Figure 11. Half-Bridge Motor Driver

Applications Information (Continued)

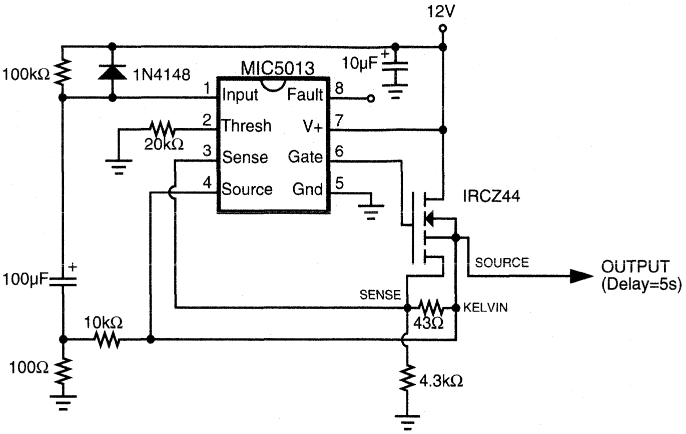


Figure 12. Time-Delay Relay with 30A Over-Current Protection

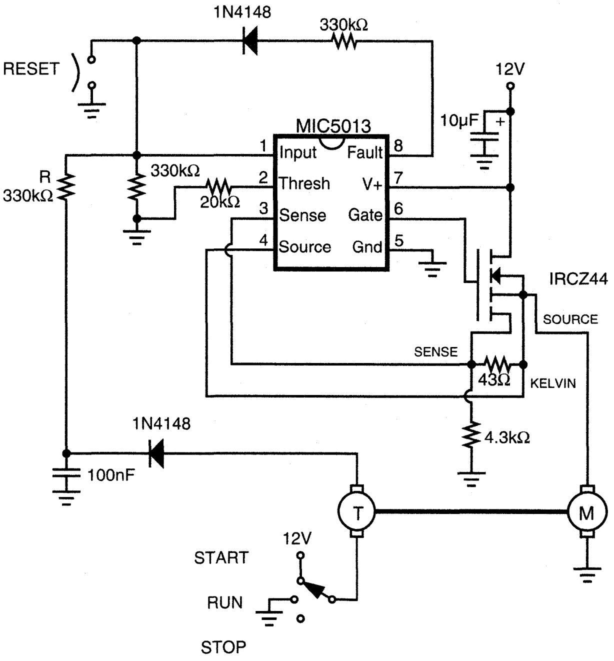


Figure 13. Motor Stall Shutdown

Applications Information (Continued)

Gate Control Circuit

When applying the MIC5010, it is helpful to understand the operation of the gate control circuitry (see Figure 14). The gate circuitry can be divided into two sections: 1) charge pump (oscillator, Q1-Q5, and the capacitors) and 2) gate turn-off switch (Q6).

When the MIC5010 is in the OFF state, the oscillator is turned off, thereby disabling the charge pump. Q5 is also turned off, and Q6 is turned on. Q6 holds the gate pin (G) at ground potential which effectively turns the external MOSFET off.

Q6 is turned off when the MIC5013 is commanded on. Q5 pulls the gate up to supply (through 2 diodes). Next, the charge pump begins supplying current to the gate. The gate accepts charge until the gate-source voltage reaches 12.5V and is clamped by the zener diode.

A 2-output, three-phase clock switches Q1-Q4, providing a quasi-tripling action. During the initial phase Q4 and Q2 are ON. C1 is discharged, and C2 is charged to supply through Q5. For the second phase Q4 turns off and Q3 turns on, pushing pin C2 above supply (charge is dumped into the gate). Q3 also charges C1. On the third phase Q2 turns off and Q1 turns on, pushing the common point of the two capacitors above supply. Some of the charge in C1 makes its way to the gate. The sequence is repeated by turning Q2 and Q4 back on, and Q1 and Q3 off.

In a low-side application operating on a 12 to 15V supply, the MOSFET is fully enhanced by the action of Q5 alone. On supplies of more than approximately 14V, current flows directly from Q5 through the zener diode to ground. To prevent excessive current flow, the MIC5010 supply should be limited to 15V in low-side applications.

The action of Q5 makes the MIC5013 operate quickly in low-side applications. In high-side applications Q5 precharges the MOSFET gate to supply, leaving the charge pump to carry the gate up to full enhancement 10V above supply. Bootstrapped high-side drivers are as fast as low-side drivers since the chip supply is boosted well above the drain at turn-on.

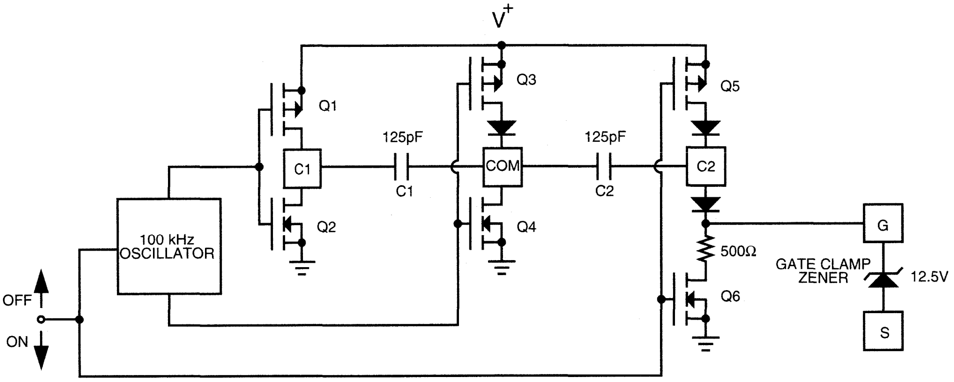


Figure 14. Gate Control Circuit Detail

MIC5014/5015

Low-Cost High- or Low-Side MOSFET Driver

General Description

MIC5014 and MIC5015 MOSFET drivers are designed for gate control of N-channel, enhancement-mode, power MOSFETs used as high-side or low-side switches. The MIC5014/5 can sustain an on-state output indefinitely.

The MIC5014/5 operates from a 2.75V to 30V supply. In high-side configurations, the driver can control MOSFETs that switch loads of up to 30V. In low-side configurations, with separate supplies, the maximum switched voltage is limited only by the MOSFET.

The MIC5014/5 has a TTL compatible control input. The MIC5014 is noninverting while the MIC5015 is inverting.

The MIC5014/5 features an internal charge pump that can sustain a gate voltage greater than the available supply voltage. The driver is capable of turning on a logic-level MOSFET from a 2.75V supply or a standard MOSFET from a 5V supply. The gate-to-source output voltage is internally limited to approximately 15V.

The MIC5014/5 is protected against automotive load dump, reversed battery, and inductive load spikes of –20V. The driver's overvoltage shutdown feature turns off the external MOSFET at approximately 35V to protect the load against power supply excursions.

The MIC5014 is an improved pin-for-pin compatible replacement in many MIC5011 applications.

The MIC5014/5 is available in plastic 8-pin DIP and 8-pin SOIC pacakges.

Typical Application

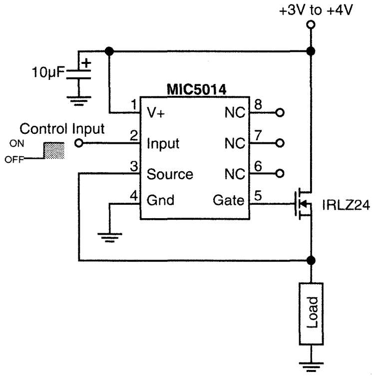


Figure 1. 3V "Sleep-Mode" Switch with a Logic-Level MOSFET

Features

- 2.75V to 30V operation
- 100µA maximum supply current (5V supply)
- 15µA typical off-state current
- Internal charge pump
- TTL compatible input
- Withstands 60V transient (load dump)
- Reverse battery protected to –20V
- Inductive spike protected to –20V
- Overvoltage shutdown at 35V
- Internal 15V gate protection
- Minimum external parts
- Operates in high-side or low-side configurations
- 1µA control input pull-off
- Inverting and noninverting versions

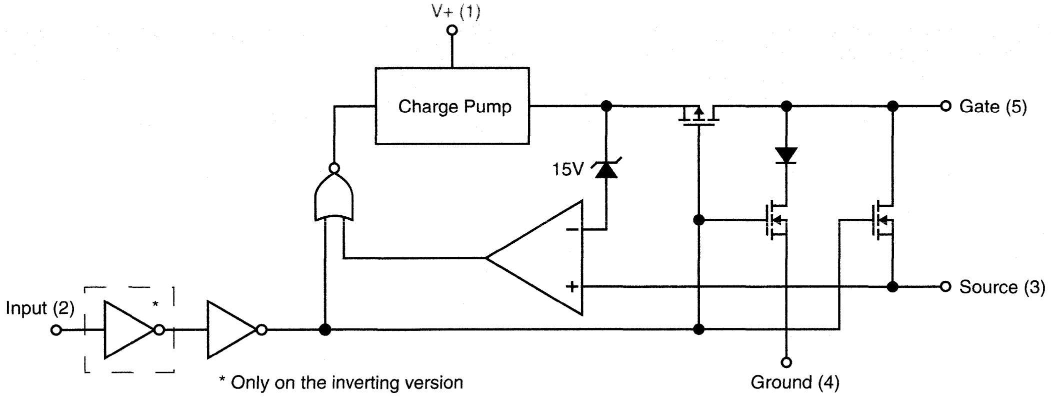
Applications

- Automotive electrical load control
- Battery-powered computer power management
- Lamp control
- Heater control
- Motor control
- Power bus switching

Ordering Information

Part Number	Temperature Range	Package
Noninverting		
MIC5014BM	–40°C to +85°C	8-pin SOIC
MIC5014BN	–40°C to +85°C	8-pin Plastic DIP
Inverting		
MIC5015BM	–40°C to +85°C	8-pin SOIC
MIC5015BN	–40°C to +85°C	8-pin Plastic DIP

Block Diagram



Pin Description

Pin Number	Pin Name	Pin Function
1	V+	Supply. Must be decoupled to isolate from large transients caused by the power MOSFET drain. 10µF is recommended close to pins 1 and 4.
2	Input	Turns on power MOSFET when taken above (or below) threshold (1.0V typical). Pin 2 requires ~ 1µA to switch.
3	Source	Connects to source lead of power MOSFET and is the return for the gate clamp zener. Pin 3 can safely swing to –20V when turning off inductive loads.
4	Ground	
5	Gate	Drives and clamps the gate of the power MOSFET.
6, 7, 8	NC	Not internally connected.

Absolute Maximum Ratings (Notes 1,2)

Supply Voltage	–20V to 60V
Input Voltage	–20V to V^+
Source Voltage	–20V to V^+
Source Current	50mA
Gate Voltage	–20V to 50V
Junction Temperature	150°C

Operating Ratings (Notes 1,2)

θ_{JA} (Plastic DIP)	160°C/W
θ_{JA} (SOIC)	170°C/W
Ambient Temperature: B version	–40°C to +85°C
Ambient Temperature: A version	+55°C to +125°C
Storage Temperature	–65°C to +150°C
Lead Temperature (max soldering time: 10 seconds)	260°C
Supply Voltage (V^+)	2.75V to 30V

Electrical Characteristics (Note 3) $T_A = –55°C$ to +125°C unless otherwise specified

Parameter	Conditions		Min	Typ	Max	Units
Supply Current	$V^+ = 30V$	V_{IN} De-Asserted (Note 5)		10	25	µA
		V_{IN} Asserted (Note 5)		5.0	10	mA
	$V^+ = 5V$	V_{IN} De-Asserted		10	25	µA
		V_{IN} Asserted		60	100	
	$V^+ = 3V$	V_{IN} De-Asserted		10	25	µA
		V_{IN} Asserted		25	35	
Logic Input Voltage Threshold V_{IN}	$3.0V \le V^+ \le 30V$	Digital Low Level			0.8	V
	$T_A = 25°C$	Digital High Level	2.0			
Logic Input Current MIC5014 (non-inverting)	$3.0V \le V^+ \le 30V$	V_{IN} Low	–2.0	0		µA
		V_{IN} High		1.0	2.0	
Logic Input Current MIC5015 (inverting)	$3.0V \le V^+ \le 30V$	V_{IN} Low	–2.0	–1.0		µA
		V_{IN} High		–1.0	2.0	
Input Capacitance				5.0		pF
Gate Enhancement $V_{GATE} – V_{SUPPLY}$	$3.0V \le V^+ \le 30V$	V_{IN} Asserted	4.0		17	V
Zener Clamp $V_{GATE} – V_{SOURCE}$	$8.0V \le V^+ \le 30V$	V_{IN} Asserted	13	15	17	V
Gate Turn-on Time, t_{ON} (Note 4)	$V^+ = 4.5V$ $C_L = 1000pF$	V_{IN} switched on, measure time for V_{GATE} to reach $V^+ + 4V$		2.5	8.0	ms
	$V^+ = 12V$ $C_L = 1000pF$	As above, measure time for V_{GATE} to reach $V^+ + 4V$		90	140	µs
Gate Turn-off Time, t_{OFF} (Note 4)	$V^+ = 4.5V$ $C_L = 1000pF$	V_{IN} switched off, measure time for V_{GATE} to reach 1V		6.0	30	µs
	$V^+ = 12V$ $C_L = 1000pF$	As above, measure time for V_{GATE} to reach 1V		6.0	30	µs
Overvoltage Shutdown Threshold			35	37	41	V

Note 1: **Absolute Maximum Ratings** indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its specified **Operating Ratings**.

Note 2: The MIC5014/5015 is ESD sensitive.

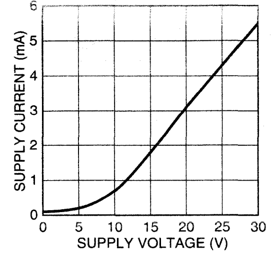
Note 3: Minimum and maximum **Electrical Characteristics** are 100% tested at $T_A = 25°C$ and $T_A = 85°C$, and 100% guaranteed over the entire operating temperature range. Typicals are characterized at 25°C and represent the most likely parametric norm.

Note 4: Test conditions reflect worst case high-side driver performance. Low-side and bootstrapped topologies are significantly faster—see Applications Information. Maximum value of switching time seen at 125°C, unit operated at room temperature will reflect the typical value shown.

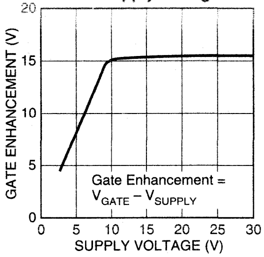
Note 5: "Asserted" refers to a logic high on the MIC5014 and a logic low on the MIC5015.

Typical Characteristics All data measured using FET probe to minimize resistive loading

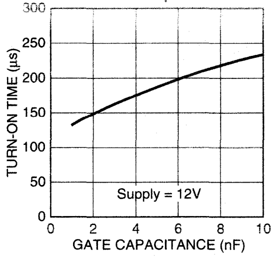
Supply Current (Output Asserted)



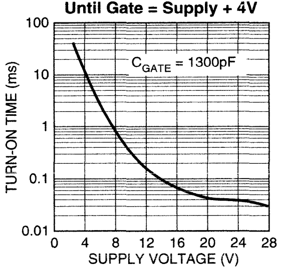
Gate Enhancement vs. Supply Voltage



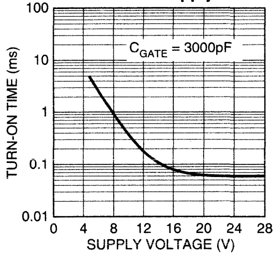
High-Side Turn-On Time vs. Gate Capacitance



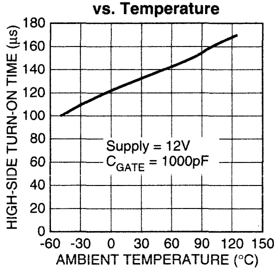
High-Side Turn-On Time Until Gate = Supply + 4V



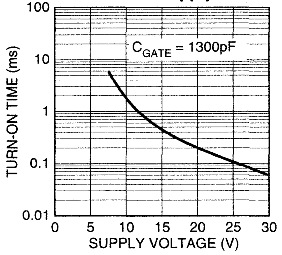
High-Side Turn-On Time Until Gate = Supply + 4V



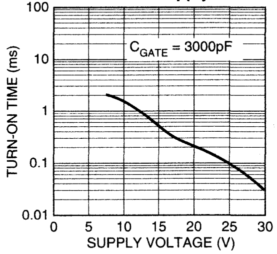
High-Side Turn-On Time vs. Temperature



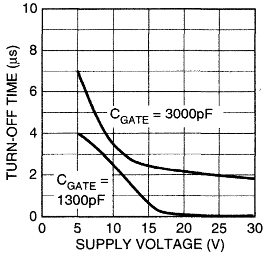
High-Side Turn-On Time Until Gate = Supply + 10V



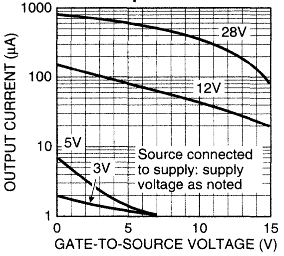
High-Side Turn-On Time Until Gate = Supply + 10V



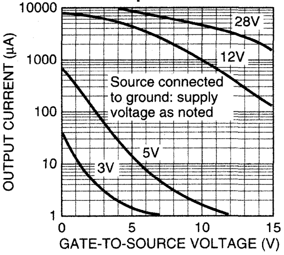
High-Side Turn-Off Time Until Gate = 1V



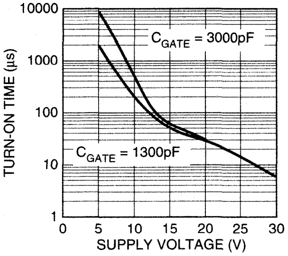
Charge-Pump Output Current



Charge-Pump Output Current



Low-Side Turn-On Time Until Gate = 4V



Applications Information

Functional Description

The MIC5014 is functionally and pin for pin compatible with the MIC5011, except for the omission of the optional speed-up capacitor pins, which are available on the MIC5011. The MIC5015 is an inverting configuration of the MIC5014.

The internal functions of these devices are controlled via a logic block (refer to block diagram) connected to the control input (pin 2). When the input is off (low for the MIC5014, and high for the MIC5015), all functions are turned off, and the gate of the external power MOSFET is held low via two N-channel switches. This results in a very low standby current; 15µA typical, which is necessary to power an internal bandgap. When the input is driven to the "ON" state, the N-channel switches are turned off, the charge pump is turned on, and the P-channel switch between the charge pump and the gate turns on, allowing the gate of the power FET to be charged. The op amp and internal zener form an active regulator which shuts off the charge pump when the gate voltage is high enough. This is a feature not found on the MIC5011.

The charge pump incorporates a 100kHz oscillator and on-chip pump capacitors capable of charging a 1,000pF load in 90µs typical. In addition to providing active regulation, the internal 15V zener is included to prevent exceeding the V_{GS} rating of the power MOSFET at high supply voltages.

The MIC5014/15 devices have been improved for greater ruggedness and durability. All pins can withstand being pulled 20V below ground without sustaining damage, and the supply pin can withstand an overvoltage transient of 60V for 1s. An overvoltage shutdown has also been included, which turns off the device when the supply exceeds 35V.

Construction Hints

High current pulse circuits demand equipment and assembly techniques that are more stringent than normal, low current lab practices. The following are the sources of pitfalls most often encountered during prototyping: *Supplies*: Many bench power supplies have poor transient response. Circuits that are being pulse tested, or those that operate by pulse-width modulation will produce strange results when used with a supply that has poor ripple rejection, or a peaked transient response. Always monitor the power supply voltage that appears at the drain of a high side driver (or the supply side of the load for a low side driver) with an oscilloscope. It is not uncommon to find bench power supplies in the 1kW class that overshoot or undershoot by as much as 50% when pulse loaded. Not only will the load current and voltage measurements be affected, but it is possible to overstress various components, especially electrolytic capacitors, with possibly catastrophic results. A 10µF supply bypass capacitor *at the chip is* recommended. *Residual resistances*: Resistances in circuit connections may also cause confusing results. For example, a circuit may employ a 50mΩ power MOSFET for low voltage drop, but unless careful construction techniques are used, one could easily add 50 to 100mΩ resistance. Do not use a socket for the MOSFET. If the MOSFET is a TO-220 type package, make high current connections to the drain tab. Wiring losses have a profound effect on high-current circuits. A floating milliohmeter can identify connections that are contributing excess drop under load.

Low Voltage Testing

As the MIC5014/MIC5015 have relatively high output impedances, a normal oscilloscope probe will load the device. This is especially pronounced at low voltage operation. It is recommended that a FET probe or unity gain buffer be used for all testing.

Circuit Topologies

The MIC5014 and MIC5015 are well suited for use with standard power MOSFETs in both low and high side driver configurations. In addition, the lowered supply voltage requirements of these devices make them ideal for use with logic level FETs in high side applications with a supply voltage of 3 to 4V. (If higher supply voltages [>4V] are used with logic level FETs, an external zener clamp must be supplied to ensure that the maximum V_{GS} rating of the logic FET [10V] is not exceeded.) In addition, a standard IGBT can be driven using these devices.

Choice of one topology over another is usually based on speed vs. safety. The fastest topology is the low side driver, however, it is not usually considered as safe as high side driving as it is easier to accidentally short a load to ground than to V_{CC}. The slowest, but safest topology is the high side driver; with speed being inversely proportional to supply voltage. It is the preferred topology for most military and automotive applications. Speed can be improved considerably by bootstrapping from the supply.

All topologies implemented using these devices are well suited to driving inductive loads, as either the gate or the source pin can be pulled 20V below ground with no effect. External clamp diodes are unnecessary, except for the case in which a transient may exceed the overvoltage trip point.

High Side Driver (Figure 1) The high side topology shown here is an implementation of a "sleep-mode" switch for a laptop or notebook computer which uses a logic level FET. A standard power FET can easily be substituted when supply voltages above 4V are required.

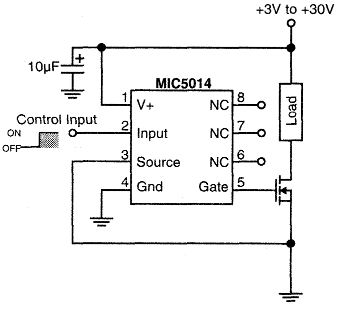


Figure 2. Low Side Driver

Low Side Driver (Figure 2) A key advantage of this topology, as previously mentioned, is speed. The MOSFET gate is driven to near supply immediately when the MIC5014/15 is turned on. Typical circuits reach full enhancement in 50µs or less with a 15V supply.

Bootstrapped High Side Driver (Figure 3) The turn-on time of a high side driver can be improved to faster than 40µs by bootstrapping the supply with the MOSFET source. The Schottky barrier diode prevents the supply pin from dropping more than 200mV below the drain supply and improves turn-on time. Since the supply current in the "off" state is only a small leakage, the 100nF bypass capacitor tends to remain charged for several seconds after the MIC5014/15 is turned off. Faster speeds can be obtained at the expense of supply voltage (the overvoltage shutdown will turn the part off when the bootstrapping action pulls the supply pin above 35V) by using a larger capacitor at the junction of the two 1N4001 diodes. In a PWM application (this circuit can be used for either PWM'ed or continuously energized loads), the chip supply is sustained at a higher potential than the system supply, which improves switching time.

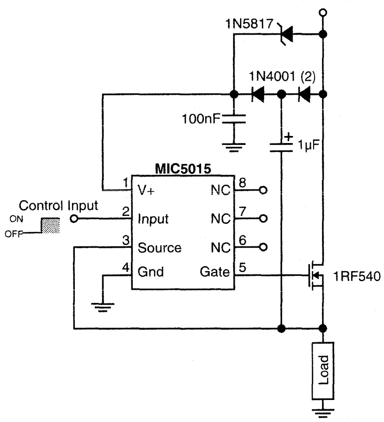


Figure 3. Bootstrapped Hgh-Side Driver

High Side Driver With Current Sense (Figure 4) Although no current sense function is included on the MIC5014/15 devices, a simple current sense function can be realized via the addition of one more active component; an LM301A op amp used as a comparator. The positive rail of the op amp is tied to V+, and the negative rail is tied to ground. This op amp was chosen as it can withstand having input transients that swing below the negative rail, and has common mode range almost to the positive rail.

The inverting side of this comparator is tied to a voltage divider which sets the voltage to $V^+ - V_{TRIP}$. The non inverting side is tied to the node between the drain of the FET and the sense resistor. If the overcurrent trip point is not exceeded, this node will always be pulled above $V^+ - V_{TRIP}$, and the output of the comparator will be high which feeds the control input of the MIC5014 (polarities should be reversed if the MIC5015 is used). One the overcurrent trip point has been reached, the comparator will go low, which shuts off the MIC5014. When the short is removed, feedback to the input pin insures that the MIC5014 will turn back on. This output can also be level shifted and sent to an I/O port of a microcontroller for intelligent control.

Current Shunts (R_S). Low valued resistors are necessary for use at R_S. Resistors are available with values ranging from 1 to 50mΩ, at 2 to 10W. If a precise overcurrent trip point is not necessary, then a nonprecision resistor or even a measured PCB trace can serve as R_S. The major cause of drift in resistor values with such resistors is temperature coefficient; the designer should be aware that a linear, 500 ppm/°C change will contribute as much as 10% shift in the overcurrent trip point. If this is not acceptable, a power resistor designed for current shunt service (drifts less than 100 ppm/°C), or a Kelvin-sensed resistor may be used.†

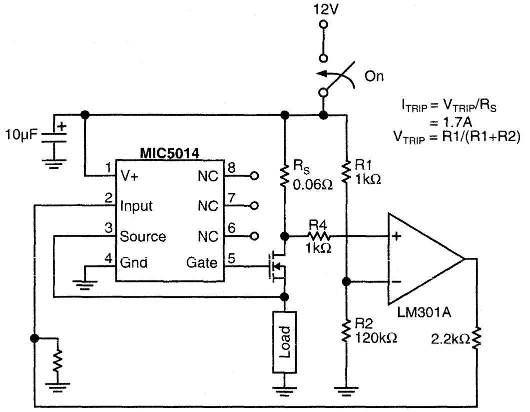


Figure 4. High Side Driver with Overcurrent Shutdown

High Side Driver With Delayed Current Sense (Figure 5) Delay of the overcurrent detection to accomodate high inrush loads such as incandescent or halogen lamps can be accomplished by adding an LM3905 timer as a one shot to provide an open collector pulldown for the comparator output such that the control input of the MIC5015 stays low for a preset amount of time without interference from the current sense circuitry. Note that an MIC5015 must be used in this application (figure 5), as an inverting control input is necessary. The delay time is set by the RC time constant of the external components on pins 3 and 4 of the timer; in this case, 6ms was chosen.

An LM3905 timer was used instead of a 555 as it provides a clean transition, and is almost impossible to make oscillate. Good bypassing and noise immunity is essential in this circuit to prevent spurious op amp oscillations.

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† Suppliers of Precision Power Resistors:
Dale Electronics, Inc., 2064 12th Ave., Columbus, NE 68601. (402) 565-3131
International Resistive Co., P.O. Box 1860, Boone,NC 28607-1860. (704) 264-8861
Isotek Corp., 566 Wilbur Ave. Swansea, MA 02777. (508) 673-2900
Kelvin, 14724 Ventura Blvd., Ste. 1003, Sherman Oaks, CA 91403-3501. (818) 990-1192
RCD Components, Inc., 520 E. Industrial Pk. Dr., Manchester, NH 03103. (603) 669-0054
Ultronix, Inc., P.O. Box 1090, Grand Junction, CO 81502 (303) 242-0810

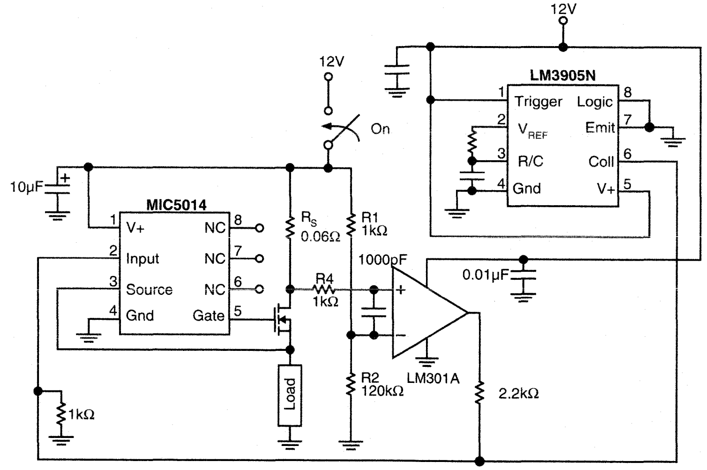


Figure 5. High Side Driver with Delayed Overcurrent Shutdown

Typical Applications

Variable Supply Low Side Driver for Motor Speed Control (Figure 6) The internal regulation in the MIC5014/15 allows a steady gate enhancement to be supplied while the MIC5014/15 supply varies from 5V to 30V, without damaging the internal gate to source zener clamp. This allows the speed of the DC motor shown to be varied by varying the supply voltage.

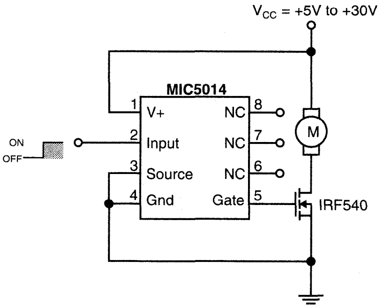


Figure 6: DC Motor Speed Control/Driver

Solenoid Valve Driver (Figure 7) High power solenoid valves are used in many industrial applications requiring the timed dispensing of chemicals or gases. When the solenoid is activated, the valve opens (or closes), releasing (or stopping) fluid flow. A solenoid valve, like all inductive loads, has a considerable "kickback" voltage when turned off, as current cannot change instantaneously through an inductor. In most applications, it is acceptable to allow this voltage to momentarily turn the MOSFET back on as a way of dissipating the inductor's current. However, if this occurs when driving a solenoid valve with a fast switching speed, chemicals or gases may be inadvertantly be dispensed at the wrong time with possibly disasterous consequences. Also, too large of a kickback voltage (as is found in larger solenoids) can damage the MIC5014 or the power FET by forcing the Source node below ground (the MIC5014 can be driven up to 20V below ground before this happens). A catch diode has been included in this design to provide an alternate route for the inductive kickback current to flow. The 5kΩ resistor in series with this diode has been included to set the recovery time of the solenoid valve.

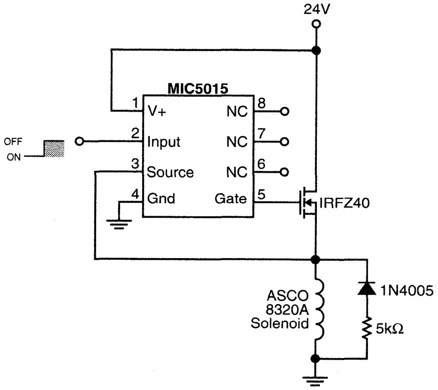


Figure 7: Solenoid Valve Driver

Incandescent/Halogen Lamp Driver (Figure 8) The combination of an MIC5014/5015 and a power FET makes an effective driver for a standard incandescent or halogen lamp load. Such loads often have high inrush currents, as the resistance of a cold filament is less than one-tenth as much as when it is hot. Power MOSFETs are well suited to this application as they have wider safe operating areas than do power bipolar transistors. It is important to check the SOA curve on the data sheet of the power FET to be used against the estimated or measured inrush current of the lamp in question prior to prototyping to prevent "explosive" results.

If overcurrent sense is to be used, first measure the duration of the inrush, then use the topology of Figure 5 with the RC of the timer chosen to accomodate the duration with suitable guardbanding.

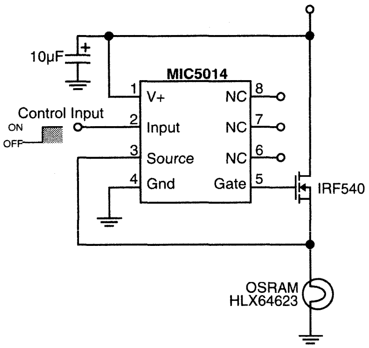


Figure 8. Halogen Lamp Driver

Relay Driver (Figure 9) Some power relay applications require the use of a separate switch or drive control, such as in the case of microprocessor control of banks of relays where a logic level control signal is used, or for drive of relays with high power requirements. The combination of an MIC5014/5015 and a power FET also provides an elegant solution to power relay drive.

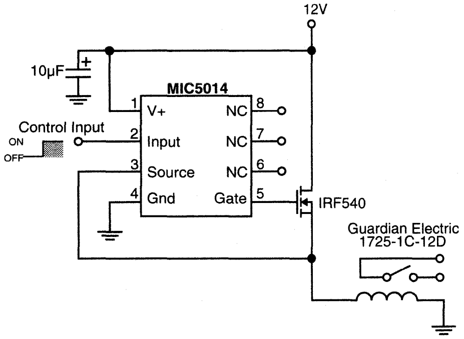


Figure 9: Relay Driver

Motor Driver With Stall Shutdown (Figure 10) Tachometer feedback can be used to shut down a motor driver circuit when a stall condition occurs. The control switch is a 3-way type; the "START" position is momentary and forces the driver ON. When released, the switch returns to the "RUN" position, and the tachometer's output is used to hold the MIC5014 input ON. If the motor slows down, the tach output is reduced, and the MIC5014 switches OFF. Resistor "R" sets the shutdown threshold.

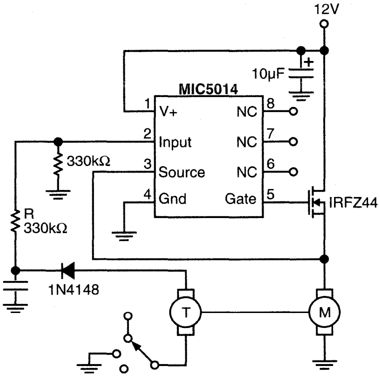


Figure 10. Motor Stall Shutdowm

Simple DC-DC Converter (Figure 11) The simplest application for the MIC5014 is as a basic one-chip DC-DC converter. As the output (Gate) pin has a relatively high impedance, the output voltage shown will vary significantly with applied load.

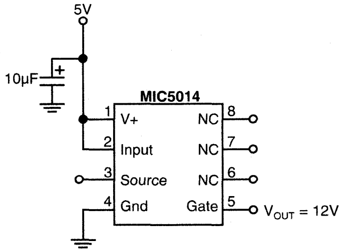


Figure 11. DC - DC Converter

High Side Driver With Load Protection (Figure 12) Although the MIC5014/15 devices are reverse battery protected, the load and power FET are not, in a typical high side configuration. In the event of a reverse battery condition, the internal body diode of the power FET will be forward biased. This allows the reversed supply access to the load. The addition of a Schottky diode between the supply and the FET eliminates this problem. The MBR2035CT was chosen as it can withstand 20A continuous and 150A peak, and should survive the rigors of an automotive environment. The two diodes are paralleled to reduce switch loss (forward voltage drop).

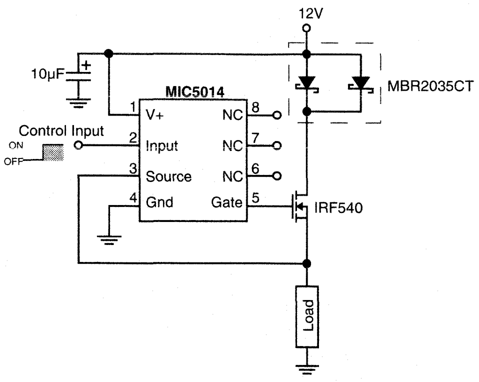


Figure 12: High Side Driver WIth Load Protection

Push-Pull Driver With No Cross-Conduction (Figure 13) As the turn-off time of the MIC5014/15 devices is much faster than the turn-on time, a simple push-pull driver with no cross conduction can be made using one MIC5014 and one MIC5015. The same control signal is applied to both inputs; the MIC5014 turns on with the positive signal, and the MIC5015 turns on when it swings low.

This scheme works with no additional components as the relative time difference between the rise and fall times of the MIC5014 is large. However, this does mean that there is considerable deadtime (time when neither driver is turned on). If this circuit is used to drive an inductive load, catch diodes must be used on each half to provide an alternate path for the kickback current that will flow during this deadtime.

This circuit is also a simple half H-bridge which can be driven with a PWM signal on the input for SMPS or motor drive applications in which high switching frequencies are not desired.

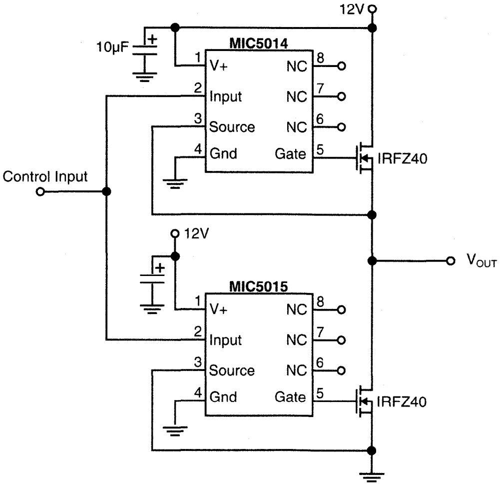


Figure 13: Push-Pull Driver

MIC5016/5017

Low-Cost Dual High- or Low-Side MOSFET Driver

General Description

MIC5016 and MIC5017 dual MOSFET drivers are designed for gate control of N-channel, enhancement-mode, power MOSFETs used as high-side or low-side switches. The MIC5016/7 can sustain an on-state output indefinitely.

The MIC5016/7 operates from a 2.75V to 30V supply. In high-side configurations, the driver can control MOSFETs that switch loads of up to 30V. In low-side configurations, with separate supplies, the maximum switched voltage is limited only by the MOSFET.

The MIC5016/7 has two TTL compatible control inputs. The MIC5016 is noninverting while the MIC5017 is inverting.

The MIC5016/7 features internal charge pumps that can sustain gate voltages greater than the available supply voltage. The driver is capable of turning on logic-level MOSFETs from a 2.75V supply or standard MOSFETs from a 5V supply. Gate-to-source output voltages are internally limited to approximately 15V.

The MIC5016/7 is protected against automotive load dump, reversed battery, and inductive load spikes of –20V. The driver's overvoltage shutdown feature turns off the external MOSFETs at approximately 35V to protect the load against power supply excursions.

The MIC5016 is an improved pin-for-pin compatible replacement in many MIC5012 applications.

The MIC5016/7 is available in plastic 14-pin DIP and 16-pin SOIC pacakges.

Typical Application

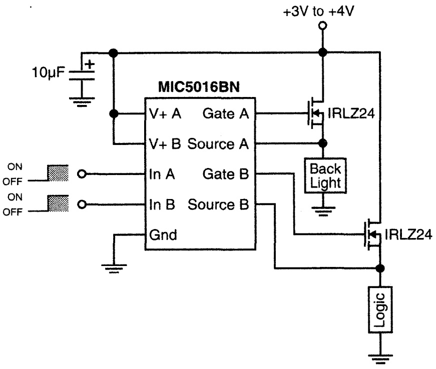


Figure 1: 3-Volt "Sleep-Mode" Switches with Logic-Level MOSFETs

Features

- 2.75V to 30V operation
- 100µA maximum supply current (5V supply)
- 15µA typical off-state current
- Internal charge pump
- TTL compatible input
- Withstands 60V transient (load dump)
- Reverse battery protected to –20V
- Inductive spike protected to –20V
- Overvoltage shutdown at 35V
- Internal 15V gate protection
- Minimum external parts
- Operates in high-side or low-side configurations
- 1µA control input pull-off
- Inverting and noninverting versions

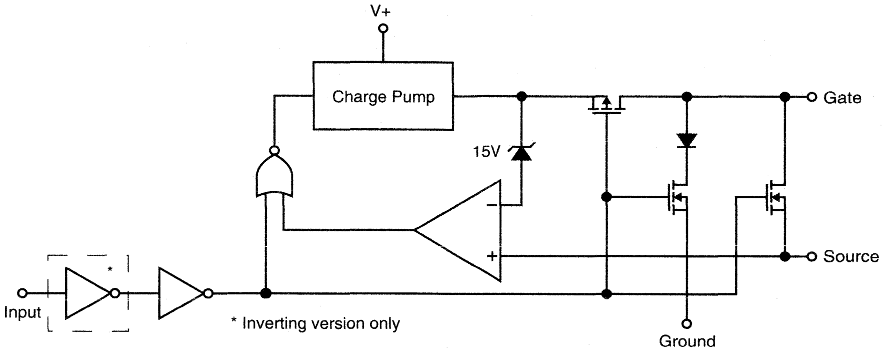
Applications

- Automotive electrical load control
- Battery-powered computer power management
- Lamp control
- Heater control
- Motor control
- Power bus switching

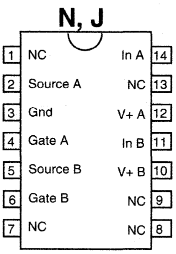
Ordering Information

Part Number	Temperature Range	Package
Noninverting		
MIC5016BWM	–40°C to +85°C	16-pin SOIC
MIC5016BN	–40°C to +85°C	14-pin Plastic DIP
Inverting		
MIC5017BWM	–40°C to +85°C	16-pin SOIC
MIC5017BN	–40°C to +85°C	14-pin Plastic DIP

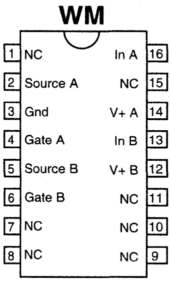
Block Diagram 1 of 2 Drivers per Package



Connection Diagram



14-pin DIP



16-pin SOIC

Pin Description

Pin Number N, J Package	Pin Number WM Package	Pin Name	Pin Function
12	14	V^+A	Supply Pin A. Must be decoupled to isolate large transients caused by power MOSFET drain. 10μF is recommended close to pins 12 and/or 10 and ground. V^+A and V^+B may be connected to separate supplies.
10	12	V^+B	Supply Pin B. See V^+A.
14	16	Input A	Turns on power MOSFET A when asserted. Requires approximately 1μA to switch.
11	13	Input B	Turns on power MOSFET B. See Input A.
4	4	Gate A	Drives and clamps the gate of power MOSFET A
6	6	Gate B	Drives and clamps the gate of power MOSFET B
2	2	Source A	Connects the source lead of MOSFET A
5	5	Source B	Connects the source lead of MOSFET B
3	3	Gnd	Ground

Absolute Maximum Ratings (Notes 1,2)

Supply Voltage	−20V to 60V
Input Voltage	−20V to V^+
Source Voltage	−20V to V^+
Source Current	50mA
Gate Voltage	−20V to 50V
Junction Temperature	150°C

Operating Ratings (Notes 1,2)

θ_{JA} (Plastic DIP)	140°C/W
θ_{JA} (SOIC)	110°C/W
Ambient Temperature: B version	−40°C to +85°C
Ambient Temperature: A version	+55°C to +125°C
Storage Temperature	−65°C to +150°C
Lead Temperature (max soldering time: 10 seconds)	260°C
Supply Voltage (V^+)	2.75V to 30V

Electrical Characteristics (Note 3) $T_A = -55°C$ to +125°C unless otherwise specified

Parameter	Conditions		Min	Typ	Max	Units
Supply Current (Each Driver Channel)	$V^+ = 30V$	V_{IN} De-Asserted (Note 5)		10	25	µA
		V_{IN} Asserted (Note 5)		5.0	10	mA
	$V^+ = 5V$	V_{IN} De-Asserted		10	25	µA
		V_{IN} Asserted		60	100	
	$V^+ = 3V$	V_{IN} De-Asserted		10	25	µA
		V_{IN} Asserted		25	35	
Logic Input Voltage Threshold V_{IN}	$3.0V \le V^+ \le 30V$	Digital Low Level			0.8	V
	$T_A = 25°C$	Digital High Level	2.0			
Logic Input Current MIC5016 (non-inverting)	$3.0V \le V^+ \le 30V$	V_{IN} Low	−2.0	0		µA
		V_{IN} High		1.0	2.0	
Logic Input Current MIC5017 (inverting)	$3.0V \le V^+ \le 30V$	V_{IN} Low	−2.0	−1.0		µA
		V_{IN} High		−1.0	2.0	
Input Capacitance				5.0		pF
Gate Enhancement $V_{GATE} - V_{SUPPLY}$	$3.0V \le V^+ \le 30V$	V_{IN} Asserted	4.0		17	V
Zener Clamp $V_{GATE} - V_{SOURCE}$	$8.0V \le V^+ \le 30V$	V_{IN} Asserted	13	15	17	V
Gate Turn-on Time, t_{ON} (Note 4)	$V^+ = 4.5V$ $C_L = 1000pF$	V_{IN} switched on, measure time for V_{GATE} to reach $V^+ + 4V$		2.5	8.0	ms
	$V^+ = 12V$ $C_L = 1000pF$	As above, measure time for V_{GATE} to reach $V^+ + 4V$		90	140	µs
Gate Turn-off Time, t_{OFF} (Note 4)	$V^+ = 4.5V$ $C_L = 1000pF$	V_{IN} switched off, measure time for V_{GATE} to reach 1V		6.0	30	µs
	$V^+ = 12V$ $C_L = 1000pF$	As above, measure time for V_{GATE} to reach 1V		6.0	30	µs
Overvoltage Shutdown Threshold			35	37	41	V

Note 1: **Absolute Maximum Ratings** indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its specified **Operating Ratings**.

Note 2: The MIC5016/5017 is ESD sensitive.

Note 3: Minimum and maximum **Electrical Characteristics** are 100% tested at $T_A = 25°C$ and $T_A = 85°C$, and 100% guaranteed over the entire operating temperature range. Typicals are characterized at 25°C and represent the most likely parametric norm.

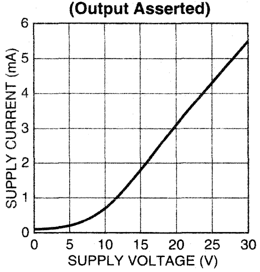
Note 4: Test conditions reflect worst case high-side driver performance. Low-side and bootstrapped topologies are significantly faster—see Applications Information. Maximum value of switching time seen at 125°C, unit operated at room temperature will reflect the typical value shown.

Note 5: "Asserted" refers to a logic high on the MIC5016 and a logic low on the MIC5017.

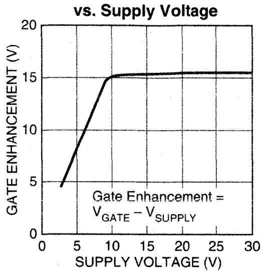
Typical Characteristics

All data measured using FET probe to minimize resistive loading

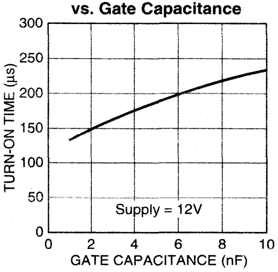
Supply Current per Channel (Output Asserted)



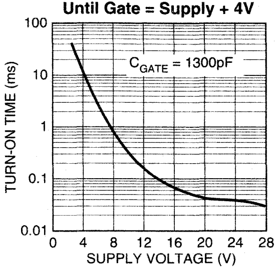
Gate Enhancement vs. Supply Voltage



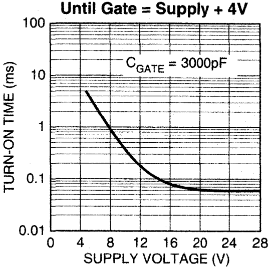
High-Side Turn-On Time vs. Gate Capacitance



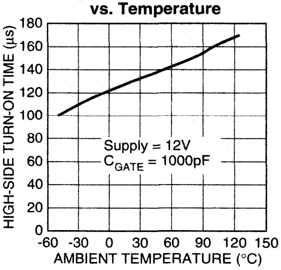
High-Side Turn-On Time Until Gate = Supply + 4V



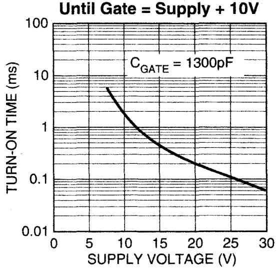
High-Side Turn-On Time Until Gate = Supply + 4V



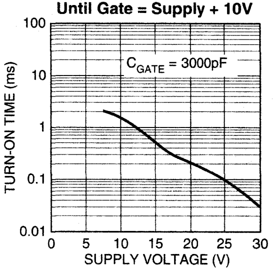
High-Side Turn-On Time vs. Temperature



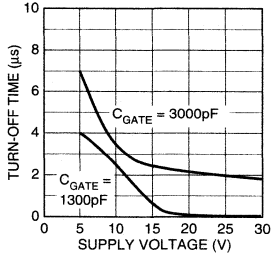
High-Side Turn-On Time Until Gate = Supply + 10V



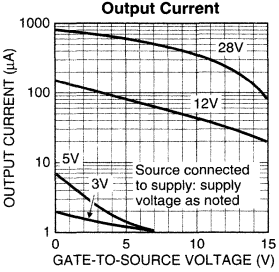
High-Side Turn-On Time Until Gate = Supply + 10V



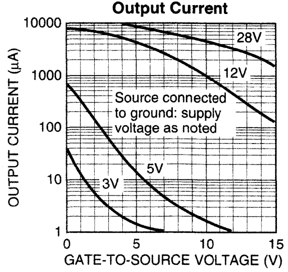
High-Side Turn-Off Time Until Gate = 1V



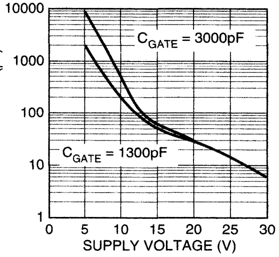
Charge-Pump Output Current



Charge-Pump Output Current



Low-Side Turn-On Time Until Gate = 4V



Applications Information

Functional Description

The MIC5016 is functionally compatible with the MIC5012, and the MIC5017 is an inverting configuration of the MIC5016.

The internal functions of these devices are controlled via a logic block (refer to block diagram) connected to the control input (pin 14). When the input is off (low for the MIC5016, and high for the MIC5017), all functions are turned off, and the gate of the external power MOSFET is held low via two N-channel switches. This results in a very low standby current; 15µA typical, which is necessary to power an internal bandgap. When the input is driven to the "ON" state, the N-channel switches are turned off, the charge pump is turned on, and the P-channel switch between the charge pump and the gate turns on, allowing the gate of the power FET to be charged. The op amp and internal zener form an active regulator which shuts off the charge pump when the gate voltage is high enough. This is a feature not found on the MIC5012.

The charge pump incorporates a 100kHz oscillator and on-chip pump capacitors capable of charging a 1,000pF load in 90µs typical. In addition to providing active regulation, the internal 15V zener is included to prevent exceeding the V_{GS} rating of the power MOSFET at high supply voltages.

The MIC5016/17 devices have been improved for greater ruggedness and durability. All pins can withstand being pulled 20 V below ground without sustaining damage, and the supply pin can withstand an overvoltage transient of 60V for 1s. An overvoltage shutdown has also been included, which turns off the device when the supply reaches 35V.

Construction Hints

High current pulse circuits demand equipment and assembly techniques that are more stringent than normal, low current lab practices. The following are the sources of pitfalls most often encountered during prototyping: *Supplies*: Many bench power supplies have poor transient response. Circuits that are being pulse tested, or those that operate by pulse-width modulation will produce strange results when used with a supply that has poor ripple rejection, or a peaked transient response. Always monitor the power supply voltage that appears at the drain of a high side driver (or the supply side of the load for a low side driver) with an oscilloscope. It is not uncommon to find bench power supplies in the 1kW class that overshoot or undershoot by as much as 50% when pulse loaded. Not only will the load current and voltage measurements be affected, but it is possible to overstress various components, especially electrolytic capacitors, with possibly catastrophic results. A 10µF supply bypass capacitor *at the chip is* recommended. *Residual resistances*: Resistances in circuit connections may also cause confusing results. For example, a circuit may employ a 50mΩ power MOSFET for low voltage drop, but unless careful construction techniques are used, one could easily add 50 to 100mΩ resistance. Do not use a socket for the MOSFET. If the MOSFET is a TO-220 type package, make high current connections to the drain tab.Wiring losses have a profound effect on high-current circuits. A floating milliohmeter can identify connections that are contributing excess drop under load.

Low Voltage Testing As the MIC5016/5017 have relatively high output impedances, a normal oscilloscope probe will load the device. This is especially pronounced at low voltage operation. It is recommended that a FET probe or unity gain buffer be used for all testing.

Circuit Topologies

The MIC5016 and MIC5017 are well suited for use with standard power MOSFETs in both low and high side driver configurations. In addition, the lowered supply voltage requirements of these devices make them ideal for use with logic level FETs in high side applications with a supply voltage of 3V to 4V. (If higher supply voltages [>4V] are used with logic level FETs, an external zener clamp must be supplied to ensure that the maximum V_{GS} rating of the logic FET [10V] is not exceeded). In addition, a standard IGBT can be driven using these devices.

Choice of one topology over another is usually based on speed vs. safety. The fastest topology is the low side driver, however, it is not usually considered as safe as high side driving as it is easier to accidentally short a load to ground than to V_{CC}. The slowest, but safest topology is the high side driver; with speed being inversely proportional to supply voltage. It is the preferred topology for most military and automotive applications. Speed can be improved considerably by bootstrapping the supply.

All topologies implemented using these devices are well suited to driving inductive loads, as either the gate or the source pin can be pulled 20V below ground with no effect. External clamp diodes are unnecessary, except for the case in which a transient may exceed the overvoltage trip point.

High Side Driver (Figure 1) The high side topology shown here is an implementation of a "sleep-mode" switch for a laptop or notebook computer which uses a logic level FET. A standard power FET can easily be substituted when supply voltages above 4V are required.

Low Side Driver (Figure 2) A key advantage of this topology, as previously mentioned, is speed. The MOSFET gate is

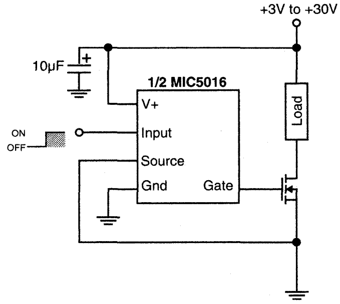


Figure 2. Low Side Driver

driven to near supply immediately when the MIC5016/17 is turned on. Typical circuits reach full enhancement in 50µs or less with a 15V supply.

Bootstrapped High Side Driver (Figure 3) The turn-on time of a high side driver can be improved to faster than 40µs by bootstrapping the supply with the MOSFET source. The Schottky barrier diode prevents the supply pin from dropping more than 200mV below the drain supply, and improves turn-on time. Since the supply current in the "OFF" state is only a small leakage, the 100nF bypass capacitor tends to remain charged for several seconds after the MIC5016/17 is turned off. Faster switching speeds can be obtained at the expense of supply voltage (the overvoltage shutdown will turn the part off when the bootstrapping action pulls the supply pin above 35V) by using a larger capacitor at the junction of the two 1N4001 diodes. In a PWM application (this circuit can be used for either PWM'ed or continuously energized loads), the chip supply is sustained at a higher potential than the system supply, which improves switching time.

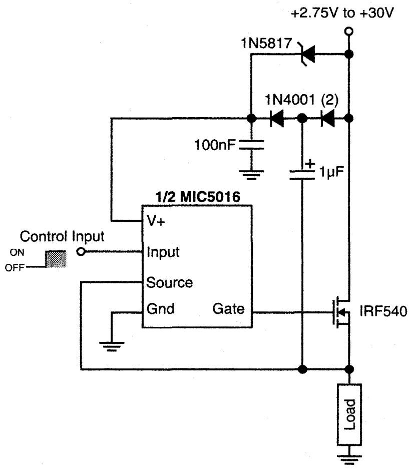


Figure 3. Bootstrapped High-Side Driver

High Side Driver With Current Sense (Figure 4) Although no current sense function is included on the MIC5016/17 devices, a simple current sense function can be realized via the addition of one more active component; an LM301A op amp used as a comparator. The positive rail of the op amp is tied to V^+, and the negative rail is tied to ground. This op amp was chosen as it can withstand having input transients that swing below the negative rail, and has common mode range almost to the positive rail.

The inverting side of this comparator is tied to a voltage divider which sets the voltage to $V^+ - V_{TRIP}$. The noninverting side is tied to the node between the drain of the FET and the sense resistor. If the overcurrent trip point is not exceeded, this node will always be above $V^+ - V_{TRIP}$, and the output of the comparator will be high which feeds the control input of the MIC5016 (polarities should be reversed if the MIC5017 is used). Once the overcurrent trip point has been reached, the comparator will go low, which shuts off the MIC5016. When the short is removed, feedback to the input pin insures that the MIC5016 will turn back on. This output can also be level shifted and sent to an I/O port of a microcontroller for intelligent control.

Current Shunts (R_S). Low valued resistors are necessary for use at R_S. Resistors are available with values ranging from 1 to 50mΩ, at 2 to10W. If a precise overcurrent trip point is not necessary, then a nonprecision resistor or even a measured PCB trace can serve as R_S. The major cause of drift in resistor values with such resistors is temperature coefficient; the designer should be aware that a linear, 500ppm/°C change will contribute as much as 10% shift in the overcurrent trip point.

If this is not acceptable, a power resistor designed for current shunt service (drifts less than 100ppm/°C), or a Kelvin-sensed resistor may be used.†

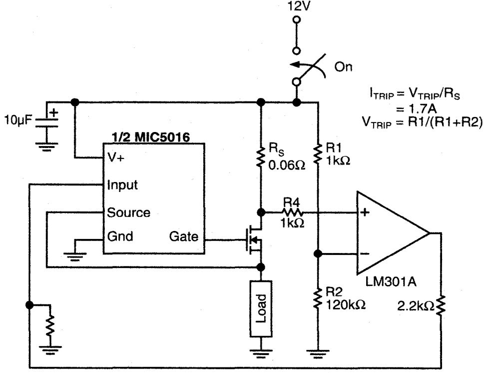


Figure 4. High Side Driver with Overcurrent Shutdown

High Side Driver With Delayed Current Sense (Figure 5) Delay of the overcurrent detection to accomodate high inrush loads such as incandescent or halogen lamps can be accomplished by adding an LM3905 timer as a one shot to provide an open collector pulldown for the comparator output such that the control input of the MIC5017 stays low for a preset amount of time without interference from the current sense circuitry. Note that an MIC5017 must be used in this application (figure 5), as an inverting control input is necessary. The delay time is set by the RC time constant of the external components on pins 3 and 4 of the timer; in this case, 6ms was chosen.

An LM3905 timer was used instead of a 555 as it provides a clean transition, and is almost impossible to make oscillate. Good bypassing and noise immunity is essential in this circuit to prevent spurious op amp oscillations.

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† Suppliers of Precision Power Resistors:
Dale Electronics, Inc., 2064 12th Ave., Columbus, NE 68601. (402) 565-3131
International Resistive Co., P.O. Box 1860, Boone,NC 28607-1860. (704) 264-8861
Isotek Corp., 566 Wilbur Ave. Swansea, MA 02777. (508) 673-2900
Kelvin, 14724 Ventura Blvd., Ste. 1003, Sherman Oaks, CA 91403-3501. (818) 990-1192
RCD Components, Inc., 520 E. Industrial Pk. Dr., Manchester, NH 03103. (603) 669-0054
Ultronix, Inc., P.O. Box 1090, Grand Junction, CO 81502 (303) 242-0810

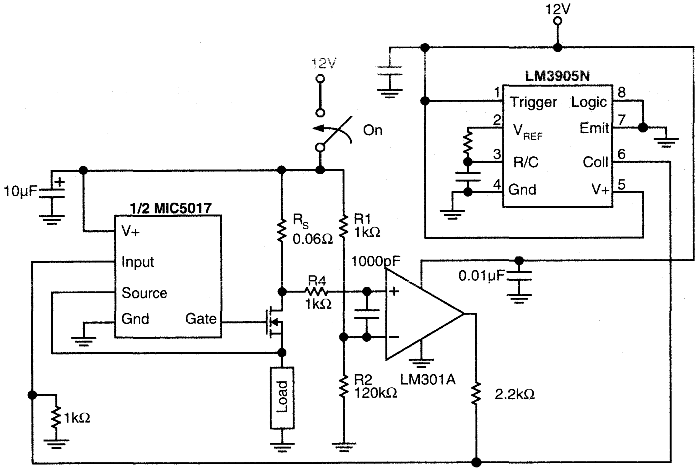


Figure 5. High Side Driver with Delayed Overcurrent Shutdown

Typical Applications

Variable Supply Low Side Driver for Motor Speed Control

(Figure 6) The internal regulation in the MIC5016/17 allows a steady gate enhancement to be supplied while the MIC5016/17 supply varies from 5V to 30V, without damaging the internal gate to source zener clamp. This allows the speed of the DC motor shown to be varied by varying the supply voltage.

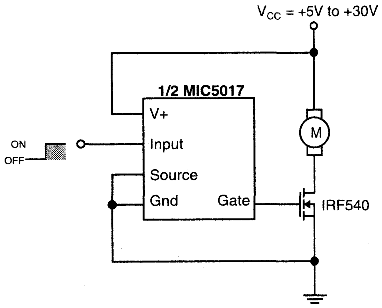


Figure 6: DC Motor Speed Control/Driver

Solenoid Valve Driver (Figure 7) High power solenoid valves are used in many industrial applications requiring the timed dispensing of chemicals or gases. When the solenoid is activated, the valve opens (or closes), releasing (or stopping) fluid flow. A solenoid valve, like all inductive loads, has a considerable "kickback" voltage when turned off, as current cannot change instantaneously through an inductor. In most applications, it is acceptable to allow this voltage to momentarily turn the MOSFET back on as a way of dissipating the inductor's current. However, if this occurs when driving a solenoid valve with a fast switching speed, chemicals or gases may inadvertantly be dispensed at the wrong time with possibly disasterous consequences. Also, too large of a kickback voltage (as is found in larger solenoids) can damage the MIC5016 or the power FET by forcing the Source node below ground (the MIC5016 can be driven up to 20V below ground before this happens). A catch diode has been included in this design to provide an alternate route for the inductive kickback current to flow. The 5kΩ resistor in series with this diode has been included to set the recovery time of the solenoid valve.

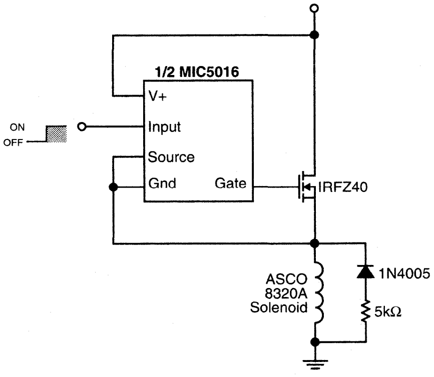


Figure 7: Solenoid Valve Driver

Incandescent/Halogen Lamp Driver (Figure 8) The combination of an MIC5016/5017 and a power FET makes an effective driver for a standard incandescent or halogen lamp load. Such loads often have high inrush currents, as the resistance of a cold filament is less than one-tenth as much as when it is hot. Power MOSFETs are well suited to this application as they have wider safe operating areas than do power bipolar transistors. It is important to check the SOA curve on the data sheet of the power FET to be used against the estimated or measured inrush current of the lamp in question prior to prototyping to prevent "explosive" results.

If overcurrent sense is to be used, first measure the duration of the inrush, then use the topology of Figure 5 with the RC of the timer chosen to accomodate the duration with suitable guardbanding.

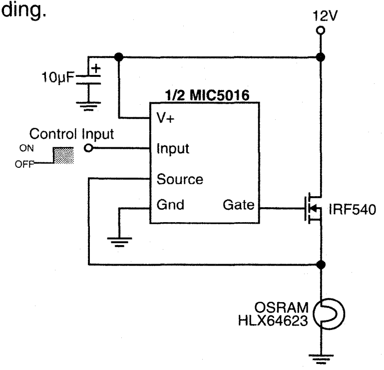


Figure 8: Halogen Lamp Driver

Relay Driver (Figure 9) Some power relay applications require the use of a separate switch or drive control, such as in the case of microprocessor control of banks of relays where a logic level control signal is used, or for drive of relays with high power requirements. The combination of an MIC5016/5017 and a power FET also provides an elegant solution to power relay drive.

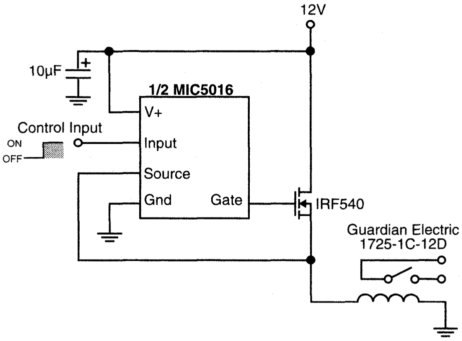


Figure 9: Relay Driver

Motor Driver With Stall Shutdown (Figure 10) Tachometer feedback can be used to shut down a motor driver circuit when a stall condition occurs. The control switch is a 3-way type; the "START" position is momentary and forces the driver ON. When released, the switch returns to the "RUN" position, and the tachometer's output is used to hold the MIC5016 input ON. If the motor slows down, the tach output is reduced, and the MIC5016 switches OFF. Resistor "R" sets the shutdown threshold.

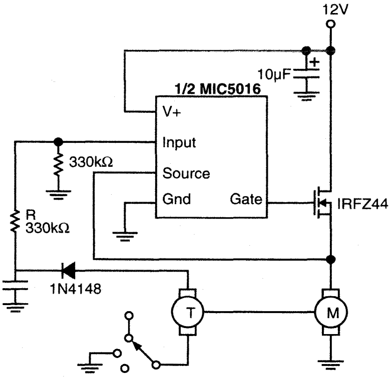


Figure 10. Motor Stall Shutdown

Simple DC-DC Converter (Figure 11) The simplest application for the MIC5016 is as a basic one-chip DC-DC converter. As the output (Gate) pin has a relatively high impedance, the output voltage shown will vary significantly with applied load.

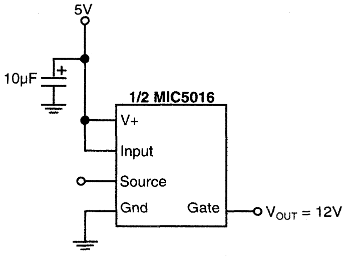


Figure 11. DC - DC Converter

High Side Driver With Load Protection (Figure 12) Although the MIC5016/17 devices are reverse battery protected, the load and power FET are not in a typical high side configuration. In the event of a reverse battery condition, the internal body diode of the power FET will be forward biased. This allows the reversed supply to drive the load.

An MBR2035CT dual Schottky diode was used to eliminate this problem. This particular diode can handle 20A continuous current and 150A peak current; therefore it should survive the rigors of an automotive environment. The diodes are paralleled to reduce the switch loss (forward voltage drop).

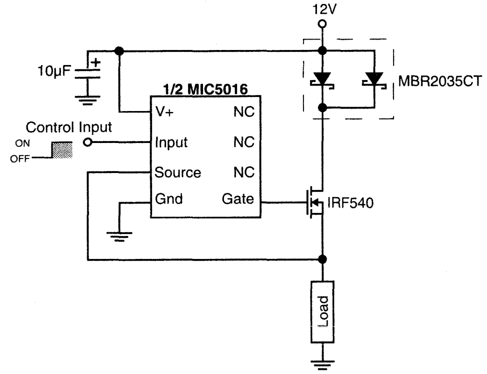


Figure 12: High Side Driver With Load Protection

Push-Pull Driver With No Cross-Conduction (Figure 13) As the turn-off time of the MIC5016/17 devices is much faster than the turn-on time, a simple dual push-pull driver with no cross conduction can be made using one MIC5016 and one MIC5017. The same control signal is applied to both inputs; the MIC5016 turns on with the positive signal, and the MIC5017 turns on when it swings low.

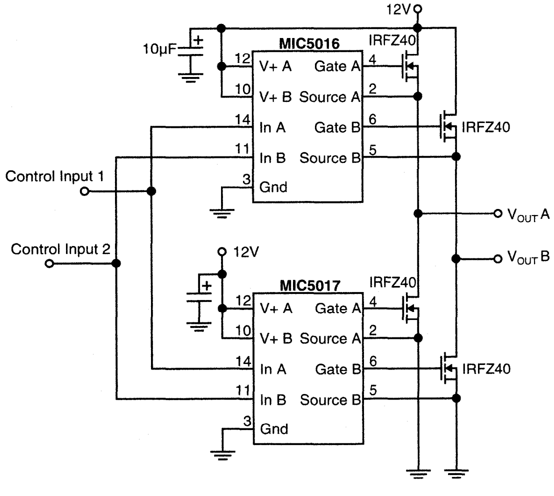


Figure 13: Push-Pull Driver

This scheme works with no additional components as the relative time difference between the rise and fall times of the MIC5014 is large. However, this does mean that there is considerable deadtime (time when neither driver is turned on). If this circuit is used to drive an inductive load, catch diodes must be used on each half to provide an alternate path for the kickback current that will flow during this deadtime.

This circuit is also a simple H-bridge which can be driven with a PWM signal on the input for SMPS or motor drive applications in which high switching frequencies are not desired.

Synchronous Rectifier (Figure 14) In applications where efficiency in terms of low forward voltage drops and low diode reverse-recovery losses is critical, power FETs are used to achieve rectification instead of a conventional diode bridge. Here, the power FETs are used in the third quadrant of the IV characteristic curve (FETs are installed essentially "backwards"). The two FETs are connected such that the top FET turns on with the positive going AC cycle, and turns off when it swings negative. The bottom FET operates opposite to the top FET.

In the first quadrant of operation, the limitation of the device is determined by breakdown voltage. Here, we are limited by the turn-on of a parasitic p-n body drain diode. If it is allowed to conduct, its reverse recovery time will crowbar the other power FET and possibly destroy it. The way to prevent this is to keep the IR drop across the device below the cut-in voltage of this diode; this is accomplished here by using a fast comparator to sense this voltage and feed the appropriate signal to the control inputs of the MIC5016 device. Obviously, it is very important to use a comparator with a fast slew rate such as the LM393, and fast recovery diodes. 3mV of positive feedback is used on the comparator to prevent oscillations.

At 3A, with an R_{DS}(ON) of 0.077Ω, our forward voltage drop per FET is ~ 0.2 V as opposed to the 0.7 to 0.8 V drop that a normal diode would have. Even greater savings can be had by using FETs with lower R_{DS}(ON)s, but care must be taken that the peak currents and voltages do not exceed the SOA of the chosen FET.

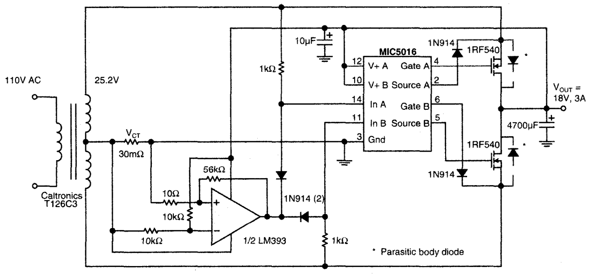


Figure 14: High Efficiency 60 Hz Synchronous Rectifier

MIC5018

IttyBitty™ High-Side MOSFET Driver

Preliminary Information

General Description

The MIC5018 IttyBitty™ high-side MOSFET driver is designed to switch an N-channel enhancement-type MOSFET from a TTL compatible control signal in high- or low-side switch applications. This driver features the tiny 4-lead SOT-143 package.

The MIC5018 is powered from a +2.7V to +9V supply and features extremely low off-state supply current. An internal charge pump drives the gate output higher than the driver supply voltage and can sustain the gate voltage indefinitely. An internal zener diode limits the gate-to-source voltage to a safe level for standard N-channel MOSFETs.

In high-side configurations, the source voltage of the MOSFET approaches the supply voltage when switched on. To keep the MOSFET turned on, the MIC5018's output drives the MOSFET gate voltage higher than the supply voltage. In a typical high-side configuration, the driver is powered from the load supply voltage. Under some conditions, the MIC5018 and MOSFET can switch a load voltage that is slightly higher than the driver supply voltage.

In a low-side configuration, the driver can control a MOSFET that switches any voltage up to the rating of the MOSFET. The gate output voltage is higher than the typical 3.3V or 5V logic supply and can fully enhance a standard MOSFET.

The MIC5018 is available in the SOT-143 package and is rated for –40°C to +85°C ambient temperature range.

Features

- +2.7V to +9V operation
- 150µA typical supply current at 5V supply
- ≤ 1µA typical standby (off) current
- Charge pump for high-side low-voltage applications
- Internal zener diode gate-to-ground MOSFET protection
- Operates in low- and high-side configurations
- TTL compatible input
- ESD protected

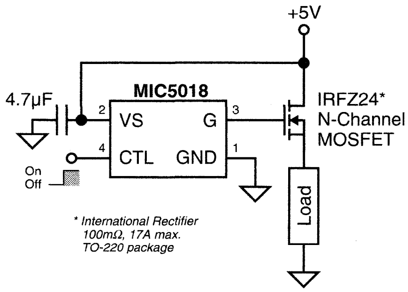
Applications

- Battery conservation
- Power bus switching
- Solenoid and motion control
- Lamp control

Ordering Information

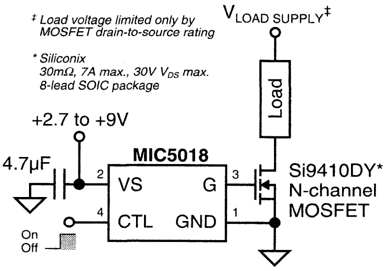
Part Number	Temp. Range	Package	Marking
MIC5018BM4	–40°C to +85°C	SOT-143	H10

Typical Applications



* International Rectifier
100mΩ, 17A max.
TO-220 package

Low-Voltage High-Side Power Switch

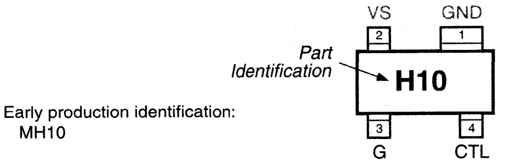


‡ Load voltage limited only by MOSFET drain-to-source rating

* Siliconix
30mΩ, 7A max., 30V V_{DS} max.
8-lead SOIC package

Low-Side Power Switch

Pin Configuration



SOT-143 (M4)

Pin Description

Pin Number	Pin Name	Pin Function
1	GND	Ground: Power return.
2	VS	Supply (Input): +2.7V to +9V supply.
3	G	Gate (Output): Gate connection to external MOSFET.
4	CTL	Control (Input): TTL compatible on/off control input. Logic high drives the gate output above the supply voltage. Logic low forces the gate output near ground.

Absolute Maximum Ratings

Supply Voltage (V_{SUPPLY}) .... +10V
Control Voltage (V_{CTL}) .... –0.6V to +16V
Gate Voltage (V_G) .... +16V
Ambient Temperature Range (T_A)............ –40°C to +85°C
Lead Temperature, Soldering 10sec. ....300°C
Package Thermal Resistance
SOT-143 θ_{JA} .... 220°C/W
SOT-143 θ_{JC} .... 130°C/W

Electrical Characteristics

Parameter	Condition (Note 1)		Min	Typ	Max	Units
Supply Current	V_{SUPPLY} = 3.3V	V_{CTL} = 0V V_{CTL} = 3.3V		0.01 70	1 140	µA µA
	V_{SUPPLY} = 5V	V_{CTL} = 0V V_{CTL} = 5V		0 150	1 300	µA µA
Control Input Voltage	$2.7V \le V_{SUPPLY} \le 9V$	V_{CTL} for logic 0 input	0		0.8	V
	$2.7V \le V_{SUPPLY} \le 5V$	V_{CTL} for logic 1 input	2.0		V_{SUPPLY}	V
	$5V \le V_{SUPPLY} \le 9V$	V_{CTL} for logic 1 input	2.4		V_{SUPPLY}	V
Control Input Current	$2.7V \le V_{SUPPLY} \le 9V$			0.01	1	µA
Control Input Capacitance		**Note 2**		5		pF
Zener Diode Output Clamp	V_{SUPPLY} = 9V		13	16	19	V
Gate Output Voltage	V_{SUPPLY} = 2.7V		6.3	7.1		V
	V_{SUPPLY} = 3.0V		7.1	8.2		V
	V_{SUPPLY} = 4.5V		11.4	13.4		V
Gate Output Current	V_{SUPPLY} = 5V	V_{OUT} = 10V, **Note 3**		9.5		µA
Gate Turn-On Time	V_{SUPPLY} = 4.5V	C_L = 1000pF, **Note 4** C_L = 3000pF, **Note 4**		0.75 2.1	1.5 4.2	ms ms
Gate Turn-Off Time	V_{SUPPLY} = 4.5V	C_L = 1000pF, **Note 5** C_L = 3000pF, **Note 5**		10 30	20 60	µs µs

General Note: Devices are ESD protected, however handling precautions are recommended.

Note 1: Typical values at T_A = 25°C. Minimum and maximum values indicate performance at $-40°C \ge T_A \ge +85°C$. Parts production tested at 25°C.

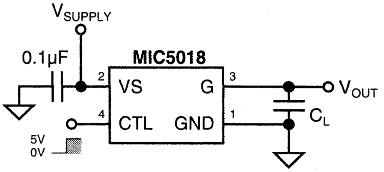
Note 2: Guaranteed by design.

Note 3: Resistive load selected for V_{OUT} = 10V.

Note 4: Turn-on time is the time required for gate voltage to rise to 4V greater than the supply voltage. This represents a typical MOSFET gate threshold voltage.

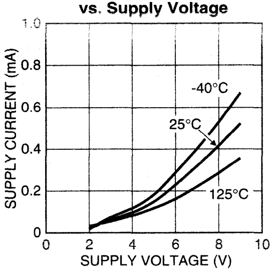
Note 5: Turn-off time is the time required for the gate voltage to fall to 4V above the supply voltage. This represents a typical MOSFET gate threshold voltage.

Test Circuit

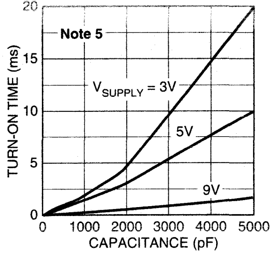


Typical Characteristics Note 4

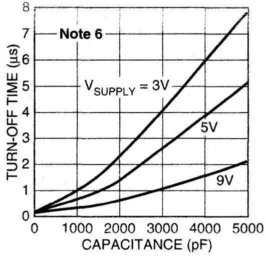
Supply Current vs. Supply Voltage



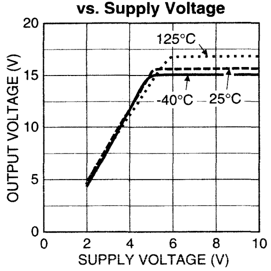
Full Turn-On Time vs. Load Capacitance



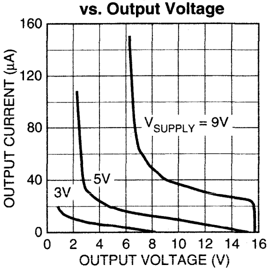
Full Turn-Off Time vs. Load Capacitance



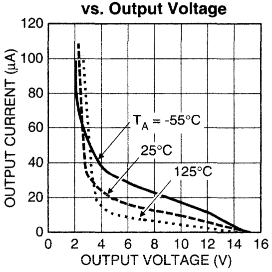
Gate Output Voltage vs. Supply Voltage



Gate Output Current vs. Output Voltage



Gate Output Current vs. Output Voltage

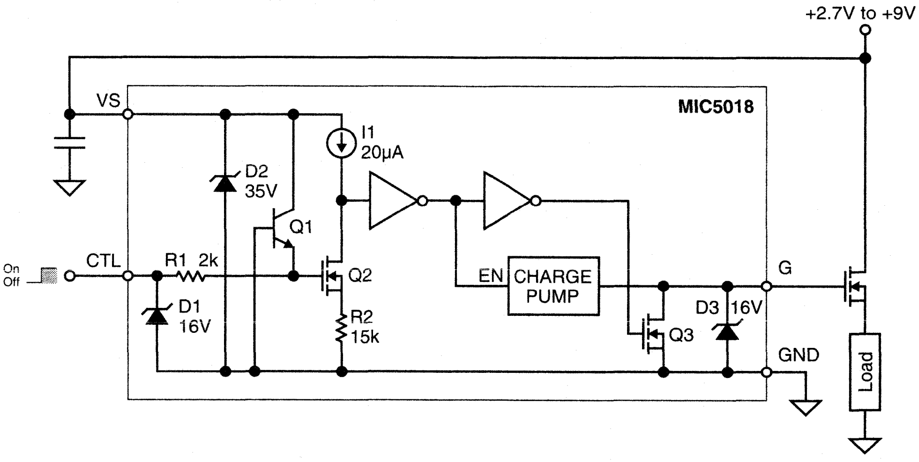


Note 4: T_A = 25°C, V_{SUPPLY} = 5V unless noted.

Note 5: Full turn-on time is the time between V_{CTL} rising to 2.5V and the V_G rising to 90% of its steady on-state value.

Note 6: Full turn-off time is the time between V_{CTL} falling to 0.5V and the V_G falling to 10% of its steady on-state value.

Functional Diagram



Functional Diagram with External Components
(High-Side Driver Configuration)

Functional Description

Refer to the functional diagram.

The MIC5018 is a noninverting device. Applying a logic high signal to CTL (control input) produces gate drive output. The G (gate) output is used to turn on an external N-channel MOSFET.

Supply

VS (supply) is rated for +2.7V to +9V. An external capacitor is recommended to decouple noise.

Control

CTL (control) is a TTL compatible input. CTL must be forced high or low by an external signal. A floating input may cause unpredictable operation.

A high input turns on Q2, which sinks the output of current source I1, making the input of the first inverter low. The inverter output becomes high enabling the charge pump.

Charge Pump

The charge pump is enabled when CTL is logic high. The charge pump consists of an oscillator and voltage quadrupler (4×). Output voltage is limited to 16V by a zener diode. The charge pump output voltage will be approximately:

$$V_G = 4 \times V_{SUPPLY} - 2.8V, \text{ but not exceeding } 16V.$$

The oscillator operates from approximately 70kHz to approximately 100kHz depending upon the supply voltage and temperature.

Gate Output

The charge pump output is connected directly to the G (gate) output. The charge pump is active only when CTL is high. When CTL is low, Q3 is turned on by the second inverter and discharges the gate of the external MOSFET to force it off.

If CTL is high, and the voltage applied to VS drops to zero, the gate output will be floating (unpredictable).

ESD Protection

D1 and D2 clamp positive and negative ESD voltages. R1 isolates the gate of Q2 from sudden changes on the CTL input. Q1 turns on if the emitter (CTL input) is forced below ground to provide additional input protection. Zener D3 also clamps ESD voltages for the gate (G) output.

Application Information

Supply Bypass

A capacitor from VS to GND is recommended to control switching and supply transients. Load current and supply lead length are some of the factors that affect capacitor size requirements.

A 4.7µF or 10µF aluminum electrolytic or tantalum capacitor is suitable for many applications.

The low ESR (equivalent series resistance) of tantalum capacitors makes them especially effective, but also makes them susceptible to uncontrolled inrush current from low impedance voltage sources (such as NiCd batteries or automatic test equipment). Avoid instantaneously applying voltage, capable of high peak current, directly to or near tantalum capacitors without additional current limiting. Normal power supply turn-on (slow rise time) or printed circuit trace resistance is usually adequate for normal product usage.

MOSFET Selection

The MIC5018 is designed to drive N-channel enhancement-type MOSFETs. The gate output (G) of the MIC5018 provides a voltage, referenced to ground, that is greater than the supply voltage. Refer to the “Typical Characteristics: Gate Output Voltage vs. Supply Voltage” graph.

The supply voltage and the MOSFET drain-to-source voltage drop determine the gate-to-source voltage.

$$V_{GS} = V_G - (V_{SUPPLY} - V_{DS})$$

where:

V_{GS} = gate-to-source voltage (enhancement)
V_G = gate voltage (from graph)
V_{SUPPLY} = supply voltage
V_{DS} = drain-to-source voltage (approx. 0V at low current, or when fully enhanced)

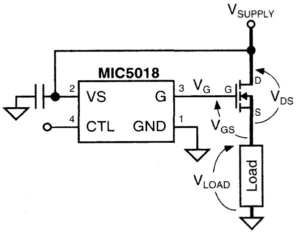


Figure 1. Voltages

The performance of the MOSFET is determined by the gate-to-source voltage. Choose the type of MOSFET according to the calculated gate-to-source voltage.

Standard MOSFET

Standard MOSFETs are fully enhanced with a gate-to-source voltage of about 10V. Their absolute maximum gate-to-source voltage is ±20V.

With a 5V supply, the MIC5018 produces a gate output of approximately 15V. Figure 2 shows how the remaining voltages conform. The actual drain-to-source voltage drop across an IRFZ24 is less than 0.1V with a 1A load and 10V enhancement. Higher current increases the drain-to-source voltage drop, increasing the gate-to-source voltage.

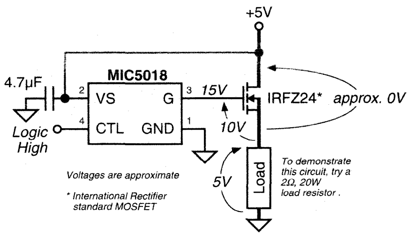


Figure 2. Using a Standard MOSFET

The MIC5018 has an internal zener diode that limits the gate-to-ground voltage to approximately 16V.

Lower supply voltages, such as 3.3V, produce lower gate output voltages which will not fully enhance standard MOSFETs. This significantly reduces the maximum current that can be switched. Always refer to the MOSFET data sheet to predict the MOSFET’s performance in specific applications.

Logic-Level MOSFET

Logic-level N-channel MOSFETs are fully enhanced with a gate-to-source voltage of approximately 5V and generally have an absolute maximum gate-to-source voltage of ±10V.

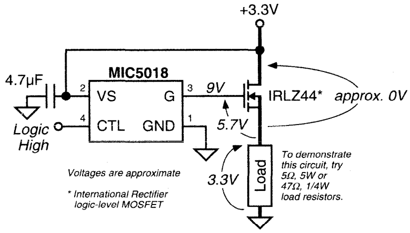


Figure 3. Using a Logic-Level MOSFET

Refer to figure 3 for an example showing nominal voltages. The maximum gate-to-source voltage rating of a logic-level MOSFET can be exceeded if a higher supply voltage is used. An external zener diode can clamp the gate-to-source voltage as shown in figure 4. The zener voltage, plus its tolerance, must not exceed the absolute maximum gate voltage of the MOSFET.

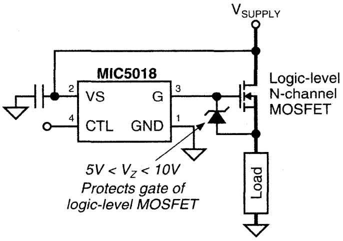


Figure 4. Gate-to-Source Protection

A gate-to-source zener may also be required when the maximum gate-to-source voltage could be exceeded due to normal part-to-part variation in gate output voltage. Other conditions can momentarily increase the gate-to-source voltage, such as turning on a capacitive load or shorting a load.

Inductive Loads

Inductive loads include relays, and solenoids. Long leads may also have enough inductance to cause adverse effects in some circuits.

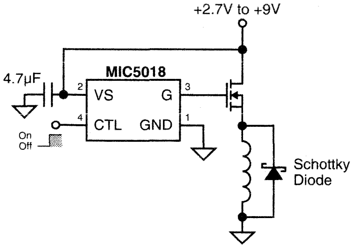


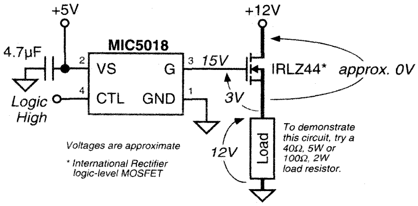
Figure 5. Switching an Inductive Load

Switching off an inductive load in a high-side application momentarily forces the MOSFET source negative (as the inductor opposes changes to current). This voltage spike can be very large and can exceed a MOSFET's gate-to-source and drain-to-source ratings. A Schottky diode across the inductive load provides a discharge current path to minimize the voltage spike. The peak current rating of the diode should be greater than the load current.

In a low-side application, switching off an inductive load will momentarily force the MOSFET drain higher than the supply voltage. The same precaution applies.

Split Power Supply

Refer to figure 6. The MIC5018 can be used to control a 12V load by separating the driver supply from the load supply.



Voltages are approximate

* International Rectifier logic-level MOSFET

To demonstrate this circuit, try a 40Ω, 5W or 100Ω, 2W load resistor.

Figure 6. 12V High-Side Switch

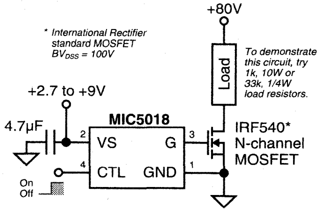
A logic-level MOSFET is required. The MOSFET's maximum current is limited slightly because the gate is not fully enhanced. To predict the MOSFETs performance for any pair of supply voltages, calculate the gate-to-source voltage and refer to the MOSFET data sheet.

$$V_{GS} = V_G - (V_{LOAD\ SUPPLY} - V_{DS})$$

V_G is determined from the driver supply voltage using the "Typical Characteristics: Gate Output Voltage vs. Supply Voltage" graph.

Low-Side Switch Configuration

The low-side configuration makes it possible to switch a voltage much higher than the MIC5018's maximum supply voltage.



* International Rectifier standard MOSFET $BV_{DSS} = 100V$

To demonstrate this circuit, try 1k, 10W or 33k, 1/4W load resistors.

Figure 7. Low-Side Switch Configuration

The maximum switched voltage is limited only by the MOSFET's maximum drain-to-source ratings.

MIC5020

Current-Sensing Low-Side MOSFET Driver

General Description

The MIC5020 low-side MOSFET driver is designed to operate at frequencies greater than 100kHz and is an ideal choice for high-speed applications such as motor control, SMPS (switch mode power supplies), and applications using IGBTS. The MIC5020 can also operate as a circuit breaker with or without automatic retry. The MIC5020's maximum supply voltage lends itself to control applications using up to 50V. The MIC5020 can control MOSFETs that switch voltages greater than 50V.

A rising or falling edge on the input results in a current source or sink pulse on the gate output. This output current pulse can turn on or off a 2000pF MOSFET in approximately 175ns. The MIC5020 then supplies a limited current (< 2mA), if necessary, to maintain the output state.

An overcurrent comparator with a trip voltage of 50mV makes the MIC5020 ideal for use with a current sensing MOSFET. An external low value resistor may be used instead of a sensing MOSFET for more precise overcurrent control. An optional external capacitor connected to the C_T pin may be used to control the current shutdown duty cycle from 20% to < 1%. A duty cycle from 20% to about 75% is possible with an optional pull-up resistor from C_T to V_{DD}. An open collector output provides a fault indication when the sense inputs are tripped.

The MIC5020 is available in 8-pin SOIC, plastic DIP, and CerDIP packages.

Other members of the MIC502x series include the MIC5021 high-side driver and the MIC5022 half-bridge driver with a cross-conduction interlock.

Features

- 11V to 50V operation
- 175ns rise/fall time driving 2000pF
- TTL compatible input with internal pull-down resistor
- Overcurrent limit
- Fault output indication
- Gate to source protection
- Compatible with current sensing MOSFETs

Applications

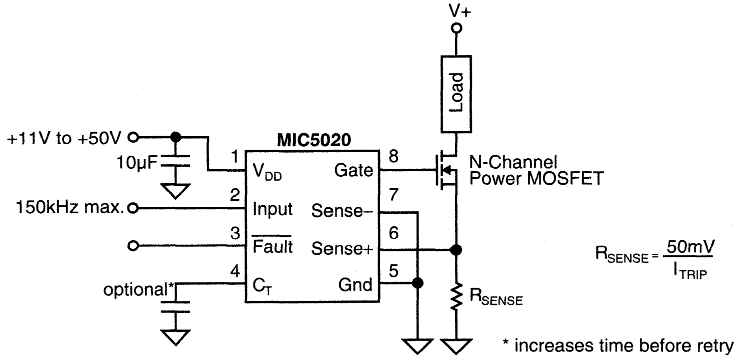
- Lamp control
- Heater control
- Motor control
- Solenoid switching
- Switch-mode power supplies
- Circuit breaker

Ordering Information

Part Number	Temperature Range	Package
MIC5020AJB*	–55°C to +125°C	8-pin CerDIP
MIC5020BM	–40°C to +85°C	8-pin SOIC
MIC5020BN	–40°C to +85°C	8-pin Plastic DIP

* AJB indicates units screened to MIL-STD 883, Method 5004, condition B, and burned-in for 1-week.

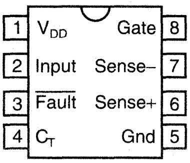
Typical Application



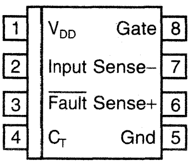
* increases time before retry

Low-Side Driver with Overcurrent Trip and Retry

Pin Configuration

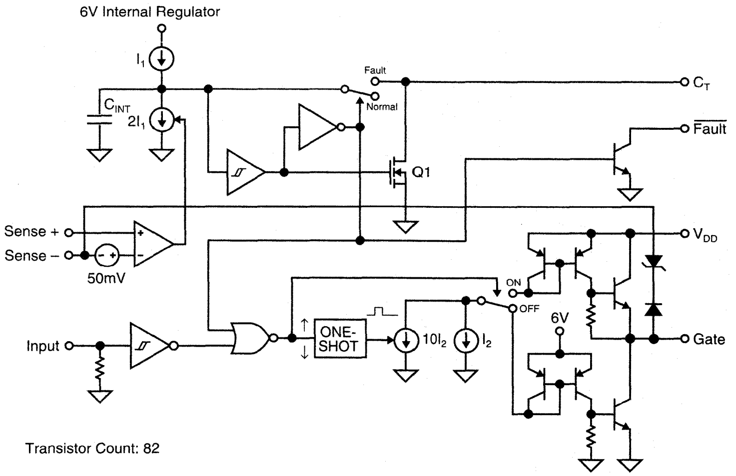


DIP Packages (N, J)



SOIC Package (M)

Block Diagram



Transistor Count: 82

Pin Description

Pin Number	Pin Name	Pin Function
1	V_{DD}	Supply: +11V to +50V. Decouple with ≥ 10µF capacitor.
2	Input	TTL Compatible Input: Logic high turns the external MOSFET on. An internal pull-down returns an open pin to logic low.
3	$\overline{\text{Fault}}$	Overcurrent Fault Indicator: When the sense voltage exceeds threshold, open collector output is open circuit for 5µs ($t_{G(ON)}$), then pulled low for $t_{G(OFF)}$. $t_{G(OFF)}$ is adjustable from C_T.
4	C_T	Retry Timing Capacitor: Controls the off time ($t_{G(OFF)}$) of the overcurrent retry cycle. (Duty cycle adjustment.) • Open = 20% duty cycle. • Capacitor to Ground = approx. 20% to <1% duty cycle. • Pull-Up resistor = approx. 20% to approx. 75% duty cycle. • Ground = maintained shutdown upon overcurrent condition.
5	Gnd	Circuit Ground
6	Sense +	Current Sense Comparator (+) Input: Connect to high side of sense resistor or current sensing MOSFET sense lead. A built-in offset in conjunction with R_{SENSE} sets the load overcurrent trip point.
7	Sense –	Current Sense Comparator (–) Input: Connect to the low side of the sense resistor (usually power ground).
8	Gate	Gate Drive: Drives the gate of an external power MOSFET. Also limits V_{GS} to 15V max. to prevent Gate to Source damage. Will sink and source current.

Absolute Maximum Ratings

Supply Voltage (V_{DD})	+55V
Input Voltage	–0.5V to +15V
Sense Differential Voltage	±6.5V
Sense + or Sense – to Gnd	–0.5V to +50V
Fault Voltage	+50V
Current into $\overline{\text{Fault}}$	50mA
Timer Voltage (C_T)	+5.5V

Operating Ratings

Supply Voltage (V_{DD})	+11V to +50V
Temperature Range	
CerDIP	–55°C to +125°C
SOIC	–40°C to +85°C
Plastic DIP	–40°C to +85°C

Electrical Characteristics

T_A = 25°C, Gnd = 0V, V_{DD} = 12V, Sense +,– = 0V, Fault = Open, C_T = Open, Gate C_L = 1500pF unless otherwise specificed

Symbol	Parameter	Condition	Min	Typ	Max	Units
	D.C. Supply Current	V_{DD} = 12V, Input = 0V		0.8	2	mA
		V_{DD} = 50V, Input = 0V		2	10	mA
		V_{DD} = 12V, Input = 5V		0.8	2	mA
		V_{DD} = 50V, Input = 5V		4	25	mA
	Input Threshold		0.8	1.4	2.0	V
	Input Hysteresis			0.1		V
	Input Pull-Down Current	Input = 5V	10	20	40	µA
	Fault Output Saturation Voltage	Fault Current = 1.6mA **Note 1**		0.15	0.4	V
	Fault Output Leakage	Fault = 50V	–1	0.01	+1	µA
	Current Limit Threshold	**Note 2**	30	50	70	mV
	Gate On Voltage	V_{DD} = 12V	10	11		V
		V_{DD} = 50V	14	15	18	V
$t_{G(ON)}$	Gate On Time, Fixed	Sense Differential > 70mV	2	5	10	µs
$t_{G(OFF)}$	Gate Off Time, Adjustable	Sense Differential > 70mV, C_T = 0pF	10	20	50	µs
t_{DLH}	Gate Turn-On Delay	**Note 3**		400	800	ns
t_R	Gate Rise Time	**Note 4**		700	1500	ns
t_{DLH}	Gate Turn-Off Delay	**Note 5**		900	1500	ns
t_F	Gate Fall Time	**Note 6**		500	1500	ns
f_{max}	Maximum Operating Frequency	**Note 7**	100	150		kHz

Note 1 Voltage remains low for time affected by C_T.

Note 2 When using sense MOSFETs, it is recommended that $R_{SENSE} < 50\Omega$. Higher values may affect the sense MOSFET's current transfer ratio.

Note 3 Input switched from 0.8V (TTL low) to 2.0V (TTL high), time for Gate transition from 0V to 2V.

Note 4 Input switched from 0.8V (TTL low) to 2.0V (TTL high), time for Gate transition from 2V to 10V.

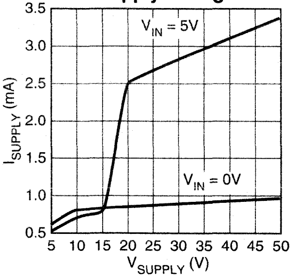
Note 5 Input switched from 2.0V (TTL high) to 0.8V (TTL low), time for Gate transition from 11V (Gate ON voltage) to 10V.

Note 6 Input switched from 2.0V (TTL high) to 0.8V (TTL low), time for Gate transition from 10V from 2V.

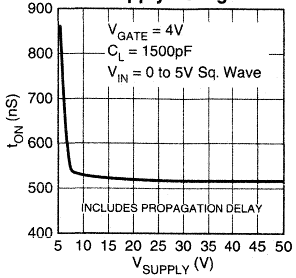
Note 7 Frequency where gate on voltage reduces to 10V with 50% input duty cycle.

Typical Characteristics

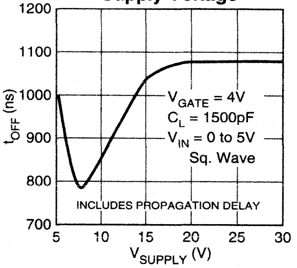
Supply Current vs. Supply Voltage



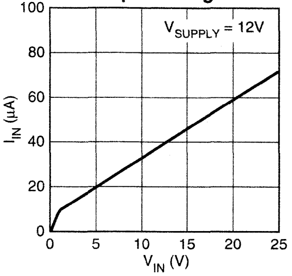
Turn-On Time vs. Supply Voltage



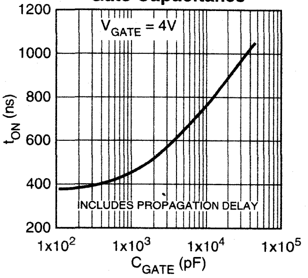
Turn-Off Time vs. Supply Voltage



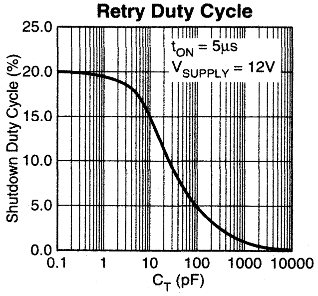
Input Current vs. Input Voltage



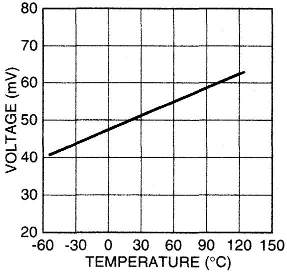
Turn-On Time vs. Gate Capacitance

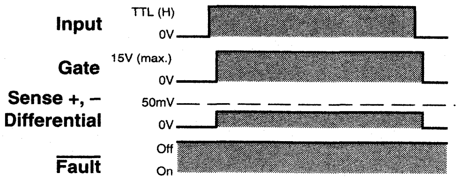


Overcurrent Shutdown Retry Duty Cycle

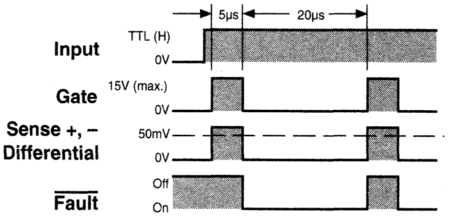


Sense Threshold vs. Temperature

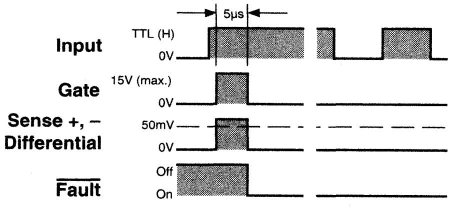




Timing Diagram 1. Normal Operation



Timing Diagram 2. Fault Condition, C_T = Open



Timing Diagram 3. Fault Condition, C_T = Grounded

Functional Description

Refer to the MIC5020 block diagram.

Input

A signal greater than 1.4V (nominal) applied to the MIC5020 INPUT causes gate enhancement on an external MOSFET turning the external MOSFET on.

An internal pull-down resistor insures that an open INPUT remains low, keeping the external MOSFET turned off.

Gate Output

Rapid rise and fall times on the GATE output are possible because each input state change triggers a one-shot which activates a high-value current sink ($10I_2$) for a short time. This draws a high current through a current mirror circuit causing the output transistors to quickly charge or discharge the external MOSFET's gate.

A second current sink continuously draws the lower value of current used to maintain the gate voltage for the selected state.

An internal 15V Zener diode protects the external MOSFET by limiting the gate output voltage when V_{DD} is connected to higher voltages.

Overcurrent Limiting

Current source I_1 charges C_{INT} upon power up. An optional external capacitor connected to C_T is discharged through MOSFET Q1.

A fault condition (> 50mV from SENSE + to SENSE –) causes the overcurrent comparator to enable current sink $2I_1$ which overcomes current source I_1 to discharge C_{INT} in a short time. When C_{INT} is discharged, the INPUT is disabled, which turns off the GATE output; the FAULT output is enabled; and C_{INT} and C_T are ready to be charged.

When the GATE output turns the MOSFET off, the overcurrent signal is removed from the sense inputs which deactivates current sink $2I_1$. This allows C_{INT} and the optional capacitor connected to C_T to recharge. A Schmitt trigger delays the retry while the capacitor(s) recharge. Retry delay is increased by connecting a capacitor to C_T (optional).

The retry cycle will continue until the the fault is removed or the input is changed to TTL low.

If C_T is connected to ground, the circuit will not retry upon a fault condition.

Fault Output

The FAULT output is an open collector transistor. FAULT is active at approximately the same time the output is disabled by a fault condition (5µs after an overcurrent condition is sensed). The FAULT output is open circuit (off) during each successive retry (5µs).

Applications Information

The MIC5020 MOSFET driver is intended for low-side switching applications where higher supply voltage, overcurrent sensing, and moderate speed are required.

Supply Voltage

A feature of the MIC5020 is that its supply voltage rating of up to 50V is higher than many other low-side drivers.

The minimum supply voltage required to fully enhance an N-channel MOSFET is 11V.

A lower supply voltage may be used with logic level MOSFETs. Approximately 6V is needed to provide 5V of gate enhancement.

Low-Side Switch Circuit Advantages

A moderate-speed low-side driver is generally much faster than a comparable high-side driver. The MIC5020 can provide the gate drive switching times and low propagation delay times that are necessary for high-frequency high-efficiency circuit operation in PWM (pulse width modulation) designs used for motor control, SMPS (switch mode power supply) and heating element control. Switched loads (on/off) can benefit from the MIC5020's fast switching times by allowing use of MOSFETs with smaller safe operating areas. (Larger MOSFETs are often required when using slower drivers.)

Overcurrent Limiting

A 50mV comparator is provided for current sensing. The low level trip point minimizes I^2R losses when power resistors are used for current sensing. Flexibility in choosing drain or source side sensing is provided by access to both SENSE + and SENSE – comparator inputs.

The adjustable retry feature can be used to handle loads with high initial currents, such as lamps, motors, or heating elements and can be adjusted from the C_T connection.

C_T to ground causes maintained gate drive shutdown following overcurrent detection.

C_T open, or through a capacitor to ground, causes automatic retry. The default duty cycle (C_T open) is approximately 20%. Refer to the electrical characteristics when selecting a capacitor for a reduced duty cycle.

C_T through a pull-up resistor to V_{DD} increases the duty cycle. *Increasing the duty cycle increases the power dissipation in the load and MOSFET.* Circuits may become unstable at a duty cycles of about 75% or higher, depending on the conditions. *Caution: The MIC5020 may be damaged if the voltage on C_T exceeds the absolute maximum rating.*

An overcurrent condition is externally signaled by an open collector (FAULT) output.

The MIC5020 may be used without current sensing by connecting SENSE + and SENSE – to ground.

Current Sense Resistors

Lead length can be significant when using low value (< 1Ω) resistors for current sensing. Errors caused by lead length can be avoided by using four-terminal current sensing resistors. Four-terminal resistors are available from several manufacturers.

Lamp Driver Application

Incandescent lamps have a high inrush current (low resistance) when turned on. The MIC5020 can perform a "soft start" by pulsing the MOSFET (overcurrent condition) until the filament is warm enough for its current to decrease (resistance increases). The sense resistor is selected so the voltage across the sense resistor drops below the sense threshold (50mV) as the filament becomes warm. The MOSFET is no longer pulsed to limit current and the lamp turns completely on.

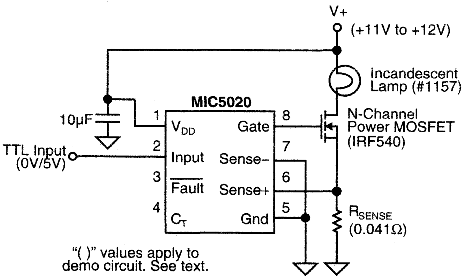


Figure 1. Lamp Driver with Current Sensing

A lamp may not fully turn on if the filament does not heat up adequately. Changing the duty cycle, sense resistor, or both to match the filament characteristics can correct the problem.

Soft start can be demonstrated using a #1157 dual-filament automotive lamp. The value of R_S shown in figure 1 allows for soft start of the higher-resistance filament (measures approx. 2.1Ω cold or 21Ω hot).

Solenoid Driver Application

The MIC5020 can be directly powered by the control voltage supply in typical 11Vdc through 50Vdc control applications. Current sensing has been omitted as an example.

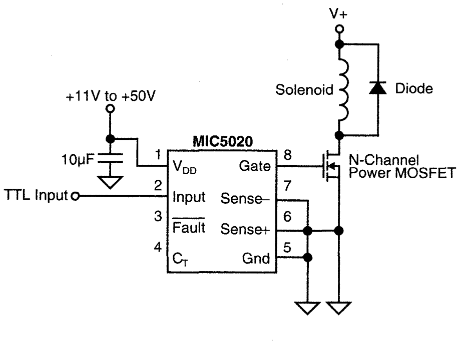


Figure 2. Solenoid Driver, Without Current Sensing

A diode across the load protects the MOSFET from the voltage spike generated by the inductive load upon MOSFET turn off. The peak forward current rating of the diode should be greater than the load current.

Current Sensing MOSFET Application

A current sensing MOSFET allows current sensing without adding additional resistance to the power switching circuit.

A current sensing MOSFET has two source connections: a "power source" for power switching and a "current source" for current sensing. The current from the current source is approximately proportional to the current through the power source, but much smaller. A current sensing ratio (I_{SOURCE}/I_{SENSE}) is provided by the MOSFET manufacturer.

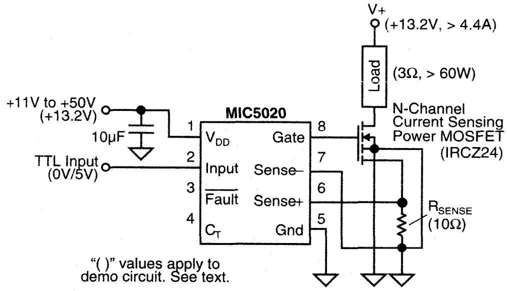


Figure 3. Using a Current Sensing MOSFET

The MOSFET current source is used to develop a voltage across a sense resistor. This voltage is monitored by the MIC5020 (SENSE + and SENSE – pins) to identify an overcurrent condition.

The value of the sense resistor can be estimated with:

$$R_{SENSE} = (r\ V_{TRIP}\ R_{DS(ON)}) / (I_{LOAD}\ R_{DS(ON)} - V_{TRIP})$$

where:

R_{SENSE} = external "sense" resistor

V_{TRIP} = 50mV (0.050V) for the MIC5020

r = manufacturer's current sense ratio: (I_{SOURCE}/I_{SENSE})

$R_{DS(ON)}$ = manufacturer's power source on resistance

I_{LOAD} = load current (power source current)

The drain to source voltage under different fault conditions affects the behavior of the MOSFET current source; that is, the current source will respond differently to a slight overcurrent condition ($V_{DS(ON)}$ very small) than to a short circuit (where $V_{DS(ON)}$ is approximately equal to the supply voltage). Adjustment of the sense resistor value by experiment starting from the above formula will provide the quickest selection of R_{SENSE}.

Refer to manufacture's data sheets and application notes for detailed information on current sensing MOSFET characteristics.

Figure 3 includes values which can be used to demonstrate circuit operation. The IRCZ24 MOSFET has a typical sense ratio of 780 and a $R_{DS(ON)}$ of 0.10Ω. A large 3Ω wirewound load resistor will cause inductive spikes which should be suppressed using a diode (using the same configuration as figure 2).

Faster MOSFET Switching

The MIC5020's GATE current can be multiplied using a pair of bipolar transistors to permit faster charging and discharging of the external MOSFET's gate.

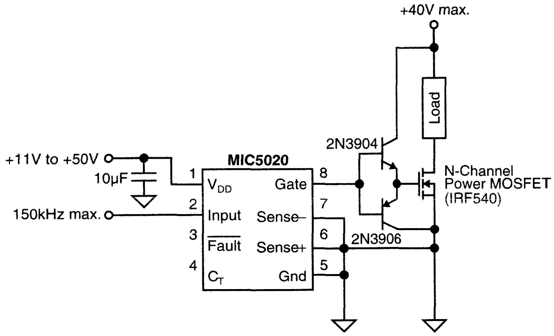


Figure 4. Faster MOSFET Switching Circuit

NPN and PNP transistors are used to respectively charge and discharge the MOSFET gate. The MIC5020 gate current is multiplied by the transistor β.

The switched circuit voltage can be increased above 40V by selecting transistors with higher ratings.

Remote Overcurrent Limiting Reset

In circuit breaker applications where the MIC5020 maintains an off condition after an overcurrent condition is sensed, the C_T pin can be used to reset the MIC5020.

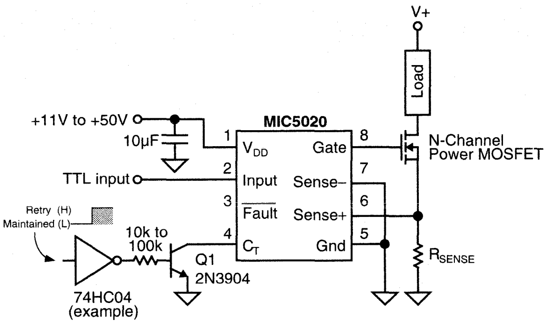


Figure 5. Remote Control Circuit

Switching Q1 on pulls C_T low which keeps the MIC5020 GATE output off when an overcurrent is sensed. Switching Q1 off causes C_T to appear open. The MIC5020 retries in about 20µs and continues to retry until the overcurrent condition is removed.

For test purposes, a 680Ω load resistor and 3Ω sense resistor will produce an overcurrent condition when the load's supply (V+) is approximately 12V or greater.

MIC5021

High-Speed High-Side MOSFET Driver

General Description

The MIC5021 high-side MOSFET driver is designed to operate at frequencies up to 100kHz and is an ideal choice for high speed applications such as motor control, SMPS (switch mode power supplies), and applications using IGBTs. The MIC5021 can also operate as a circuit breaker with or without automatic retry.

A rising or falling edge on the input results in a current source pulse or sink pulse on the gate output. This output current pulse can turn on a 2000pF MOSFET in approximately 550ns. The MIC5021 then supplies a limited current (< 2mA), if necessary, to maintain the output state. An external 0.01µF boost capacitor is required for fast turn on.

An overcurrent comparator with a trip voltage of 50mV makes the MIC5021 ideal for use with a current sensing MOSFET. An external low value resistor may be used instead of a sensing MOSFET for more precise overcurrent control. An optional external capacitor placed from the C_T pin to ground may be used to control the current shutdown duty cycle (dead time) from 20% to < 1%. A duty cycle from 20% to about 75% is possible with an optional pull-up resistor from C_T to V_{DD}.

The MIC5021 is available in 8-pin SOIC, plastic DIP and ceramic DIP packages.

Other members of the MIC502x family include the MIC5020 low-side driver and the MIC5022 half-bridge driver with a cross-conduction interlock.

Features

- 12V to 36V operation
- 550ns rise/fall time driving 2000pF
- TTL compatible input with internal pull-down resistor
- Overcurrent limit
- Gate to source protection
- Internal charge pump
- 100kHz operation guaranteed over full temperature and operating voltage range
- Compatible with current sensing MOSFETs
- Current source drive reduces EMI

Applications

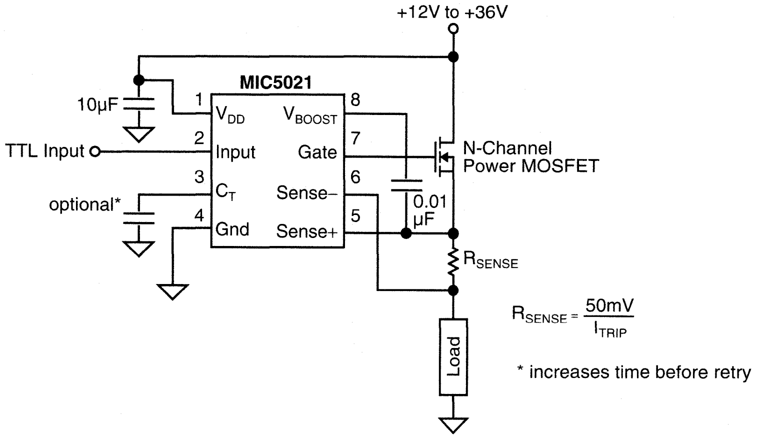
- Lamp control
- Heater control
- Motor control
- Solenoid switching
- Switch-mode power supplies
- Circuit breaker

Ordering Information

Part Number	Temperature Range	Package
MIC5021AJB*	–55°C to +125°C	8-pin CerDIP
MIC5021BM	–40°C to +85°C	8-pin SOIC
MIC5021BN	–40°C to +85°C	8-pin Plastic DIP

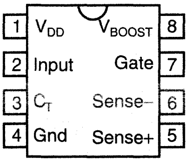
* AJB indicates units screened to MIL-STD 883, Method 5004, condition B, and burned-in for 1-week.

Typical Application

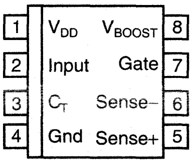


High-Side Driver with Overcurrent Trip and Retry

Pin Configuration

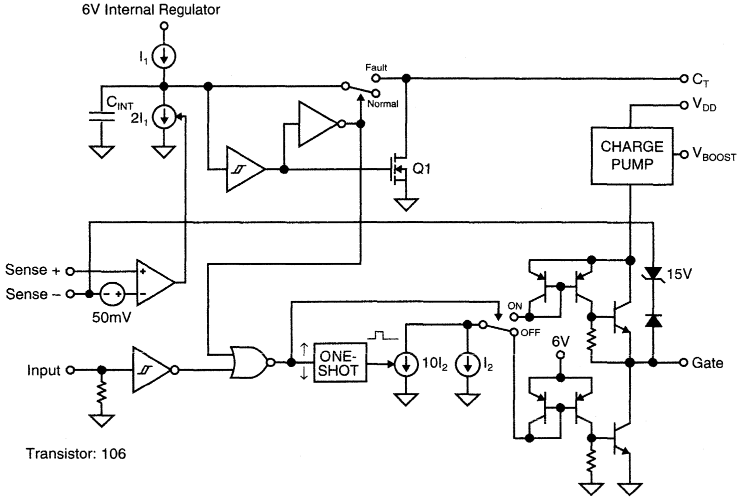


DIP Packages
(N, J)



SOIC Package
(M)

Block Diagram



Transistor: 106

Pin Description

Pin Number	Pin Name	Pin Function
1	V_{DD}	Supply: +12V to +36V. Decouple with ≥ 10µF capacitor.
2	Input	TTL Compatible Input: Logic high turns the external MOSFET on. An internal pull-down returns an open pin to logic low.
3	C_T	Retry Timing Capacitor: Controls the off time ($t_{G(OFF)}$) of the overcurrent retry cycle. (Duty cycle adjustment.) • Open = approx. 20% duty cycle. • Capacitor to Ground = approx. 20% to < 1% duty cycle. • Pull-up resistor = approx. 20% to approx. 75% duty cycle. • Ground = maintained shutdown upon overcurrent condition.
4	Gnd	Circuit Ground
5	Sense +	Current Sense Comparator (+) Input: Connect to high side of sense resistor or current sensing MOSFET sense lead. A built-in offset in conjunction with R_{SENSE} sets the load overcurrent trip point.
6	Sense –	Current Sense Comparator (–) Input: Connect to the low side of the sense resistor (usually the high side of the load).
7	Gate	Gate Drive: Drives the gate of an external power MOSFET. Also limits V_{GS} to 15V max. to prevent Gate-to-Source damage. Will sink and source current.
8	V_{BOOST}	Charge Pump Boost Capacitor: A 0.01µF bootstrap capacitor from V_{BOOST} to the FET source pin supplies charge to quickly enhance the Gate output during turn-on.

Absolute Maximum Ratings

Supply Voltage (V_{DD})	+40V
Input Voltage	−0.5V to +15V
Sense Differential Voltage	±6.5V
Sense + or Sense – to Gnd	−0.5V to +36V
Timer Voltage (C_T)	+5.5V
V_{BOOST} Capacitor	0.01µF

Operating Ratings

Supply Voltage (V_{DD})	+12V to +36V
Temperature Range	
CerDIP	−55°C to +125°C
PDIP	−40°C to +85°C
SOIC	−40°C to +85°C

Electrical Characteristics

$T_A = 25°C$, Gnd = 0V, $V_{DD} = 12V$, C_T = Open, Gate $C_L = 1500pF$ (IRF540 MOSFET) unless otherwise specified

Symbol	Parameter	Condition	Min	Typ	Max	Units
	D.C. Supply Current	$V_{DD} = 12V$, Input = 0V		1.8	4	mA
		$V_{DD} = 36V$, Input = 0V		2.5	6	mA
		$V_{DD} = 12V$, Input = 5V		1.7	4	mA
		$V_{DD} = 36V$, Input = 5V		2.5	6	mA
	Input Threshold		0.8	1.4	2.0	V
	Input Hysteresis			0.1		V
	Input Pull-Down Current	Input = 5V	10	20	40	µA
	Current Limit Threshold	**Note 1**	30	50	70	mV
	Gate On Voltage	$V_{DD} = 12V$ **Note 2**	16	18	21	V
		$V_{DD} = 36V$ **Note 2**	46	50	52	V
$t_{G(ON)}$	Gate On Time, Fixed	Sense Differential > 70mV	2	6	10	µs
$t_{G(OFF)}$	Gate Off Time, Adjustable	Sense Differential > 70mV, $C_T = 0pF$	10	20	50	µs
t_{DLH}	Gate Turn-On Delay	**Note 3**		500	1000	ns
t_R	Gate Rise Time	**Note 4**		400	500	ns
t_{DLH}	Gate Turn-Off Delay	**Note 5**		800	1500	ns
t_F	Gate Fall Time	**Note 6**		400	500	ns
f_{max}	Maximum Operating Frequency	**Note 7**	100	150		kHz

Note 1 When using sense MOSFETs, it is recommended that $R_{SENSE} < 50\Omega$. Higher values may affect the sense MOSFET's current transfer ratio.

Note 2 DC measurement.

Note 3 Input switched from 0.8V (TTL low) to 2.0V (TTL high), time for Gate transition from 0V to 2V.

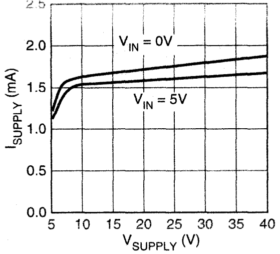
Note 4 Input switched from 0.8V (TTL low) to 2.0V (TTL high), time for Gate transition from 2V to 17V.

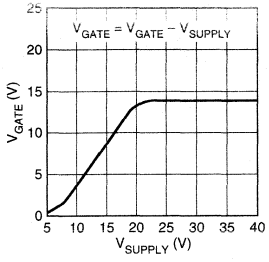
Note 5 Input switched from 2.0V (TTL high) to 0.8V (TTL low), time for Gate transition from 20V (Gate on voltage) to 17V.

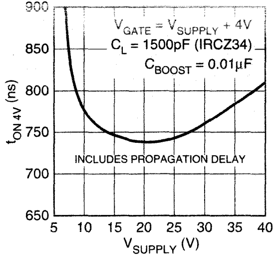
Note 6 Input switched from 2.0V (TTL high) to 0.8V (TTL low), time for Gate transition from 17V to 2V.

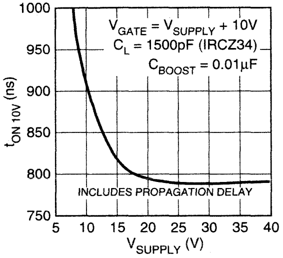
Note 7 Frequency where gate on voltage reduces to 17V with 50% input duty cycle.

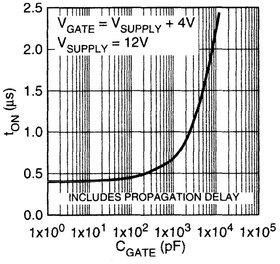
Typical Characteristics

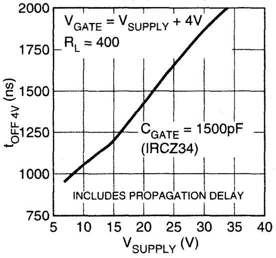

Supply Current vs. Supply Voltage

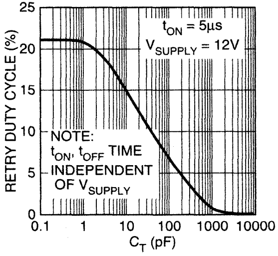

Gate Voltage Change vs. Supply Voltage

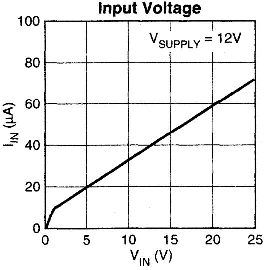

Gate Turn-On Delay vs. Supply Voltage

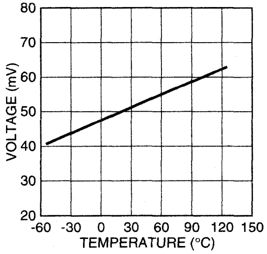

Gate Turn-On Delay vs. Supply Voltage

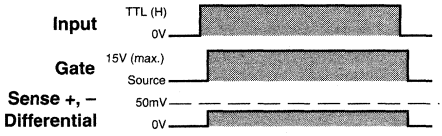

Gate Turn-On Delay vs. Gate Capacitance


Gate Turn-Off Delay vs. Supply Voltage

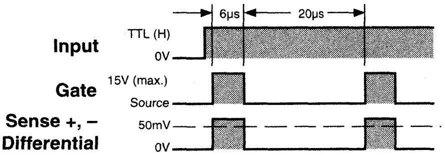

Overcurrent Retry Duty Cycle vs. Timing Capacitance


Input Current vs. Input Voltage

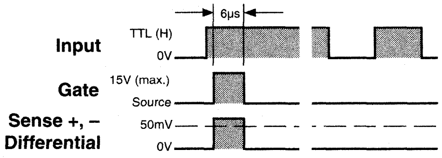

Sense Threshold vs. Temperature



Timing Diagram 1. Normal Operation



Timing Diagram 2. Fault Condition, C_T = Open



Timing Diagram 3. Fault Condition, C_T = Grounded

Functional Description

Refer to the MIC5021 block diagram.

Input

A signal greater than 1.4V (nominal) applied to the MIC5021 INPUT causes gate enhancement on an external MOSFET turning the MOSFET on.

An internal pull-down resistor insures that an open INPUT remains low, keeping the external MOSFET turned off.

Gate Output

Rapid rise and fall times on the GATE output are possible because each input state change triggers a one-shot which activates a high-value current sink ($10I_2$) for a short time. This draws a high current though a current mirror circuit causing the output transistors to quickly charge or discharge the external MOSFET's gate.

A second current sink continuously draws the lower value of current used to maintain the gate voltage for the selected state.

An internal charge pump utilizes an external "boost" capacitor connected between V_{BOOST} and the source of the external MOSFET. (Refer to typical application.) The boost capacitor stores charge when the MOSFET is off. As the MOSFET turns on, its source to ground voltage increases and is added to the voltage across the capacitor, raising the V_{BOOST} pin voltage. The boost capacitor charge is directed through the GATE pin to quickly charge the MOSFET's gate to 16V maximum above V_{DD}. The internal charge pump maintains the gate voltage.

An internal zener diode protects the external MOSFET by limiting the gate to source voltage.

Sense Inputs

The MIC5021's 50mV (nominal) trip voltage is created by internal current sources that force approximately 5µA out of SENSE + and approximately 15µA (at trip) out of SENSE –. When SENSE – is 50mV or more below SENSE +, SENSE – steals base current from an internal drive transistor shutting off the external MOSFET.

Overcurrent Limiting

Current source I_1 charges C_{INT} upon power up. An optional external capacitor connected to C_T is kept discharged through a MOSFET Q1.

A fault condition (> 50mV from SENSE + to SENSE –) causes the overcurrent comparator to enable current sink $2I_1$ which overcomes current source I_1 to discharge C_{INT} in a short time. When C_{INT} is discharged, the INPUT is disabled, which turns off the gate output, and C_{INT} and C_T are ready to be charged.

When the gate output turns the MOSFET off, the overcurrent signal is removed from the sense inputs which deactivates current sink $2I_1$. This allows C_{INT} and the optional capacitor connected to C_T to recharge. A Schmitt trigger delays the retry while the capacitor(s) recharge. Retry delay is increased by connecting a capacitor to C_T (optional).

The retry cycle will continue until the fault is removed or the input is changed to TTL low.

If C_T is connected to ground, the circuit will not retry upon a fault condition.

Applications Information

The MIC5021 MOSFET driver is intended for high-side switching applications where overcurrent limiting and high speed are required. The MIC5021 can control MOSFETs that switch voltages up to 36V.

High-Side Switch Circuit Advantages

High-side switching allows more of the load related components and wiring to remain near ground potential when compared to low-side switching. This reduces the chances of short-to-ground accidents or failures.

Speed Advantage

The MIC5021 is about two orders of magnitude faster than the low cost MIC5014 making it suitable for high-frequency high-efficiency circuit operation in PWM (pulse width modulation) designs used for motor control, SMPS (switch mode power supply) and heating element control.

Switched loads (on/off) benefit from the MIC5021's fast switching times by allowing use of MOSFETs with smaller safe operating areas. (Larger MOSFETs are often required when using slower drivers.)

Supply Voltage

The MIC5021's supply input (V_{DD}) is rated up to 36V. The supply voltage must be equal to or greater than the voltage applied to the drain of the external N-channel MOSFET.

A 16V minimum supply is recommended to produce continuous on-state, gate drive voltage for standard MOSFETs (10V nominal gate enhancement).

When the driver is powered from a 12V to 16V supply, a logic-level MOSFET is recommended (5V nominal gate enhancement).

PWM operation may produce satisfactory gate enhancement at lower supply voltages. This occurs when fast switching repetition makes the boost capacitor a more significant voltage supply than the internal charge pump.

Logic-Level MOSFET Precautions

Logic-level MOSFETs have lower maximum gate-to-source voltage ratings (typically ±10V) than standard MOSFETs (typically ±20V). When an external MOSFET is turned on, the doubling effect of the boost capacitor can cause the gate-to-source voltage to momentarily exceed 10V. Internal zener diodes clamp this voltage to 16V maximum which is too high for logic-level MOSFETs. To protect logic-level MOSFETs, connect a zener diode ($5V \le V_{Zener} < 10V$) from gate to source.

Overcurrent Limiting

A 50mV comparator is provided for current sensing. The low level trip point minimizes I^2R losses when a power resistor is used for current sensing.

The adjustable retry feature can be used to handle loads with high initial currents, such as lamps or heating elements, and can be adjusted from the C_T connection.

C_T to ground maintains gate drive shutdown following an overcurrent condition.

C_T open, or a capacitor to ground, causes automatic retry. The default duty cycle (C_T open) is approximately 20%. Refer to the electrical characteristics when selecting a capacitor for reduced duty cycle.

C_T through a pull-up resistor to V_{DD} increases the duty cycle. *Increasing the duty cycle increases the power dissipation in the load and MOSFET under a "fault" condition.* Circuits may become unstable at a duty cycle of about 75% or higher, depending on conditions. *Caution: The MIC5021 may be damaged if the voltage applied to C_T exceeds the absolute maximum voltage rating.*

Boost Capacitor Selection

The boost capacitor should be 0.01µF. Larger capacitors can damage the MIC5021.

Current Sense Resistors

Lead length can be significant when using low value (< 1Ω) resistors for current sensing. Errors caused by lead length can be avoided by using four-teminal current sensing resistors. Four-terminal resistors are available from several manufacturers.

Circuits Without Current Sensing

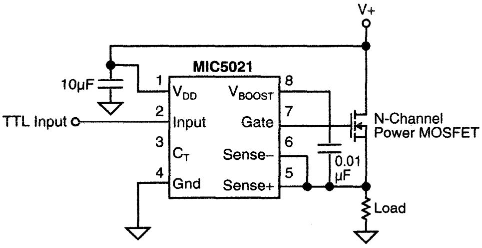


Figure 1a. Connecting Sense to Source

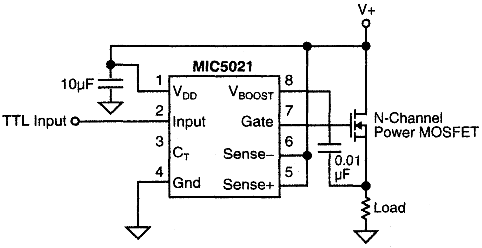


Figure 1b. Connecting Sense to Supply

Current sensing may be omitted by connecting the SENSE + and SENSE – pins to the source of the MOSFET or to the supply. Connecting the SENSE pins to the supply is preferred for inductive loads. Do not connect the SENSE pins to ground.

Inductive Load Precautions

Circuits controlling inductive loads, such as solenoids (figure 2) and motors, require precautions when controlled by the MIC5021. Wire wound resistors, which are sometimes used to simulate other loads, can also show significant inductive properties.

An inductive load releases stored energy when its current flow is interrupted (when the MOSFET is switched off). The voltage across the inductor reverses and the inductor attempts to force current flow. Since the circuit appears open (the MOSFET appears as a very high resistance) a very large negative voltage occurs across the inductor.

Limiting Inductive Spikes

The voltage across the inductor can be limited by connecting a Schottky diode across the load. The diode is forward biased only when the load is switched off. The Schottky diode clamps negative transients to a few volts. This protects the MOSFET from drain-to-source breakdown and prevents the transient from damaging the charge pump by way of the boost capacitor. Also see *Sense Pin Considerations* below.

The diode should have a peak forward current rating greater than the load current. This is because the current through the diode is the same as the load current at the instant the MOSFET is turned off.

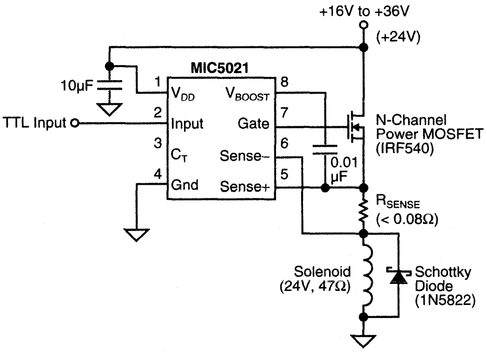


Figure 2. Solenoid Driver with Current Sensing

Sense Pin Considerations

The sense pins of the MIC5021 are sensitive to negative voltages. Forcing the sense pins much below –0.5V effectively reverses the supply voltage on portions of the driver resulting in unpredictable operation or damage.

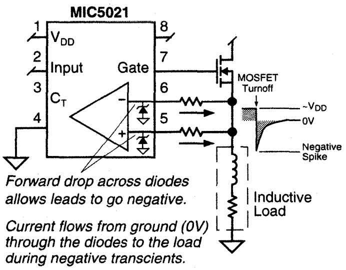


Figure 3. Inductive Load Turnoff

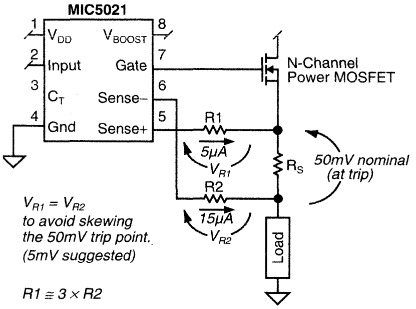
Figure 3 shows current flowing out of the sense leads of an MIC5021 during a negative transient (inductive kick). Internal

Schottky diodes attempt to limit the negative transient by maintaining a low forward drop.

Although the internal Schottky diodes can protect the driver in low-current resistive applications, they are inadequate for inductive loads or the lead inductance in high-current resistive loads. Because of their small size, the diodes' forward voltage drop quickly exceeds 0.5V as current increases.

External Protection

Resistors placed in series with each SENSE connection limit the current drawn from the internal Schottky diodes during a negative transient. This minimizes the forward drop across the diodes.



$V_{R1} = V_{R2}$
to avoid skewing
the 50mV trip point.
(5mV suggested)

$R1 \cong 3 \times R2$

Figure 4. Resistor Voltage Drop

During normal operation, sensing current from the sense pins is unequal (5µA and 15µA). The internal Schottky diodes are reverse biased and have no effect. To avoid skewing the trip voltage, the current limiting resistors must drop equal voltages at the trip point currents. See figure 4. To minimize resistor tolerance error, use a voltage drop lower than the trip voltage of 50mV. 5mV is suggested.

External Schottky diodes are also recommended. See D2 and D3 in figure 5. The external diodes clamp negative transients better than the internal diodes because their larger size minimizes the forward voltage drop at higher currents.

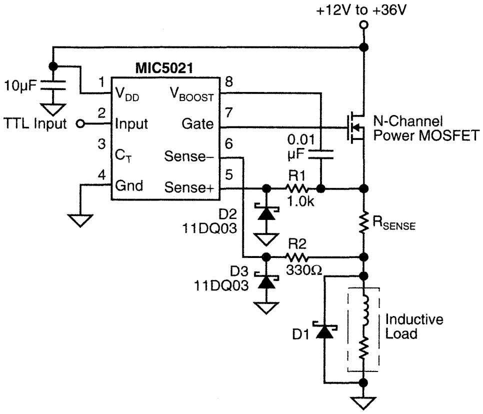


Figure 5. Protection from Inductive Kick

High-Side Sensing

Sensing the current on the high side of the MOSFET isolates the SENSE pins from the inductive spike.

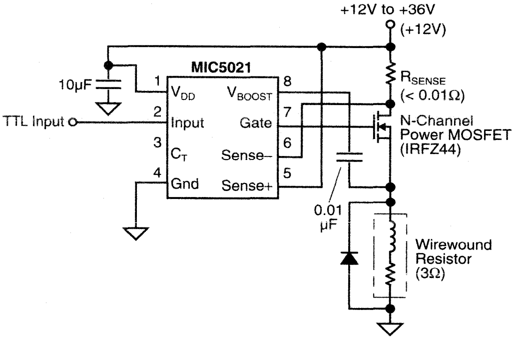
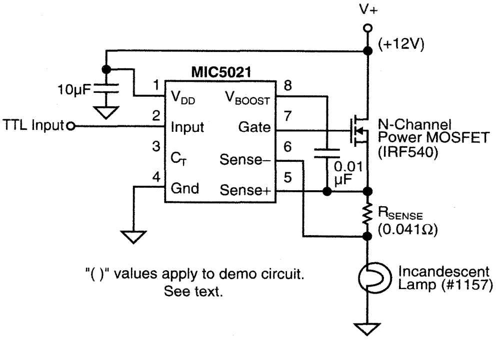


Figure 6. High Side Sensing

Lamp Driver Application

Incandescent lamps have a high inrush current (low resistance) when turned on. The MIC5021 can perform a "soft start" by pulsing the MOSFET (overcurrent condition) until the filament is warm and its current decreases (resistance increases). The sense resistor value is selected so the voltage drop across the sense resistor decreases below the sense threshold (50mV) as the filament becomes warm. The FET is no longer pulsed and the lamp turns completely on.



"( )" values apply to demo circuit.
See text.

Figure 7. Lamp Driver with Current Sensing

A lamp may not fully turn on if the filament does not heat up adequately. Changing the duty cycle, sense resistor, or both to match the filament characteristics can correct the problem.

Soft start can be demonstrated using a #1157 dual filament automotive lamp. The value of R_S shown in figure 7 allows for soft start of the higher-resistance filament (measures approx. 2.1Ω cold or 21Ω hot).

Remote Overcurrent Limiting Reset

In circuit breaker applications where the MIC5021 maintains an off condition after an overcurrent condition is sensed, the C_T pin can be used to reset the MIC5021.

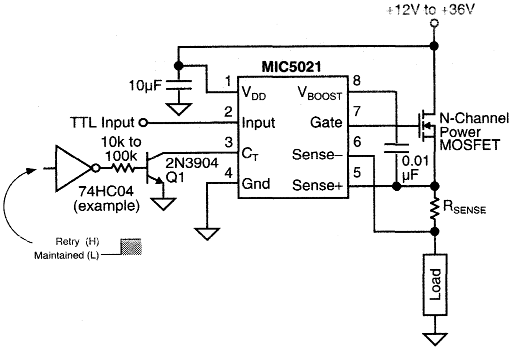


Figure 8. Remote Control Circuit

Switching Q1 on pulls C_T low which keeps the MIC5021 GATE output off when an overcurrent is sensed. Switching Q1 off causes C_T to appear open. The MIC5021 retries in about 20µs and continues to retry until the overcurrent condition is removed.

For demonstration purposes, a 680Ω load resistor and 3Ω sense resistor will produce an overcurrent condition when the load's supply (V+) is approximately 12V or greater.

MIC5022

Half-Bridge MOSFET Driver

General Description

The MIC5022 half-bridge MOSFET driver is designed to operate at frequencies up to 100kHz and is an ideal choice for high speed applications such as motor control and SMPS (switch mode power supplies).

A rising or falling edge on the input results in a current source pulse or sink pulse on the gate outputs. This output current pulse can turn on a 2000pF MOSFET in approximately 1µs. The MIC5022 then supplies a limited current (< 2mA), if necessary, to maintain the output states. An external 0.01µF boost capacitor is required for fast turn on.

Two overcurrent comparators with nominal trip voltages of 50mV make the MIC5022 ideal for use with current sensing MOSFETs. External low value resistors may be used instead of sensing MOSFETs for more precise overcurrent control. Optional external capacitors placed on the C_{TH} and C_{TL} pins may be used to individually control the current shutdown duty cycles from approximately 20% to <1%. Duty cycles from 20% to about 75% are possible with individual pull-up resistors from C_{TL} and C_{TH} to V_{DD}. An open collector output provides a fault indication when either sense input is tripped.

The MIC5022 is available in 16-pin surface mount and 14-pin plastic DIP and Ceramic DIP packages.

Other members of the MIC502x family include the MIC5020 low-side driver and the MIC5021 high-side driver.

Features

- 12V to 36V operation
- 600ns rise time into 1000pF (high side)
- TTL compatible input with internal pull-down resistor
- Outputs interlocked to prevent cross conduction
- TTL compatible enable
- Fault output indication
- Individual overcurrent limits
- Gate protection
- Internal charge pump (high-side)
- Current source drive scheme reduces EMI

Applications

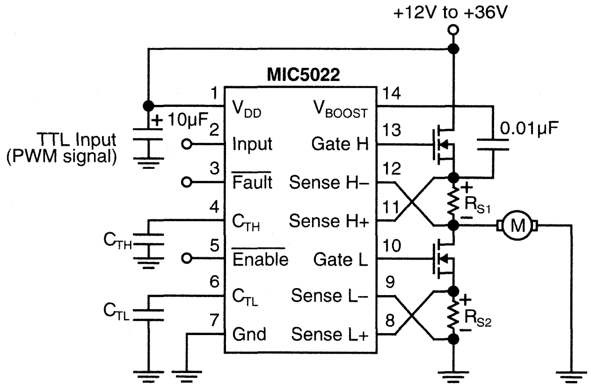
- Motor control
- Switch-mode power supplies

Ordering Information

Part Number	Temperature Range	Package
MIC5022AJB*	–55°C to +125°C	14-pin CerDIP
MIC5022BWM	–40°C to +85°C	16-pin Wide SOIC
MIC5022BN	–40°C to +85°C	14-pin Plastic DIP

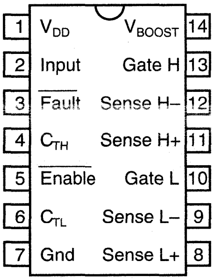
* AJB indicates units screened to MIL-STD 883, Method 5004, condition B, and burned-in for 1-week.

Typical Application

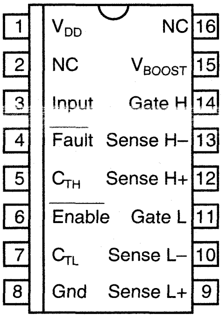


DC Motor Control Application

Pin Configuration



DIP Packages (N, J)

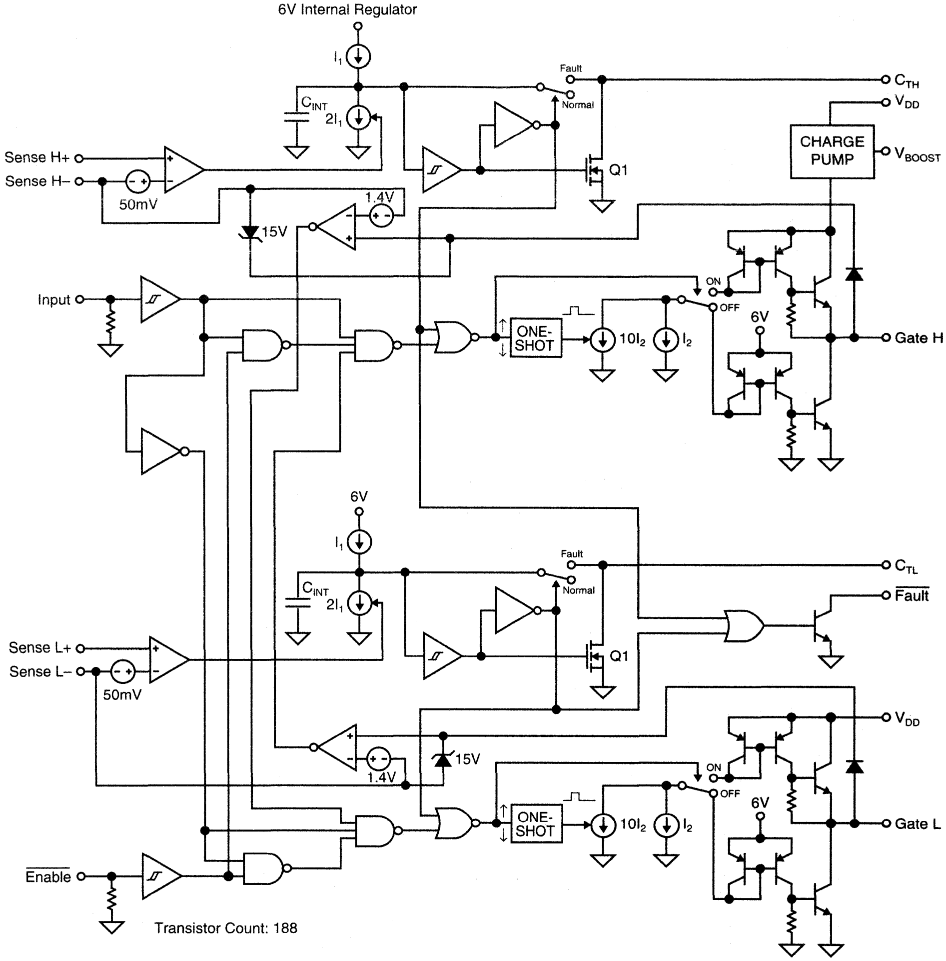


SOIC Package (WM)

Pin Description

DIP Pin No.	SOIC Pin No.	Pin Name	Pin Function
1	1	V_{DD}	Supply: +12V to +36V. Decouple with ≥ 10µF capacitor.
2	3	Input	TTL Compatible Input: Logic high turns the high-side external MOSFET on and the low-side external MOSFET off. Logic low turns the high-side external MOSFET off and the low-side external MOSFET on. An internal pull-down returns an open pin to logic low.
3	4	$\overline{\text{Fault}}$	When either sense voltage exceeds threshold, open collector output is open circuit for 5µs ($t_{G(ON)}$), then pulled low for $t_{G(OFF)}$. $t_{G(OFF)}$ is adjustable from C_T.
4	5	C_{TH}	Retry Trimming Capacitor, High Side: Controls the off time ($t_{G(OFF)}$) of the overcurrent retry cycle. (Duty cycle adjustment.) • Open = approx. 20% duty cycle. • Capacitor to Ground = approx. 20% to < 1% duty cycle. • Pullup resistor = approx. 20% to approx. 75% duty cycle. • Ground = maintained shutdown upon overcurrent condition.
5	6	$\overline{\text{Enable}}$	Output Enable: Disables operation of the output drivers; active high. An internal pull-down returns an open pin to logic low.
6	7	C_{TL}	Retry Trimming Capacitor, Low Side: Same function as C_{TH}.
7	8	Gnd	Circuit Ground
8	8	Sense L +	Current Sense Comparator (+) Input, Low Side: Connect to source of low-side MOSFET. A built-in offset (nominal 50mV) in conjunction with R_{SENSE} sets the load overcurrent trip point.
9	10	Sense L –	Current Sense Comparator (–) Input, Low Side: Connect to the negative side of the low-side sense resistor.
10	11	Gate L	Gate Drive, Low Side: Drives the gate of an external power MOSFET. Also limits V_{GS} to 15V max. to prevent Gate to Source damage. Will sink and source current.
11	12	Sense H +	Current Sense Comparator (+) Input, High Side: Connect to source of high-side MOSFET. A built-in offset (nominal 50mV) in conjunction with R_{SENSE} sets the load overcurrent trip point.
12	13	Source H –	Current Sense Comparator (–) Input, High Side: Connect to the negative side of the high-side sense resistor.
13	14	Gate H	Gate Drive, High Side: Drives the gate of an external power MOSFET. Also limits V_{GS} to 15V max. to prevent Gate to Source damage. Will sink and source current.
14	15	V_{BOOST}	Charge Pump Boost Capacitor: A 0.01µF bootstrap capacitor from V_{BOOST} to the MOSFET source pin supplies charge to quickly enhance the external MOSFET's gate .

Block Diagram



Absolute Maximum Ratings

Supply Voltage (V_{DD})	+40V
Input Voltage	−0.5V to 15V
Sense Differential Voltage	±6.5V
Sense + or Sense − to Gnd	−0.5V to +36V
$\overline{\text{Fault}}$ Voltage	+36V
Current into $\overline{\text{Fault}}$	50mA
Timer Voltage (C_T)	+5.5V
V_{BOOST} Capacitor	0.01µF

Operating Ratings

Supply Voltage (V_{DD})	+12V to +36V
Temperature Range	
CerDIP	−55°C to +125°C
SOIC	−40°C to +85°C
PDIP	−40°C to +85°C

Electrical Characteristics

T_A = 25°C, Gnd = 0V, V_{DD} = 12V, Gate C_L = 1500pF (IRF540 MOSFET) unless otherwise specificed

Symbol	Parameter	Condition	Min	Typ	Max	Units
	D.C. Supply Current	V_{DD} = 12V, Input = 0V		2.5	5	mA
		V_{DD} = 36V, Input = 0V		6.0	10	mA
		V_{DD} = 12V, Input = 5V		2.4	5	mA
		V_{DD} = 36V, Input = 5V		3.0	25	mA
	Input Threshold		0.8	1.4	2.0	V
	Input Hysteresis			0.1		V
	Input Pull-Down Current	Input = 5V	10	20	40	µA
	Enable Threshold		0.8	1.4	2.0	V
	Enable Hysteresis			0.1		V
	Fault Output Saturation Voltage	Fault Current = 1.6mA **Note 1**		0.15	0.4	V
	Fault Output Leakage	Fault = 36V	–1	0.01	+1	µA
	Current Limit Thresh., Low-Side	**Note 2**	30	50	70	mV
	Current Limit Thresh., High-Side	**Note 2**	30	50	70	mV
	Gate On Voltage, High-Side	V_{DD} = 12V, **Note 3**	16	18	21	V
		V_{DD} = 36V, **Note 3**	46	49	52	V
	Gate On Voltage, Low-Side	V_{DD} = 12V, **Note 3**	10	11		V
		V_{DD} = 36V, **Note 3**	14	15	18	V
$t_{G(ON)}$	Gate On Time, Fixed	Sense Differential > 70mV	2	5	10	µs
$t_{G(OFF)}$	Gate Off Time, Adjustable	Sense Differential > 70mV, C_T = 0pF	10	20	50	µs
t_{DLH}	Gate Turn-On Delay, High-Side	**Note 4**		1.4	2.0	µs
t_R	Gate Rise Time, High-Side	**Note 5**		0.8	1.5	µs
t_{DHL}	Gate Turn-Off Delay, High-Side	**Note 6**		1.2	2.0	µs
t_F	Gate Fall Time, High-Side	**Note 7**		0.6	1.5	µs
t_{DLH}	Gate Turn-On Delay, Low-Side	**Note 4**		1.7	2.5	µs
t_R	Gate Rise Time, Low-Side	**Note 8**		0.7	1.5	µs
t_{DHL}	Gate Turn-Off Delay, Low-Side	**Note 9**		0.5	1.0	µs
t_F	Gate Fall Time, Low-Side	**Note 10**		1.0	1.5	µs

Note 1 Voltage remains low for time affected by C_T.

Note 2 When using sense MOSFETs, it is recommended that R_{SENSE} < 50Ω. Higher values may affect the sense MOSFET's current transfer ratio.

Note 3 DC measurement.

Note 4 Input switched from 0.8V (TTL low) to 2.0V (TTL high), time for Gate transition from 0V to 2V.

Note 5 Input switched from 0.8V (TTL low) to 2.0V (TTL high), time for Gate transition from 2V to 17V.

Note 6 Input switched from 2.0V (TTL high) to 0.8V (TTL low), time for Gate transition from 20V (Gate on voltage) to 17V.

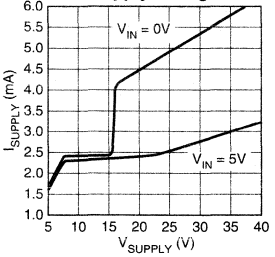
Note 7 Input switched from 2.0V (TTL high) to 0.8V (TTL low), time for Gate transition from 17V to 2V.

Note 8 Input switched from 0.8V (TTL low) to 2.0V (TTL high), time for Gate transition from 2V to 10V.

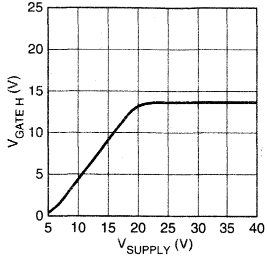
Note 9 Input switched from 2.0V (TTL high) to 0.8V (TTL low), time for Gate transition from 15V (Gate on voltage) to 10V.

Note 10 Input switched from 2.0V (TTL high) to 0.8V (TTL low), time for Gate transition from 10V to 2V.

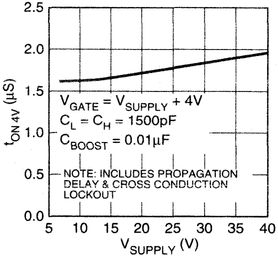
Typical Characteristics



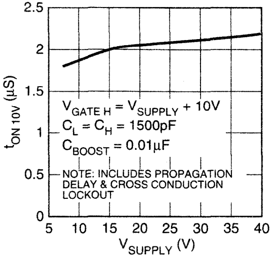
Supply Current vs. Supply Voltage



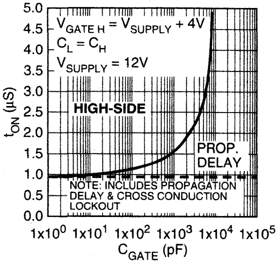
Gate to Source Voltage vs. Supply Voltage



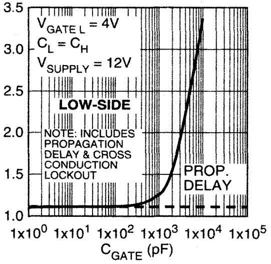
Gate Turn-On Delay vs. Supply Voltage



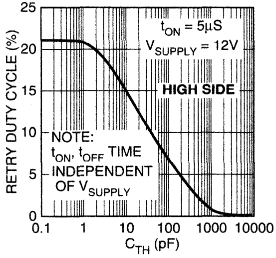
Gate Turn-On Delay vs. Supply Voltage



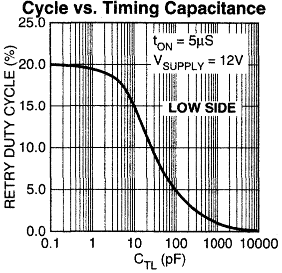
Gate Turn-On/Off Delay vs. Gate Capacitance



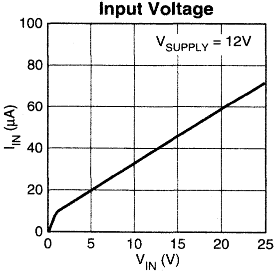
Gate Turn-On/Off Delay vs. Gate Capacitance



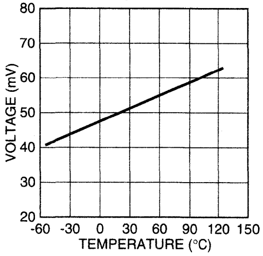
Overcurrent Retry Duty Cycle vs. Timing Capacitance



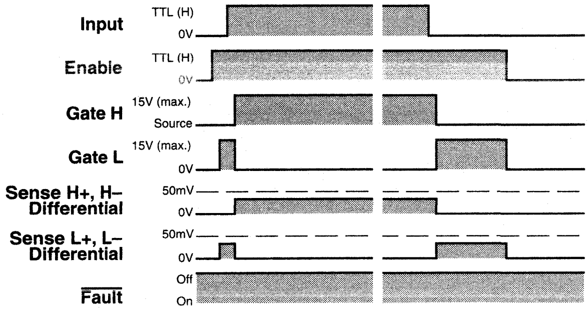
Overcurrent Retry Duty Cycle vs. Timing Capacitance



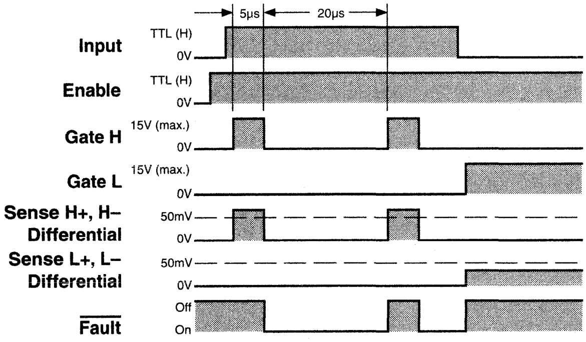
Input Current vs. Input Voltage



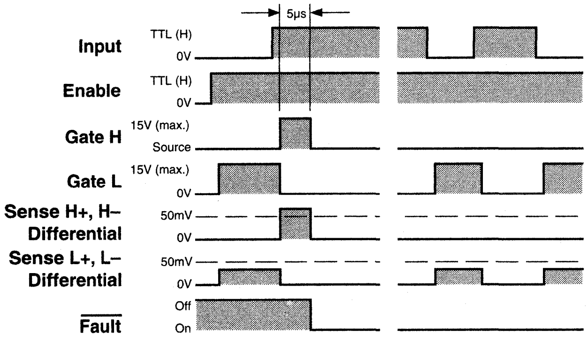
Sense Threshold vs. Temperature



Timing Diagram 1. Normal Operation



Timing Diagram 2. Overcurrent Fault with Retry



Timing Diagram 3. Overcurrent Fault with Maintained Off

Functional Description

Refer to the MIC5022 block diagram.

Input

A signal greater than 1.4V (nominal) applied to the MIC5022 INPUT causes gate enhancement on an external MOSFET connected to GATE H turning the high-side MOSFET on.

At the same time internal logic removes gate enhancement from an external MOSFET connected to GATE L, turning the low-side MOSFET off.

An internal pull-down resistor insures that an open INPUT remains low, keeping the external high-side MOSFET turned off and the low-side MOSFET turned on.

Enable

A signal greater than 1.4V (nominal) applied to the MIC5022 ENABLE keeps both GATE outputs off. An internal pull-down resistor insures that the MIC5022 is enabled if the pin is open.

Gate Outputs

Rapid rise and fall times on the GATE output are possible because each input state change triggers a one-shot which activates a high-value current sink ($10I_2$) for a short time. This draws a high current though a current mirror circuit causing the output transistors to quickly charge or discharge the external FET's gate.

A second current sink continuously draws the lower value of current used to maintain the gate voltage for the selected state.

Internal 15V Zener diodes protect the external high-side and low-side MOSFETs by limiting the gate to source voltage.

Charge Pump (High-Side)

An internal charge pump utilizes an external "boost" capacitor connected between V_{BOOST} and the source of the external FET (refer to Typical Application). The boost capacitor stores charge when the FET is off. As the FET begins to turn on the voltage on the source side of the capacitor increases (because it is on the high side of the load) raising the V_{BOOST} pin voltage. The boost capacitor charge is directed through the gate pin to quickly charge the FET's gate to 15V maximum above V_{DD}. The internal charge pump maintains the gate voltage by supplying a small current as needed.

Overcurrent Limiting (High or Low-Side)

Current source I_1 charges C_{INT} upon power up. An optional external capacitor connected to C_T is kept discharged through a FET Q1.

A fault condition (> 50mV from SENSE + to SENSE –) causes the overcurrent comparator to enable current sink $2I_1$ which overcomes current source I_1 to discharge C_{INT} in about 5µs time. When C_{INT} is discharged, the INPUT is disabled, the FAULT output is enabled, and C_{INT} and C_T are ready to be charged. Since the INPUT is disabled the GATE output turns off.

When the GATE output turns off the FET, the overcurrent signal is removed from the sense inputs which deactivates current sink $2I_1$. This allows C_{INT} and the optional capacitor connected to C_T to recharge. A Schmitt trigger delays the retry while the capacitor(s) recharge. Retry delay is increased by connecting a capacitor connected to C_T (optional).

The MIC5022's low-side driver may be used without current sensing by grounding both SENSE + and SENSE – pins. The high-side driver may be used without current sensing by connecting SENSE + and SENSE – to the source of the external high-side MOSFET.

Fault Output

The FAULT output is an open collector transistor. FAULT is active at approximately the same time the output is disabled by a fault condition (5µs after an overcurrent condition is sensed). The FAULT output is open circuit (off) during each successive retry (5µs).

Typical Full-Bridge Application

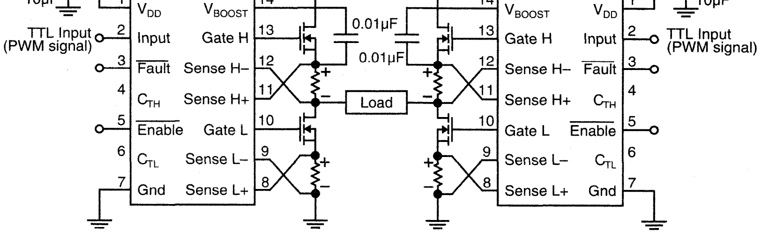


Figure 1. Basic Full-Bridge Circuit

Applications Information

The MIC5022 MOSFET driver is designed for half-bridge switching applications where overcurrent limiting and high speed are required. The MIC5022 can control MOSFETs that switch voltages up to 36V.

The MIC5022 is functionally a MIC5020 low-side driver and MIC5021 high-side driver with additional circuitry to coordinate the operation of the high and low-side drivers. Since most output considerations are similar, *refer to the MIC5020 and MIC5021 data sheets for additional applications information.*

Supply Voltage

The MIC5022's supply input (V_{DD}) is rated up to 36V. The supply voltage must be equal to or greater than the voltage applied to the drain of the external N-channel MOSFET.

A 16V minimum supply is recommended to produce continuous on-state, gate drive voltage for standard MOSFETs (10V nominal gate enhancement).

When the driver is powered from a 12V to 16V supply, a logic-level MOSFET is recommended (5V nominal gate enhancement).

PWM operation may produce satisfactory gate enhancement at lower supply voltages. This occurs when fast switching repetition makes the boost capacitor a more significant voltage supply than the internal charge pump.

Overcurrent Limiting

Separate high and low-side 50mV comparators are provided for current sensing. The low level trip point minimizes I^2R losses when a power resistor is used for current sensing.

The adjustable retry feature can be used to handle loads with high initial currents, such as lamps or heating elements, and can be adjusted from the C_T connection.

C_T to ground causes maintained gate drive shutdown following an overcurrent condition.

C_T open, or a capacitor to ground, causes automatic retry. The default duty cycle (C_T open) is approximately 20% (the high side is slightly greater than the low side). Refer to the typical characteristics when selecting a capacitor for a reduced duty cycle.

C_T through a pull-up resistor to V_{DD} increases the duty cycle. *Increasing the duty cycle increases the power dissipation in the load and MOSFET under a "fault" condition.* Circuits may become unstable at a duty cycle of about 75% or higher, depending on conditions. *Caution: The MIC5022 may be damaged if the voltage applied to C_T exceeds the absolute maximum voltage rating.*

Boost Capacitor Selection

The boost capacitor should be 0.01µF. Larger capacitors can damage the MIC5022.

Circuits Without Current Sensing

Current sensing may be omitted by connecting the high-side SENSE + and SENSE – pins to the source of the MOSFET or the supply and the low-side SENSE + and SENSE – pins to ground. Do not connect the high-side sense pins to ground.

Inductive Load Precautions

Circuits controlling inductive loads require precautions when controlled by the MIC5022. Wire wound resistors, which are sometimes used to simulate other loads, can also show significant inductive properties.

Sense Pin Considerations

The sense pins of the MIC5022 are sensitive to negative voltages. If a voltage spike is too negative (below approximately –0.5V), current will be drawn from functional sections of the IC resulting in unpredictable circuit behavior or damage. Resistors and Schottky diodes may be used to protect the sense pins from the negative spikes. Refer to the MIC5021 data sheet for details.

High-Side Sensing

For the high-side driver, sensing the current on the supply side of the high-side MOSFET locates the SENSE pins away from the inductive spike. Refer to the MIC5021 data sheet for details.

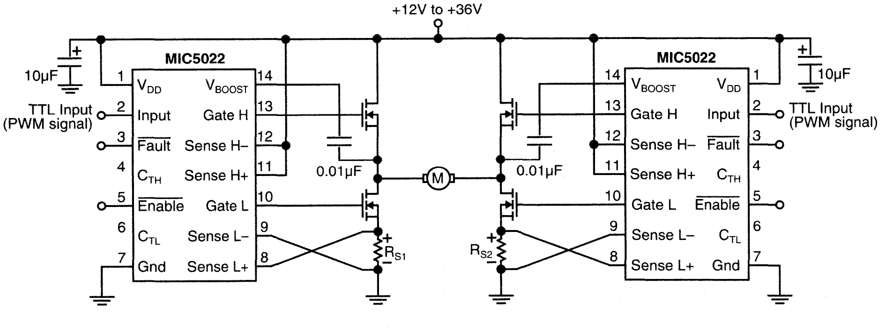


Figure 2. Full-Bridge Motor Control Application

Full-Bridge Motor Control

An application for two MIC5022s is the full-bridge motor control circuit.

Two high or two low-side sense inputs may be used for overcurrent detection. (Low-side sensing is shown in figure 2). Sensing at four locations is usually unnecessary.

When switching inductive loads, such as motors, it is desirable to place the high-side sense inputs on the supply side of the MOSFETs. The helps prevent the inductive spikes that occur upon load shutoff from affecting the sense inputs.

Synchronous Rectifier Converter

The MIC5022 can be part of a synchronous rectifier in SMPS (switch mode power supply) applications.

This circuit uses the MIC38C43 SMPS controller IC to switch a pass transistor (Q1) and a "synchronous rectifier" transistor (Q2) using the MIC5022.

The MIC38C43 controller switches the transistors at 50kHz. Output regulation is maintained using PWM. When the pass transistor is on, the synchronous rectifier is off and current is forced through the inductor to the output capacitor and load. When the pass transistor is switched off, the synchronous rectifier is switched on allowing current to continue to flow as the inductor returns stored energy.

The synchronous rectifier MOSFET has a lower voltage drop than the forward voltage drop across a Schottky diode. This increases converter efficiency which extends battery life in portable equipment.

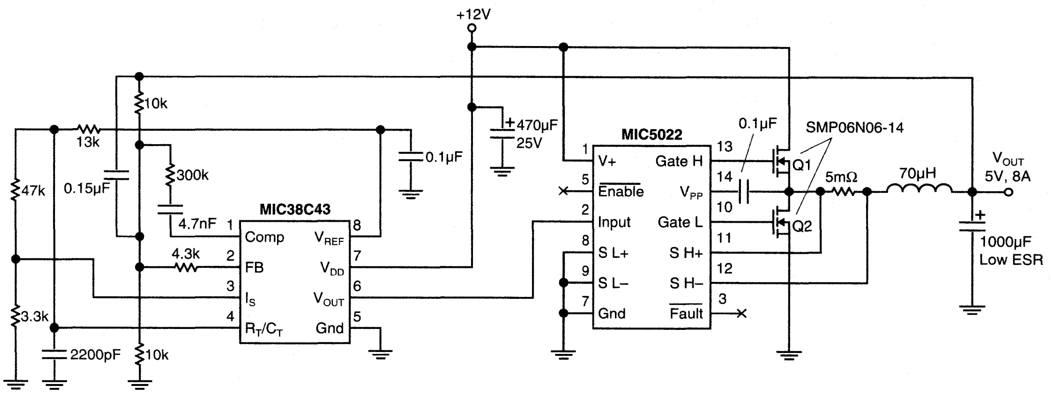


Figure 3. 50kHz Synchronous Rectifier Converter

Application Note 1

MIC5011 Design Techniques

by Mitchell Lee

Introduction

Power MOSFETs are often preferred over bipolar transistors as high current switches. In static switching applications the MOSFET takes no drive power, where a bipolar transistor requires a large base current. Bipolar transistors also exhibit inferior SOA when compared to power MOSFETs. In high side switching circuits N-channel MOSFETs are preferred over P-channel devices owing to the lower cost of an N-channel device for a given "on" resistance. Unfortunately, N-channel MOSFETs are not well-suited in high-side switch applications because in order to fully enhance the MOSFET, the gate must be driven to a potential higher than the drain supply. While a separate supply could be used for the gate drive circuitry, this is unnecessary if a charge pump is used to drive the MOSFET's gate.

A simple charge pump voltage doubler is shown in Figure 1. The object is to charge C1 from the supply, and then transfer its charge to C2. Since C2 is referred to V_{DD}, V_{OUT} will be greater than V_{DD}.

The switch is first connected to ground, charging C1 (through D1) to the supply voltage. Next, the switch is toggled to supply. C1 dumps its charge through D2 into C2. If the process is repeated, C2 will eventually charge to a potential equal to V_{DD}, lifting V_{OUT} to 2 x V_{DD} (neglecting switch and diode losses). If V_{OUT} is used to drive the gate of an N-channel MOSFET, the device will be enhanced by an amount equal to V_{DD}. A similar technique is employed by the MIC5011 high side MOSFET pre-driver to enhance an N-channel MOSFET without the need for a second supply.

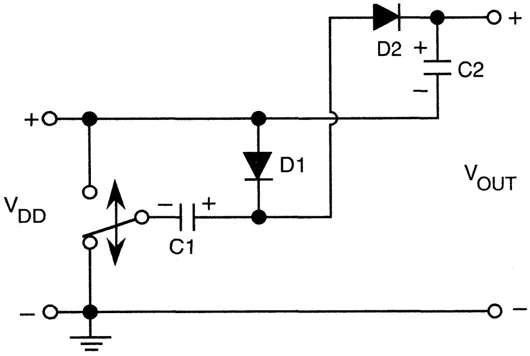


Figure 1. Charge Pump Voltage Doubler

The MIC5011

A simplified block diagram of the MIC5011 is shown in Figure 2. The charge pump is configured as a tripler, and operates at a 100 kHz rate. The oscillator is enabled by the control logic to turn the MOSFET on. For supplies greater than 13V the charge pump can develop in excess of 20V gate drive–more than the average power MOSFET can safely handle. A clamp is included on-chip to limit the gate drive to approximately 12.5V. Figure 3 shows gate drive as a function of supply voltage.

Turning the MOSFET off involves more than just stopping the charge pump oscillator: charge stored on the gate of the MOSFET must be dumped by an active pull-down. The pull-down is turned off when the MIC5011 is commanded to turn the power MOSFET back on.

Small charge pump capacitors (≈100pF) are included on-chip, and provision is made for adding external pump capacitors (pins 6, 7, and 8) where faster switching is desired. A useful increase in turn-on switching speed will be observed for values of 100pF to 1nF. Full enhancement gate rise times range from several hundred microseconds for low supply voltage, a large MOSFET, and no external charge pump capacitors, to less than 50µs for supplies of 12 to 15V and 1nF external charge pump capacitors. The output rise time is very fast when operating on high (15V) supply voltages, as the charge pump drives the MOSFET gate up to V_{DD} within 2µs of the input going high.

The control input turns the MOSFET on for any input greater than approximately 3.5V, so the MIC5011 interfaces directly with CMOS logic, open collector gates, opto-isolators, switches, etc. Interfacing techniques are discussed in greater detail in a later section.

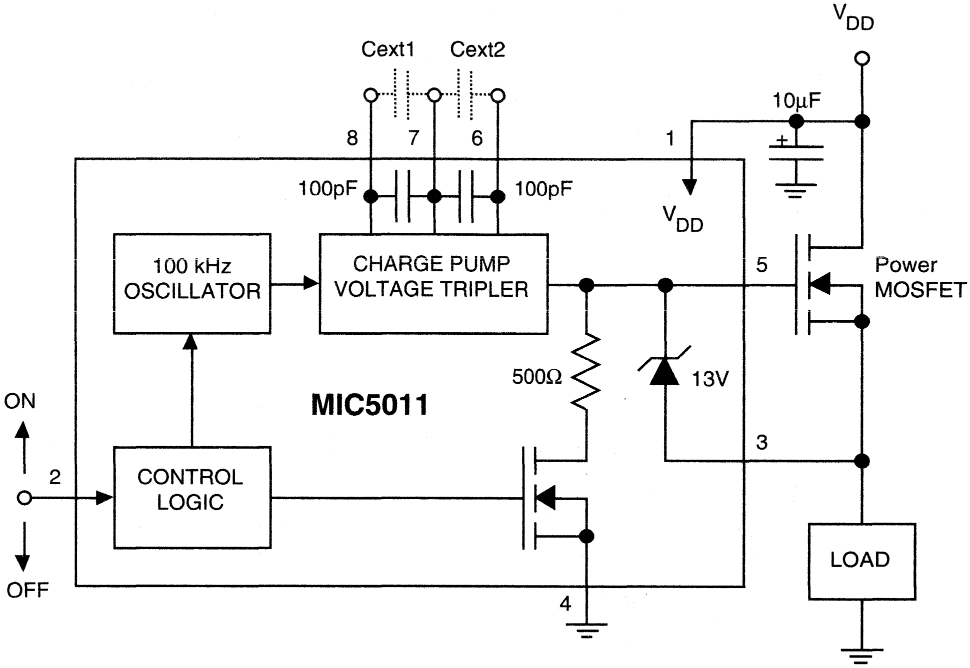


Figure 2. MIC5011 Block Diagram

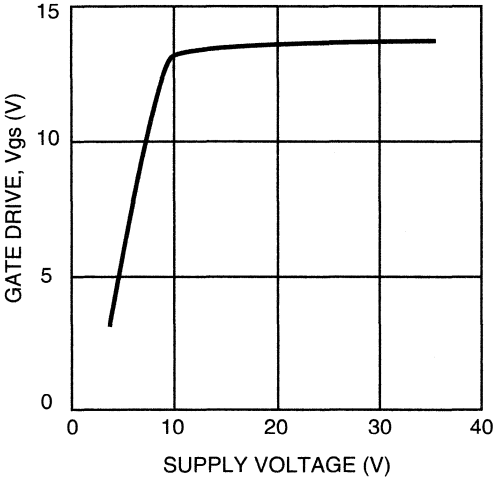


Figure 3. Gate Drive vs. Supply Voltage

Inductive Loads

Many loads such as solenoids, motors, and relays, exhibit inductive characteristics. When an inductive load is commutated a negative voltage spike results (see Figure 4). The spike is clamped by the power MOSFET's source as the MIC5011 holds the gate at ground potential. The load inductance drives the source as far negative as necessary to threshold the MOSFET and force it to carry the load current (typically 5 to 8V below ground). In Figure 4 the spike develops 29V across the MOSFET while it carries the full load current. No clamp diode is necessary since the MOSFET performs this task, but safe operating area (SOA) and the additional dissipation should not be forgotten. SOA is often not an issue, such as in this example where the IRF530 can handle 25A at 29V V_{DS} (the load is only 0.5A).

Motors, which are often considered "inductive" loads present a different problem. A spinning motor continues to generate a voltage after the MIC5011 shuts off. In applications where feedback is employed to control the MIC5011, the motor voltage may interfere with the operation of the circuit. The circuits of Figure 5 and "Push Button Control" of Figure 7 will not work with motor loads.

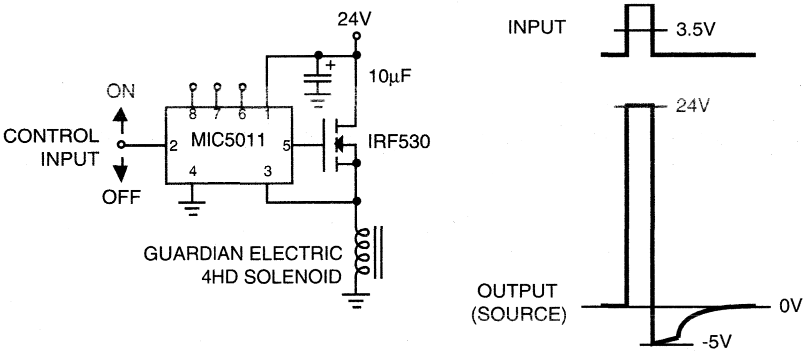


Figure 4. Clamping Inductive Transients

Noise Immunity

In combination with an appropriate power MOSFET, the MIC5011 can control virtually any load that operates on a 4.75 to 32V supply. Aside from the negative spike produced by inductive loads, other pitfalls await the unwary high-side switch designer. For example, ground noise generated when switching a high-power load, especially one with a high inrush current such as an incandescent lamp, can cause oscillations at turn-on or turn-off with slow-moving inputs. Good bypassing is essential; a 10μF aluminum electrolytic capacitor is recommended from supply to ground. Don't confuse charge pump action with spurious oscillations. A slight "ripple" (synchronous with the charge pump clock at pin 8) is normally present on the rising edge of the output; rail-to-rail oscillations at the output are indicative of spurious feedback.

Attention should be paid to layout. For example, the MIC5011 ground pin should be returned to the input signal ground, not the load ground. The MIC5011 is non-inverting, and hysteresis is easily added for any load other than a motor (see Figure 5). Any arbitrary noise margin is added by selecting the appropriate resistor ratio.

5V Operation

The MIC5011 is suitable for use in high-side driver circuits down to about 7V. A low-side driver topology works down to 4.75V, and is suitable for operation on a 5V logic supply. Figure 6 shows a complete low-side driver for use on 4.75 to 15V supplies. Pin 3 is grounded to clamp the gate potential at 12.5V.

Only the power MOSFET breakdown ratings limit the load voltage. In fact, half- or full-wave rectified ac could be applied to the load where economy is important. Don't forget to add a clamp diode to inductive loads.

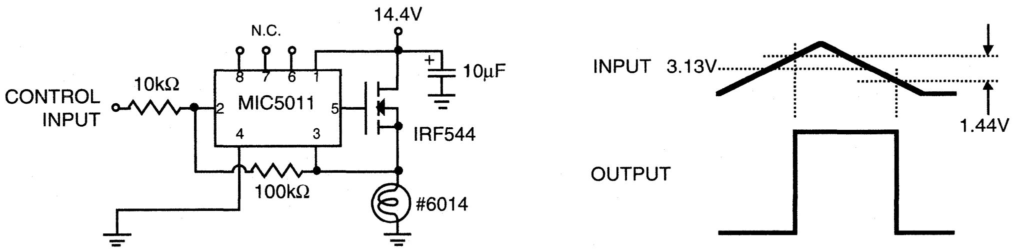


Figure 5. Adding Hysteresis to Suppress Oscillations with Slow-Moving Inputs

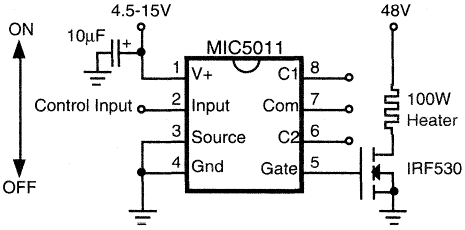
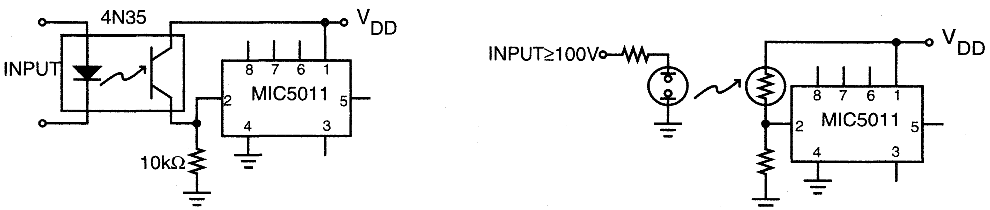


Figure 6. Low-Side Driver

Control Inputs

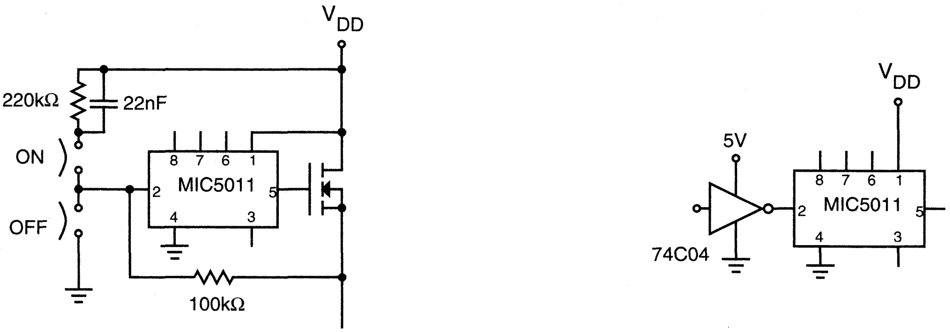
The MIC5011 is easily interfaced to any control signal. The input threshold is approximately 3.5V, and the input current is less than 1µA. Some examples of typical control inputs are shown in Figure 7. For industrial applications, electrical isolation may be desirable for either safety or noise reasons. Opto-isolators are a good choice for this use and with the hysteresis circuit shown, they provide clean switching. High voltages can be sensed and acted upon with a neon light and a light-dependent resistor.

Familiar momentary "ON/OFF" push buttons are easily accommodated as shown. The "ON" button is AC coupled so that any contention between the "ON" and "OFF" buttons is resolved in favor of the "OFF" button. Hysteresis is used to latch the output into the appropriate state. 5V logic commands are interfaced by a CMOS gate. Since the MIC5011 input includes electrostatic discharge protection to the supply, the logic gate should not be powered from a supply higher than V_{DD}.



OPTICALLY ISOLATED INPUT

HIGH VOLTAGE INPUT (POSITIVE OR NEGATIVE POLARITY)



PUSH BUTTON CONTROL

5V LOGIC INTERFACE

Figure 7. Various Interface Circuits

Application Note 3

Driving Halogen Lamps

by Brenda Kovacevic

Introduction

Halogen lamps are preferable to incandescents in many applications due to their increased brightness and longevity. Halogen bulbs are used in many varied applications, such as:

- automotive headlamps
- police vehicle-top flashers
- ambulance, tow truck, fire engine-top flashers
- machine vision
- fiber optic illumination
- large scale lighting displays
- medical and analytical equipment
- school bus flashers

Halogen Lamps vs. Incandescent

A typical incandescent lamp is a glass bulb filled with an inert gas (such as krypton or argon) with a tungsten filament in the center. The filament glows as a potential difference is applied across the terminals of the bulb, giving off light and heat. However, the tungsten molecules are evaporating from the filament to cause this glow; the convection currents of the fill gas carry these molecules to the cooler inner surface of the bulb wall where they are deposited. This decreases bulb output and life in two ways: first, the effective filament diameter is decreased, which increases the resistance of the bulb, and second, the glass is "blackened" by these deposits. This mechanism limits the wattage that a conventional lamp can be used at if a satisfactory lifetime is to be achieved.

A halogen lamp operates in the same manner, except that a small amount of halogen gas has been added to the fill gas; this halogen is normally bromine. When the bulb wall temperature reaches roughly 250°C, the "halogen regenerative cycle" begins to take place. The evaporated tungsten molecules now combine with the free halogens to form a tungsten halide compound with a condensation temperature below the wall temperature. Hence, the tungsten does not settle on the glass wall, but returns to the filament where it is redeposited. This process accounts for the almost infinite lifetime of halogens as compared to incandescents. As this cycle begins at a wall temperature of 250° C, the filament must not only generate light but must also maintain this high temperature. Gas pressure is also higher in a halogen bulb than in an incandescent bulb, which retards the tungsten evaporation and allows operation at higher temperatures and greater efficiencies. This is why they are brighter than normal incandescent bulbs.

Basic Considerations

Although halogens operate similarly to incandescents, they do have some key differences that must be taken into consideration while designing/prototyping with them. Most obviously, it is important not to touch or look directly at them while testing as they do operate at greatly increased temperatures and brightness levels. Tinted safety glasses or sunglasses should be worn while working with halogens. Also, as the condition of the glass wall is crucial to the halogen regenerative cycle, it is important not to leave finger marks or imprints on the glass surface. At best, the imprint will be permanently etched into the glass. At worst, the bulb will explode due to the change in pressure (halogens operate at a high internal gas pressure). To remedy this, any finger marks can be cleaned off the bulb prior to use with acetone or propanol.

As the filament must generate the heat necessary to maintain the wall temperature of 250 ° C, it is important not to operate the lamp at any more than 10% (continuously) below its rated design voltage. As halogen lamps are usually designed to their maximum limits, it is also not recommended that they be operated at a continuous voltage higher than the rated design voltage. Operation above rated voltage is considered the single most damaging factor in terms of lamp lifetime. Unfortunately, since incandescents do not have this restriction, this is commonly overlooked.

Special sockets/holders are also required due to the high temperatures generated. For bulbs rated at 35 Watts or below, heat resistant phenolic (hard plastic) holders are adequate. Bulbs rated at 50 Watts or above require the use of special ceramic holders; two excellent sources of supply for such holders are Gilway Technical Lamp, and GTE Sylvania.

A Simple Power MOSFET Drive CIrcuit

A major consideration when driving halogen lamps is the inrush current generated when starting up a cold filament. This inrush can range from 20 A to100 A and lasts from 10 to100 ms depending on the construction of the lamp. As power MOSFETs have large peak currents and wider SOAs (safe operating areas) than do bipolar junction transistors, they are a good choice for driving halogen lamps. N-channel MOSFETs are more cost effective and have lower on resistances than P-channel MOSFETs. However, N-channel MOSFETs require a significant gate enhancement above the positive rail when driving a grounded load. This necessitates the use of a charge pump.

A MIC5010 family MOSFET predriver and an N-channel power MOSFET make an excellent drive circuit for a halogen lamp. The MIC5010 family of predrivers have an on-board charge pump, which saves space and design time. The MIC5013 also offers an over current sense feature to detect a short circuit and turn off the power FET in time (10μs typical shutdown time) to prevent damage. This overcurrent shutdown can be delayed such that the initial inrush current doesn't cause a false triggering of this protection feature. This can easily be accomplished by adding an RC network to the threshold pin of the MIC5013 such that the initial trip point is very high, but decays with time to a reasonable value (figure 1).

The design equations as shown are used in this circuit to set a final current trip point of roughly twice the current needed by the lamp. R_{TH2} is used to increase the current limit at turn-on to roughly 10X the steady-state value. The choice of C_{TH} governs the time constant or decay of the high initial trip point, and will need to be varied depending on the time constant of the inrush current of the particular lamp used. This design has a 20 ms time constant.

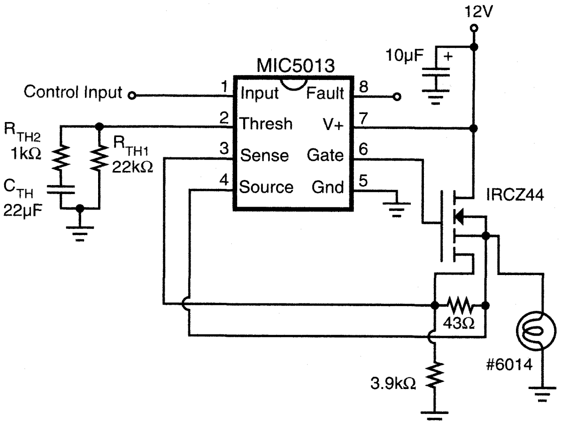


Figure 1. Time-Variable Trip Threshold

$$R_S = \frac{SR\,(V_{TRIP} + 100mV)}{R\,I_L - (V_{TRIP} + 100mV)}$$

$$R1 = \frac{V + SRR_S}{100mV\,(SR + R_S)}$$

$$R_{TH} = \frac{220}{V_{TRIP}} - 1000$$

For this example:

I_L = 30A (trip current)
V_{TRIP} = 100mV

If the lamp being driven by this circuit is pulse-width modulated, extra care must be taken in choosing a PWM frequency and capacitor value. When the device is switched off, the threshold pin appears as an open circuit and C_{TH} is discharged through the two resistors. This is a slower process than the turn-on time constant; any residual charge in the capacitor will act to reducethe current limit. If the device is switched at certain frequencies, (dependent on capacitor value) the capacitor will have time to charge during every cycle, but not to discharge properly. This can lead to erroneous over current shutdown at normal operating currents.

A 75X/Minute Halogen Flasher Circuit

Illustrated in Figure 2 is a 75X/minute, 50% duty cycle halogen flasher circuit, prototyped using six MIC5011s and six 100 Watt halogen bulbs. Over current sensing was not used for this prototype, but could easily be added to each lamp by using MIC5013s per figure 1. The drains of the power FETs, the timing circuit and the MIC5011s were all driven from one power supply.

Potential applications for this design are tops of emergency vehicles such as ambulances and police cars, school bus flashers, turn signals, beacons, and large scale lighting displays.

Government specification KKK – A – 1822C, which governs flashers for emergency vehicles, dictates that a 50% duty cycle with a variation of no more than 3% be used. The timing circuit shown in figure 2 achieves this by first creating a clean 50% duty cycle signal from a 7555 (CMOS 555) at twice the needed flashing frequency, or 150 X/minute. This is accomplished by using equal resistors and diodes, as shown. This clean, but not quite in-spec, oscillator is then fed into a CD4013 D flip-flop configured as a simple "divide-by-two" circuit. This ensures that the duty cycle is 50% with very little error. It is crucial to bypass both chips with a 0.01 μF ceramic disc capacitor from V_{CC} to ground, as system noise will greatly affect the accuracy of this oscillator.

This design has one set of three lamps flashing 180 degrees out of phase with the other group of three, emulating the red and blue halves of a police car-top. This is accomplished easily by using the $\overline{Q}$ output of the flip-flop for the one set and the Q output for the other. The set and reset functions of the flip-flop, tied to ground in this prototype, could be used to provide external control of the flasher (ie, to turn it on constantly or shut it down).

This specification also stipulates that the maximum voltage drop across the entire flasher be not more than 0.5V. The best way to achieve this is by the use of low R_{DS}(on) power FETs.

This is crucial for other reasons as well; the current requirements are very stringent for this system. If the switch loss is not kept to a minimum, the lamps may not receive adequate voltage for turn on. Also, the I^2 R loss associated with the switch creates a great deal of heating that can cause the early demise of the power FET. Chosen for this design was the IRFZ40,which has an R_{DS}(on) of 28 mΩ, a peak drain current rating of 160A, and a continuous drain current rating of 35A. A high peak as well as continuous current rating is crucial as the inrush currents for each lamp may be as high as 100A, and the continuous current will be 5 to 10A. (This of course, varies widely from lamp to lamp). The drawback that this power FET has is that it is only rated to 50V. If a system with high voltage spikes is used, then some form of protection such as power zeners or Transzorbs will be necessary (a FET with a higher peak V_{DS} can be used if a higher R_{DS}(on) can be tolerated).

Prototyping this design requires that the FETs be adequately heat sunk to prevent damage. A large 1/8" thick aluminum heat sink was employed, with the power FETs spaced roughly 2" apart. The final package used should also allow for adequate heat sinking, to prolong the operating life. The lamps should NOT be heat sunk, as they must reach high temperatures to initiate the halogen cycle.

As the lamps are driven in parallel, the currents are additive.Very high currents are generated during the inrush stage; this requires that #10 (or similar) copper wire be used for the V_{CC} and ground connections to the power supply. If the power supply used in prototyping doesn't have the current capability to start up the lamps, a car battery may be used.

Finally, the lamps and MIC5011s must be operated from a common ground. If connected to ground via long wires or to separate grounds, a "ground loop" or situation where one ground is actually at some potential above the other ground may result. Such a resistive ground may result in a current flow that prevents proper lamp turn off between flashes. Use of either a single point ground or a chassis ground to form a ground plane will prevent this. If this is impossible, optoisolators may be effectively used to "open" such ground loops, eliminating this problem (see the Hewlett Packard Optoelectronics Applications Handbook for more details).

A 120X/Minute Flasher Design

As an alternative to the above design, a higher frequency design with longer on-time is shown in figure 3. The design methodology is to prolong lamp life by maximizing on time. This design does not meet the government specification referenced earlier, but is suggested for applications where long service life is essential.

Possible applications include hazard lighting, beacons, large scale lighting displays, emergency vehicle tops not covered by the referenced specification, and large scale lighted store front signs.

Timing is controlled via a simple 7555 (CMOS 555) circuit, set to flash the lamps 120X/minute. The duty cycle is set to insure an on time of 65% and an off time of 35%, which gives a visible flashing while allowing the lamps to remain on long enough to achieve the necessary wall temperatures. Slower flashing frequencies (or shorter on-times at this frequency) will reduce the lifetime of the lamps by allowing them to cool down between blinks. This reduced filament life is due to the lamp completely reheating during each on cycle. If a slower flashing frequency is to be used, the duty cycle should be adjusted such that the lamps are on for the longest portion of the time possible that still allows for visible flashing (i.e., the lamp must be given time to visibly blink). Once again, the 7555 must be adequately bypassed to prevent system noise from interfering with duty cycle and frequency. If greater accuracy is desired, a film capacitor may be substituted for the indicated tantalum.

The power FET chosen for this design is an IRF540, which has an R_{DS}(on) of 77 mΩ , but a peak voltage capability of 100 V. It has a peak drain current specification of 110 A maximum, and a continuous drain current specification of 28 A maximum. Although it does have a higher R_{DS}(on) than the IRFZ40, it is a more rugged part in terms of withstanding systems transients and noisy environments. It will require more rigorous heat sinking than the IRFZ40. FETs with higher R_{DS} (on) that the IRF540 are not recommended for this design due to the high peak currents encountered, and the amount of heat that would be generated.

All lamps are flashing in unison in this design; if this is not desirable an inverter can be used in conjunction with the 7555 such that 180 degrees out of phase flashing of two (or more) sets of lamps can be accomplished.

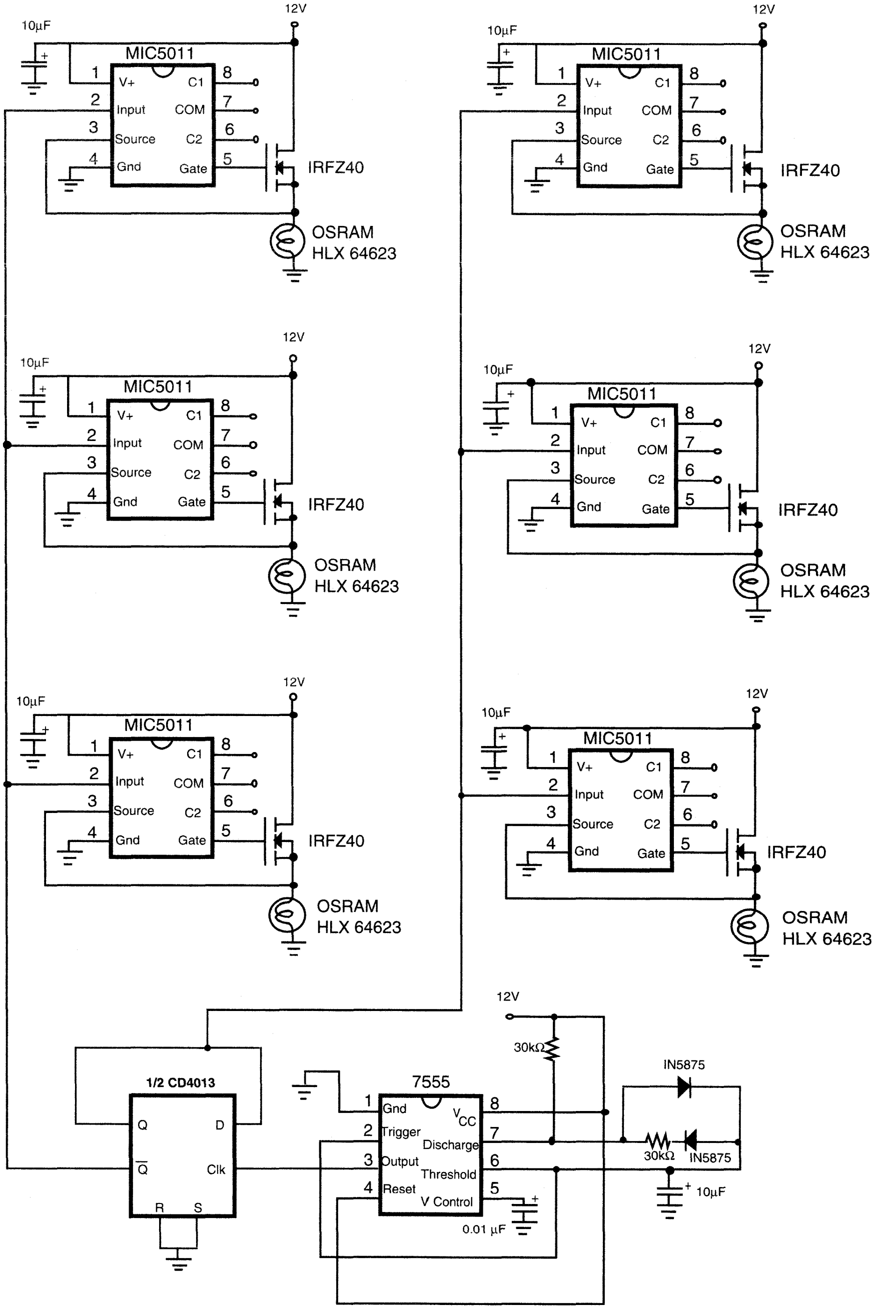


Figure 2: A 75X/Minute, 50% Duty Cycle Halogen Flasher

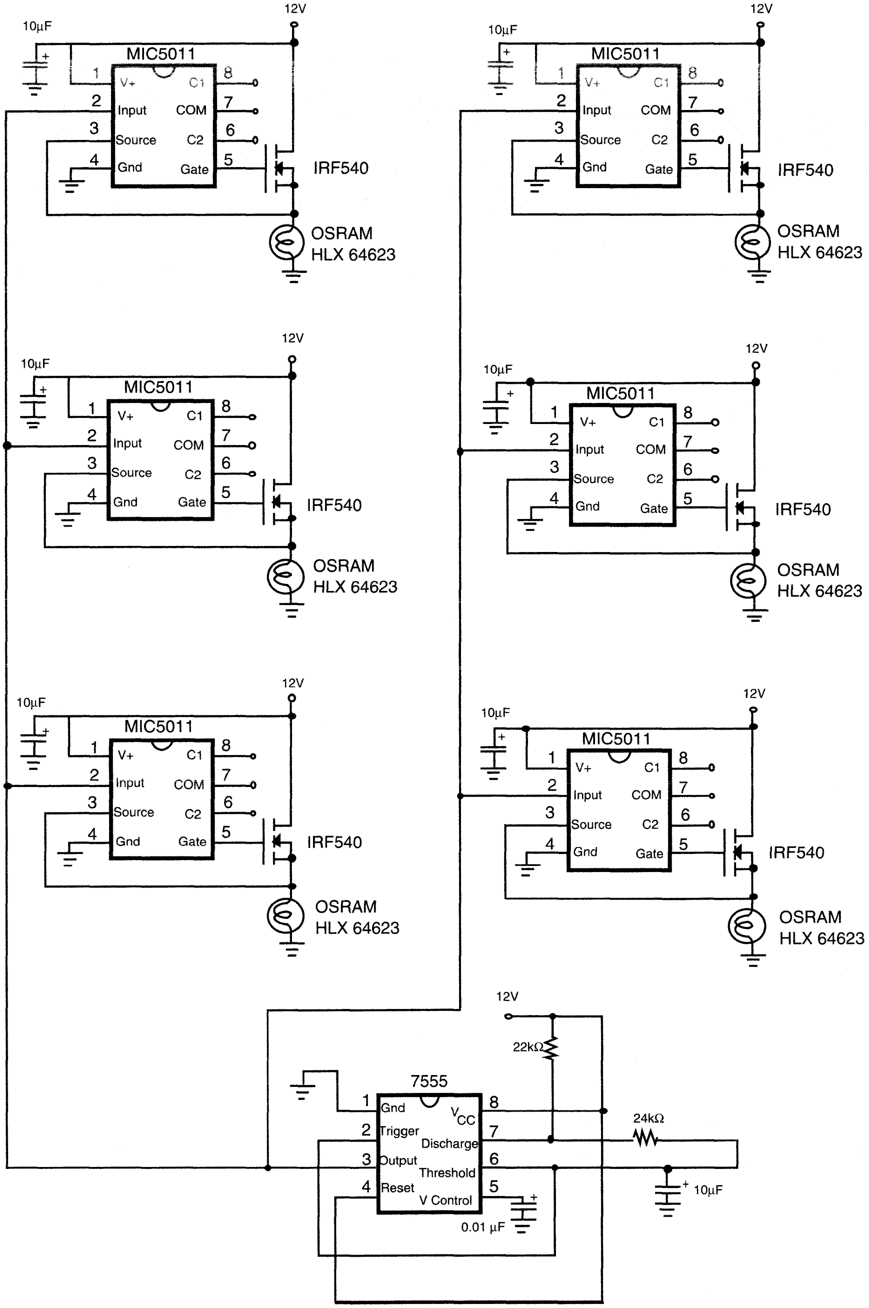


Figure 3: A 120X/Minute Halogen Flasher

MICREL

Application Note 4

Using the MIC5010 Family in Automobile Alarm Systems

by Bob Wolbert

Introduction

For better or worse, automobile alarm systems are a fast-growing segment of the automotive aftermarket. This note briefly describes some of the more common systems, some ideas for future development, and how the MIC5010 family of high side MOSFET drivers can ease their design while improving performance and reliability.

Automotive Alarm Background

The typical automotive alarm system consists of three main blocks: sensors for intrusion detection, the control unit, and output devices for alerting passersby or disabling the vehicle.

Sensors vary from electronic ultrasonic intrusion detectors and audio devices (microphones and audio amplifiers) for vibration and glass breakage detection, through a mercury switch for motion detection, to electromechanical contact switches showing an open door, trunk or hood.

The control unit is the processing device. It enables and disables the sensors and output devices, and knows whether an input is expected or is cause for alarm.

Alarm system output devices range from simple, already installed standard automobile accessories such as the horn and headlamps, through accessory sirens, to more exotic systems such as an alerting transmitter or ignition "kill" switch. Some proposed systems have provisions for cellular telephone output for calling the authorities(!). "Help me! I'm being stolen......! This is a recording....." Figure 1 shows a typical alarm system, including sensors, a control unit, and outputs, and Table 1 shows some typical inputs and actions.

Alarms have three main modes: disarmed, armed, and alert (or emergency). In disarmed mode, the alarm is transparent to the user. When armed, the control unit enables the sensors and awaits input. There are usually two types of alerts—one is immediate, triggered by breaking glass, for example; the

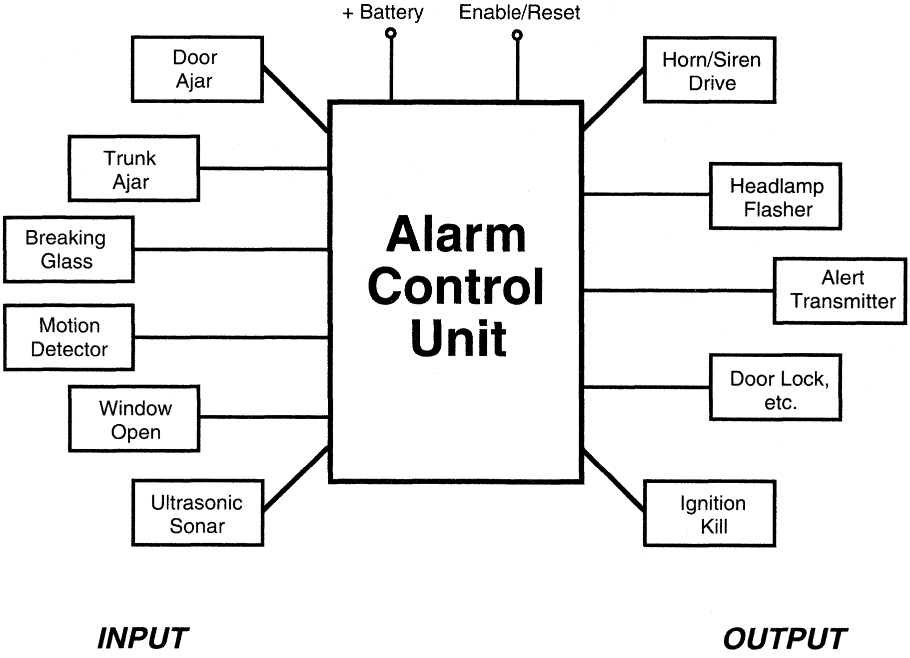


Figure 1. Automobile Alarm System Typical Block Diagram

Table 1. Alarm System Typical Input & Output

Input	Output (Set Mode)	Output (Emergency Mode)
Door Ajar Switch	Raise Window	Horn
Hood Ajar Switch	Lock Door	Flash Headlamps
Trunk Ajar Switch	Close & Lock Sunroof or Moonroof	Siren
Motion detector	Lights off (timer)	Pager/Alert Transmitter
Glass Breakage Detector (audio)	Close Convertible Top	Kill Ignition
Ultrasonic Detector	Enable Alarm	(Phone police)

other is delayed and occurs after a door is opened, allowing the owner time to disarm the system. Output devices are turned on, either immediately or after a reset delay.

Newer systems have an additional mode—a set mode, where the car is readied for safe parking. Upon initialization, the control unit checks the status of door locks, windows, sunroof/moonroof, convertible top, etc., and closes and locks each if necessary. Then normal alarm arming takes place.

Design Philosophy

Like most automotive products, several design goals are specified. Automobile alarms must be small in size, operate from the 12V negative ground battery system, have low standby current drain, operate over a wide temperature range, withstand reversed supply polarity and electrical load dumps, etc.

The control unit is designed for high reliability and low power consumption. CMOS logic is extensively employed. The output devices are moderate to high current drains, and require power switching devices. "High Side", or positive rail, switching is preferred due to the chassis negative ground electrical system.

Some systems use a single system board while others use distributed control, sense, and drive boards. If distributed, communications is provided through serial or 4 bit parallel data busses.

All systems require one or more power switches to cause or control actions in the "real" world by switching anywhere from 1 to 30 Amperes.

Load Switching

Switching 1A to 30A or so loads is non-trivial. Most present-day systems use relays for load control. Relays have several problems associated with their use (see Table 2). A far more ideal switch is the Power MOSFET, with its smaller size, lower cost, higher reliability, and minute drive requirements. Almost all automotive electrical systems have a negative chassis ground. Safety and this "common" point constraint requires that most electrical power switching be done in the positive path—"High-Side" switching is preferred. Thus, alarm system outputs should be high-side controlled. Using a Power MOSFET in the high-side mode requires the FET gate voltage be switched from a low level "OFF" state to an "ON" state where the gate is at a voltage higher than V_{CC}. Generating and controlling this high switching voltage has required large amounts of external circuitry in the past, effectively restricting the Power MOSFET from the automobile. The MIC5010 High Side FET Driver family combines all necessary high side driving functions into a single IC package, and allows the economic and reliable introduction of DMOS to automotive electronics.

The MIC5010 FET Driver Family

The MIC5010 family of high- and low-side FET drivers is ideally suited to this application. Configured as a high side driver, the MIC5010 will take a CMOS control input and drive the gate of an N-Channel MOSFET above the positive supply. The low power MIC5010 family employs CMOS logic for compatibility and a charge-pump voltage tripler with internal capacitors for gate voltage generation. CMOS input compatibility guarantees proper termination for the controller logic, and the power MOSFET can be protected by adjustable current limiting, all controlled by the MIC5010 (or MIC5013). The relatively fast switching speed of the MIC5010 family of drivers reduces the power dissipation of the MOSFET by quickly transiting from the no current, high V_{DS} off state to the high current, low voltage ON state. The benefit is both increased reliability and little or no heat sinking required (depending on the size of power MOSFET employed).

The MIC5010 family has four members, the "full featured" MIC5010, with over-current limiting, fault detection, speed-up capacitor options, and an extra ENABLE input; the no-external-parts MIC5011; the dual driver MIC5012; and the MIC5013, offering over-current protection with fault signalling in an 8-pin package. Table 3 summarizes the features and differences between the variants.

Table 2. Switches for Alarm Outputs

Power MOSFET Advantages vs. Relays

- Extremely low drive current requirement
- Smaller size
- Lighter weight
- Non-mechanical (much longer life)
- No contact bounce
- Lower cost

Power MOSFET Advantages vs. PNP

- No fixed voltage drop
- Extremely low drive current requirement
- Larger Safe Operating Region

MIC5011

The lowest cost member of the 5010 family, the 8-pin MIC5011 requires no external components for high-side driving applications. As shown in Figure 2, when a logic HIGH is forced on the input, the oscillator and charge pump begin their voltage tripling action. The output charges the FET gate capacitor and turns on the FET. Standard Power MOSFETs are damaged if V_{GS} is greater than 20V, but are not fully on unless V_{GS} is around 10V. The internal 12.5V zener diode connecting the FET gate and source limits the voltage multiplication action so that V_{GS} is approximately 12.5V, a value that ensures low ON resistance as well as long FET life.

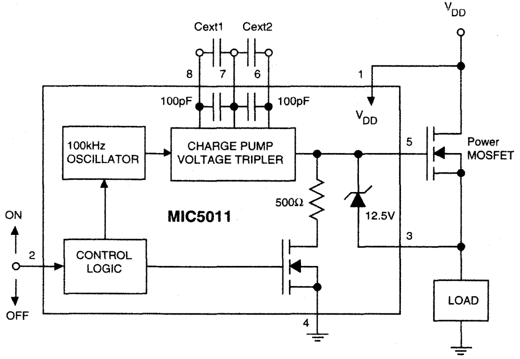


Figure 2. MIC5011 Block Diagram

Inductive loads, such as the horn or headlight relay, give many drivers problems. The MIC5011 takes inductive loads in stride, however, and a "catch" diode to clamp inductive flyback spikes is not even necessary (see Figure 3). As an inductive load is switched off, a negative flyback pulse is applied to the FET source. The MIC5011 holds the gate firmly near ground level, sourcing or sinking current as required. The resultant $+V_{GS}$ (V_G=0, V_S=negative) temporarily biases ON the FET and dissipates the spike (See Application Note 1, *MIC5011 Design Techniques*, for full details).

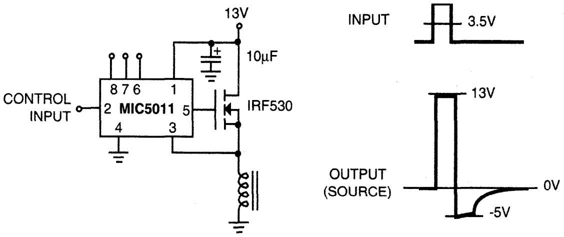


Figure 3. Inductive Spike Clamping

MIC5012

The MIC5012 is a dual version of the MIC5011. Two completely independent drivers control two loads from one 14-pin (16-pin surface mount) package. Operationally, each half of the MIC5012 is identical to the MIC5011.

MIC5013

When over-current protection is required, the 8-pin MIC5013 should be used. In a basic application, MIC5013 circuitry is similar to the MIC5011 or MIC5012. However, by adding four resistors, the MIC5013 can act as a circuit breaker; its output switches off if load current exceeds a user-determined value. As shown in Figure 4, the user has three design variables for limit selection, allowing a small sense resistor, R_S, for best efficiency. R_{TH} sets the internal voltage comparison threshold; current limit is inversely proportional to R_{TH}. R_1 and R_2 may be eliminated in many applications where the load is generally resistive and open loads are not expected. See the MIC5013 datasheet for full details on flexibly programming the current trip point.

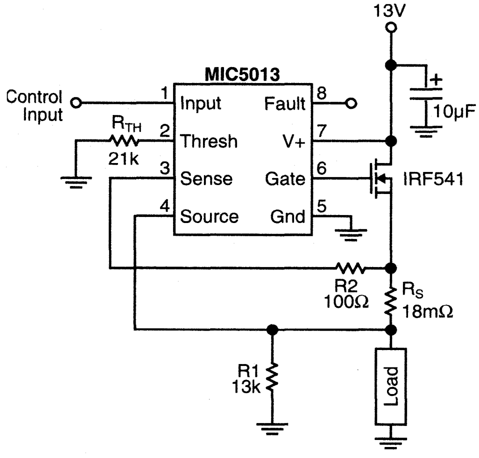


Figure 4. Current Protected Driver

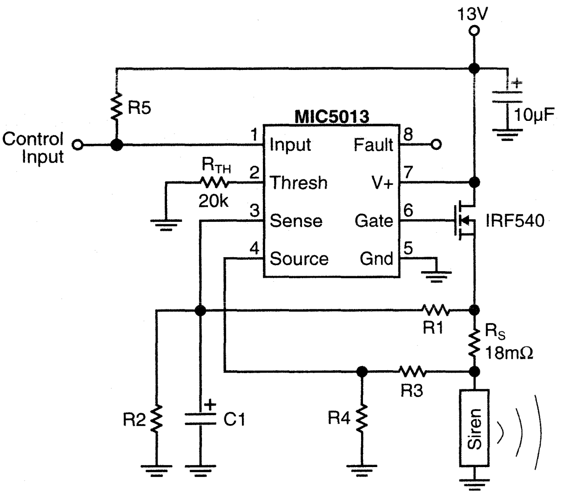
Automotive Alarm Hint: Remote Siren Drive with Automatic Shutdown

High security alarm systems provide an alert mechanism if the control unit is compromised. Figure 5 shows a circuit that :

- Is controlled by a single small gauge wire
- Is remotely mounted, perhaps under the hood
- **Will automatically switch ON if the control line is cut**
- Will reset itself after a time delay
- Requires only a MIC5013, a FET, and a few passive components

The circuit is built on a small board, and may be attached to the siren (or other output device) directly. The MIC5013 is configured with a direct battery line, ground and a single control line. If the alarm output unit is compromised by severing the control line, pull-up resistor R_5 enables the MIC5013, which activates the FET, and the siren sounds.

Basically, the circuit operates in a standard current detect mode. The difference is that an additional capacitor, C_1, begins to charge through R1 as soon as the alarm activates.



Circuit sounds immediately upon Control Input triggering or Control Input disconnect (cut) and will reset after t ≈ 120 seconds.

R1 = 91kΩ
R2 = R3 =100 kΩ
R4 = 68kΩ
R5 = 470kΩ
C1 = 100µF

Figure 5. MIC5013 Driver With Automatic Sound/Reset

As the voltage across C_1 exceeds the voltage on Pin 4 plus the V_{TH} set by R_{TH}, an over-current condition is simulated, and the output is shut down. Reset occurs with control line cycling or power interruption. This means that the siren will sound once, for a fixed amount of time, and then silence itself in accordance with some local laws and good engineering practice (not to mention preventing total battery discharge).

Because the MIC5013 takes almost no current in the OFF or standby modes (0.1µA, typical), both it and the driven FET can be directly connected to the battery.

Conclusion

The automotive alarm marketplace demands smaller and less expensive yet more reliable methods for output load drive and control. In alarm applications, where standby current drain is paramount, the low power MIC5010 series allows easy interface with low power CMOS logic control while providing all necessary drive control for small, efficient Power MOSFETs. For applications where the output devices are original equipment—horns and headlamps, for example—and the control unit drives the stock horn relay or headlamp relay, the MIC5011 or MIC5012 dual FET drivers are suggested. Where high current loads are directly driven, the protection offered by the MIC5013 is attractive.

The winning combination of MIC5010 drivers and Power MOSFET switches enables configuring a simple, hence reliable, and rugged alarm system.

Table 3. Comparing the MIC5010 Family Options

Device	Features
MIC5010	• Over Current Sensing • Fault Flag Output • 14-Pin DIP or Surface Mount Packages • Provision for Optional Speed-Up Capacitors • Over Current Enable Pin
MIC5011	• No External Components Required • Provision for Optional Speed-Up Capacitors • 8-Pin DIP or Surface Mount Packages
MIC5012	• Dual High Side Driver • No External Components Required • 14-Pin DIP or 16-Pin Surface Mount Packages
MIC5013	• Over Current Sensing • Fault Flag Output • 8-Pin DIP or Surface Mount Packages

Application Note 5

Solid State Circuit Breakers

by Brenda Kovacevic

Introduction

Until very recently, few alternatives to electromechanical and magnetic circuit breakers existed. Designers were forced to live with such undesirable characteristics as arcing and switch bounce (with corresponding noise and wear), while accomodating large unwieldly packages in their high power systems.

Solid state technology applied to this traditional device has resulted in circuit breakers free from arcing and switch bounce, that offer correspondingly higher reliability and longer lifetimes as well as faster switching times. A typical solid state circuit breaker will switch in a matter of microseconds, as opposed to milliseconds or even seconds for a mechanical version.

New solid state products currently on the market utilize the many benefits associated with power MOSFETs to deliver a product far superior to earlier silicon versions. Power MOSFETs offer low on resistances (as compared to bipolar transistors), low voltage drops, low EMI, faster switching times and good thermal stability of key parameters.

However, two key advantages that the electromechanical devices have over the solid state versions are simplicity and low cost. For example, a simple commercial circuit breaker relay combination will sell for $4.00 to $6.00 in low volume . The existing solid state circuit breakers will run from several times that amount, and typically include many bells and whistles that the average designer can do without. This cost difference is somewhat less in military versions, as the mechanical devices must also undergo extensive testing.

One reason for the corresponding complexity of the silicon based systems is the power MOSFET drive circuitry required. If N-channel FETs are to be used (N-channel FETs are preferable to P-channel as they have roughly 2.5 times lower R_{DS} (On) and correspondingly lower cost), a charge pump or voltage tripler must be supplied to provide sufficient gate enhancement to turn on the FET. This involves supplying an oscillator as well as the necessary diodes and capacitors, which definitely take board/hybrid package space.

A simple, inexpensive solid state circuit breaker can be made using the MIC5013 power MOSFET predriver with overcurrent sense. This predriver was designed for driving N-channel FETs, and has an on-board charge pump to provide sufficient gate enhancement. This eliminates the issue of providing this enhancement externally; providing a one component solution to what once consumed extensive "real estate".

As any size FET can be driven by the MIC5013, almost any load can be accomodated. High inrush or inductive loads are driven with equal ease, greatly expanding the realm of possibilities for these circuit breaker topologies.

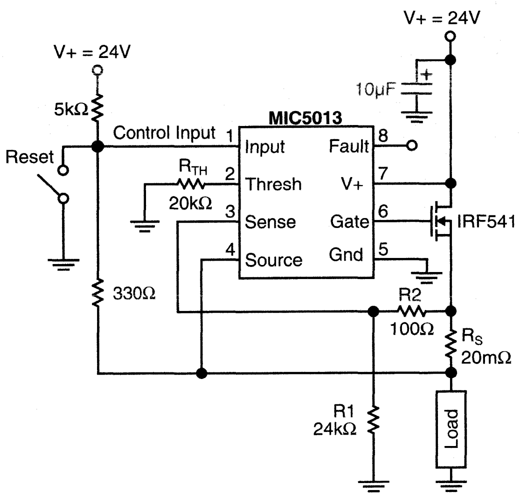
An internal comparator is used to sense an over-current condition; this feature allows the use of this product as a circuit breaker that can be programmed to trip at a specified current via choice of an external sense resistor. An overcurrent flag provides this information externally, allowing easy digital interface /control of the device. This feature allows its use in more complex, remotely controlled designs such as those currently used in high reliability applications.

Using this highly versatile device, four circuit breaker configurations have been devised; a low parts count, low cost externally resettable version, a minimal parts count remotely resettable version with indicator, a minimal parts count automatically resettable version, and a full blown power controller design with Z8™ microcontroller interface. Typical applications for the first three versions include a variety of commercial, industrial and military applications, such as battery pack circuit breakers/current limiting, electric vehicles, and heavy machinery. The latter design is useful in high end applications such as military avionics or industrial automation. It offers a substantial cost savings over the currently available remotely controllable electromechanical units, as well as most currently available hybrid designs of this complexity.

Minimum Parts Count Configuration

Figure 1 illustrates the most basic configuration. The overcurrent trip point is set via the design equations in this figure. The current sense operates via a comparator which compares the voltage on the sense pin to an offset version of the voltage on the source pin. The current on the threshold pin, set by choice of R_{TH}, is mirrored and returned to the source by a 1 kΩ resistor.

This sets the trip voltage of the comparator. When a fault condition occurs, an internal current sense latch is set, which turns off the power FET. The control input pin must be toggled low then high by the reset switch before the FET will be switched on again (after the short has been removed). A 330kΩ resistor is provided to hold the input low and keep the FET off until the circuit is reset. Advantages of this topology are its simplicity and correspondingly low cost.



$R1 = V+ / 1mA$

$R2 = 100\Omega$

$R_S = (100mV + V_{TRIP}) / I_L$

$R_{TH} = (2200/V_{TRIP}) - 1000$

For this example:
$I_L = 10A$ (trip current)

$V_{TRIP} = 105mV$

Figure 1: Basic Circuit Breaker/Switch Configuration

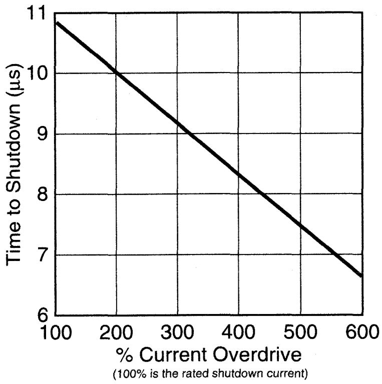


Figure 2: Shutdown Time vs. % Current Overdrive

Response Time

Figure 2 illustrates an advantage that is common to all MIC5013 based topologies: fast response times. A graph of shutdown time versus current overdrive is shown. The data was taken using this simple topology without the 330kΩ pulldown resistor, however, all configurations (with similar loads) will have a similar response as it is mostly a function of device parameters. (Note: This data was averaged from a small sample size; about 5-10% variation from this line may occur).

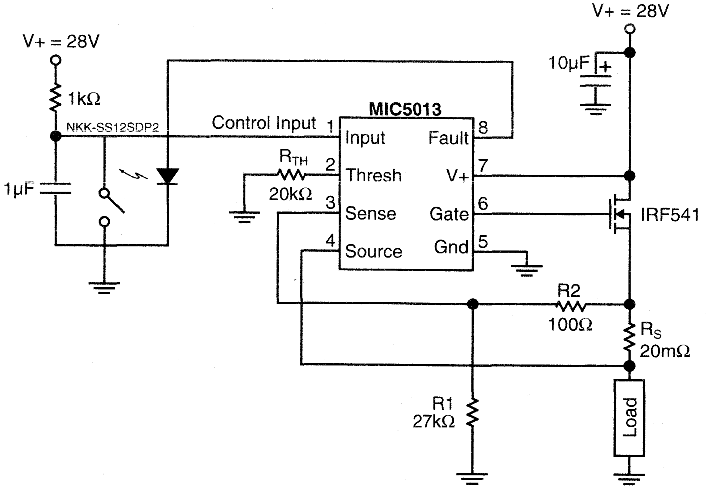


Figure 3: Remotely Resettable Circuit Breaker

Response times in the order of µs means that a short circuit can be detected in time to prevent extensive damage, and is an improvement of an order of magnitude over electromechanical circuit breakers.

Remotely Resettable Configuration

The circuit breaker configuration of Figure 3 is designed to be used for applications requiring remote indication and reset capability. When the breaker is tripped, the fault output pin switches high (to a diode drop below the positive rail). This output is used to drive a remotely located LED. (If an incandescent lamp is desired, the fault output should be used to drive a power FET switch that could withstand the inrush generated). Resetting of the breaker is accomplished by toggling the control input with a remotely located switch. If the distance between the control point and the breaker is large, an optocoupler is recommended to open any ground loops that may occur. Many switch manufacturers offer a package that combines both the switch and the indicator while providing internal isolation, making this circuit even more compact. Shown here is the NKK-SS12SDP2-LE, a small slide switch suitable for instrument or control panels where space is at a premium.

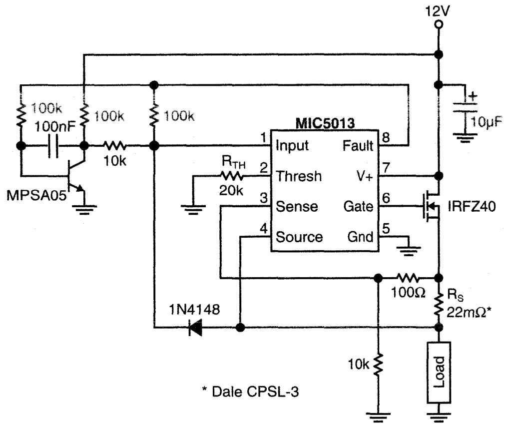
Potential applications for this circuit include use as remotely controlled circuit breakers in aircraft with the indicator/switch located in the cockpit, industrial control panels, heavy machinery, and robotics.

Automatically Resettable Configuration

The third circuit,shown in Figure 4, is useful when automatic resetting is desired. This is accomplished by adding feedback from the fault pin back to the control input. A simple Miller integrator circuit is used to test the load every 18 ms until the short is removed. When the short condition no longer exists, the circuit latches on and operates as before. Although no reset button is necessary, an indicator could be added to the fault line if remote notification of a short circuit condition is desired.

The beauty of this configuration is that no human intervention is necessary once a short has occured. A possible drawback is that the gate does briefly turn on every 18ms to test the load. However, if the short still exists, it shuts down again in 10µs. This time duration is short enough to be acceptable in most applications.

Potential applications for this circuit include industrial automation, automotive circuitry, motor drive (stall sensing), and protection for power supplies/battery packs.



* Dale CPSL-3

Figure 4: Automatically Resettable 10 A Circuit Breaker

Microcontroller Based Power Controller

A current trend in power electronics is the combination of intelligent power circuitry with microcontrollers; a so called "brains and brawn" combination. The power circuitry provides, in this case, the high current drive and circuit breaker function. The microcontroller can be used to make decisions in the event of a short, i.e., it can drive a warning signal, shut down other components of the system, or switch in a reserve or auxiliary motor (or pump, fan, heater, etc.).

An example of a microcontroller based power controller designed and built using the MIC5013 is shown in Figure 5. Here, three functions are monitored by the microcontroller; condition of the power supply (low or off), open load, and shorted load. If any of these three conditions exist, power is taken from the load and the control input of the MIC5013 and an appropriate LED is turned on. An additional LED is used to flag a hardware fault when an impossible condition (such as an open and short load) are flagged to the microcontroller.

Under normal operation (no fault condition exists), the microcontroller provides drive to the MIC5013 control input, and keeps bit 4 on I/O port 2 (P24) low, supplying drive to an LED signifying that conditions are "OK". (Note: a buffer may be necessary, as the MIC5013 is not TTL compatible).

The circuit breaker subsystem operates similarly to the other cases described earlier, however, all resetting is accomplished by the microcontroller. When the fault output goes high, indicating a short circuit has occurred, one input of the NOR gate is pulled high, causing a low output on the NOR gate. This toggles P32 (bit 2, port 3,) low, initiating the cond_init subroutine (see Figure 6 for Z8 code). This subroutine scans P20-P22 to determine which flag caused the NOR gate to go low. Upon determining that it was P20, P35 is brought low, providing the necessary toggling of the MIC5013 control input such that operation can resume once the short is removed (The MIC5013 current sense comparator output is connected to an internal latch which must be reset). Power has already been removed from the gate output of the MIC5013 by its internal current sense mechanism, shutting down the power FET and corresponding load. P26 is pulled low, lighting an LED that signifies that a fault has occurred.

When the fault is removed, the Z8 will restore power to the "OK" LED, shut down the "Overcurrent" LED, and restore power to the control input of the MIC5013. No isolation between the microcontroller and the MIC5013 was deemed necessary in this case, as the fault output is current limited by the voltage divider resistors, and tends to be fairly clean.

Open load detection is accomplished via the use of an LM301 op amp configured as a comparator. The LM301 was chosen for this application as it has more headroom than most op amps. The inverting input of the LM301 is set to 25 mV below the positive rail, which the non-inverting input will never reach unless the load is removed. The output of the op amp/comparator is fed to the HCPL-2602 optocoupler with the enable pin tied high. Under normal conditions, the output of the HCPL-2602 will be low; it toggles high in the event of an open load condition. The HCPL-2602 is also used to provide isolation between the digital and analog portions of the circuit. A high output from the HCPL-2602 causes the NOR gate to switch low, triggering the cond_int subroutine. The microcontroller reacts as before, removing power from the MIC5013 control input, and flagging the user that a problem has occurred.

The 1000 pF capacitor placed between the inverting and non-inverting inputs of the LM301 along with the 100 kΩ resistor serves as a noise filter, which prevents oscillations. Another way of doing this is to provide a small amount of hysteresis from the output back to the non-inverting input (See reference 4).

Low power detection is accomplished via the use of an optocoupler, the HCPL-3700, that also contains a Schmidt trigger. This provides hysteresis, allowing us to shut the system down when power reaches roughly 50% of rated value, and not turn back on again until we are at roughly 75% of rated value (These levels are chosen via selection of input resistor values and can be changed to meet the requirements of most systems. See the Hewlett-Packard Optoelectronics Designer's Manual for more details). Again, the optoisolator also provides isolation between the digital and analog portions of the circuit.

Shutdown and resetting of the system in the case of a low power condition is accomplished as before, by triggering the cond_int subroutine, which in turn scans port 2 to find the appropriate cause for the trigger and lights the corresponding LED.

If subroutine cond_int detects an impossible combination of conditions, i.e. short and open, a hardware fault has probably occurred. The microcontroller then lights an indicator LED attached to P34, and hangs up until the problem is removed.

The emergency override feature allows a pilot (or vehicle commander) to keep the system alive even though a short circuit has been detected. In a combat or other emergency situation, the equipment could be kept operating until the short circuit causes the FET to blow.

A switch located in the cockpit is used to provide this function. When it is depressed, IRQ2 (P31) is pulled low, causing the internal timer/counter to begin an 11 ms switch debounce count. If IRQ2 is still low (switch is still depressed) after 11 ms, then internal interrupt IRQ5 is activated on time out. Interrupt service routine T1_int then keeps power flowing to the control input of the MIC5013 , and toggles P23 high. This turns on the base of Q1, which pulls the signal on the sense input of the MIC5013 to ground, disabling the current sense function of the part. (If a 14-pin MIC5010 is used instead of the MIC5013, an external inhibit pin is available).

A key advantage of this circuit is that 2/4 interrupt lines and one complete I/O port is left unused. This would allow the microcontroller to be used for other functions in addition to power management.

If this is to be a dedicated power management system and the unused I/O has no other potential purpose, then some ideas for modifications include using an alphanumeric display instead of indicator LEDs, and including a self test mode with indicators on power-up.

If a PWM'ed load is to be used, the Z8 can be used to provide a variable frequency, variable pulse width signal by using the internal counter/timer registers (See the Z8 Design Manual for details). In this case, P36 should be connected to the control input of the MIC5013 instead of P35, and switch debounce will have to be performed in hardware instead of firmware. The MIC5013 can be switched up to a maximum frequency of 20kHz. Digital closed loop motion control can also be performed using the controller.

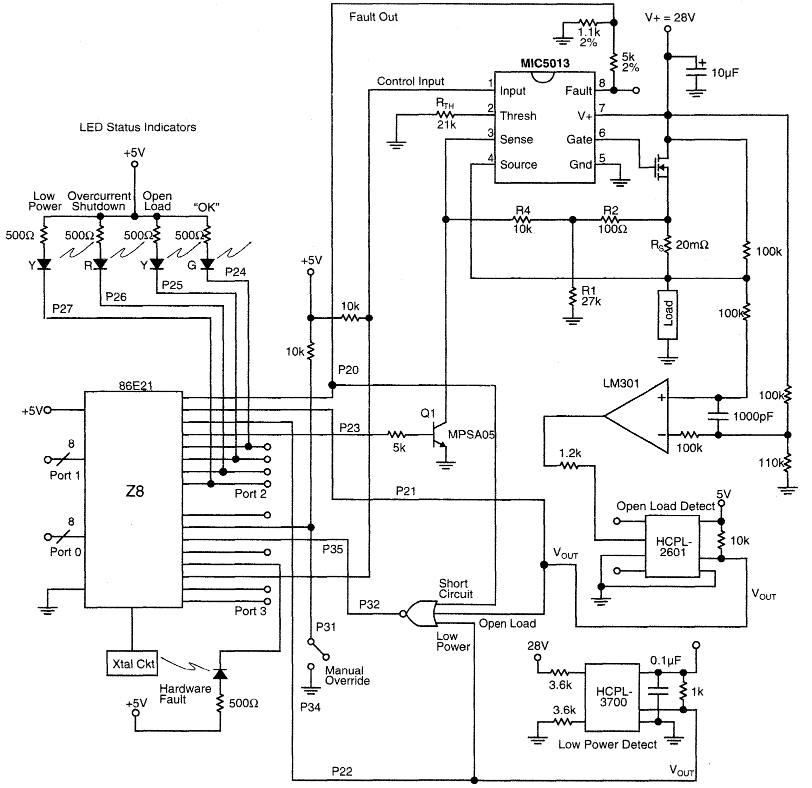


Figure 5: Z8 Based Power Controller

Summary

The MIC5013 MOSFET predriver with over current protection brings a whole new dimension to the world of power management with its versatility, ease of use, and quick response times. Four different lab tested circuit breaker configurations were presented and discussed; a minimum parts count version, a remotely resettable version, an automatically resettable version, and a complete microcontroller based power management system. Many more unique configurations are possible; a configuration to fit most needs can potentially be designed using the MIC5013.

References

1. The Z8 Design Manual, Zilog, 1985

2. The Optoelectronics Applications Manual, HP Optoelectronics, McGraw-Hill, 1981

3. Micrel Databook, 1995

4. Pease, R. A. , Troubleshooting Analog Circuits , Butterworth - Heinemann, 1991

5. Faber, Al and Kennelly, Bob, "Hybrid Power Controller Outperforms Conventional Circuit Breakers", *PCIM ,* November 1990, pg. 40

6. HP Application Note 1004, "Threshold Sensing For Industrial Control Systems With the HCPL-3700 Interface Optocoupler"

7. Frank, Randy and Psaenich, Al "Surviving Short Circuits", *Machine Design* , March 8,1990, pg 89

8. Conner, Margery, "Devices Let Aircraft Use Higher Voltages", *EDN ,* August 17, 1989, pg 59

9. asmS8™ Super 8/Z8™ Cross Assembler User's Guide, Zilog 1985

Figure 6: Z8 Microcode

```
.title CIRBR.S
.page 53                            ; set maximum lines/page to 55
.title                      CIRCUIT BREAKER CODE
;*****************************************************************************************
;          TITLE                    P32.S
;          PROGRAMMER:              BRENDA KOVACEVIC
;          PURPOSE: THE FOLLOWING PROGRAM ENABLES THE Z8
;            MICROCONTROLLER TO RECEIVE DIAGNOSTIC INFORMATION
;            FROM A  SOLID STATE POWER CONTROLLER AND FEED THIS
;            INFORMATION BACK TO THE USER. FOUR INDICATIONS
;            ARE GIVEN; SHORT CIRCUIT, LOW POWER, OPEN LOAD,
;            AND 'OK' CONDITIONS ARE FLAGGED VIA THE USE OF LEDS
;            DRIVEN DIRECTLY BY THE Z8.
;
;*****************************************************************************************


;*****************************************************************************************
;                             EQUATES AND VARIABLES
;*****************************************************************************************

          dbnce_actv: .EQU    R0            ; working register r0 is the '
                                            ; 'debounce timer active' flag


;*****************************************************************************************
          .BEGIN
          .ORG        %8400
          int0:       jp       null_iret    ; unused interrupt
          int1:       jp       null_iret    ; unused interrupt
          int2:       jp       null_iret    ; unused interrupt
          int3:       jp       null_iret    ; unused interrupt
          int4:       jp       null_iret    ; unused interrupt.
          int5:       jp       T1_int       ; Counter/Timer 1 interrupt.


; First user-available location in RAM is at %8500
          .ORG %8500

start:
          jp          init                  ; jump around ascii data,
                                            ; strings,...

 .ascii 'created 2/26/91 by BLK.'

init:
; 1) Set up interrupts:  Interrupts are configured here.

          di                                ;
          clr         imr                   ; mask out all interrupts
          clr         irq                   ; clear out any pending
                                            ; interrupts
          ei                                ; initialize interrupt request
                                            ; enable latch.
          di
          ld          IPR,#00001000b        ; irq5 has highest priority

          ld          IMR,#00100000b        ; enables interrupt 5(internal
                                            ; timer interrupt);masks off
                                            ; unused interrupts

;  2) Initialize Register pointer and stack:
          srp         #%50                  ; put scratch "working register"
                                            ; set at %50-%60
          ld          SPH,#%A0
          ld          SPL,#%00              ; top of external memory is the
                                            ; top of the stack
;  3) Initialize I/O Ports:

          ld          P01M,#11010011b       ; port 0 address and data, port 1
                                            ; output, external stack, normal
                                            ; timing
          ld          P2M,#00000111b        ; P20-P22 inputs; P23-P27
                                            ; outputs
          ld          P3M,#01000000b        ; Port 2 pullups open drain,P30-
                                            ; P33 int. inputs, P34-P37
                                            ; outputs  : P31 = Tin
;  4) Initialize Counter/Timers.

          ld          PRE1,#10000010b       ; set prescaler to 64 (decimal),
                                            ; single pass
          ld          T1,#10000000b         ; loads 256 in the timer, allows
                                            ; 11 ms count
          ld          TMR,#00101100b        ; load and enable t1, triggered
                                            ; internal clock mode
```

```
; 5) Initialize flag.
        clr     dbnce_actv              ; start with a clean debounce
                                        ; timer flag

; 6) All set up.  Enable interrupts and go!
        ei                              ; enable interrupts

status_check:
        tm      P3,#00000100b           ; check for bad condition
        jr      z,chk_pwr_cond          ; active low

good_status:
        ld      p2,#11100111b           ; sends power to 'OK' LED
        ld      p3,#00110000b           ; sends power to control input
                                        ; of MIC5013
        jr      ovrd_chk                ; jump over subroutine call

chk_pwr_cond:
        call    cond_int                ; check power circuits
ovrd_chk:
        tm      dbnce_actv,#1           ; If the emergency override has
                                        ; already been pressed, skip the
                                        ; test for emer. override.
        jr      nz,status_check         ; go back and start status check
                                        ; over the timer's already
                                        ; running
        tm      P3,#00000010b           ; Has the emergency override
                                        ; (P31) been pressed?
        jr      z,emer_ovrd             ; If yes, trigger debounce timer

        jr      status_check            ; no - start over again looking
                                        ; for status
emer_ovrd:
        or      dbnce_actv,#1           ; set debounce timer active flag
                                        ; to indicate that the timer's
                                        ; rolling.
        or      TMR,#00100011b          ; start debounce timer rolling
        jr      status_check            ; continue to wait for something
                                        ; else to happen


;****************************************************************************************************
;                       ****************************
;                       Subroutine cond_int
;                       ****************************
;****************************************************************************************************
;Subroutine:  P32 low , signals power malfunction
;Function:    Is tripped for any of the three malfunction conditions;
;Action       Subroutine cond_int reads port 2 to determine which
;             condition exists, and toggles the appropriate diagnostic bits
;             of port 2 or 3.
;************************************************************************************************
cond_int:

short_test:
        tm      P2,#00000001b           ; see if P20 is high (short
                                        ; condition)
        jr      z,open_test             ; jump if no short
        and     P3,#11011111b           ; reset bit 5 of P3 to shut down
                                        ; MIC5013
        ld      P2,#10110111b           ; reset P26 to turn on
                                                    ; overcurrent LED
                                        ; fall through to test open load
                                        ; condition, open and short
                                        ; coincident indicates h/w fault
open_test:
        tm      P2,#00000010b           ; see if P21 is high (open load
                                        ; condition).
        jr      z,low_test              ; jump if no open load condition

        tm      P2,#00000001b           ; Do we also have a short
                                        ; condition (illegal)?
        jr      z,open_only             ; Jump if not

        jr      hw_fault                ; Catastrophic h/w failure -
                                        ; indicate separately.
open_only:
        and     P3,#11011111b           ; reset P35 to shut down the
                                        ; MIC5013
        ld      P2,#11010111b           ; reset P25 to turn on "Open
                                        ; Load" LED
                                        ; fall through to low voltage test
```

```
low_test:
        tm      P2,#00000100b           ; see if P22 is high (low power
                                        ; condition).
        jr      z,end_cond_int          ; jump if no low-voltage fault

        and             P3,#11011111b   ; reset P35 to shutdown the
                                        ; MIC5013
        ld              P2,#01110111b   ; reset P27 to turn on "low
                                        ; power" LED
        jr              end_cond_int    ; done with power condition
                                        ; tests
hw_fault:
        and             P3,#11001111b   ; reset P34 to turn on "h/w fault"
                                        ; LED - we have a circuit
                                        ; breaker malfunction - and
                                        ; turn off the MIC5013!
        or              P2,#00010000b   ; turn off the "OK" LED, we have
                                        ; a HW fault and things are
                                        ; NOT OK!!

end_cond_int:
        ret

;************************************************************************************************
;Interrupt:  Emergency Override Switch Timer Interrupt
;Function:   Keeps the MIC5013 alive while shorted in emergency situations.
;Action:     When the manual override switch is depressed, internal timer
;            T1 begins counting for 11 ms (see main). At the end of this debounce
;            routine, interrupt IRQ5 is asserted.  This takes priority over the cond_int
;            subroutine, and keeps the control input to the MIC5013 on while
;            disabling the current sense by pulling the sense pin
;             to ground through transistor Q1.
;************************************************************************************************
T1_int:
        di                                      ; disable interrupts
        and             dbnce_actv,#0           ; reset 'debounce active' flag
        and             irq,#11011111b          ; Reset the interrupt source

        tm              P2,#00000001b           ; Don't take action if there is no
                                                ; short
        jr              nz, end_T1_int          ; Bail out.

        tm              P3,#00000010b           ; Check to see if override switch
                                                ; is still depressed
        jr              nz,end_T1_int           ; If not, then it was just noise
                                                ; triggered
                                                ; go back to main.
        or              P2,#00010000b           ; Sends power to Q1 to disable
                                                ; current sense
        or              P3,#00100000b           ; Makes sure the control input is
                                                ; still on
end_T1_int:

        ei
        iret




;************************************************************************************************
;Interrupt:  Null interrupt
;Function:   Intercept any spurious interrupts.
;Action:     None. Just return from the interrupt.
;****************************************************************************************************
null_iret:
        and             irq,#00100000b          ; Reset any spurious pending
                                                ; interrupt.
        iret

        .END
```

Application Hint 5

Logic Controlled Power Switch

by Bob Wolbert

Introduction

In battery powered applications, such as laptop computers, power control has a major impact on battery life. For example, laptop or notebook computers often have a "sleep" mode, where the hard drive spins down and the display backlighting turns off while the RAM—containing valuable user data—is maintained. A microprocessor can easily make such power management decisions, but implementing the hardware for the actual switching can be complicated. "High-side" switching is required; i.e., the positive supply voltage must be controlled. Common grounds for busses and shielding limits the possibility of "low side" switching in a standard negative ground system. This note discusses a logic controlled power switch that simplifies microprocessor driven high-side supply switching.

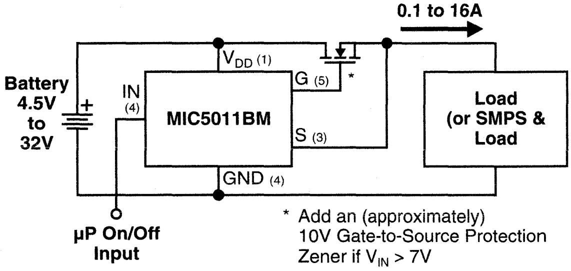


Figure 1. MIC5011 DB-1 Schematic Diagram.

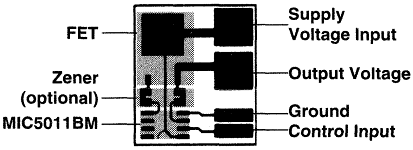


Figure 2. MIC5011 DB-1 Low Voltage Logic Controlled Power Switch

Power Switches

These high-side implementations have historically taken one of two forms: relays or PNP transistors. Both have drawbacks in that relatively large drive current is required: neither can be switched directly from a microprocessor port or standard logic. Mechanical relays are bulky, expensive, and have limited lifetimes. Bipolar transistors exhibit a fixed voltage drop that reduce margins, especially in 5V logic systems. This voltage drop has a devastating effect on defining battery end-of-life (per charge cycle).

Another method of power switching is the N-Channel DMOS FET. This FET has no inherent voltage drop, except for the I x r_{DS} loss, and requires almost no drive power; unfortunately, it does need a gate driving voltage of from 4V to 10V above the supply voltage in high-side applications. In other words, it is an *almost* ideal switch.

DMOS FET Advantages vs. Relays

- Non-mechanical (much longer life)
- No contact bounce
- Extremely low drive current requirement
- Smaller Size
- Lighter weight
- Lower cost

DMOS FET Advantages vs. PNP

- No fixed voltage drop
- Extremely low drive current requirement
- Larger Safe Operating Region

The Micrel MIC5010 Family

The MIC5011 and its relatives control the N-Channel DMOS FET by generating a gate drive control voltage 4V to 10V above the supply. Its CMOS compatible control input directly interfaces with microprocessors, and its BCD (Bipolar-CMOS-DMOS) construction allows nearly zero power drain in the OFF state. Pairing the MIC5011 with a low cost DMOS FET gives you a simple, reliable, easy-to-interface method of power management.

The MIC5011 is designed for this application and features:

- 4.5V to 32V Operation
- Very low OFF power consumption—0.1µA typical
- No external components required
- Built-in zener clamp for protecting standard DMOS gates
- Available in small 8-pin surface mount packages

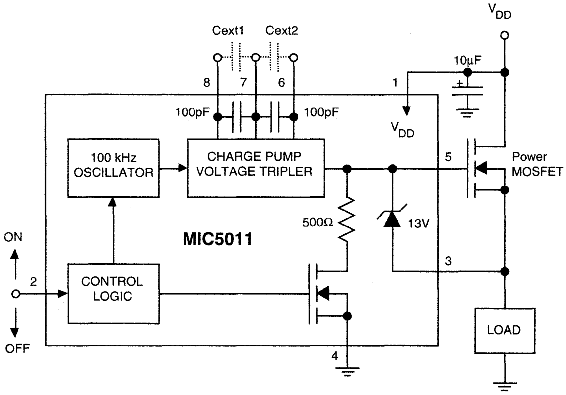


Figure 3. MIC5011 Block Diagram and Typical Application

The IRLR024 N-Channel DMOS FET

The 100mΩ surface mount IRLR024 is employed as the pass device in this demonstration circuit. This N-Channel DMOS FET features "Logic Level" gate drive voltages and can pass over 50A of peak current (limited by power dissipation considerations). Key features include:

- Low ON resistance—100mΩ maximum
- "Logic Level" gate threshold—ON at V_{GS}=4V; V_{GS}=5V for full enhancement.
- High pass current
- Surface mount package

One drawback of this "logic level" device is that its sensitive gate cannot withstand more than 10V of V_{GS} drive. Although the MIC5011 includes a protective zener clamp, the zener's 12.5V threshold is inadequate. With supply voltages from 4.5V to 7V, this is not a problem; however, above 7V, either an external zener clamp must be added to the MIC5011 gate drive output or else a standard threshold FET should be used.

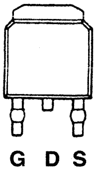


Figure 4. IRLR024 DMOS FET

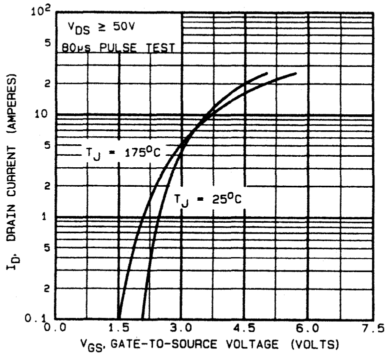


Figure 5. IRLR024 Characteristics

The Micrel MIC5011 DB-1 Demonstration Unit

This demonstration unit is built on a single sided board using surface mount techniques. It has been designed to control 4.5V to 7V supplies, but can easily be modified to use 4.5V to 32V supply voltages. The first thing you will notice from the schematic, Figure 1, is its simplicity; only two components are needed. The MIC5011 contains all of the necessary intelligence and the drive circuitry required by the N-Channel DMOS FET.

Four lines provide +V_{CC}, Switched-V_{CC}, Control, and Ground. V_{CC} and Switched-V_{CC} are current carrying lines, so thick, low resistances traces are necessary. Both Control and Ground are low current lines, so thin traces are sufficient.

Simply connect V_{CC} to 4.5V to 7V, Switched-V_{CC} to your load, Control to a logic output, and Ground. When the logic level is high (greater than approximately 3.5V), the load will be energized. The IRLR024 will exhibit less than 100mΩ of resistance, so voltage drop, hence power loss, with typical peripherals will be low. Current drain of up to 16A continuous, 64A peak, can be drawn with suitable heatsinking (limit current to 3A without additional heatsinking). With a low logic level, the load will be switched off. Total power drain from the V_{CC} line will be negligible; only approximately 0.1µA (leakage current) flows.

Application Notes

Operating Voltages

This circuit, as designed, controls 4.5V to 7V digital supply voltages. If higher voltages must be switched, one of two modifications must be made. To switch widely varying supplies in the 4.5V to 32V range, use an approximately 7.5V zener clamp, such as the MLL4693 or equivalent, across the gate and source of the FET. If your application switches 7V to 32V, replace the "logic level" FET with a standard gate N-Channel DMOS FET, such as the IRF540, BUZ1LS2, or the SMP60N05. Regardless of the FET employed, the MIC5011 allows power control from a standard CMOS-level logic signal.

TO-220 Package FETs

The MIC5011-DB1 demonstration board also allows using a standard TO-220 package FET. Connect the gate and source to the zener diode pads, and solder the tab (drain) to the drain heatsink pad. Remove the center lead drain connection. The TO-220 tab will extend from the top of the board a short distance.

Faster Switching

If switching time is critical, adding a 1000pF capacitor from pins 6-7 on the MIC5011 will help. Another 1000pF capacitor from pins 7-8 will further accelerate switching time, but by a smaller margin.

Dual Independent Switches

When two separate circuits require switching, the MIC5012 Dual High Side FET Driver provides two independent drivers in a single 14-pin DIP or 16-pin surface mount package.

Over Current Protection

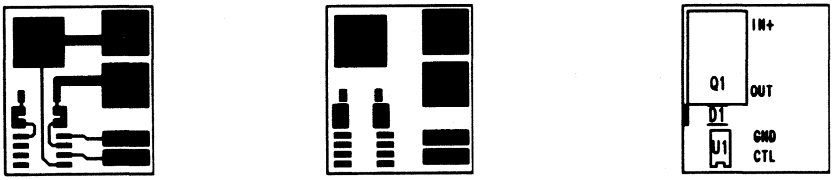
Replace the MIC5011 with the MIC5013 to enable over current protection with fault detection and signalling. See the MIC5013 datasheet for further information and suggested component values.

Parts List

- **MIC5011BM Surface mount MOSFET driver**
- **IRLR024 Surface mount DMOS FET**
- **MLL4693 Surface mount 7.5V zener diode (optional)**

Additional Notes

Although the MIC5011 datasheet specifically states that a minimum of 7V of supply voltage is required for high-side driving, the introduction of "logic level" N-Channel DMOS FETs requiring only 4V to 5V V_{GS} for full ON operation enables this minimum operating voltage to be lowered. The MIC5011 provides gate enhancement with supply voltages down to below 3.5V. Variations in the control voltage threshold, however, restrict low voltage operations to somewhat less than 4.5V (for lower voltage devices, please contact the factory).



Component Side **Solder Mask** **Silk Screen**

Figure 6. MIC5011 DB-1 Board Layout

Application Hint 9

Low Voltage Operation of the MIC5014 Family

by Brenda Kovacevic

Introduction

The current trend for more efficient use of power has led to a new standard in logic based systems: the use of 3.3V logic as opposed to 5V logic. Efficient power management is especially important in battery based systems such as portable laptop/notebook PCs and cellular phones where maximum use time is determined by battery life. **The MIC5014 family has a minimum required supply rail of 2.75V, which is the lowest required voltage of any high side driver in the industry!** This makes the MIC5014 family ideal for use in any low voltage environment where power switching is necessary. This note briefly describes the characteristics of these devices at low voltages, and shows several example applications where the low voltage feature is used.

Typical Parameters at $V^+ = 3.3V$

Table I shows the typical parameters expected at a 3.3V supply voltage. At 15μA quiescent current and 35μA operating current, we offer very little battery drain at this voltage. Also worthy of attention is the fact that these devices offer a full 4.5V gate enhancement with a supply voltage of only 3.0V! Perhaps the only drawback is the rise time at these low voltages, which is on the order of 35 to 40ms. For most power switching applications in this voltage range, this has not been seen to present difficulties and is a small price to pay for the greatly lowered battery drain. If faster switching speeds are desired, the rise time can be improved to 20 to 30ms by bootstrapping off the positive supply, as shown in figure 1. Faster times than this can be attained by increasing the size of the bootstrap capacitor at the expense of the additional space required. Fall times remain on the order of 6 to10μs.

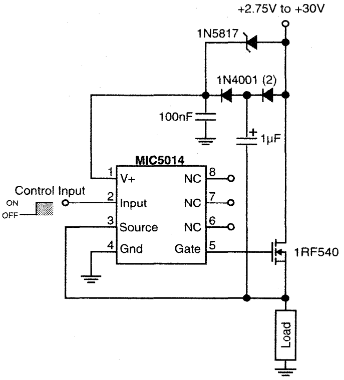


Figure 1. Low Voltage Bootstrapped High Side Switch

Table 1: Typical Parameters at $V^+ = 3.3V$

Parameter	Typical Value	Units
Supply Current,Off State	15	μA
Supply Current,On State	35	μA
High Side Turn-On Time (C_L = 1300 pF)	35	ms
Turn-Off Time	6	μs
Gate Enhancement ($V_{GATE} - V_{SUPPLY}$)	4.5	V
Logic Input Current (High State)	1	μA

Typical Low Voltage Applications

Sleep Mode Switching

One commonly employed technique for extending battery life is the use of a "sleep mode" switch, in which the microprocessor shuts down all the functions that represent power drain after a preset time of nonuse while maintaining the system memory. This type of a switch must typically be a high side switch, or a switch that controls the availablity of the positive supply, as standard computer or logic based systems often have common ground busses and /or shielding.

The MIC5016 plus two logic level FETs make an ideal dual sleep mode switch (figure 2) without the bulk and unreliability of relays or the voltage drop of bipolar transistors (See Application Hint 5 for more information plus a board layout for sleep mode switching with regards to our MIC5011 high side driver).

A logic level FET is very similar to a regular power FET except for the threshold voltage requirements, which are VGS = 4 V for turn-on and 5 V for full enhancement. A regular power FET would require a minimum of 10V for full enhancement. This feature makes the logic level FET ideal for this kind of switching. The only drawback it has is that it's gate cannot withstand more than 10V of enhancement. The MIC5014/5016 devices are equipped with an internal zener clamp, but at 15V it will not save us here! We recommend that an external zener clamp or regular power FET be used if a supply higher than 4V is required.

As the MIC5014 is pin to pin compatible with the MIC5011, the board layout for a single sleep mode switch as featured in Application Hint 5 will also work for the MIC5014.

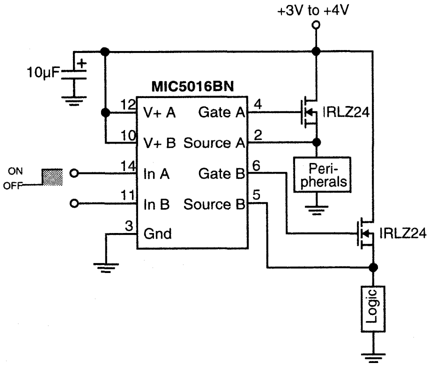


Figure 2: 3 to 4 V Dual Sleep Mode Switch

Low Battery Sense and Disconnect

When a battery is discharged to the point that the load goes significantly out of regulation, it is often beneficial to disconnect the load from the battery to prevent further discharge. In the case of NiCd or NiMH batteries, repeated deep discharging has a negative impact on battery life. A simple scheme can be formulated using the MIC2951 super low drop out regulator to generate a well regulated 3.3V supply from four 1.2V battery cells. When the output drops to below 5% of the rated value, the ERROR flag goes low, pulling down the RESETof the latch which shuts down the control input to the MIC5014. This turns off the MOSFET switch connecting the battery to the regulator. It is important to hold the SET input to the latch low for 30 to 40ms on start-up to allow the regulator to kick in. This output can also be fed to a microcontroller, signalling the user that it is time to charge his batteries.

Although it is possible to use feedback from the ERROR output to the shutdown input of the MIC2951 to perform this function, the addition of the MIC5014 and FET switch results in less current drain (20 to 25µA extra for the MIC5014 plus latch as opposed to the current required to bias and drive a bipolar transistor). It also allows the MIC2951 to act as the central controlling point for shutdown in applications where the unregulated battery voltage is fed to other subsystems, such as an SMPS converter, in addition to the MIC2951.

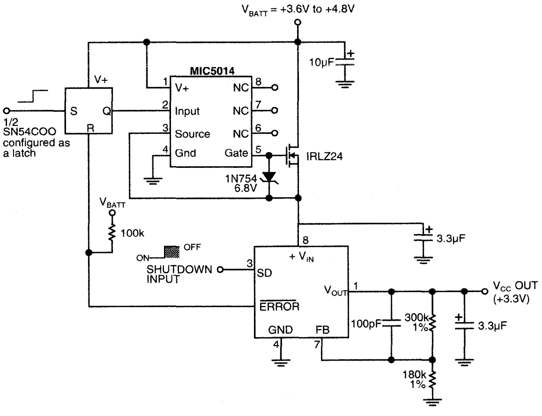


Figure 3: Low Battery Shutdown Switch

Table of Contents

Section 6: Open-Drain Drivers

Open-Drain Driver Selection Guide

Device	Function	Logic	Single	Dual	Current	ON Resistance	Package
MIC4401	Open-Drain Driver	Inverting	•		6A	1.7Ω	8-pin DIP, SOIC
MIC4402	Open-Drain Driver	Non-Inverting	•		6A	1.7Ω	8-pin DIP, SOIC
MIC4403	Floating-Load Driver	–	•		1.5A	3Ω	8-pin DIP, SOIC
MIC4604	Open-Drain Driver	Inverting		•	1.5A	7Ω	8-pin DIP, SOIC
MIC4605	Open-Drain Driver	Non-Inverting		•	1.5A	7Ω	8-pin DIP, SOIC
MIC4606	Open-Drain Driver	Inverting		•	3A	3.5Ω	8-pin DIP, SOIC
MIC4607	Open-Drain Driver	Non-Inverting		•	3A	3.5Ω	8-pin DIP, SOIC
MIC4608	Open-Drain Driver	Inverting	•		9A	1.0Ω	8-pin DIP, SOIC
MIC4609	Open-Drain Driver	Non-Inverting	•		9A	1.0Ω	8-pin DIP, SOIC
MIC4610	Open-Drain Driver	Inverting	•		12A	1.0Ω	8-pin DIP, SOIC
MIC4611	Open-Drain Driver	Non-Inverting	•		12A	1.0Ω	8-pin DIP, SOIC

MIC4401/4402

6A-Peak Open-Drain MOSFET Driver

Preliminary Information

General Description

The MIC4401/4402 are BiCMOS/DMOS buffer-drivers constructed with complementary MOS outputs, where the drains of the final output totem poles have been left disconnected so individual connections can be made to the pull-up and pull-down sections of the output, thus allowing the user to define the rates of rise and fall times desired for a capacitive load, or a reduced output swing if driving a resistive load, or to limit base current when driving a bipolar transistor. Minimum rise and fall times, with no resistors, will be less than 30ns for a 10,000pF load. There is no upper limit.

These devices are rugged due to extra steps taken to protect them from failures. A modern Bipolar/CMOS/DMOS process guarantees freedom from latchup. Proprietary circuits allow the input to swing negative as much as 5V without damaging the part.

For driving MOSFETs in motor-control applications, where slow-on/fast-off operation is desired, the MIC4401/4402 is superior to the previously-used technique of adding a diode-resistor combination between the driver output and the MOSFET, because it allows accurate control of turn-on, while maintaining fast turn-off and maximum noise immunity for the device being driven.

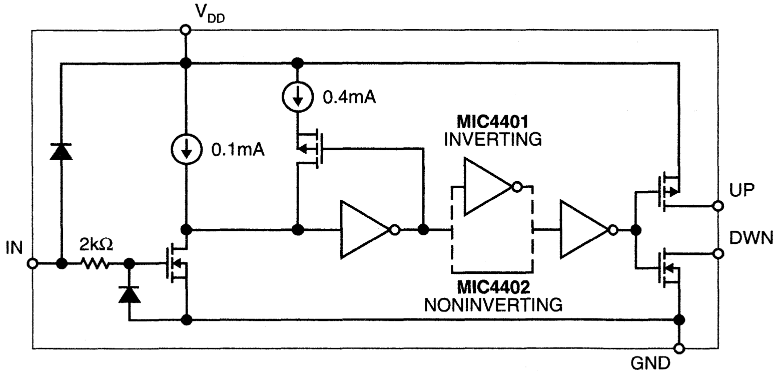
Features

- Independently Programmable Rise and Fall Times
- High Peak Output Current .... 6A peak
- Low Output Impedance .... 1.7Ω typ
- High Speed t_R, t_F .... <20 ns with 2500pF load
- Short Delay Times .... 25ns Typical
- Wide Operating Range .... 4.5V to 18V
- Latch-up Protected: Fully Isolated Process is Inherently Immune to any Latchup.
- Input Withstands Negative Swings to –5V
- ESD Protected 2kV

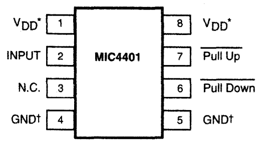
Applications

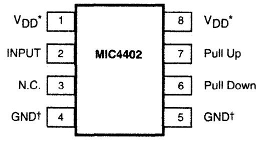
- Motor Controls
- Self-Commutating MOSFET Bridge Driver
- Driving Bipolar Transistors
- Driver for Non-overlapping Totem Poles
- Reach-Up/Reach-Down Driver

Functional Diagram



Pin Configuration





* Pins 1 and 8 must be externally connected for proper operation.
† Pins 4 & 5 must be externally connected for proper operation.

When used to drive bipolar transistors, this driver maintains high speeds and allows insertion of a base current-limiting resistor, and also provides a separate half-output for fast turn-off. By proper positioning of the resistor, either NPN or PNP transistors can be driven.

For driving many loads in low-power systems, this driver, since it has very low quiescent current (80µA) and eliminates shoot-through current in the output stage, requires significantly less power than other drivers. This can be helpful in meeting low-power budgets.

Due to independent drains, this device can also be used as an open-drain buffer/driver where both drains are available in one device, thus minimizing chip count. An unused pull-down should be returned to the ground; an unused pull-up should be returned to V_{DD}. This is to prevent static damage. Alternatively, in situations requiring greater current-carrying capacity, multiple MIC4608 or MIC4608s may be paralleled.

The MIC4608/4609 will not latch under any conditions within its power and voltage ratings. It is not subject to damage when up to 5V of noise spiking of either polarity occurs on the ground pin. It can accept, without damage or logic upset, up to 1.5 amps of reverse current (of either polarity) being forced back into the outputs.

Absolute Maximum Ratings (Note 1)

Supply Voltage .... +22V
Logic Input Voltage .... V_{DD} + 0.3V to GND – 5V
Logic Input Current ($V_{IN} > V_{DD}$) 50mA
Maximum Die Temperature .... +150°C
Storage Temperature Range .... –65°C to +150°C
Lead Temperature (Soldering, 10 sec) .... +300°C
Power Dissipation, $T_A \leq 25°C$
  PDIP 1W
  SOIC 500mW
  CerDIP 800mW
Package Thermal Resistance
  CerDIP θ_{JA} .... 150°C/W
  CerDIP θ_{JC} .... 55°C/W
  PDIP θ_{JA} .... 125°C/W
  PDIP θ_{JC} .... 45°C/W
  SOIC θ_{JA} .... 160°C/W
  SOIC θ_{JC} .... 75°C/W

Ordering Information

Part Number	Logic	Package	Temperature Range
MIC4401AJ	Inverting	8-pin CerDIP	–55°C to +125°C
MIC4401BN	Inverting	8-pin PDIP	–40°C to +85°C
MIC4401BM	Inverting	8-pin SOIC	–40°C to +85°C
MIC4402BN	Non-Inverting	8-pin PDIP	–40°C to +85°C
MIC4402BM	Non-Inverting	8-pin SOIC	–40°C to +85°C

Note 1: Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specification is not implied. Exposure to Absolute Maximum Rating Conditions for extended periods may affect device reliability. Static-sensitive device. Unused devices must be stored in conductive material. Protect devices from static discharge and static fields.

Electrical Characteristics

Unless otherwise specified, specifications measured at $T_A = 25°C$ with $4.5V \le V_{DD} \le 18V$.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Input						
V_{IH}	Logic 1 High Input Voltage		2.4		$V_{DD} + 0.3$	V
V_{IL}	Logic 0 Low Input Voltage		–5		0.8	V
I_{IN}	Input Current	$0V \le V_{IN} \le V_{DD}$	–10		10	µA
Output						
V_{OH}	High Output Voltage		$V_{DD} - 0.025$			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance, Pull-Up	$I_{OUT} = 10mA$, $V_{DD} = 18V$		1.5	2.8	Ω
R_O	Output Resistance, Pull-Down	$I_{OUT} = 10mA$, $V_{DD} = 18V$		1.7	2.5	Ω
I_{PK}	Peak Output Current			6		A
I_R	Latch-up Protection Withstand Reverse Current		>1500			mA
Switching Time						
t_R	Rise Time	Figure 1, $C_L = 2500pF$		12	35	ns
t_F	Fall Time	Figure 1, $C_L = 2500pF$		13	35	ns
t_{D1}	Delay Time	Figure 1, $C_L = 2500pF$		18	75	ns
t_{D2}	Delay Time	Figure 1, $C_L = 2500pF$		48	75	ns
Power Supply						
I_S	Power Supply Current	$V_{IN} = 3V$		0.45	1.5	mA
		$V_{IN} = 0V$		0.09	0.15	mA

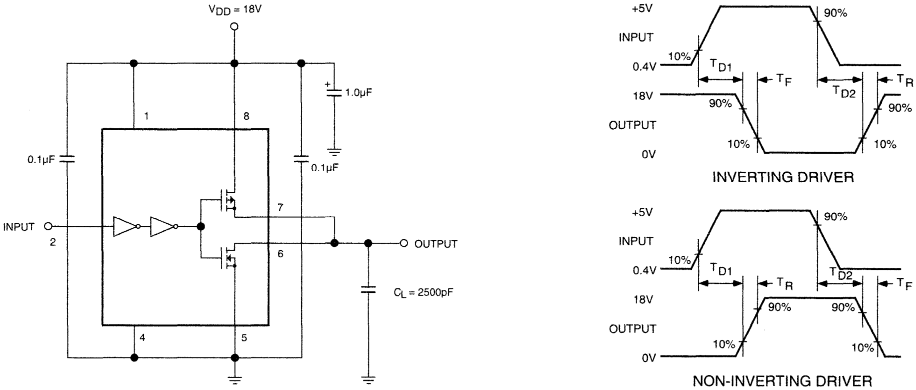


Figure 1. MIC4401/4402 Switching time test circuit.

Electrical Characteristics, continued

Specifications measured **over operating temperature range** with $4.5V \leq V_{DD} \leq 18V$, unless otherwise specified.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Input						
V_{IH}	Logic 1 High Input Voltage		2.4			V
V_{IL}	Logic 0 Low Input Voltage				0.8	V
I_{IN}	Input Current	$0V \leq V_{IN} \leq V_{DD}$	–10		10	µA
Output						
V_{OH}	High Output Voltage		$V_{DD} - 0.025$			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance, Pull-Up	$I_{OUT} = 10mA$, $V_{DD} = 18V$		2.2	5	Ω
R_O	Output Resistance, Pull-Down	$I_{OUT} = 10mA$, $V_{DD} = 18V$		3.5	5	Ω
Switching Time						
t_R	Rise Time	Figure 1, $C_L = 2500pF$		16	60	ns
t_F	Fall Time	Figure 1, $C_L = 2500pF$		25	60	ns
t_{D1}	Delay Time	Figure 1, $C_L = 2500pF$		25	100	ns
t_{D2}	Delay Time	Figure 1, $C_L = 2500pF$		70	100	ns
Power Supply						
I_S	Power Supply Current	$V_{IN} = 3V$		0.5	3	mA
		$V_{IN} = 0V$		0.12	0.4	mA

MIC4403

1.5A-Peak High-Speed Floating-Load Driver

Preliminary Information

General Description

The MIC4403 is a modified version of the MIC4425 power MOSFET driver, intended to drive floating or isolated loads requiring high-current pulses. The load is intended to be connected between the outputs without other reference to supply or ground. Only when both logic inputs are high and the V_{DD} supply is energized, is power supplied to the load. This construction allows the implementation of a wide variety of redundant input controllers.

The low off-state output leakage and independence of the two half-circuits permit a wide variety of testing schemes to be utilized to assure functionality. The high peak current capability, short internal delays, and fast output rise and fall times ensure sufficient power will be available to the load when it is needed. The TTL and CMOS compatible inputs allow operation from a wide variety of input devices. The ability to swing the inputs negative without affecting device performance allows negative biases to be placed on the inputs for greater safety. In addition, the capacitive nature of the inputs allows the use of series resistors on the inputs for extra noise suppression.

Input voltage excursions above the supply voltage or below ground are clamped internally without damaging the device. The output stages are power CMOS and DMOS FETs with high speed body diodes to prevent damage to the driver from inductive kickbacks.

Features

- Built Using Contemporary BiCMOS/DMOS Process
- Latch-Up Protected: Fully Isolated Process is Inherently Immune to any Latch-Up
- Low Quiescent Current .... 300μA Max
- Low Capacitive Inputs With 300mV Hysteresis
- Both Inputs Must Be Driven to Drive Load
- Low Output Leakage
- High Peak Current Capability
- Fast Output Rise Time
- Outputs Individually Testable
- 3A Single Ended (1.5A with Floating Load)

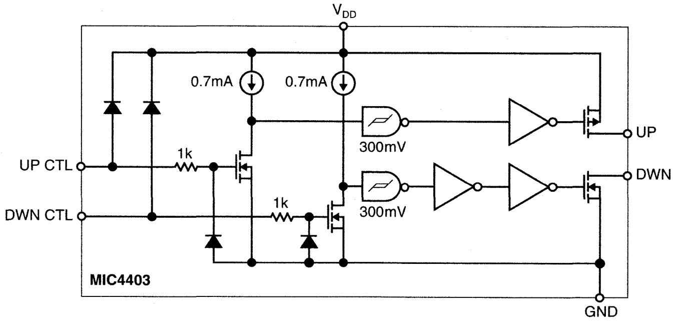
Applications

- Squib Drivers
- Isolated Load Drivers
- Pulsers
- Safety Interlocks

Ordering Information

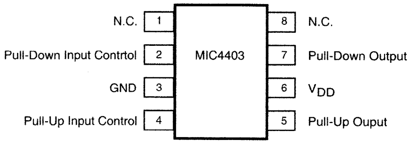
Part Number	Temperature Range	Package
MIC4403BM	–40°C to +85°C	8-pin SOIC
MIC4403BN	–40°C to +85°C	8-pin PDIP

Functional Diagram



Functional Diagram for One Driver (Four Drivers per Package–Ground Unused Inputs)

Pin Configuration



Absolute Maximum Ratings (Note 1)

Supply Voltage	+22V
Maximum Die Temperature	+150°C
Storage Temperature Range	–65°C to +150°C
Lead Temperature (Soldering, 10 sec)	+300°C

Package Thermal Resistance

CerDIP θ_{JA}	150°C/W
CerDIP θ_{JC}	55°C/W
PDIP θ_{JA}	125°C/W
PDIP θ_{JC}	45°C/W
SOIC θ_{JA}	250°C/W
SOIC θ_{JC}	75°C/W

Note 1: Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specification is not implied. Exposure to Absolute Maximum Rating Conditions for extended periods may affect device reliability. Static-sensitive device. Unused devices must be stored in conductive material. Protect devices from static discharge and static fields.

Electrical Characteristics

Unless otherwise specified, specifications measured at $T_A = 25°C$ with $4.5V \le V_{DD} \le 18V$.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Input						
V_{IH}	Logic 1 High Input Voltage		2.4		$V_{DD} + 0.3$	V
V_{IL}	Logic 0 Low Input Voltage		–5		0.8	V
I_{IN}	Input Current	$0V \le V_{IN} \le 5V_{DD}$	–1	±0.01	1	µA
Output						
V_{OH}	High Output Voltage		$V_{DD} - 0.025$			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance, Pull-Up	$I_{OUT} = 10mA$, $V_{DD} = 18V$		2.8	5	Ω
R_O	Output Resistance, Pull-Down	$I_{OUT} = 10mA$, $V_{DD} = 18V$		3.5	5	Ω
I_{PK}	Peak Output Current			1.5		A
Switching Time						
t_R	Rise Time	Figure 1, $C_L = 1800pF$		23	35	ns
t_F	Fall Time	Figure 1, $C_L = 1800pF$		25	35	ns
t_{D1}	Delay Time	Figure 1, $C_L = 1800pF$		17	75	ns
t_{D2}	Delay Time	Figure 1, $C_L = 1800pF$		23	75	ns
Power Supply						
I_S	Power Supply Current	$V_{IN} = 3V$ (both inputs)		1.4	2.5	mA
		$V_{IN} = 0V$ (both inputs)		0.17	0.25	mA

Electrical Characteristics, continued

Specifications measured **over operating temperature range** with 4.5V ≤ V_{DD} ≤18V, unless otherwise specified.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Input						
V_{IH}	Logic 1 High Input Voltage		2.4		V_{DD} + 0.3	V
V_{IL}	Logic 0 Low Input Voltage		–5		0.8	V
I_{IN}	Input Current	0V ≤ V_{IN} ≤ V_{DD}	–10	±0.01	10	µA
Output						
V_{OH}	High Output Voltage		V_{DD} – 0.025			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance, Pull-Up	I_{OUT} = 10mA, V_{DD} = 18V V_{IN} ≥ 2.4V		3.7	8	Ω
R_O	Output Resistance, Pull-Down	I_{OUT} = –10mA, V_{DD} = 18V V_{IN} ≥ 2.4V		5.5	8	Ω
Switching Time						
t_R	Rise Time	Figure 1, C_L = 1800pF		24	60	ns
t_F	Fall Time	Figure 1, C_L = 1800pF		32	60	ns
t_{D1}	Delay Time	Figure 1, C_L = 1800pF		19	100	ns
t_{D2}	Delay Time	Figure 1, C_L=1800pF		19	100	ns
Power Supply						
I_S	Power Supply Current	V_{IN} = 3V (both inputs)		1.6	3.5	mA
		V_{IN} = 0V (both inputs)		0.25	0.3	mA

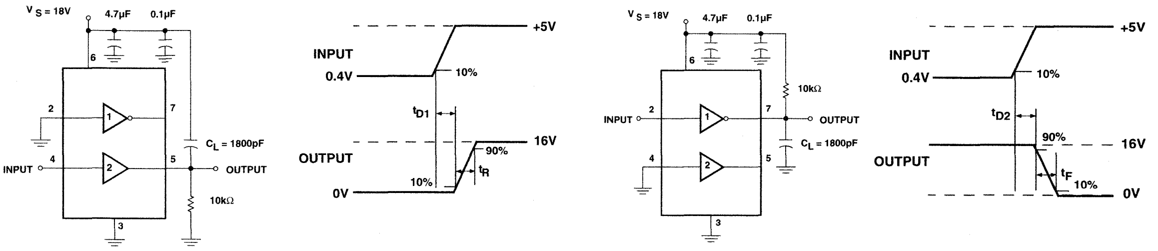


Figure 1. MIC4403 Switching time test circuit.

MIC4604/4605

Dual 1.5A-Peak Open-Drain MOSFET Driver

Preliminary Information

General Description

The MIC4604 and MIC4605 are BiCMOS/DMOS buffer-drivers constructed with complementary MOS outputs, where the drains of the final output totem pole have been left disconnected so individual connections can be made to the pull-up and pull down sections of the output. This allows the insertion of individual drain-current-limiting resistors in the pull up and pull down sections of the output, thus allowing the user to define the rates of rise and fall desired for a capacitive load, or a reduced output swing if driving a resistive load, or to limit base current when driving a bipolar transistor. Minimum rise and fall times, with no resistors, will be less than 20ns for a 1000pF load. There is no upper limit.

These devices are rugged due to extra steps taken to protect them from failures. A modern Bipolar/CMOS/DMOS process guarantees freedom from latchup. Proprietary circuits allow the input to swing negative as much as 5V without damaging the part.

For driving MOSFETs in motor-control applications, where slow on/fast off operation is desired, these devices are superior to the previously used technique of adding a diode resistor combination between the driver output and the MOSFET, because they allow accurate control of turn-ON, while maintaining fast turn-OFF and maximum noise immunity for an OFF device.

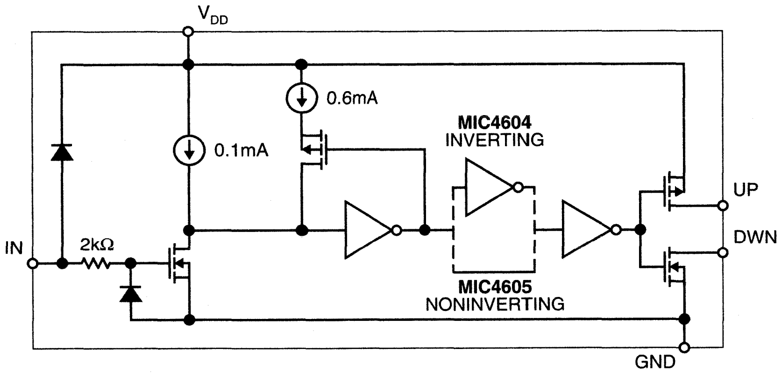
Features

- Independently Programmable Rise and Fall Times
- Low Output Impedance .... 6Ω Typ
- High Speed t_R, t_F .... <30ns with 1000pF Load
- Short Delay Times .... <25ns typ
- Wide Operating Range .... 4.5V to 18V
- Latch-Up Protection: Fully Isolated Process is Inherently Immune to to Any Latch-up
- Input Withstands Negative Swings to –5V
- ESD Protected 2kV

Applications

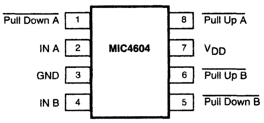
- Motor Controls
- Self-Commutating MOSFET Bridge Driver
- Driving Bipolar Transistors
- Drive for Nonoverlapping Totem Poles
- Level Shifters
- Power Management

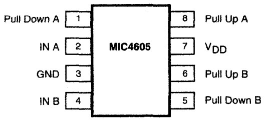
Functional Diagram



Functional Diagram for One Driver
(Two Drivers per Package—Ground Unused Inputs)

Pin Configuration





When used to drive bipolar transistors, this driver maintains high speeds and allows insertion of a base current-limiting resistor, and also provides a separate half-output for fast turn-off. By proper positioning of the resistor, either NPN or PNP transistors can be driven.

These drivers, since they eliminate shoot-through currents in the output stage, require significantly less power at higher frequencies. This can be helpful in meeting low-power budgets.

Due to independent drains, this device can also be used as an open-drain buffer/driver where both drains are available in one device, thus minimizing chip count. An unused pull-down should be returned to the ground; an unused pull-up should be returned to V_{DD}. This is to prevent static damage. Alternatively, in situations requiring greater current-carrying capacity, multiple MIC4604 or MIC4605s may be paralleled.

The MIC4604/4605 will not latch under any conditions within its power and voltage ratings. It is not subject to damage when up to 5V of noise spiking of either polarity occurs on the ground pin. It can accept, without damage or logic upset, up to 1.5 amps of reverse current (of either polarity) being forced back into the outputs.

Absolute Maximum Ratings (Note 1)

Supply Voltage	+22V
Maximum Chip Temperature	+150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec)	+300°C
Package Thermal Resistance	
CerDIP $\theta_{J\text{-}A}$	150°C/W
CerDIP $\theta_{J\text{-}C}$	55°C/W
PDIP $\theta_{J\text{-}A}$	125°C/W
PDIP $\theta_{J\text{-}C}$	45°C/W
SOIC $\theta_{J\text{-}A}$	250°C/W
SOIC $\theta_{J\text{-}C}$	75°C/W

Ordering Information

Part Number	Logic	Package	Temperature Range
MIC4604BM	Inverting	8-pin SOIC	–40°C to +85°C
MIC4604BN	Inverting	8-pin PDIP	–40°C to +85°C
MIC4605BM	Non-Inverting	8-pin SOIC	–40°C to +85°C
MIC4605BN	Non-Inverting	8-pin PDIP	–40°C to +85°C

Note 1: Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specification is not implied. Exposure to Absolute Maximum Rating Conditions for extended periods may affect device reliability. Static-sensitive device. Unused devices must be stored in conductive material. Protect devices from static discharge and static fields.

Electrical Characteristics

Unless otherwise specified, specifications measured at T_A = 25°C with 4.5V ≤ V_{DD} ≤ 18V.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Input						
V_{IH}	Logic 1 High Input Voltage		2.4		V_{DD} + 0.3	V
V_{IL}	Logic 0 Low Input Voltage		–5		0.8	V
I_{IN}	Input Current	0V ≤ V_{IN} ≤ V_{DD}	–1		1	µA
Output						
V_{OH}	High Output Voltage		V_{DD} – 0.025			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance, Pull-Up	I_{OUT} = 10mA, V_{DD} = 18V		6	10	Ω
R_O	Output Resistance, Pull-Down	I_{OUT} = 10mA, V_{DD} = 18V		6	10	Ω
I_{PK}	Peak Output Current	Any Drain		1.5		A
I_R	Latch-up Protection	Any Drain Reverse Current	>500			mA
Switching Time						
t_R	Rise Time	Figure 1, C_L = 1000pF		18	30	ns
t_F	Fall Time	Figure 1, C_L = 1000pF		27	35	ns
t_{D1}	Delay Time	Figure 1, C_L = 1000pF		17	30	ns
t_{D2}	Delay Time	Figure 1, C_L = 1000pF		23	50	ns
Power Supply						
I_S	Power Supply Current	V_{IN} = 3V (both inputs)		1.4	2.5	mA
		V_{IN} = 0V (both inputs)		0.18	0.25	mA

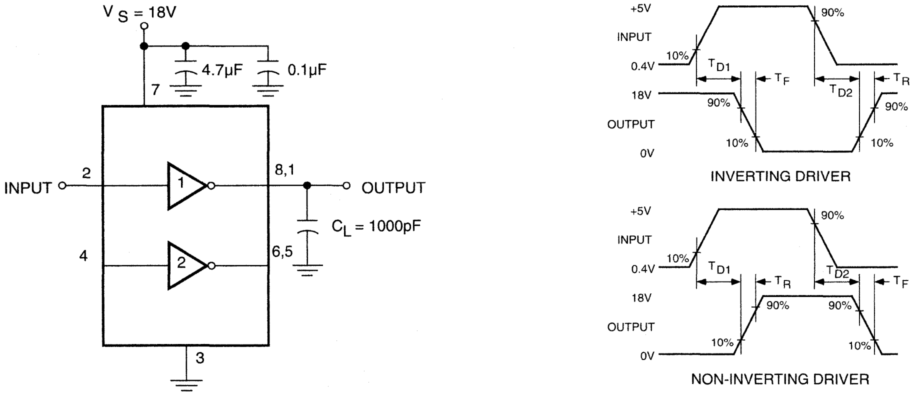


Figure 1. MIC4604/4605 Switching time test circuit.

Electrical Characteristics, continued

Specifications measured **over operating temperature range** with $4.5V \leq V_{DD} \leq 18V$, unless otherwise specified.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Input						
V_{IH}	Logic 1 High Input Voltage		2.4		$V_{DD} + 0.3$	V
V_{IL}	Logic 0 Low Input Voltage				0.8	V
I_{IN}	Input Current	$0V \leq V_{IN} \leq V_{DD}$	–10		10	µA
Output						
V_{OH}	High Output Voltage		$V_{DD} - 0.025$			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance, Pull-Up	$I_{OUT} = 10mA$, $V_{DD} = 18V$		8	12	Ω
R_O	Output Resistance, Pull-Down	$I_{OUT} = 10mA$, $V_{DD} = 18V$		9	12	Ω
I_{PK}	Peak Output Current	Any Drain		1.5		A
I_R	Latch-up Protection	Any Drain Reverse Current	>500			mA
Switching Time						
t_R	Rise Time	Figure 1, $C_L = 1000pF$		20	40	ns
t_F	Fall Time	Figure 1, $C_L = 1000pF$		30	40	ns
t_{D1}	Delay Time	Figure 1, $C_L = 1000pF$		20	40	ns
t_{D2}	Delay Time	Figure 1, $C_L = 1000pF$		30	60	ns
Power Supply						
I_S	Power Supply Current	$V_{IN} = 3V$ (both inputs)		1.5	3.5	mA
		$V_{IN} = 0V$ (both inputs)		0.2	0.3	mA

MIC4606/4607

Dual 3A-Peak Open-Drain MOSFET Driver

Preliminary Information

General Description

The MIC4606 and MIC4607 are BiCMOS/DMOS buffer-drivers constructed with complementary MOS outputs, where the drains of the final output totem pole have been left disconnected so individual connections can be made to the pull-up and pull-down sections of the output. This allows the insertion of individual drain current-limiting resistors in the pull-up and pull-down sections of the outputs, thus allowing the user to define the rates of rise and fall desired for a capacitive load, or to limit base current when driving a bipolar transistor. Minimum rise and fall times, with no resistors, will be less than 25ns for a 1800pF load.

These devices are rugged due to extra steps taken to protect them from failures. A modern Bipolar/CMOS/DMOS process guarantees freedom from latchup. Proprietary circuits allow the input to swing negative as much as 5V without damaging the part.

For driving MOSFETs in motor-control applications, where slow-on/fast-off operation is desired, these devices are superior to the previously-used technique of adding a diode-resistor combination between the driver output and the MOSFET, because they allow accurate control of turn-on, while maintaining fast turn-off and maximum noise immunity for the device being driven.

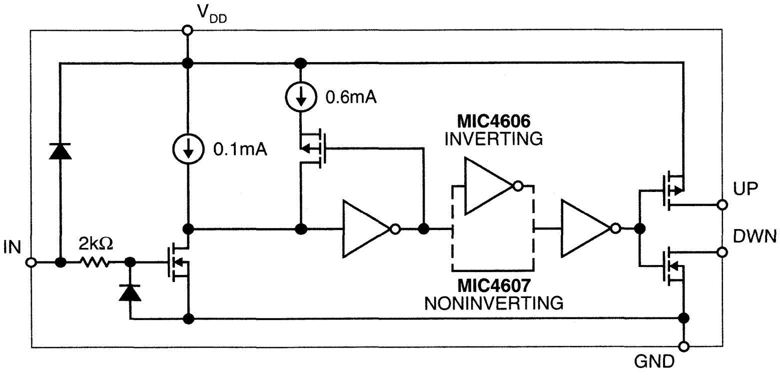
Features

- Independently-Programmable Rise and Fall Times
- Low Output Impedance .... 3Ω typ.
- High Speed t_R, t_F .... <25ns with 1800pF Load
- Short Delay Times .... <25ns typ.
- Wide Operating Range .... 4.5V to 18V
- Latch-Up Protected: Fully Isolated Process is Inherently Immune to any Latchup
- Input Withstands Negative Swings to –5V
- ESD Protected 2kV

Applications

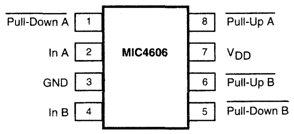
- Motor Controls
- Self-Commutating MOSFET Bridge Driver
- Driving Bipolar Transistors
- Driver for Nonoverlapping Totem Poles
- Level Shifters
- Power Management

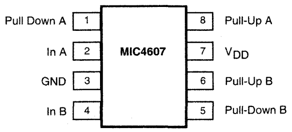
Functional Diagram



Functional Diagram for One Driver
(Two Drivers per Package—Ground Unused Inputs)

Pin Description





When used to drive bipolar transistors, these drivers allow insertion of a base current limiting resistor, while providing a separate half-output for fast turn-off. By proper positioning of the resistor, either NPN or PNP transistors can be driven.

These drivers, since they have very low quiescent current (<250μA) and eliminate shoot-through currents in the output stage, require significantly less power than similar drivers. This can be helpful in meeting low-power budgets.

Due to independent drains, this device can also be used as an open-drain buffer/driver where both drains are available in one device, thus minimizing chip count. An unused pull-down should be returned to the ground; an unused pull-up should be returned to V_{DD}. This is to prevent static damage. Alternatively, in situations requiring greater current-carrying capacity, multiple MIC4606 or MIC4607s may be paralleled.

The MIC4606/4407 will not latch under any conditions within its power and voltage ratings. It is not subject to damage when up to 5V of noise spiking of either polarity occurs on the ground pin. It can accept, without damage or logic upset, up to 500mA of reverse current (of either polarity) being forced back into the outputs All terminals are fully protected against up to 2kV of electrostatic discharge.

Absolute Maximum Ratings (Note 1)

Supply Voltage	+22V
Maximum Die Temperature	+150°C
Storage Temperature Range	–65°C to +150°C
Lead Temperature (Soldering, 10 sec)	+300°C
Package Thermal Resistance	
CerDIP θ_{JA}	150°C/W
CerDIP θ_{JC}	55°C/W
PDIP θ_{JA}	125°C/W
PDIP θ_{JC}	45°C/W
SOIC θ_{JA}	250°C/W
SOIC θ_{JC}	75°C/W

Ordering Information

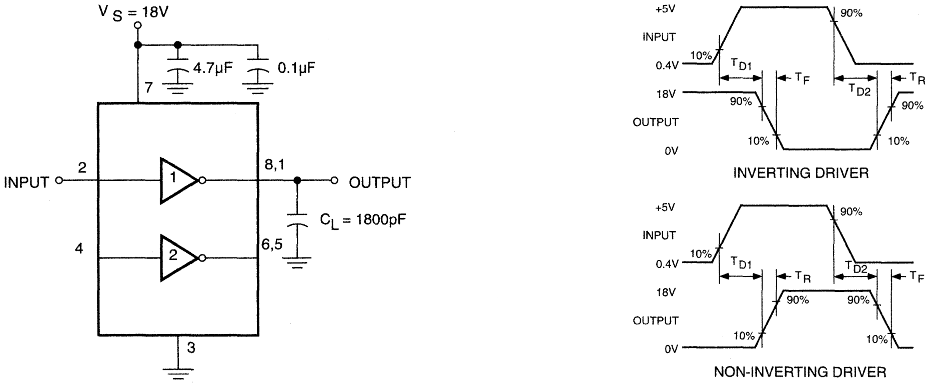
Part Number	Logic	Package	Temperature Range
MIC4606BN	Inverting	8-pin PDIP	–40°C to +85°C
MIC4606BM	Inverting	8-pin SOIC	–40°C to +85°C
MIC4607BN	Noninverting	8-pin PDIP	–40°C to +85°C
MIC4607BM	Noninverting	8-pin SOIC	–40°C to +85°C

Note 1: Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specification is not implied. Exposure to Absolute Maximum Rating Conditions for extended periods may affect device reliability. Static-sensitive device. Unused devices must be stored in conductive material. Protect devices from static discharge and static fields.

Electrical Characteristics

Unless otherwise specified, specifications measured at $T_A = 25°C$ with $4.5V \le V_{DD} \le 18V$.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Input						
V_{IH}	Logic 1 High Input Voltage		2.4		$V_{DD} + 0.3$	V
V_{IL}	Logic 0 Low Input Voltage		–5		0.8	V
I_{IN}	Input Current	$0V \le V_{IN} \le V_{DD}$	–1		1	μA
Output						
V_{OH}	High Output Voltage		$V_{DD} - 0.025$			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance, Pull-Up	$I_{OUT} = 10mA, V_{DD} = 18V$		2.8	5	Ω
R_O	Output Resistance, Pull-Down	$I_{OUT} = 10mA, V_{DD} = 18V$		5.5	5	Ω
I_{PK}	Peak Output Current	Any Drain		3		A
I_R	Latch-up Protection Withstand Reverse Current	Any Drain	>500			mA
Switching Time						
t_R	Rise Time	Figure 1, $C_L = 1800pF$		23	35	ns
t_F	Fall Time	Figure 1, $C_L = 1800pF$		25	35	ns
t_{D1}	Delay Time	Figure 1, $C_L = 1800pF$		17	75	ns
t_{D2}	Delay Time	Figure 1, $C_L = 1800pF$		23	75	ns
Power Supply						
I_S	Power Supply Current	$V_{IN} = 3V$ (both inputs)		1.4	2.5	mA
		$V_{IN} = 0V$ (both inputs)		0.17	0.25	mA



INVERTING DRIVER

NON-INVERTING DRIVER

Figure 1. MIC4606/4607 Switching time test circuit.

Electrical Characteristics (continued)

Specifications measured **over operating temperature range** with 4.5V ≤ V_{DD} ≤ 18V, unless otherwise specified.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Input						
V_{IH}	Logic 1 High Input Voltage		2.4		V_{DD} + 0.3	V
V_{IL}	Logic 0 Low Input Voltage		–5		0.8	V
I_{IN}	Input Current	0V ≤ V_{IN} ≤ V_{DD}	–10		10	µA
Output						
V_{OH}	High Output Voltage		V_{DD} – 0.025			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance, Pull-Up	I_{OUT} = 10mA, V_{DD} = 18V		3.7	8	Ω
R_O	Output Resistance, Pull-Down	I_{OUT} = 10mA, V_{DD} = 18V		5.5	8	Ω
I_{PK}	Peak Output Current	Any Drain		3		A
I_R	Latch-up Protection Withstand	Any Drain Reverse Current	>500			mA
Switching Time						
t_R	Rise Time	Figure 1, C_L = 1800pF		24	60	ns
t_F	Fall Time	Figure 1, C_L = 1800pF		32	60	ns
t_{D1}	Delay Time	Figure 1, C_L = 1800pF		19	100	ns
t_{D2}	Delay Time	Figure 1, C_L=1800pF		27	100	ns
Power Supply						
I_S	Power Supply Current	V_{IN} = 3V (both inputs)		1.6	3.5	mA
		V_{IN} = 0V (both inputs)		0.25	0.3	mA

MIC4608/4609

9A-Peak Open-Drain MOSFET Driver

Preliminary Information

General Description

The MIC4608/4609 are BiCMOS/DMOS buffer-drivers constructed with complementary MOS outputs, where the drains of the final output totem poles have been left disconnected so individual connections can be made to the pull-up and pull-down sections of the output, thus allowing the user to define the rates of rise and fall times desired for a capacitive load, or a reduced output swing if driving a resistive load, or to limit base current when driving a bipolar transistor. Minimum rise and fall times, with no resistors, will be less than 30ns for a 10,000pF load. There is no upper limit.

These devices are rugged due to extra steps taken to protect them from failures. A modern Bipolar/CMOS/DMOS process guarantees freedom from latchup. Proprietary circuits allow the input to swing negative as much as 5V without damaging the part.

For driving MOSFETs in motor-control applications, where slow-on/fast-off operation is desired, the MIC4608/4609 is superior to the previously-used technique of adding a diode-resistor combination between the driver output and the MOSFET, because it allows accurate control of turn-on, while maintaining fast turn-off and maximum noise immunity for the device being driven.

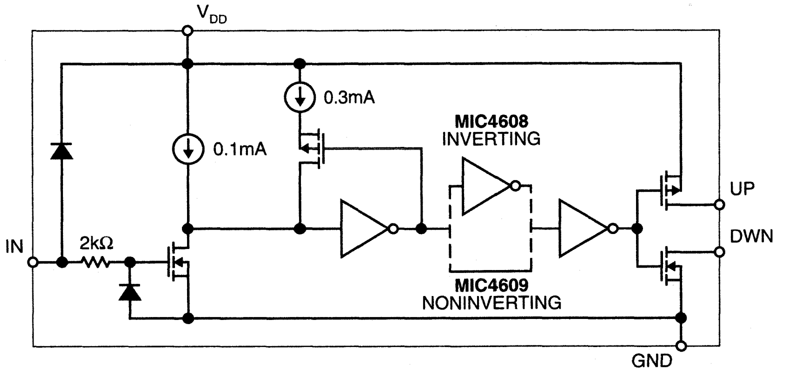
Features

- Independently Programmable Rise and Fall Times
- High Peak Output Current .... 9A peak
- Low Output Impedance .... 1Ω typ.
- High Speed t_R, t_F .... <30ns with 10,000pF
- Short Delay Times .... <30ns typ.
- Wide Operating Range .... 4.5V to 18V
- Latch-up Protected: Fully Isolated Process is Inherently Immune to Any Latch-Up.
- Input Withstands Negative Swings to –5V
- ESD Protected 2kV

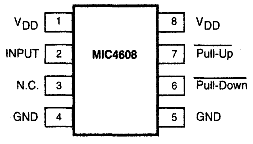
Applications

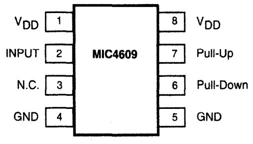
- Power Switch
- Motor Controls
- Self-Commutating MOSFET Bridge Driver
- Driving Bipolar Transistors
- Driver for Nonoverlapping Totem Poles
- Pulse Generator
- Line Driver
- Power Management
- Level Shifters

Functional Diagram



Pin Configuration





When used to drive bipolar transistors, this driver maintains high speeds and allows insertion of a base current-limiting resistor, and also provides a separate half-output for fast turn-off. By proper positioning of the resistor, either NPN or PNP transistors can be driven.

For driving many loads in low-power systems, this driver, because it has very low quiescent current (<80µA) and eliminates shoot-through current in the output stage, requires significantly less power than similar drivers and can be helpful in meeting low-power budgets.

Due to independent drains, this device can also be used as an open-drain buffer/driver where both drains are available in one device, thus minimizing chip count. An unused pull-down should be returned to the ground; an unused pull-up should be returned to V_{DD}. This is to prevent static damage. Alternatively, in situations requiring greater current-carrying capacity, multiple MIC4608 or MIC4609s may be paralleled.

The MIC4608/4609 will not latch under any conditions within its power and voltage ratings. It is not subject to damage when up to 5V of noise spiking of either polarity occurs on the ground pin. It can accept, without damage or logic upset, up to 1.5 amps of reverse current (of either polarity) being forced back into the outputs.

Absolute Maximum Ratings (Note 1)

Supply Voltage	+22V
Maximum Die Temperature	+150°C
Storage Temperature Range	–65°C to +150°C
Lead Temperature (Soldering, 10 sec)	+300°C
Package Thermal Resistance	
CerDIP θ_{JA}	150°C/W
CerDIP θ_{JC}	55°C/W
PDIP θ_{JA}	125°C/W
PDIP θ_{JC}	45°C/W
SOIC θ_{JA}	250°C/W
SOIC θ_{JC}	75°C/W

Ordering Information

Part Number	Logic	Package	Temperature Range
MIC4608BN	Inverting	8-pin PDIP	–40°C to +85°C
MIC4608BM	Inverting	8-pin SOIC	–40°C to +85°C
MIC4609BN	Non-inverting	8-pin PDIP	–40°C to +85°C
MIC4609BM	Non-inverting	8-pin SOIC	–40°C to +85°C

Note 1: Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specification is not implied. Exposure to Absolute Maximum Rating Conditions for extended periods may affect device reliability. Static-sensitive device. Unused devices must be stored in conductive material. Protect devices from static discharge and static fields.

Electrical Characteristics

Unless otherwise specified, specifications measured at $T_A = 25°C$ with $4.5V \le V_{DD} \le 18V$.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Input						
V_{IH}	Logic 1 High Input Voltage		2.4		$V_{DD} + 0.3$	V
V_{IL}	Logic 0 Low Input Voltage		–5		0.8	V
I_{IN}	Input Current	$0V \le V_{IN} \le V_{DD}$	–10		10	µA
Output						
V_{OH}	High Output Voltage		$V_{DD} – 0.025$			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance, Pull-Up	$I_{OUT} = 10mA$, $V_{DD} = 18V$		0.9	1.7	Ω
R_O	Output Resistance, Pull-Down	$I_{OUT} = 10mA$, $V_{DD} = 18V$		1.0	2.5	Ω
I_{PK}	Peak Output Current			9		A
I_R	Latch-up Protection Withstand Reverse Current	t < 300µs, Duty Cycle ≤ 2%	>1500			mA
Switching Time						
t_R	Rise Time	Figure 1, $C_L = 10,000pF$		25	60	ns
t_F	Fall Time	Figure 1, $C_L = 10,000pF$		25	60	ns
t_{D1}	Delay Time	Figure 1, $C_L = 10,000pF$		30	60	ns
t_{D2}	Delay Time	Figure 1, $C_L = 10,000pF$		33	60	ns
Power Supply						
I_S	Power Supply Current	$V_{IN} = 3V$		0.4	1.5	mA
		$V_{IN} = 0V$		0.08	0.15	mA

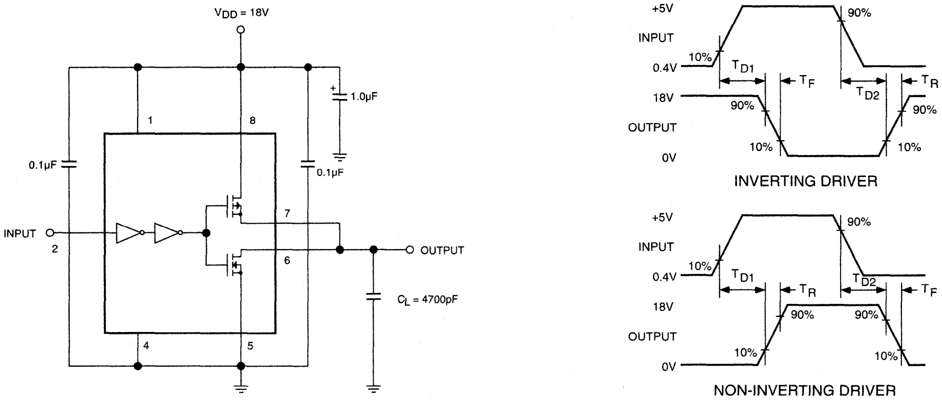


Figure 1. MIC4608/4609 Switching time test circuit.

Electrical Characteristics, continued

Specifications measured **over operating temperature range** with $4.5V \le V_{DD} \le 18V$, unless otherwise specified.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Input						
V_{IH}	Logic 1 High Input Voltage		2.4		$V_{DD} + 0.3$	V
V_{IL}	Logic 0 Low Input Voltage		–5		0.8	V
I_{IN}	Input Current	$0V \le V_{IN} \le V_{DD}$	–10		10	µA
Output						
V_{OH}	High Output Voltage		$V_{DD} - 0.025$			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance, Pull-Up	$I_{OUT} = 10mA$, $V_{DD} = 18V$		1.4	5	Ω
R_O	Output Resistance, Pull-Down	$I_{OUT} = 10mA$, $V_{DD} = 18V$		1.5	5	Ω
Switching Time (Note 1)						
t_R	Rise Time	Figure 1, $C_L = 10{,}000pF$		30	80	ns
t_F	Fall Time	Figure 1, $C_L = 10{,}000pF$		40	80	ns
t_{D1}	Delay Time	Figure 1, $C_L = 10{,}000pF$		30	80	ns
t_{D2}	Delay Time	Figure 1, $C_L=10{,}000pF$		40	80	ns
Power Supply						
I_S	Power Supply Current	$V_{IN} = 3V$		0.6	3	mA
		$V_{IN} = 0V$		0.1	0.2	mA

MIC4610/4611

12A-Peak Open-Drain MOSFET Driver

Preliminary Information

General Description

The MIC4610/4611 are CMOS buffer-drivers constructed with complementary MOS outputs, where the drains of the final output totem poles have been left disconnected so individual connections can be made to the pull-up and pull-down sections of the output, thus allowing the user to define the rates of rise and fall times desired for a capacitive load, or a reduced output swing if driving a resistive load, or to limit base current when driving a bipolar transistor. Minimum rise and fall times, with no resistors, is 40ns for a 15,000pF load. There is no upper limit.

These devices are rugged due to extra steps taken to protect them from failures. A modern Bipolar/CMOS/DMOS process guarantees freedom from latchup. Proprietary circuits allow the input to swing negative as much as 5V without damaging the part.

For driving MOSFETs in motor-control applications, where slow-on/fast-off operation is desired, the MIC4610/4611 is superior to the previously-used technique of adding a diode-resistor combination between the driver output and the MOSFET, because it allows accurate control of turn-on, while maintaining fast turn-off and maximum noise immunity for the device being driven.

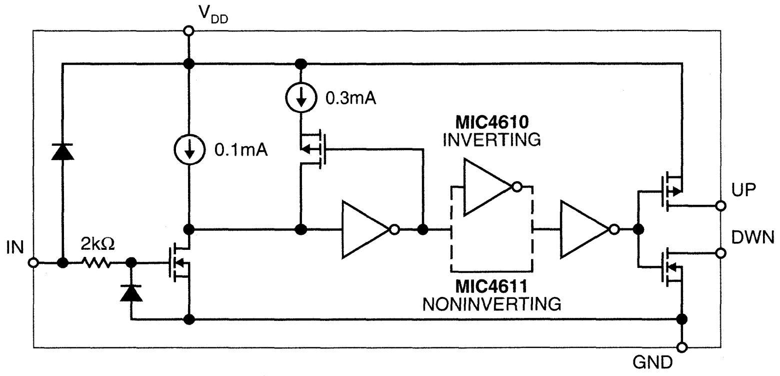
Features

- Independently - Programmable Rise and Fall Times
- High Peak Output Current .... 12A peak
- Low Output Impedance .... 1Ω Typ
- High Speed t_R, t_F .... <40 ns with 15,000pF load
- Short Delay Times .... 30ns Typical
- Wide Operating Range .... 4.5V to 18V
- Latch-up Protected: Fully Isolated Process is Inherently Immune to Any Latch-Up.
- Input Withstands Negative Swings to –5V
- ESD Protected 2kV

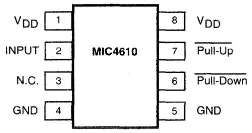
Applications

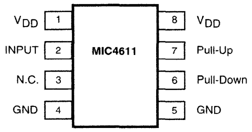
- Power Switch
- Motor Controls
- Self-Commutating MOSFET Bridge Driver
- Driving Bipolar Transistors
- Driver for Nonoverlapping Totem Poles
- Pulse Generator
- Line Driver
- Power Management
- Level Shifters

Functional Diagram



Pin Configuration





When used to drive bipolar transistors, this driver maintains high speeds and allows insertion of a base current-limiting resistor, and also provides a separate half-output for fast turn-off. By proper positioning of the resistor, either NPN or PNP transistors can be driven.

For driving many loads in low-power systems, this driver, since it has very low quiescent current (<80μA) and eliminates shoot-through current in the output stage, requires significantly less power than similar drivers. This can be helpful in meeting low-power budgets.

Due to independent drains, this device can also be used as an open-drain buffer/driver where both drains are available in one device, thus minimizing chip count. An unused pull-down should be returned to the ground; an unused pull-up should be returned to V_{DD}. This is to prevent static damage. Alternatively, in situations requiring greater current-carrying capacity, multiple MIC4610 or MIC4611s may be paralleled.

The MIC4610/4611 will not latch under any conditions within its power and voltage ratings. It is not subject to damage when up to 5V of noise spiking of either polarity occurs on the ground pin. It can accept, without damage or logic upset, up to 1.5 amps of reverse current (of either polarity) being forced back into the outputs.

Absolute Maximum Ratings

Supply Voltage	+22V
Maximum Die Temperature	+150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec)	+300°C
Package Thermal Resistance	
CerDIP θ_{JA}	150°C/W
CerDIP θ_{JC}	55°C/W
PDIP θ_{JA}	125°C/W
PDIP θ_{JC}	45°C/W
SOIC θ_{JA}	250°C/W
SOIC θ_{JC}	75°C/W

Ordering Information

Part Number	Logic	Package	Temperature Range
MIC4610BN	Inverting	8-pin PDIP	−40°C to +85°C
MIC4610BM	Inverting	8-pin SOIC	−40°C to +85°C
MIC4611BN	Non-inverting	8-pin PDIP	−40°C to +85°C
MIC4611BM	Non-inverting	8-pin SOIC	−40°C to +85°C

Note 1: Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specification is not implied. Exposure to Absolute Maximum Rating Conditions for extended periods may affect device reliability. Static-sensitive device. Unused devices must be stored in conductive material. Protect devices from static discharge and static fields.

Electrical Characteristics

Unless otherwise specified, specifications measured at $T_A = 25°C$ with $4.5V \le V_{DD} \le 18V$.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Input						
V_{IH}	Logic 1 High Input Voltage		2.4		$V_{DD} + 0.3$	V
V_{IL}	Logic 0 Low Input Voltage		–5		0.8	V
I_{IN}	Input Current	$0V \le V_{IN} \le V_{DD}$	–10		10	µA
Output						
V_{OH}	High Output Voltage		$V_{DD} - 0.025$			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance, Pull-Up	$I_{OUT} = 10mA$, $V_{DD} = 18V$		1.0	1.5	Ω
R_O	Output Resistance, Pull-Down	$I_{OUT} = 10mA$, $V_{DD} = 18V$		0.9	1.5	Ω
I_{PK}	Peak Output Current			12		A
I_R	Latch-up Protection Withstand Reverse Current	t < 300µs, Duty Cycle ≤ 2%	>1500			mA
Switching Time						
t_R	Rise Time	Figure 1, C_L = 15,000pF		40	60	ns
t_F	Fall Time	Figure 1, C_L = 15,000pF		40	60	ns
t_{D1}	Delay Time	Figure 1, C_L = 15,000pF		30	60	ns
t_{D2}	Delay Time	Figure 1, C_L = 15,000pF		33	60	ns
Power Supply						
I_S	Power Supply Current	V_{IN} = 3V		0.4	1.5	mA
		V_{IN} = 0V		0.08	0.15	mA

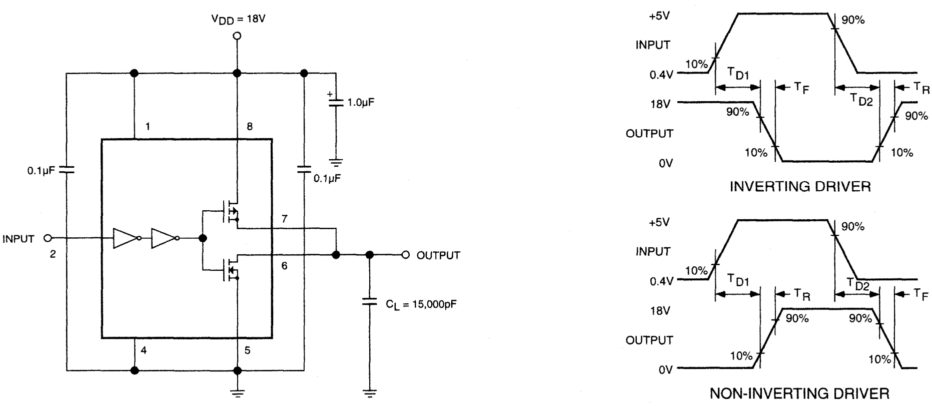


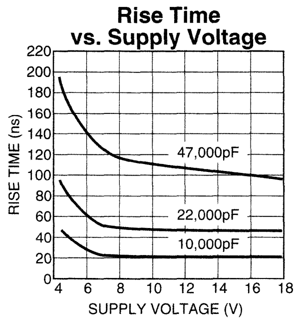
Figure 1. MIC4610/4611 Switching time test circuit.

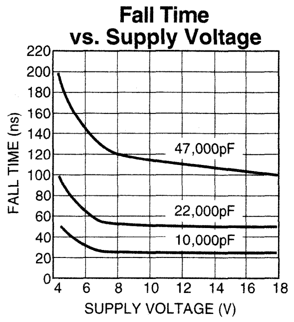
Electrical Characteristics, continued

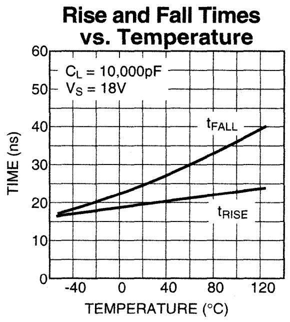
Specifications measured **over operating temperature range** with 4.5V ≤ V_{DD} ≤ 18V, unless otherwise specified.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
Input						
V_{IH}	Logic 1 High Input Voltage		2.4		V_{DD} + 0.3	V
V_{IL}	Logic 0 Low Input Voltage		–5		0.8	V
I_{IN}	Input Current	0V ≤ V_{IN} ≤ V_{DD}	–10		10	µA
Output						
V_{OH}	High Output Voltage		V_{DD} – 0.025			V
V_{OL}	Low Output Voltage				0.025	V
R_O	Output Resistance, Pull-Up	I_{OUT} = 10mA, V_{DD} = 18V		1.5	2.2	Ω
R_O	Output Resistance, Pull-Down	I_{OUT} = 10mA, V_{DD} = 18V		1.4	2.2	Ω
Switching Time (Note 1)						
t_R	Rise Time	Figure 1, C_L = 15,000pF		60	100	ns
t_F	Fall Time	Figure 1, C_L = 15,000pF		60	100	ns
t_{D1}	Delay Time	Figure 1, C_L = 15,000pF		45	80	ns
t_{D2}	Delay Time	Figure 1, C_L=15,000pF		45	80	ns
Power Supply						
I_S	Power Supply Current	V_{IN} = 3V		0.6	3	mA
		V_{IN} = 0V		0.1	0.2	mA

Typical Performance Characteristics

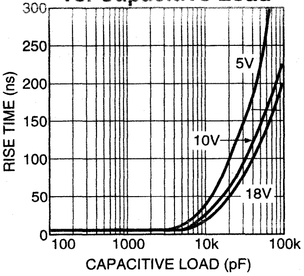

Rise Time vs. Supply Voltage


Fall Time vs. Supply Voltage

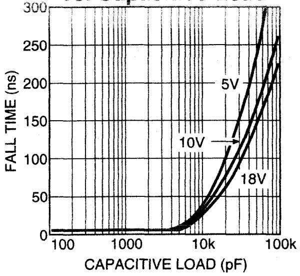

Rise and Fall Times vs. Temperature

Typical Performance Characteristics, continued

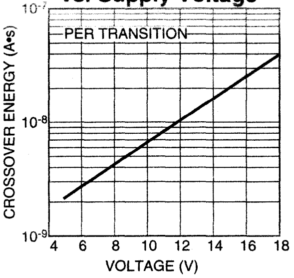
Rise Time vs. Capacitive Load



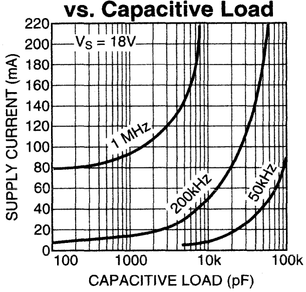
Fall Time vs. Capacitive Load



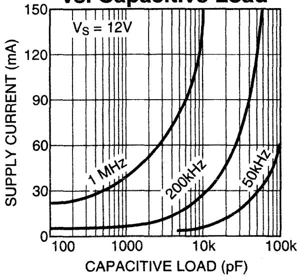
Crossover Energy vs. Supply Voltage



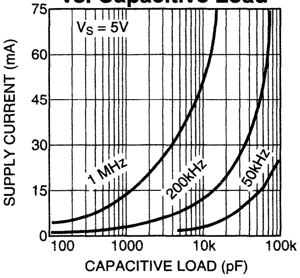
Supply Current vs. Capacitive Load



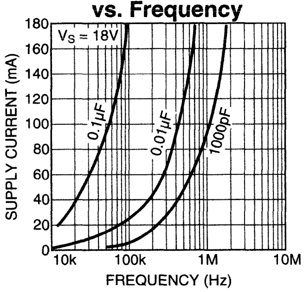
Supply Current vs. Capacitive Load



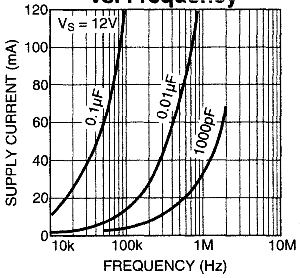
Supply Current vs. Capacitive Load



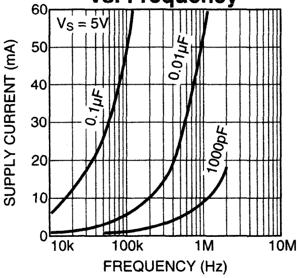
Supply Current vs. Frequency



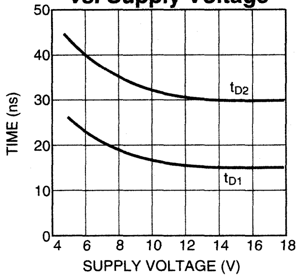
Supply Current vs. Frequency



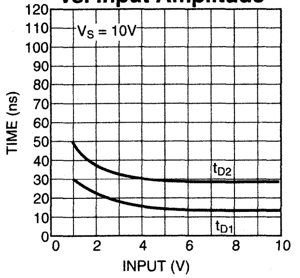
Supply Current vs. Frequency



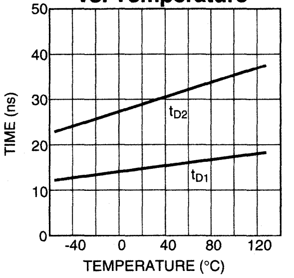
Propagation Delay vs. Supply Voltage



Propagation Delay vs. Input Amplitude

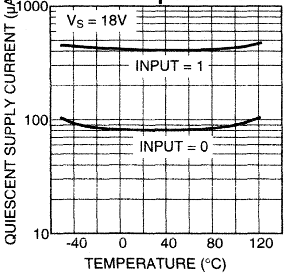


Propagation Delay vs. Temperature

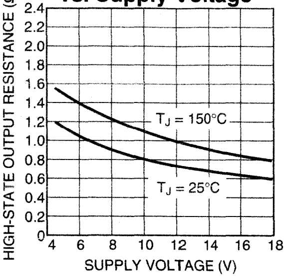


Typical Performance Characteristics, continued

Quiescent Supply Current vs. Temperature



High-State Output Resist. vs. Supply Voltage



Low-State Output Resist. vs. Supply Voltage

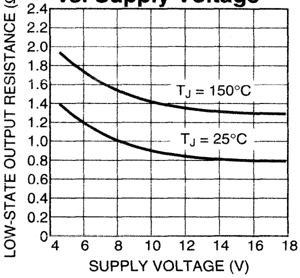


Table of Contents

Section 7: MOSFET Switches

MIC2505/2506

2A / Dual 1A / Integrated High-Side Switches

Preliminary Information

General Description

The MIC2505 and MIC2506 are single and dual integrated high-side power switches that consist of TTL compatible inputs, a charge pump, and protected N-channel MOSFETs. The MIC2505/6 can be used instead of separate high-side drivers and MOSFETs in many low-voltage applications.

The MIC2505 switches voltages ranging from 2.7V to 7.5V and can deliver at least 2A continuous current. An MIC2506 can deliver at least 1A continuous current from each output. A slow turn on feature prevents high inrush current when switching capacitive loads. The internal control circuitry is powered from the same 2.7V to 7.5V. An MIC2505/6 output can be forced higher than the input voltage safely while in the off mode.

Multipurpose open-drain fault flag outputs indicate overcurrent limiting, open-load detection, thermal shutdown, or undervoltage lockout for each channel.

Overcurrent limiting is internally fixed and requires no external components.

Open-load detection is active when the switch is off. When off, a normal load pulls the output pin low. If the load is open, an optional, external, high-value resistor pulls the output pin high, triggering the fault flag.

Thermal shutdown turns off the output if the die temperature exceeds approximately 135°C. The switch automatically restarts when the temperature falls 10°C.

Undervoltage lockout (UVLO) shuts off the output if the supply drops below 2.3V typical and reenables the output when the supply exceeds 2.5V typical.

The MIC2505/6 is available in the 8-pin SOIC package with a temperature range of –40°C to +85°C.

Features

- Low MOSFET on resistance to 2.7V
  - 30mΩ typical at 5V (MIC2505)
  - 35mΩ typical at 3.3V (MIC2505)
  - 75mΩ typical at 5V (each MIC2506 output)
  - 80mΩ typical at 3.3V (each MIC2506 output)
- 2.7V to 7.5V input
- 110µA typical on-state supply current
- 1µA typical off-state supply current
- Output can be forced higher than input (off-state)
- Current limit
- Thermal shutdown
- 2.5V undervoltage lockout (UVLO)
- Open-load detection
- Open-drain fault flag
- 5ms (slow) turn-on and fast turnoff

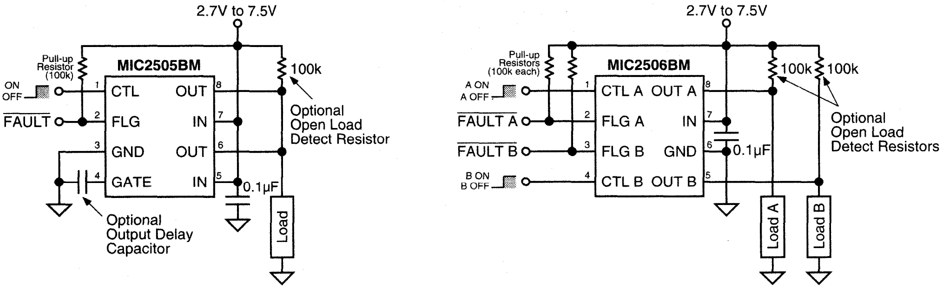
Applications

- 3.3V and 5V power management
- PC Card card inrush limiting switch
- Hot plug-in power supplies
- Battery-charger circuits

Ordering Information

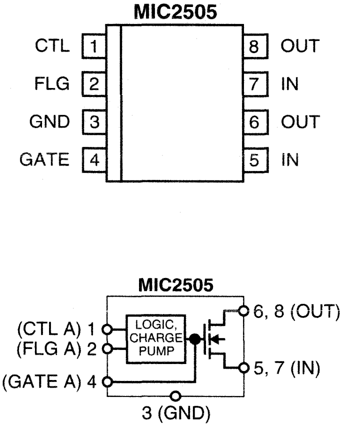
Part Number	Temperature Range	Package
Single Switch		
MIC2505BM	–40°C to +85°C	8-lead SOIC
Dual Switch		
MIC2506BM	–40°C to +85°C	8-lead SOIC

Typical Applications

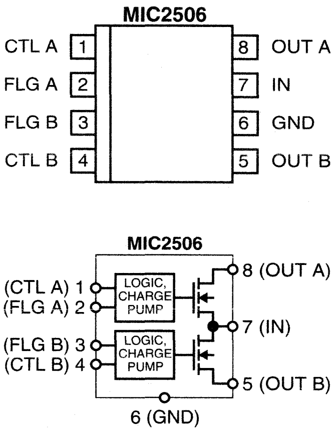


Single and Dual Switch/Circuit Breakers with Open-Load Detection and Fault Output

Pin Configuration



8-Pin SOIC (M)



8-Pin SOIC (M)

Pin Description

Pin Number MIC2505	Pin Number MIC2506	Pin Name	Pin Function
1	1 / 4	CTL (A/B)	Control (Input): Noninverting TTL compatible control input. High (> 1.8V typical) = on, low (< 1.6V typical) = off.
2	2 / 3	FLG (A/B)	Fault Flag (Output): Active-low, open-drain output. If CTL is low, indicates open load. If CTL is high, indicates current limit, thermal shutdown, or UVLO.
3	6	GND	Ground: Return.
4	—	GATE	Output MOSFET Gate: Open for fastest rise and fall times. Connect capacitor to ground to slow rise and fall times.
5, 7	7	IN	Supply Input: Output MOSFET drain. Also supplies IC's internal circuitry. Connect to supply. *MIC2505 only:* pins 5 and 7 must be externally connected.
6, 8	8 / 5	OUT (A/B)	Switch Output: Output MOSFET source. Typically connect to switched side of load. Output voltage can be pulled above input voltage in off mode. *MIC2505 only:* pins 6 and 8 must be externally connected.

Absolute Maximum Ratings

Supply Voltage ($V_{IN\ max}$)	8.0V
Fault Flag Voltage ($V_{FLG\ max}$)	7.5V
Fault Flag Current ($I_{FLG\ max}$)	50mA
Output Voltage ($V_{OUT\ max}$)	7.5V
Output Current ($I_{OUT\ max}$)	Internally Limited
Gate Voltage ($V_{GATE\ max}$)	V_{IN} + 15V
Control Input ($V_{CTL\ max}$)	–0.3V to 15V
Storage Temperature	–65°C to +150°C
Lead Temperature (Soldering 5 sec.)	260°C

Operating Ratings

Supply Voltage (V_{IN})	+2.7V to +7.5V
Ambient Operating Temperature (T_A)	–40°C to +85°C
Thermal Resistance, SOIC (θ_{JA})	160°C/W

Electrical Characteristics

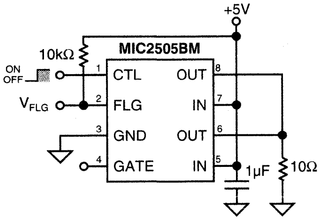
Parameter	Condition (Note 1)		Min	Typ	Max	Units
Supply Current	MIC2505	CTL = logic 0, OUT = open CTL = logic 1, OUT = open		.75 110	5 160	µA µA
	MIC2506	CTL = logic 0, OUT = open CTL = logic 1, OUT = open		.75 110	5 160	µA µA
Control Input Voltage		CTL = logic 0 → logic 1 transition CTL = logic 1 → logic 0 transition	 0.8	2.1 1.9	2.4 	V V
Control Input Current		CTL = logic 0 CTL = logic 1		0.01 0.01	1 1	µA µA
Control Input Capacitance				1		pF
Output MOSFET Resistance	MIC2505	IN = 5V, T_A = 25°C IN = 5V, –40°C < T_A < +85°C IN = 3.3V, T_A = 25°C IN = 3.3V, –40°C < T_A < +85°C		30 35 	50 60 60 75	mΩ mΩ mΩ mΩ
	MIC2506	IN = 5V, T_A = 25°C IN = 5V, –40°C < T_A < +85°C IN = 3.3V, T_A = 25°C IN = 3.3V, –40°C < T_A < +85°C		75 80 	125 150 135 165	mΩ mΩ mΩ mΩ
Output Turn-On Delay	MIC2505	R_L = 10Ω	200	850	2000	µs
	MIC2506	R_L = 10Ω each output	100	700	2000	µs
Output Turn-On Rise Time	MIC2505	R_L = 10Ω	500	3000	7500	µs
	MIC2506	R_L = 10Ω each output	200	2000	6000	µs
Output Turn-Off Delay	MIC2505	R_L = 10Ω		0.7	20	µs
	MIC2506	R_L = 10Ω each output		0.8	20	µs
Output Turn-Off Fall Time	MIC2505	R_L = 10Ω		1.5	20	µs
	MIC2506	R_L = 10Ω each output		0.7	20	µs
Output Leakage Current					10	µA
Current Limit Threshold	MIC2505		2	4		A
	MIC2506		1	2		A
Open Load Threshold		CTL = logic low, **Note 2**	0.5	1	1.5	V
Overtemperature Shutdown Threshold		T_J increasing T_J decreasing		135 125		°C °C
Error Flag Output Resistance		IN = 5V, I_L = 10mA IN = 3.3V, I_L = 10mA		10 15	25 40	Ω Ω
Error Flag Off Current		V_{FLAG} = 5V		0.01	1	µA
UVLO Threshold		IN = increasing IN = decreasing	2.2 2.0	2.5 2.3	2.7 2.5	V V

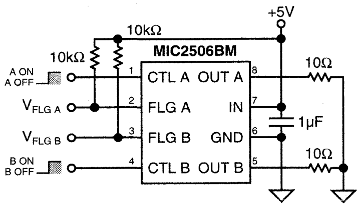
General Note: Devices are ESD protected; however, handling precautions are recommended.

Note 1 Typical values at 25°C, minimum and maximum values at –40°C ≤ T_A ≤ +85°C, IN = +5V, GATE = open, unless noted.

Note 2 Open load threshold is the OUT voltage where FLG becomes active (low). OUT driven high externally.

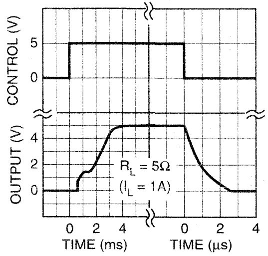
Test Circuits



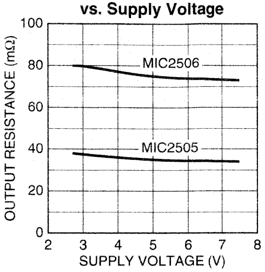


Typical Characteristics Note 2

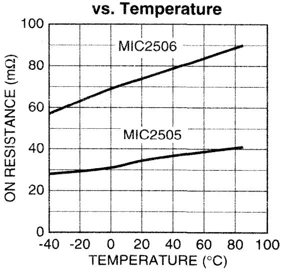
MIC2505 Turn-On, Turn-Off Characteristics



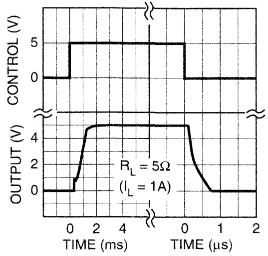
Output On Resistance vs. Supply Voltage



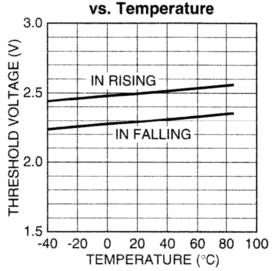
Output On Resistance vs. Temperature



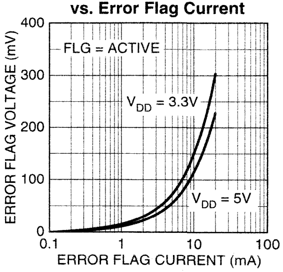
MIC2506 Turn-On, Turn-Off Characteristics



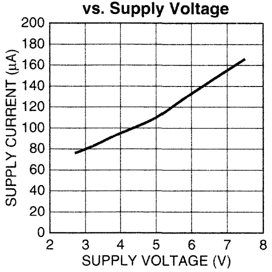
UVLO Threshold Voltage vs. Temperature



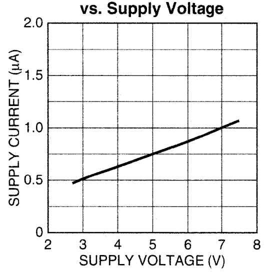
Error Flag Voltage vs. Error Flag Current



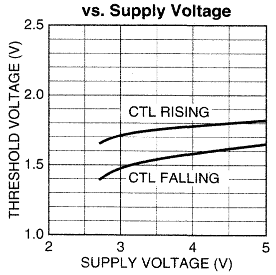
On-State Supply Current vs. Supply Voltage



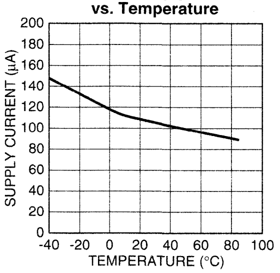
Off-State Supply Current vs. Supply Voltage



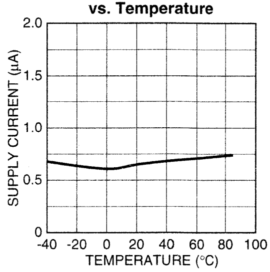
Control Threshold vs. Supply Voltage



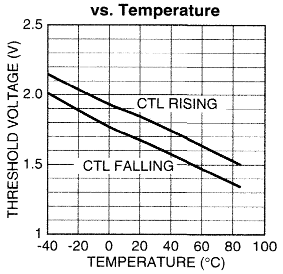
On-State Supply Current vs. Temperature



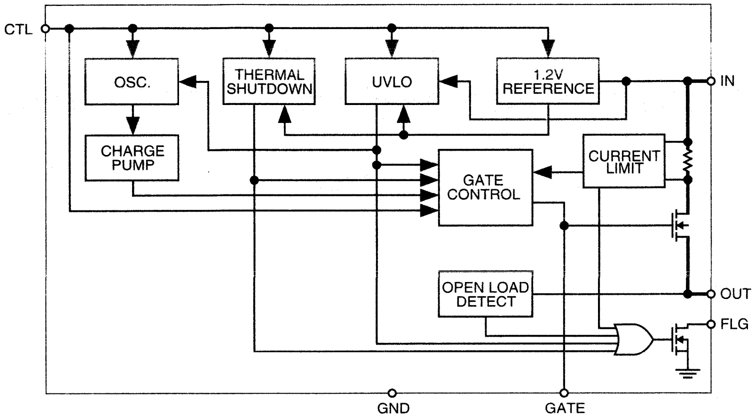
Off-State Supply Current vs. Temperature



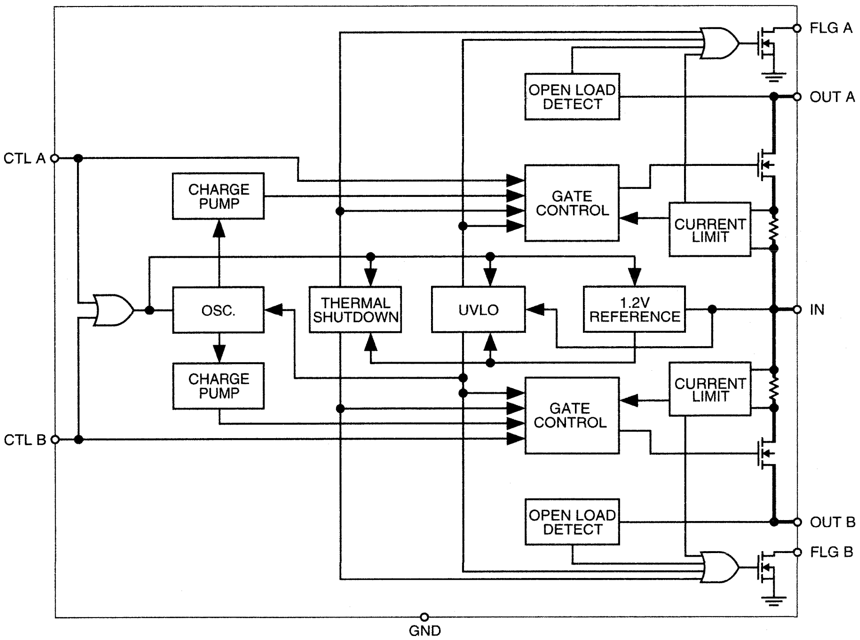
Control Threshold vs. Temperature



Block Diagrams



MIC2505 Block Diagram



MIC2506 Block Diagram

Functional Description

The MIC2505/6 is a noninverting high-side switch. A logic-high control input turns on the output transistor, and a logic-low turns off the output transistor. Fault conditions turn off or inhibit turn on of the output transistor.

Control Input

Applying a logic-high input to CTL (control input) activates the oscillator, thermal shutdown, UVLO, 1.2V reference, and gate control circuits. If there are no fault conditions, the output MOSFET turns on.

Reference

The 1.2V bandgap reference supplies a regulated voltage to the thermal shutdown and undervoltage lockout circuits. The reference is only active when CTL is high.

Oscillator/Charge Pump

The oscillator produces an 80kHz square wave output which drives the charge pump. The oscillator is disabled when CTL is low or during UVLO.

The charge pump is a voltage quintupler (5×). The charge pump capacitors are self contained.

Gate Control

The gate control circuit charges the output MOSFET gate from the charge pump output or discharges the MOSFET gate to ground as determined by CTL, thermal shutdown, or UVLO (undervoltage lockout).

An optional, external capacitor may be connected to the MIC2505 GATE to lengthen the rise and fall times. This slows the turn on and turn off of the MOSFET output switch.

Input and Output

IN (input) is the supply connection to the logic circuitry and the drain of the output MOSFET. OUT (output) is the source of the output MOSFET. In a typical circuit, current flows through the switch from IN to OUT toward the load.

The output MOSFET and driver circuitry are also designed to allow the MOSFET source to be externally forced to a higher voltage than the drain ($V_{OUT} > V_{IN}$) when CTL is low (switch off). In this situation, the MIC2505/6 avoids undesirable drain to body diode current flow by grounding the body when the switch is off. (The conventional method for optimum turn on threshold has the source connected to the body. This would allow a large current to flow when $V_{source} > V_{drain} + 0.6V$.)

MIC2505 only

Duplicate IN and OUT leads are not internally connected and must be connected externally for proper operation.

Thermal Shutdown

Thermal shutdown shuts off the output MOSFET and signals the fault flag if the die temperature exceeds 135°C. 10°C of hysteresis prevents the switch from turning on until the die temperature drops to 125°C.

Overtemperature detection functions only when the control input is high (output MOSFET is on).

Undervoltage Lockout

UVLO (undervoltage lockout) prevents the output MOSFET from turning on until IN (input voltage) exceeds 2.5V typical. After the switch turns on, if the voltage drops below 2.3V typical, UVLO shuts off the output MOSFET and signals the fault flag.

Undervoltage detection functions only when the control input is high (output MOSFET is on).

Overcurrent Limit

The overcurrent limit is preset internally. The preset level prevents damage to the output MOSFET but allows a minimum current of 2A through the output MOSFET for the MIC2505 and 1A for each output MOSFET for the MIC2506. Output current is monitored by sensing the voltage drop across the output MOSFET drain metal resistance.

Overcurrent detection functions only when the control input is high (output MOSFET is on).

Open-Load Detection

Open-load detection indicates the absence of an output load by signaling the fault flag. Open-load detection is optional and is enabled by connecting a high-value pull-up resistor between IN and OUT. If there is no load, the circuit detects a high OUT (output) voltage (typically ≥1V) and signals the fault flag. Under normal conditions, the low resistance of a typical load pulls OUT low.

Open-load detection functions only when the control input is low (output MOSFET is off).

Fault Flag

FLG is an N-channel, open-drain MOSFET output. The fault-flag is active (low) for one or more of the following conditions: open load, undervoltage, current limit, or thermal shutdown. The flag output MOSFET is capable of sinking a 10mA load to typically 100mV above ground.

Applications Information

Supply Filtering

A 0.1µF to 1µF bypass capacitor from IN to GND, located at the MIC2505/6, is strongly recommended to control supply transients. Without a bypass capacitor, an output short may cause sufficient ringing on the input (from supply lead inductance) to destroy the internal control circuitry.

Input transients must not exceed the absolute maximum supply voltage ($V_{IN\ max}$ = 7.5V) even for a short duration.

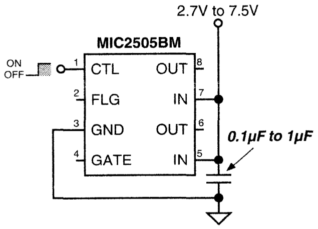


Figure 1. Supply Bypassing

The bypass capacitor may be omitted only if board design precautions are followed, such as using extremely short supply leads or power and ground planes.

Control Input

CTL must be driven logic high or logic low, or be pulled high or low for a clearly defined input. Floating the input may cause unpredictable operation.

Open-Load Detection

Refer to Typical Applications (first page).

The optional open-load detection resistor supplies a small current to the load when the MIC2505/6 is off. (A 100k resistor will draw 50µA from a 5V supply.) Normally, the load dominates, pulling OUT low. If the load is absent, the optional resistor pulls OUT high, activating the fault flag.

Open-load detection will not function with a pure capacitive load.

Omit the resistor when open load detection is not required and for the minimum off-state supply current.

Power Bus Switch

The MIC2505/6 features a MOSFET switch circuit that prevents current from flowing backwards (from OUT to IN) when CTL is low (switch off). In figure 2, when U1 is on and U2 is off, this feature prevents current flow from the load (5V) backward through U2 to the 3.3V supply. (If a discrete MOSFET and driver were used, the MOSFET's internal body diode would short the 5V load to the 3.3V supply.)

In a bus switch circuit, FLG will be active (low) on any switch that is off, whenever the load voltage is greater than the open load threshold (approximately 1V).

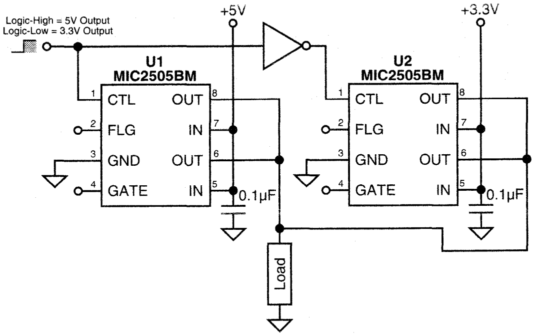


Figure 2. 5V/3.3V Switch Concept

This circuit's function would otherwise require a dual driver, two MOSFETs, plus two diodes (or a dual driver plus four MOSFETs).

Hot Plug-In Applications

The MIC2505/6 can be used to protect the socket-side and card-side of a supply circuit from transients caused when a capacitive load is connected to an active supply.

The switch presents a high impedance when off, and slowly becomes a low impedance as it turns on. This reduces the inrush current and related voltage drop that result from charging a capacitive load.

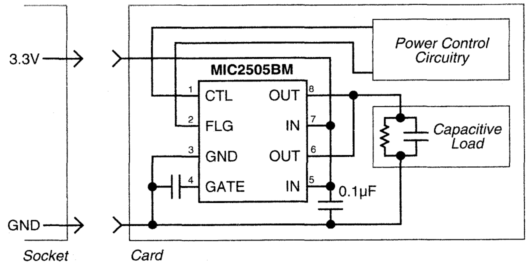


Figure 3. Hot Plug-In Concept

The gate capacitor slows the turn on time even more, reducing the inrush.

MIC94001BLM

P-Channel MOSFET

General Description

The MIC94001BLM is a silicon gate P-channel MOSFET designed for low ON-resistance, high-side switch applications.

The MIC94001BLM has a maximum ON resistance of 0.4Ω at 4.5V gate-to-source voltage.

Improved ESD protection is provided by the gate protection network shown in the schematic diagram.

The MIC94001BLM is supplied in a low-profile version of the 8-lead SOIC package.

The MIC94001 die can be assembled in a 4-terminal configuration with the body not shorted to the source for use in analog switch applications. Contact the factory for more information.

Features

- 15V minimum drain-to-source breakdown
- 0.4Ω maximum ON resistance at 4.5V gate-to-source
- Functional at 2.7V gate-to-source
- 0.063" maximum height

Applications

- High-side switch
- Power management
- Stepper motor control
- 1.8" PCMCIA disk-drive V_{CC} switch

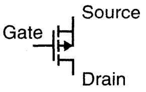
Ordering Information

Part Number	Temperature Range*	Package
MIC94001BLM	–55°C to +150°C	8-lead SOIC†

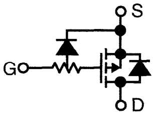
* Operating Junction Temperature

† Low Profile Leads, see Package Information

Schematic Information

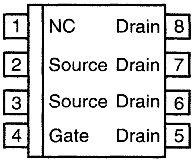


Schematic Symbol



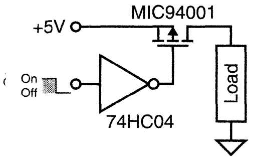
Schematic Diagram

Pin Configuration



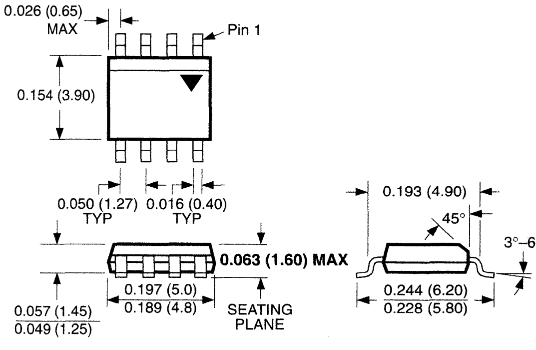
8-lead Low-Profile SOIC Package (LM)

Typical Application



Power Switch Application

Package Information



Patent 5,355,008

Absolute Maximum Ratings

Voltage and current values are negative. Signs not shown for clarity.

Drain-to-Source Voltage 15V

Gate-to-Source Voltage 15V

Continuous Drain Current
$T_A = 25°C$ 1.6A
$T_A = 100°C$ 1A

Operating Juction Temperature .... –55°C to +150°

Storage Temperature .... –55°C to +150°C

Total Power Dissipation
$T_A = 25°C$ 1W
$T_A = 100°C$ 0.4W

Thermal Resistance
θ_{JA} .... 125°C/W
θ_{JC} .... 76°C/W

Lead Temperature
1/16" from case, 10s .... +300°C

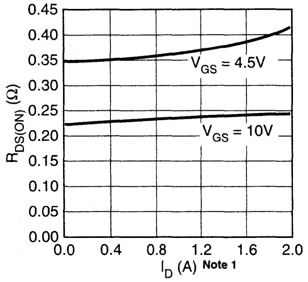
Electrical Characteristics $T_A = 25°C$ unless noted. *All values are negative. Signs not shown for clarity.*

Symbol	Parameter	Condition	Min	Typ	Max	Units
V_{BDSS}	Drain-Source Breakdown Voltage	$V_{GS} = 0V$, $I_D = 250\mu A$	15			V
V_{GS}	Gate Threshold Voltage	$V_{DS} = V_{GS}$, $I_D = 250\mu A$	1		3	V
I_{GSS}	Gate-Body Leakage	$V_{DS} = 0V$, $V_{GS} = 15V$, **Note 2**			100	nA
I_{DSS}	Zero Gate Voltage Drain Current	$V_{DS} = 15V$, $V_{GS} = 0V$			25	µA
		$V_{DS} = 15V$, $V_{GS} = 0V$, $T_J = 125°C$			250	µA
$I_{D(ON)}$	On-State Drain Current	$V_{DS} \geq 10V$, $V_{GS} = 10V$, **Note 1**		5.5		A
$R_{DS(ON)}$	Drain-Source ON-State Resist.	$V_{GS} = 4.5V$, $I_D = 50mA$		0.35	0.40	Ω
g_{FS}	Forward Transconductance	$V_{DS} = 15V$, $I_D = 1A$, **Note 1**		0.7		S

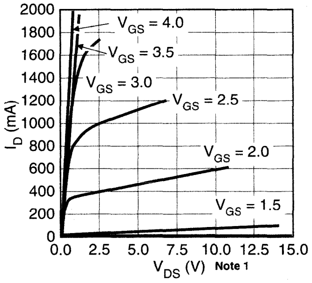
Note 1 Pulse Test: Pulse Width ≤ 300µsec, Duty Cycle ≤ 2%

Note 2 ESD gate protection diode conducts during positive gate-to-source voltage excursions.

On Resistance vs. Drain Current



Drain Characteristics



MIC94002BLM

Dual P-Channel MOSFET

General Description

The MIC94002BLM contains two silicon gate P-channel MOSFETs designed for low ON-resistance, high-side switch applications.

The MIC94002BLM has a maximum ON resistance of 0.4Ω at 4.5V gate-to-source voltage. ON resistance can also be reduced to half by connecting both MOSFETs in parallel.

Improved ESD protection is provided by the gate protection network shown in the schematic diagram.

The MIC94002BLM is supplied in a low-profile version of the 8-lead SOIC package.

The MIC94002 can be assembled with the body not shorted to the sources for use in analog switch applications. Contact the factory for more information.

Features

- 15V minimum drain-to-source breakdown
- 0.4Ω maximum ON resistance at 4.5V gate-to-source voltage (each MOSFET)
- Functional at 2.7V gate-to-source voltage
- 0.063" maximum height

Applications

- High-side switch
- Power management
- Stepper motor control
- 1.8" PCMCIA disk drive V_{CC} switch

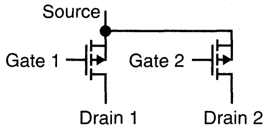
Ordering Information

Part Number	Temperature Range*	Package
MIC94002BLM	–55°C to +150°C	8-lead SOIC†

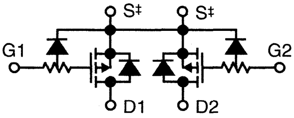
* Operating Junction Temperature

† Low Profile Leads, see Package Information

Schematic Information

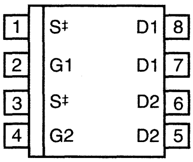


Schematic Symbols



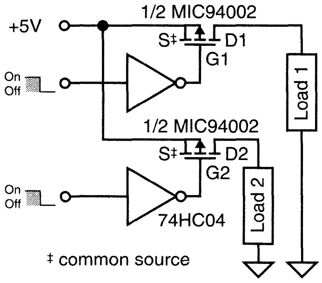
Schematic Diagram

Pin Configuration



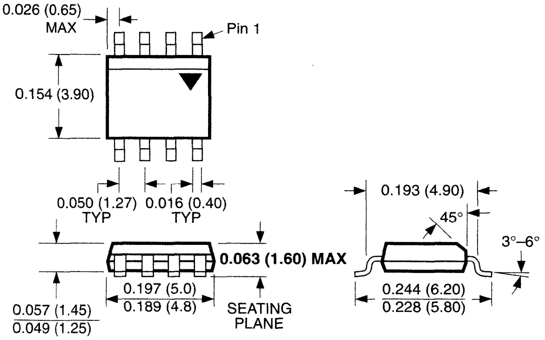
8-lead Low-Profile SOIC Package (LM)

Typical Application



Dual Power Switch Application

Package Information



Patent 5,355,008

Absolute Maximum Ratings

Voltage and current values are negative. Signs not shown for clarity.

Drain-to-Source Voltage 15V
Gate-to-Source Voltage 15V
Continuous Drain Current (each MOSFET, both on)
T_A = 25°C 1.2A
T_A = 100°C 0.7A
Operating Juction Temperature .... –55°C to +150°
Storage Temperature .... –55°C to +150°C

Total Power Dissipation
T_A = 25°C 1W
T_A = 100°C 0.4W
Thermal Resistance
θ_{JA} .... 125°C/W
θ_{JC} .... 76°C/W
Lead Temperature
1/16″ from case, 10s .... +300°C

Electrical Characteristics

Note 1 T_A = 25°C unless noted. *All values are negative. Signs not shown for clarity.*

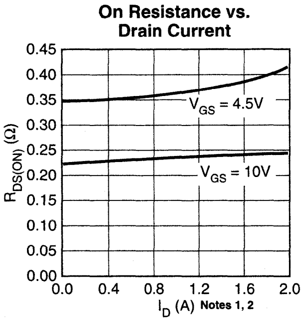
Symbol	Parameter	Condition	Min	Typ	Max	Units
V_{BDSS}	Drain-Source Breakdown Voltage	V_{GS} = 0V, I_D = 250µA	15			V
V_{GS}	Gate Threshold Voltage	$V_{DS} = V_{GS}$, I_D = 250µA	1		3	V
I_{GSS}	Gate-Body Leakage	V_{DS} = 0V, V_{GS} = 15V, **Note 3**			100	nA
I_{DSS}	Zero Gate Voltage Drain Current	V_{DS} = 15V, V_{GS} = 0V			25	µA
		V_{DS} = 15V, V_{GS} = 0V, T_J = 125°C			250	µA
$I_{D(ON)}$	On-State Drain Current	$V_{DS} \geq$ 10V, V_{GS} = 10V, **Note 2**		5.5		A
$R_{DS(ON)}$	Drain-Source ON-State Resist.	V_{GS} = 4.5V, I_D = 50mA		0.35	0.40	Ω
g_{FS}	Forward Transconductance	V_{DS} = 15V, I_D = 1A, **Note 2**		0.7		S

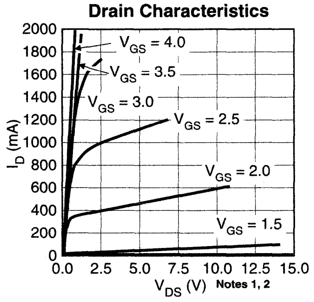
Note 1 Values for each MOSFET

Note 2 Pulse Test: Pulse Width ≤ 300µs, Duty Cycle ≤ 2%

Note 3 ESD gate protection diode conducts during positive gate-to-source voltage excursions.

Typical Characteristics





MIC94030/94031

P-Channel TinyFET™ MOSFET

Preliminary Information

General Description

The MIC94030 and MIC94031 are 4-terminal silicon gate P-channel MOSFETs that provide low ON resistance in a very small package.

Designed for high-side switch applications where space is critical, the MIC94030/1 exhibits an ON resistance of typically 0.75Ω at 4.5V gate-to-source voltage. The MIC94030/1 also operates with only 2.7V gate-to-source voltage.

The MIC94030 is the basic 4-lead P-channel MOSFET. The MIC94031 is a variation that includes an internal gate pull-up resistor that can reduce the system parts count in many applications.

The 4-terminal SOT-143 package permits a substrate connection separate from the source connection. This 4-terminal configuration improves the θ_{JA} (improved heat dissipation) and makes analog switch applications practical.

The small size, low threshold, and low $R_{DS(ON)}$ make the MIC94030/1 the ideal choice for PCMCIA card sleep mode or distributed power management applications.

Features

- 13.5V minimum drain-to-source breakdown
- 0.75Ω typical ON resistance at 4.5V gate-to-source voltage
- 0.45Ω typical ON resistance at 10V gate-to-source voltage
- Operates with 2.7V gate-to-source voltage
- Separate substrate connection for added control
- Industry's smallest surface mount package

Applications

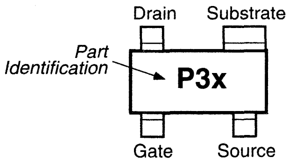
- Distributed power management
- PCMCIA card power management
- Battery-powered computers, peripherals
- Hand-held bar-code scanners
- Portable communications equipment

Ordering Information

Part Number	Temperature Range*	Package
MIC94030BM4	–55°C to +150°C	SOT-143
MIC94031BM4	–55°C to +150°C	SOT-143

* Operating Junction Temperature

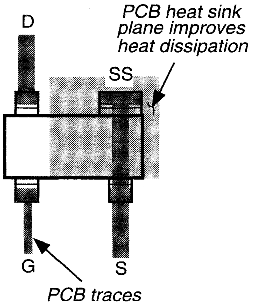
Pin Configuration



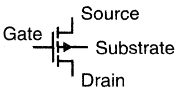
Part Number	Identification
MIC94030BM4	P30
MIC94031BM4	P31

SOT-143 Package (M4)

Typical PCB Layout

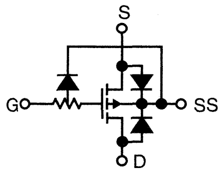


Schematic Symbol

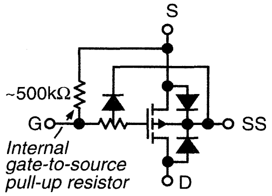


Schematic Symbol

Functional Diagrams



MIC94030



MIC94031

TinyFET is a trademark of Micrel Inc. Patent 5,355,008

Absolute Maximum Ratings

Voltage and current values are negative. Signs not shown for clarity.

Drain-to-Source Voltage (pulse) 16V

Gate-to-Source Voltage (pulse) 16V

Continuous Drain Current

T_A = 25°C 1A

T_A = 100°C 0.5A

Operating Junction Temperature .... –55°C to +150°

Storage Temperature ....–55°C to +150°C

Total Power Dissipation

T_A = 25°C 568mW

T_A = 100°C 227mW

Thermal Resistance

θ_{JA} ....220°C/W

θ_{JC} ....130°C/W

Lead Temperature

1/16″from case, 10s ....+300°C

Electrical Characteristics *Voltage and current values are negative. Signs not shown for clarity.*

Symbol	Parameter	Condition (Note 1)	Min	Typ	Max	Units
V_{BDSS}	Drain-Source Breakdown Voltage	V_{GS} = 0V, I_D = 250µA	13.5			V
V_{GS}	Gate Threshold Voltage	V_{DS} = V_{GS}, I_D = 250µA	0.6	1.0	1.4	V
I_{GSS}	Gate-Body Leakage	V_{DS} = 0V, V_{GS} = 12V, **Note 2**, **Note 3**			1	µA
R_{GS}	Gate-Source Resistor	V_{DS} = 0V, V_{GS} = 12V, **Note 2**, **Note 4**	500	750	1000	kΩ
C_{ISS}	Input Capacitance	V_{GS} = 0V, V_{DS} = 12V		100		pF
I_{DSS}	Zero Gate Voltage Drain Current	V_{DS} = 12V, V_{GS} = 0V			25	µA
		V_{DS} = 12V, V_{GS} = 0V, T_J = 125°C		0.010	250	µA
$I_{D(ON)}$	On-State Drain Current	V_{DS} = 10V, V_{GS} = 10V, **Note 5**		6.3		A
$R_{DS(ON)}$	Drain-Source On-State Resist.	V_{GS} = 10V, I_D = 100mA		0.45		Ω
		V_{GS} = 4.5V, I_D = 100mA		0.75	1.00	Ω
		V_{GS} = 2.7V, I_D = 100mA		1.20		Ω
g_{FS}	Forward Transconductance	V_{DS} = 10V, I_D = 200mA, **Note 5**		480		mS

Note 1 T_A = 25°C unless noted. Substrate connected to source for all conditions

Note 2 ESD gate protection diode conducts during positive gate-to-source voltage excursions.

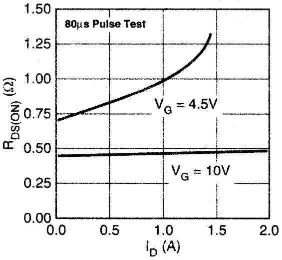
Note 3 MIC94030 only

Note 4 MIC94031 only

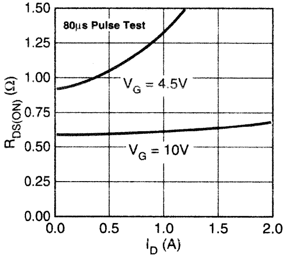
Note 5 Pulse Test: Pulse Width ≤ 80µsec, Duty Cycle ≤ 0.5%

Typical Characteristics

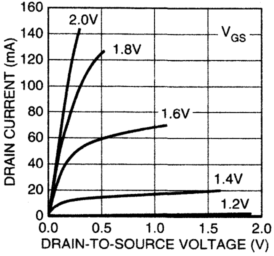
On Resistance vs. Drain Current at 25°C



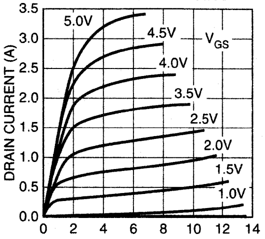
On Resistance vs. Drain Current at 125°C



Drain Characteristics

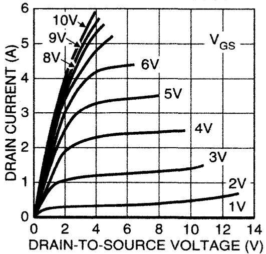


Drain Characteristics



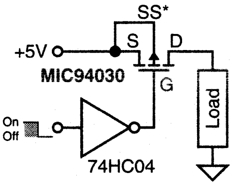
300µs Pulse Test

Drain Characteristics



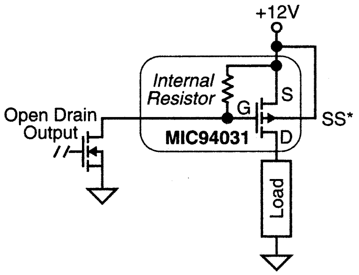
80µs Pulse Test

Typical Applications



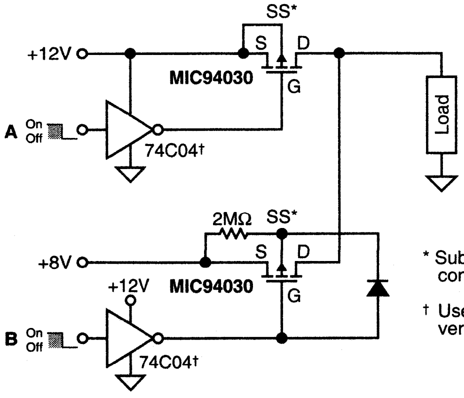
* Substrate must be connected to source

Figure 1. Power Switch Application



* Substrate must be connected to source

Figure 2. Power Control Application



A	B	Output
Off	Off	0V
On	Off	+12V
Off	On	+8V
On	On	*don't!*

* Substrate must be connected to source

† Use "C" version only. "HC" versions not rated to 12V.

Figure 3. Analog Switch Application

Table of Contents

Section 8: Latched Drivers

Latched Driver Selection Guide

All Micrel Latched Drivers are available in die form. Special package options available on most latched drivers: please contact factory for details.

DEVICE	Sink Output	Source Output	Number of Output	Maximum Voltage	Nominal Drive Current (mA)	Parallel Input	Serial Input	Over T, I, UVLO Protection	Temperature	PACKAGE
MIC4807 Protected Addressable Low-Side Driver	•		8	80	200	•		•	A B	18-pin CerDIP 18-pin PDIP
MIC5800 Latched Driver	•		4	50	500	•			A B	14-pin CerDIP 14-pin PDIP, SOIC
MIC5801 Latched Driver	•		8	50	500	•			A B	22-pin CerDIP 22-pin PDIP; 28-pin PLCC
MIC58P01 Protected Latched Driver	•		8	80	500	•		•	A B	22-pin CerDIP 22-pin PDIP; 28-pin PLCC
MIC5821 Serial Input Latched Driver	•		8	50	500		•		B	16-pin PDIP
MIC5822 Serial Input Latched Driver	•		8	80	500		•		A B	16-pin CerDIP 16-pin PDIP
MIC5841 Serial Input Latched Driver	•		8	50	500		•		A B	18-pin CerDIP 18-pin PDIP, SOIC; 20-pin PLCC
MIC5842 Serial Input Latched Driver	•		8	80	500		•		A B	18-pin CerDIP 18-pin PDIP, SOIC; 20-pin PLCC
MIC58P42 Protected Serial Input Latched Driver	•		8	80	500		•	•	A B	18-pin CerDIP 18-pin PDIP, SOIC; 20-pin PLCC
MIC5891 Latched Source Driver		•	8	50			•		A B	16-pin CerDIP 16-pin PDIP, SOIC
MIC59P50 Protected Parallel Input Latched Driver	•		8	80	500	•		•	A B	24-pin CerDIP (skinny) 24-pin PDIP, SOIC; 28-pin PLCC
MIC59P60 Protected Serial Input Latched Driver	•		8	80	500		•	•	A B	20-pin CerDIP 20-pin PDIP, SOIC, PLCC

Temperature Code:

A = –55°C to +125°C
B = –40°C to +85°C
C = 0°C to +70°C

MIC4807

80V 8-Channel Addressable Low-Side Driver

General Description

The MIC4807 is an 80V, 8-channel, addressable low side driver with latches and TTL/CMOS compatible logic inputs. Each logic input is composed of a comparator with a 1.4V bandgap-derived reference serving as the trip point. The addresses (A_{IN}, B_{IN}, and C_{IN}) and Data-in logic inputs have an internal 50µA pull-up current source, while the Output Enable (OE), $\overline{\text{Chip Select}}$ ($\overline{CS}$), and $\overline{\text{Clear}}$ logic inputs have an internal 75µA pull-down sink. If the logic lines to the MIC4807 are severed, these currents guarantee that the outputs will turn OFF.

Individual latches in the MIC4807 are selected by a binary address presented at inputs A_{IN}, B_{IN}, and C_{IN}. Data-in is directed to the addressed latch while $\overline{CS}$ is held low, allowing an individual output to be pulse-width modulated. When $\overline{CS}$ is set high again, the last Data-in is stored in the latch. If Data-in = "1", the addressed output is turned on, and if Data-in = "0", the addressed output is turned off.

Information presented to Data-in and the address inputs is transferred to the latches while $\overline{CS}$ is pulled low. For application, where several outputs must be (Continued)

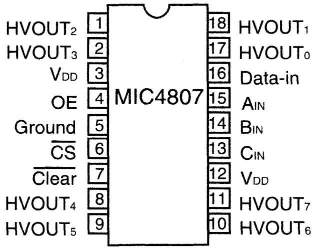
Features

- 4.5V to 16V Operation
- Eight 80V 100mA Outputs
- Off-state Leakage less than 10µA at 25°C
- Short-Circuit Proof
- Thermal Shutdown with Hysteresis
- DMOS Output Devices ($R_{ON} \leq 7\Omega$ at 25°C)

Applications

- Lamp Drivers
- Solenoid Drivers
- Display Drivers
  - -Electroluminescent
  - -Vacuum Fluorescent
  - -Plasma
- Relay Drivers
- Print Head Drivers
- Heater Drivers
- Power Semiconductor Drivers
- Security Systems
- Environmental Controls
- Process Controllers

Pin Diagram

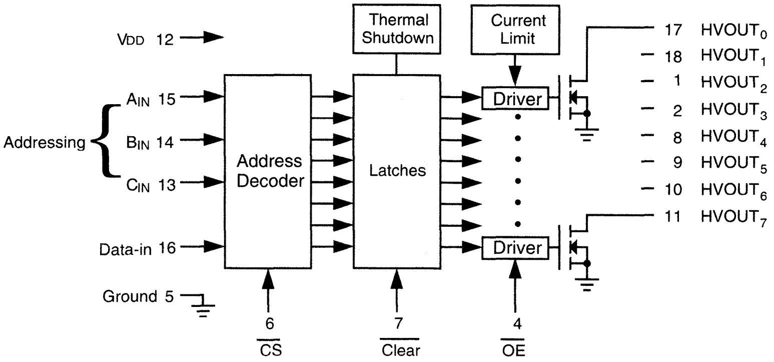


Ordering Information

Part Number	Operating Temperature-Range	Package
MIC4807AJB*	-55°C to 125°C	18-Pin Ceramic DIP
MIC4807BN	-40°C to 85°C	18-Pin Plastic DIP

* AJB indicates units screened to MIL-STD 883, Method 5004, condition B, and burned-in for 1-week.

Block Diagram



General Description (Continued)

turned on simultaneously, Gray Code address sequencing can be applied to Ain, Bin, Cin, while Data-in is held high and $\overline{CS}$ is held low. Data-in will be transferred to each address in turn, without the need to toggle $\overline{CS}$. Similarly, a set of outputs could be simultaneously turned off by setting Data-in low. Gray Code ensures that no intermediate addresses are inadvertently accessed. A typical Gray Code is 0, 1, 3, 2, 6, 7, 5, 4.

Each output drive circuit has a high-voltage, power DMOS device configured as a transconductance loop. This loop limits the output current to typically 200mA. While current limiting keeps the output device within its allowable safe-operating area (SOA), the power dissipation may be excessive. Long-term survival is guaranteed by thermal shutdown.

When operated below current limit, the outputs appear as small-valued resistors (typically 5.1Ω at 25°C) connected to ground. The "ON" resistance (R_{ON}) has a strong, positive temperature coefficient (approximately 7500 ppm/°C) which promotes current sharing if two or more outputs are paralleled.

Absolute Maximum Ratings (Notes 1, 2 and 3)

Output Voltage (V_{OUT}, OFF)	100V
Supply Voltage (V_{DD})	16.5V
Logic Input Voltage (V_{IN})	–0.3V TO V_{DD} + 0.3
Continuous Output Current (I_{OUT})	Internally Limited
Power Dissipation (P_D, Note 2)	Internally Limited
Ambient Temperature (T_A):	
B Version	–40°C to +85°C
A version	–55°C to +125°C
Maximum Junction Temperature (T_{JMAX})	150°C
Storage Temperature	–65°C to +150°C
θ_{JA} - Plastic DIP	130°C/W
θ_{JA} - Ceramic DIP	90°C/W

Electrical Characteristics: (Note 6) MIC4807BN, T_A = 25°C, V_{DD} = 15V unless otherwise specified (see Test Circuit).

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{DD}	Supply Voltage		4.5		16	V
I_{DD}	Supply Current	OE = L (Note 3) OE = H (Note 4)		5.5 1.5	10 3	mA mA
V_{IN} (0)	Logic Input Voltage	4.5V ≤ V_{DD} ≤ 16V			0.8	V
V_{IN} (1)			2.0			V
I_{IN} (0)	Logic Input Current for A_{IN}, B_{IN}, C_{IN}, and Data-in	V_{IN} = 0V	–150	–70	–25	µA
I_{IN} (1)	Logic Input Current for $\overline{CS}$, OE, and $\overline{Clear}$	V_{IN} = V_{DD}	25	130	250	µA
I_{OUT}	Output Leakage Current	OE = 0V, V_{OUT} = 80V		1	10	µA
R_{ON}	Output "ON" Resistance	Output is ON, V_{OUT} = 0.7V,V_{DD} = 10V		5.1	7	Ω
I_{SC}	Short Circuit Current	Output is ON< V_{OUT} = 50V 10V ≤ V_{DD} ≤ 15V (Note 5)	140	190	250	mA
V_{OUT}	Output Voltage (OFF)				80	V
V_{OUT}	Output Voltage (ON)	I_{OUT} = 50mA,V_{DD} = 10V I_{OUT} = 100mA, V_{DD} = 10V		0.26 0.51	0.35 0.7	V V
	Data and Address Set-up Time	V_{DD} = 10V for all timing tests (A, see **Timing Diagram**)	400			ns
	Data and Address Hold Time	(B)	50			ns
	$\overline{CS}$ Pulse Width	(C)	500			ns
	Turn-on Delay	(D)			2.5	ns

Electrical Characteristics: (Note 6) MIC4807BN, T_A = 25°C, V_{DD} = 15V unless otherwise specified (see Test Circuit).

Symbol	Parameter	Conditions	Min	Typ	Max	Units
	Turn-Off Delay	(E)			2.5	µs
	Output Disable Response Time	(F)			2	µs
	Output Enable Response Time	(G)			2	µs
	$\overline{\text{Clear}}$ Response Time	(H)			2.5	µs
	$\overline{\text{Clear}}$ Pulse Width	(I)	500			ns

Electrical Characteristics: (Note 6) MIC4807AJB, T_A = –55°C to +125°C, V_{DD} = 15V unless otherwise specified (see Test Circuit).

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{DD}	Supply Voltage		4.5		16	V
I_{DD}	Supply Current	OE = L (Note 3) OE = H (Note 4)			15 4	mA mA
V_{IN} (0)	Logic Input Voltage	4.5V ≤ V_{DD} ≤ 16V			0.8	V
V_{IN} (1)			2.0			V
I_{IN} (0)	Logic Input Current for A_{IN}, B_{IN}, C_{IN}, and Data-in	V_{IN} = 0V	–250		–10	µA
I_{IN} (1)	Logic Input Current for $\overline{\text{CS}}$, OE, and $\overline{\text{Clear}}$	V_{IN} = V_{DD}	25		400	µA
I_{OUT}	Output Leakage Current	OE = 0V, V_{OUT} = 80V		5.1	7	µA
R_{ON}	Output "ON" Resistance	Output is ON, V_{OUT} =0.7V,V_{DD}=10V			12	Ω
I_{SC}	Short Circuit Current	Output is ON< V_{OUT} = 50V 10V ≤ V_{DD} ≤ 15V (Note 5)	100		300	mA
V_{OUT}	Output Voltage (OFF)				80	V
V_{OUT}	Output Voltage (ON)	I_{OUT} = 50mA,V_{DD} = 10V I_{OUT} = 100mA, V_{DD} = 10V			0.6 1.2	V V
	Data and Address Set-up Time	V_{DD} = 10V for all timing tests (A, see **Timing Diagram**)	700			ns
	Data and Address Hold Time	(B)	50			ns
	$\overline{\text{CS}}$ Pulse Width	(C)	1000			ns
	Turn-on Delay	(D)			5	µs

Electrical Characteristics: (Note 6) MIC4807BN, T_A = 25°C, V_{DD} = 15V unless otherwise specified (see Test Circuit).

Symbol	Parameter	Conditions	Min	Typ	Max	Units
	Turn-Off Delay	(E)			5	µs
	Output Disable Response Time	(F)			4	µs
	Output Enable Response Time	(G)			4	µs
	$\overline{\text{Clear}}$ Response Time	(H)			5	µs
	$\overline{\text{Clear}}$ Pulse Width	(I)	1000			ns

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its specified operating ratings.

Note 2: The junction temperature is internally limited by a thermal shutdown circuit. The maximum power dissipation is a function of T_{JMAX}, θ_{JA}, and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{JMAX} - T_A) / \theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 150°C, and the MIC4807 will go into thermal shutdown.

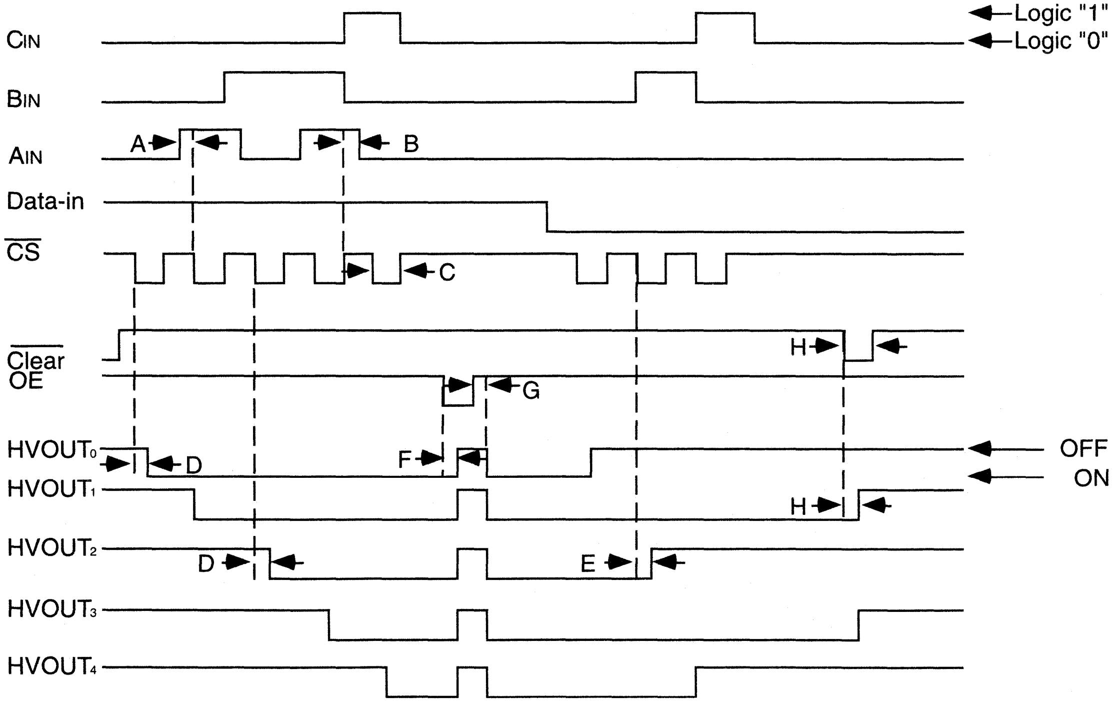
Note 3: All outputs are off when **OUTPUT ENABLE** is pulled low.

Note 4: All outputs are turned on during this test.

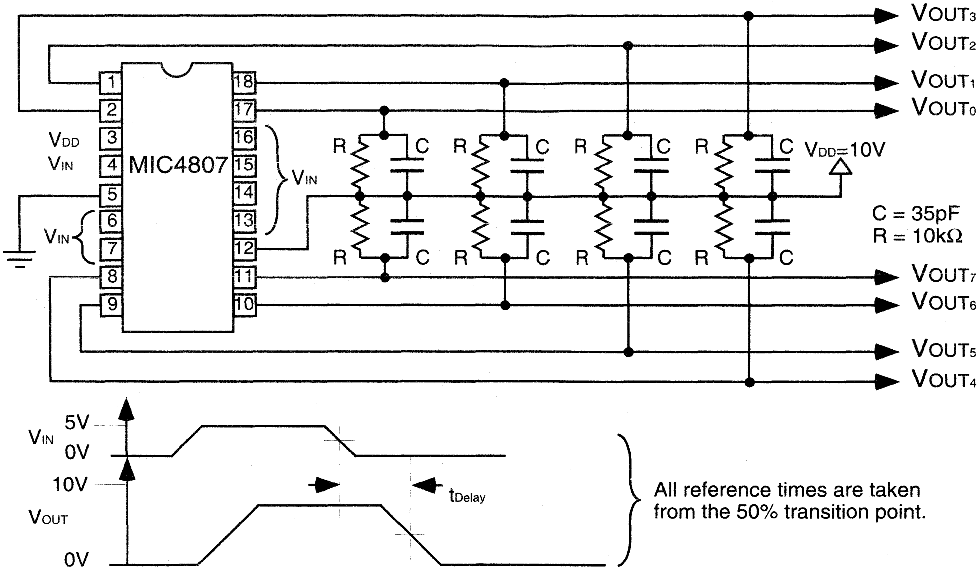
Note 5: Pulse testing is used to avoid thermal shutown.

Note 6: Minimum and Maximum limits are tested and 100% guaranteed over the temperature range specified. Typicals are measured at 25°C and represent the most likely parametric norm.

Timing Diagram

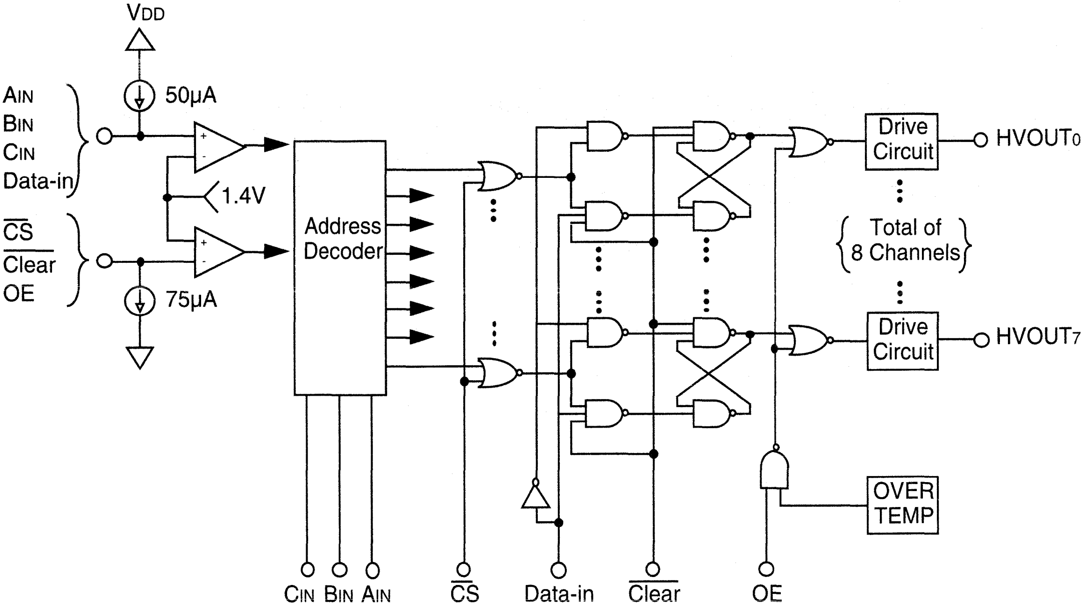


Test Circuit and AC Waveform Measurement Standards



All reference times are taken from the 50% transition point.

Equivalent Logic Diagram



Truth Table

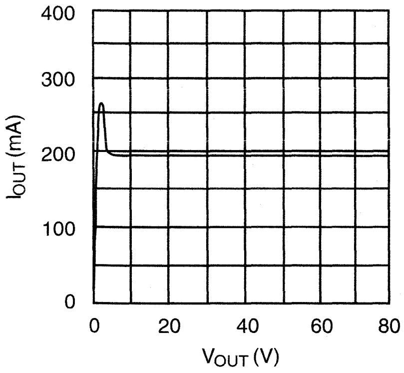
$\overline{CS}$	$\overline{Clear}$	Data-In	C_{IN}	B_{IN}	A_{IN}	OE	$HVOUT_0$	$HVOUT_1$	$HVOUT_2$	$HVOUT_3$	$HVOUT_4$	$HVOUT_5$	$HVOUT_6$	$HVOUT_7$	Functional Mode
X	L	X	X	X	X	X	H	H	H	H	H	H	H	H	Clear
H	H	X	X	X	X	H	P	P	P	P	P	P	P	P	Memory
L	H	D	L	L	L	H	$\overline{D}$	P	P	P	P	P	P	P	Address $HVOUT_0$
L	H	D	L	L	H	H	P	$\overline{D}$	P	P	P	P	P	P	Address $HVOUT_1$
L	H	D	L	H	L	H	P	P	$\overline{D}$	P	P	P	P	P	Address $HVOUT_2$
L	H	D	L	H	H	H	P	P	P	$\overline{D}$	P	P	P	P	Address $HVOUT_3$
L	H	D	H	L	L	H	P	P	P	P	$\overline{D}$	P	P	P	Address $HVOUT_4$
L	H	D	H	L	H	H	P	P	P	P	P	$\overline{D}$	P	P	Address $HVOUT_5$
L	H	D	H	H	L	H	P	P	P	P	P	P	$\overline{D}$	P	Address $HVOUT_6$
L	H	D	H	H	H	H	P	P	P	P	P	P	P	$\overline{D}$	Address $HVOUT_7$
X	X	X	X	X	X	L	H	H	H	H	H	H	H	H	Blanking

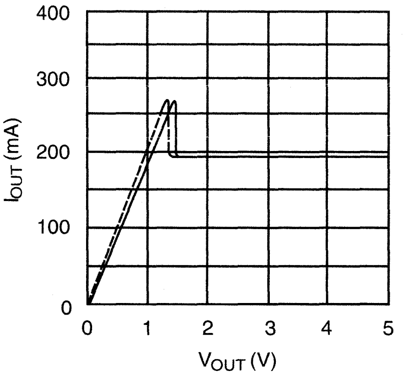
L = Low Logic Level
H = High Logic Level
D = Data (High or Low)
X = Don't Care
P = Previous State

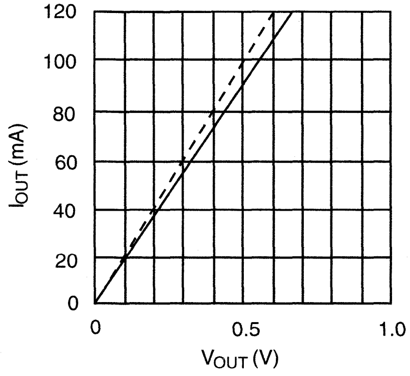
Typical DC Output Characteristics for the "On" State:

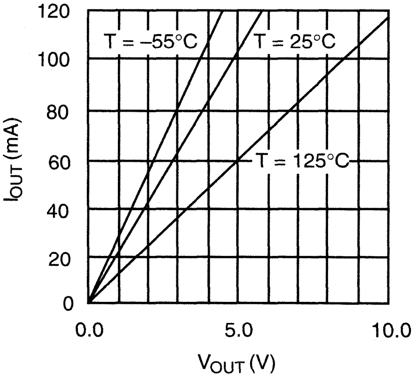
(V_{DD} = 10V and T_A = 25°C unless other wise specified)

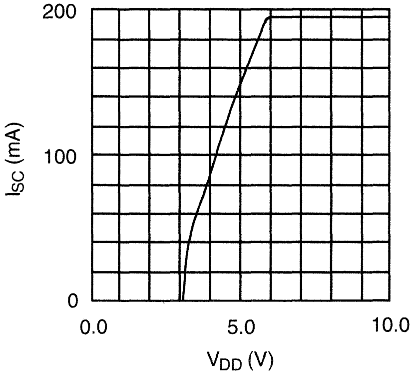
———— V_{DD} = 10V
— — — V_{DD} = 15V

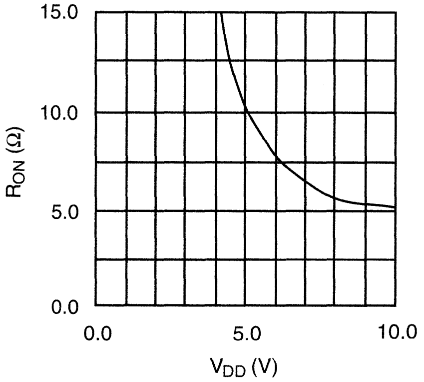

SHORT CIRCUIT CURRENT


EXPANDED VERSION OF SHORT CIRCUIT CURRENT FOR LOW OUTPUT VOLTAGE (V_{OUT})


I_{OUT} FOR SEPARATE V_{DD}


I_{OUT} AT 3 TEMPERATURES


SHORT CIRCUIT CURRENT LIMIT (I_{SC})


ON RESISTANCE (R_{ON})

Pin Description

Pin No.	Pin Name	Functional Description
5	Ground	Electrical ground to chip substrate.
12	V_{DD}	Positive logic supply voltage (10V-15V).
1, 2, 8, 9,10, 11, 17,18	$HVOUT_0$ through $HVOUT_7$	These are the high voltage (HV) open outputs, each of which is capable of sinking 100mA when switched on, and standing off 80V when switched off. In addition, each output channel is equipped with an analog current limiter to protect it from shorts to the positive high voltage supply. When an output is shorted (up to 80V), a maximum of 225mA (200mA nominal) will flow through it to ground.
13, 14, 15	C_{IN}, B_{IN}, &A_{IN}	When these inputs are combined together they form the BCD address used to select the desired output. Each input is TTL compatible with an internal pull-up current source of 50mA.
6	CS	When $\overline{\text{CS}}$ is at logic "0" the device is actively addressed, and when $\overline{\text{CS}}$ is at logic "1" the decoded address and input Data are inhibited, making the part unaddressable. $\overline{\text{CS}}$ is TTL compatible with an internal pull-down current sink of 75µA.
7	$\overline{\text{Clear}}$	$\overline{\text{Clear}}$ resets all the outputs to the off state when pulled to logic "0", and is TTL compatible with an internal pull-down current sink of 75µA.
16	Data-in	Data-in determines the state of the output being addressed. When Data-in is at logic "0" the addressed output is turned off, and when Data-in is at logic "1" the addressed output is turned on. Data-in is TTL compatible with an internal pull-up current source of 50µA.
4	OE	OE allows the bank of eight outputs to be duty cycled together. When OE is at logic "1" the outputs are enabled to follow their respective latches, and when OE is at logic "0" all the outputs are turned off. OE is TTL Compatible with a pull-down current sink of 75µA.

MIC5800/5801

4/8-Bit Parallel-Input Latched Drivers

General Description

The MIC5800/5801 latched drivers are high-voltage, high-current integrated circuits comprised of four or eight CMOS data latches, a bipolar Darlington transistor driver for each latch, and CMOS control circuitry for the common CLEAR, STROBE, and $\overline{\text{OUTPUT ENABLE}}$ functions.

The bipolar/MOS combination provides an extremely low-power latch with maximum interface flexibility. MIC5800 contains four latched drivers; MIC5801 contains eight latched drivers.

Data input rates are greatly improved in these devices. With a 5V supply, they will typically operate at better than 5MHz. With a 12V supply, significantly higher speeds are obtained.

The CMOS inputs are compatible with standard CMOS, PMOS, and NMOS circuits. TTL or DTL circuits may require the use of appropriate pull-up resistors. The bipolar outputs are suitable for use with relays, solenoids, stepping motors, LED or incandescent displays, and other high-power loads.

Both units have open-collector outputs and integral diodes for inductive load transient suppression. The output transistors are capable of sinking 500mA and will sustain at least 50V in the OFF state. Because of limitations on package power dissipation, the simultaneous operation of all drivers at maximum rated current can only be accomplished by a reduction in duty cycle. Outputs may be paralleled for higher load current capability.

Features

- 4.4MHz Minimum Data Input Rate
- High-Voltage, Current Sink Outputs
- Output Transient Protection
- CMOS, PMOS, NMOS, and TTL Compatible Inputs
- Internal Pull-Down Resistors
- Low-Power CMOS Latches

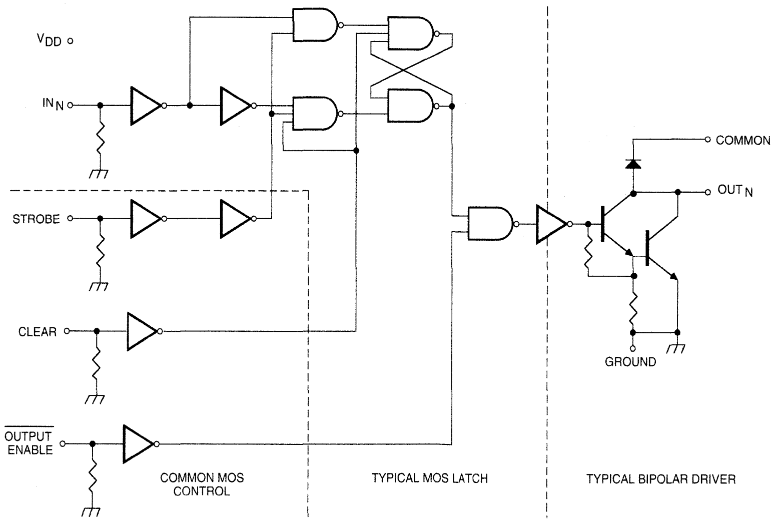
Ordering Information

Part Number	Temperature Range	Package
MIC5800BN	– 40°C to + 85°C	14–Pin Plastic DIP
MIC5800AJ	– 55°C to +125°C	14–Pin CERDIP
5962-8764002CA[1]	– 55°C to +125°C	14–Pin CERDIP
MIC5800BM	– 40°C to + 85°C	14–Pin SOIC
MIC5801BN	– 40°C to +85°C	22–Pin Plastic DIP
MIC5801AJ	– 55°C to +125°C	22–Pin CERDIP
5962-8764001WA[2]	– 55°C to +125°C	22–Pin CERDIP
MIC5801BV	– 40°C to + 85°C	28–Pin PLCC
MIC5801BWM	– 40°C to +85°C	24–Pin SOIC

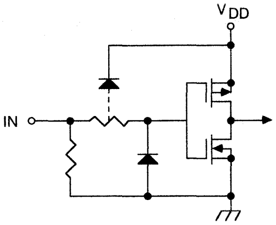
[1] Standard Military Drawing number for MIC5800AJBQ

[2] Standard Military Drawing number for MIC5801AJBQ

Functional Diagram



Typical Input



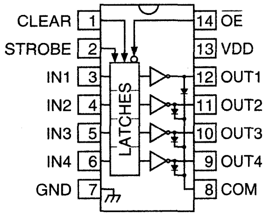
Absolute Maximum Ratings: (Notes 1-7)

at +25°C Free-Air Temperature

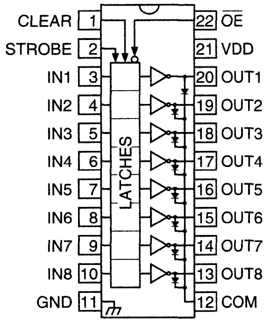
Output Voltage, V_{CE}	50V
Supply Voltage, V_{DD}	15V
Input Voltage Range, V_{IN}	$-0.3V$ to $V_{DD} + 0.3V$
Continuous Collector Current, I_C	500mA
Package Power Dissipation:	
MIC5800 Plastic DIP (Note 1)	2.1W
MIC5801 Plastic DIP (Note 2)	2.5W
MIC5800 SOIC (Note 3)	1.0W
MIC5801 PLCC (Note 4)	2.25W
MIC5800 CERDIP (Note 5)	2.8W
MIC5801 CERDIP (Note 6)	3.1W
Operating Temperature Range, T_A	–40°C to +85°C
Storage Temperature Range, T_S	–65°C to +125°C

Note 1: Derate at 16.7 mW/°C above $T_A = +25°C$
Note 2: Derate at 20 mW/°C above $T_A = +25°C$
Note 3: Derate at 8.5 mW/°C above $T_A = +25°C$
Note 4: Derate at 18.2 mW/°C above $T_A = +25°C$
Note 5: Derate at 21.7 mW/°C above $T_A = +25°C$
Note 6: Derate at 25 mW/°C above $T_A = +25°C$
Note 7: Micrel CMOS devices have input-static protection but are susceptible to damage when exposed to extremely high static electrical charges.

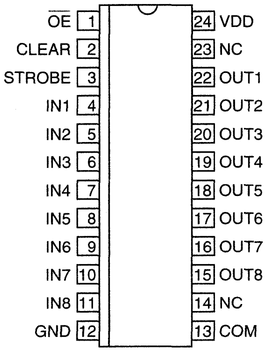
Pin Configuration



MIC5800BN, AJ, BM

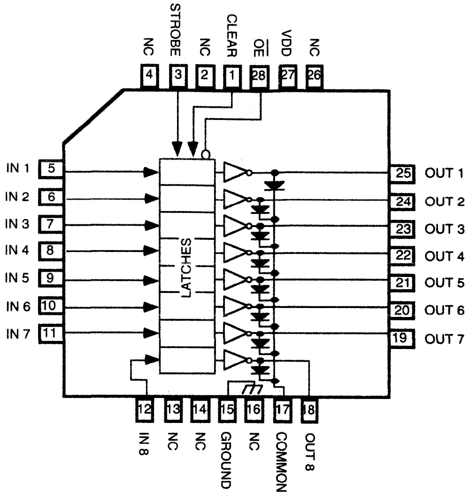


MIC5801BN, AJ



MIC5801BWM

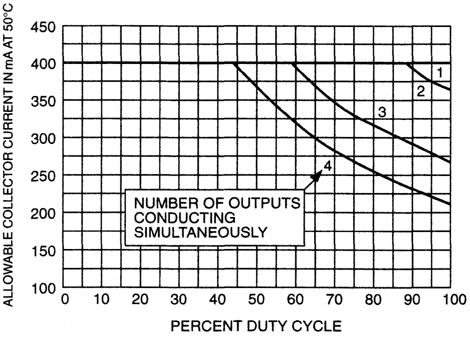
Pin Configurations (continued)



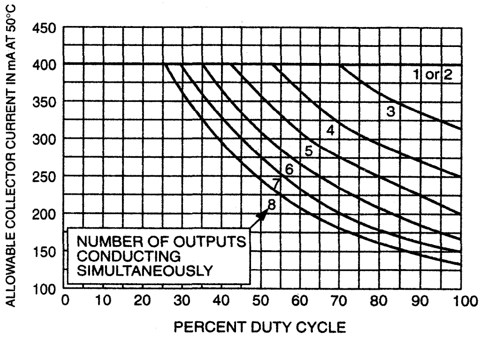
MIC5801BV

Allowable Output Current As A Function of Duty Cycle

MIC5800BN,AJ,AJB,BM



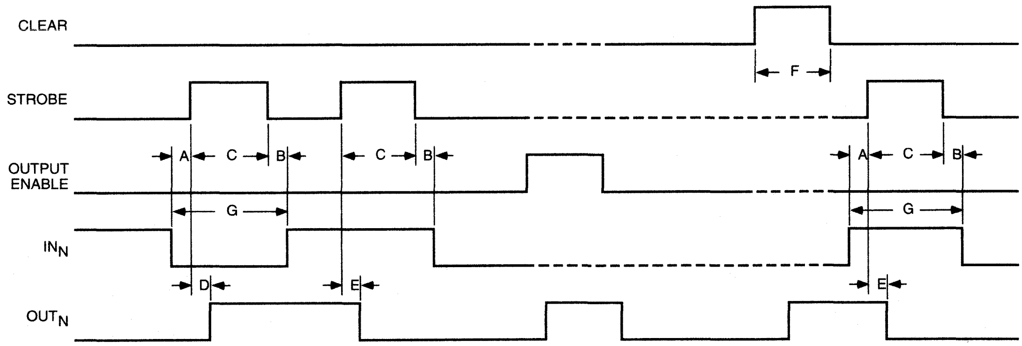
MIC5801BN,AJ,AJB



Electrical Characteristics: at T_A = +25°C, V_{DD} = 5V (unless otherwise noted)

Characteristic	Symbol	Test Conditions	Limits			Units
			Min.	**Typ.**	**Max.**	
Output Leakage Current	I_{CEX}	V_{CE} = 50 V, T_A = +25°C			50	µA
		V_{CE} = 50 V, T_A = +70°C			100	
Collector-Emitter Saturation Voltage	$V_{CE(SAT)}$	I_C = 100 mA		0.9	1.1	V
		I_C = 200 mA		1.1	1.3	
		I_C = 350 mA, V_{DD} = 7.0 V		1.3	1.6	
Input Voltage	$V_{IN(0)}$				1.0	V
	$V_{IN(1)}$	V_{DD} = 12 V	10.5			
		V_{DD} = 10 V	8.5			
		V_{DD} = 5.0 V (See Note)	3.5			
Input Resistance	R_{IN}	V_{DD} = 12 V	50	200		kΩ
		V_{DD} = 10 V	50	300		
		V_{DD} = 5.0 V	50	600		
Supply Current	$I_{DD(ON)}$ (Each Stage)	V_{DD} = 12 V, Outputs Open		1.0	2.0	mA
		V_{DD} = 10 V, Outputs Open		0.9	1.7	
		V_{DD} = 5.0 V, Outputs Open		0.7	1.0	
	$I_{DD(OFF)}$ (Total)	V_{DD} = 12 V, Outputs Open, Inputs = 0 V			200	µA
		V_{DD} = 5.0 V, Outputs Open, Inputs = 0 V		50	100	
Clamp Diode Leakage Current	I_R	V_R = 50 V, T_A = +25°C			50	µA
		V_R = 50 V, T_A = +70°C			100	
Clamp Diode Forward Voltage	V_F	I_F = 350 mA		1.7	2.0	V

NOTE : Operation of these devices with standard TTL or DTL may require the use of appropriate pull-up resistors to insure a minimum logic "1".



Timing Conditions

(Logic Levels are V_{DD} and Ground)

A. Minimum data active time before strobe enabled (data set-up time) .... 50 ns
B. Minimum data active time after strobe disabled (data hold time) .... 50 ns
C. Minimum strobe pulse width .... 125 ns
D. Typical time between strobe activation and output on to off transition .... 500 ns
E. Typical time between strobe activation and output off to on transition .... 500 ns
F. Minimum clear pulse width .... 300 ns
G. Minimum data pulse width .... 225 ns

Truth Table

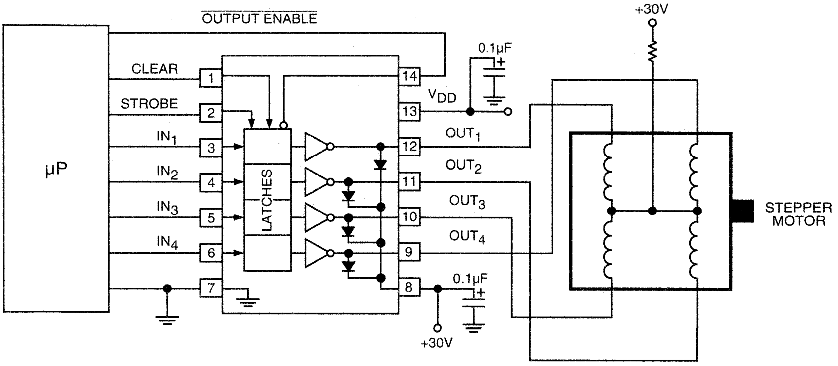
			Output	OUT_N	
IN_N	Strobe	Clear	Enable	t-1	t
0	1	0	0	X	OFF
1	1	0	0	X	ON
X	X	1	X	X	OFF
X	X	X	1	X	OFF
X	0	0	0	ON	ON
X	0	0	0	OFF	OFF

X = Irrelevant
t-1 = previous output state
t = present output state

Information present at an input is transferred to its latch when the STROBE is high. A high CLEAR input will set all latches to the output OFF condition regardless of the data or STROBE input levels. A high $\overline{\text{OUTPUT ENABLE}}$ will set all outputs to the off condition, regardless of any other input conditions. When the $\overline{\text{OUTPUT ENABLE}}$ is low, the outputs depend on the state of their respective latches.

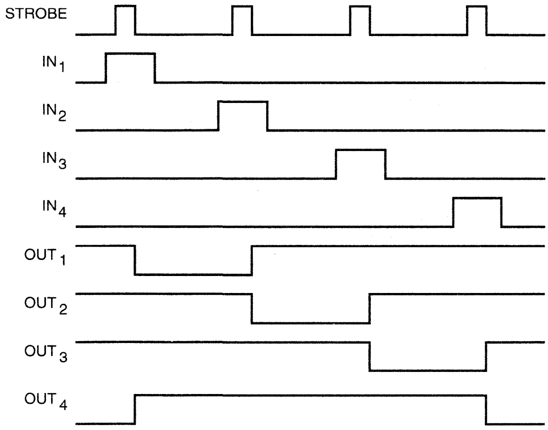
Typical Application

Unipolar Stepper-Motor Drive

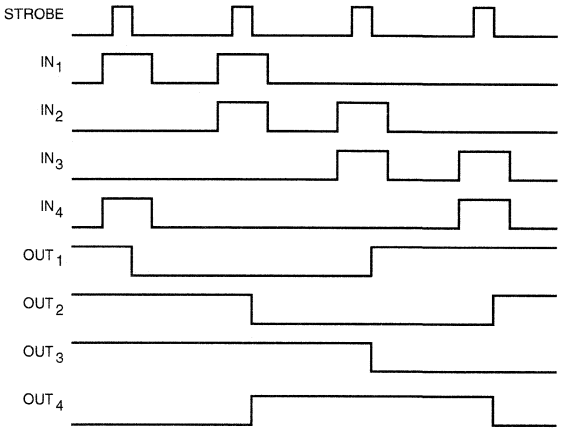


MIC5800

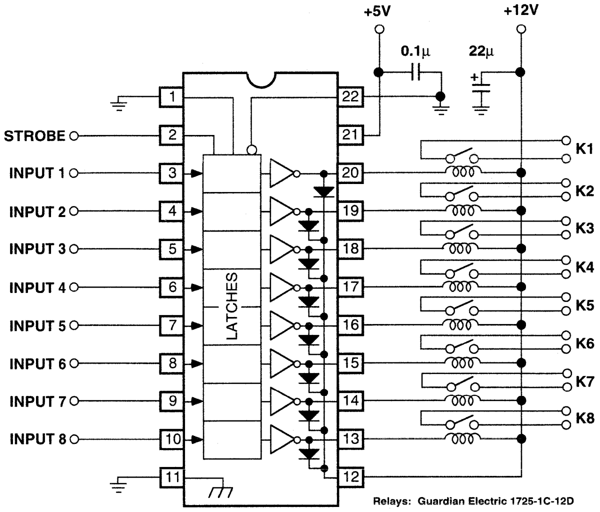
UNIPOLAR WAVE DRIVE



UNIPOLAR 2-PHASE DRIVE

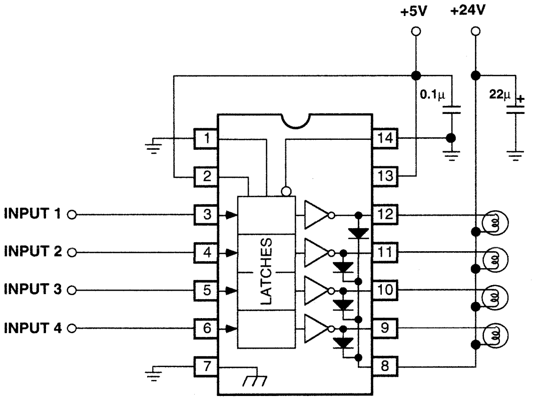


Typical Applications, Continued



Relays: Guardian Electric 1725-1C-12D

MIC5801 Relay Driver



Note:

Lamp inrush current is approximately 10× lamp operating current.

MIC5800 Incandescent/Halogen Lamp Driver

MIC58P01

8-Bit Parallel-Input Protected Latched Driver

General Description

The MIC58P01 parallel-input latched driver is a high-voltage (80V), high-current (500mA) integrated circuit comprised of eight CMOS data latches, a bipolar Darlington transistor driver for each latch, and CMOS control circuitry for the common CLEAR, STROBE, and $\overline{\text{OUTPUT ENABLE}}$ functions. Similar to the MIC5801, additional protection circuitry supplied on this device includes thermal shutdown, under voltage lockout (UVLO), and overcurrent shutdown.

The bipolar/CMOS combination provides an extremely low-power latch with maximum interface flexibility. The MIC58P01 has open-collector outputs capable of sinking 500 mA and integral diodes for inductive load transient suppression with a minimum output breakdown voltage rating of 80V (50V sustaining). The drivers may be paralleled for higher load current capability.

With a 5V logic supply, the MIC58P01 will typically operate at better than 5MHz. With a 12V logic supply, significantly higher speeds are obtained. The CMOS inputs are compatible with standard CMOS, PMOS, and NMOS circuits. TTL circuits may require pull-up resistors.

Each of these eight outputs has an independent overcurrent shutdown of 500mA. Upon current shutdown, the affected channel will turn OFF until V_{DD} is cycled or the ENABLE/RESET pin is pulsed high. Current pulses less than 2µs will not activate current shutdown. Temperatures above 165°C will shut down all outputs. The UVLO circuit disables the outputs at low V_{DD}; hysteresis of 0.5V is provided.

Features

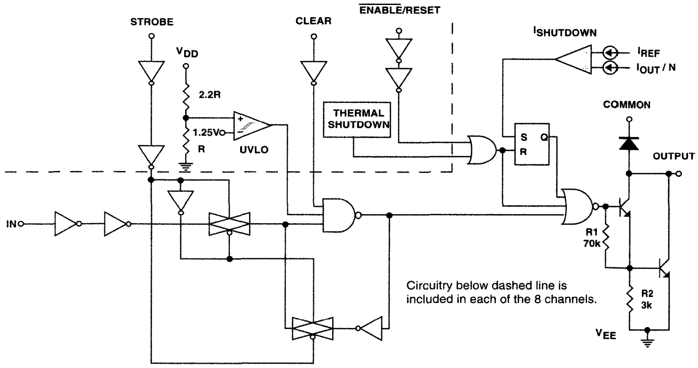
- 4.4MHz Minimum Data Input Rate
- High-Voltage, High-Current Outputs
- Per-Output Overcurrent Shutdown (500mA typical)
- Under Voltage Lockout
- Thermal Shutdown
- Output Transient Protection Diodes
- CMOS, PMOS, NMOS, and TTL Compatible Inputs
- Internal Pull-Down Resistors
- Low-Power CMOS Latches

Ordering Information

Part Number	Temperature Range	Package
MIC58P01AJ	–55°C to +125°C	22-Pin Ceramic DIP
MIC58P01AJB*	–55°C to +125°C	22-Pin Ceramic DIP
MIC58P01BN	–40°C to +85°C	22-Pin Plastic DIP
MIC58P01BV	–40°C to +85°C	28-Pin PLCC
MIC58P01BWM	–40°C to +85°C	24-Pin Wide SOIC

* AJB indicates units screened to MIL-STD 883, Method 5004, condition B, and burned-in for 1 week.

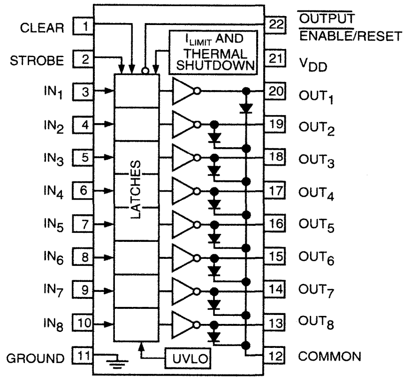
Functional Diagram



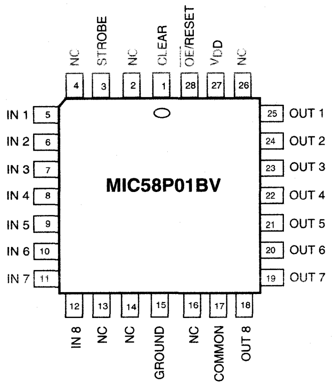
Circuitry below dashed line is included in each of the 8 channels.

Pin Configuration

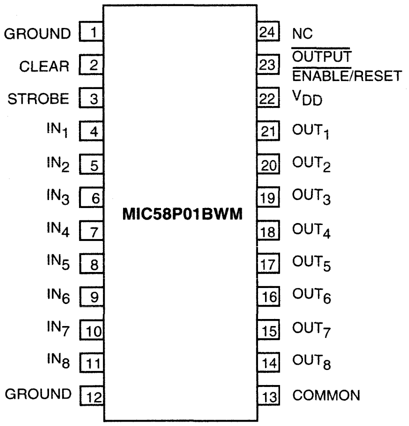
(Ceramic or Plastic DIP)



Pin Configuration, Continued



MIC58P01BV, 28–Pin PLCC



MIC58P01BWM, 24–Pin SOIC
(not pin compatible with MIC5801BWM)

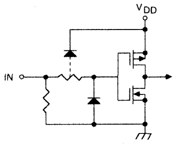
Absolute Maximum Ratings: (Note 1)

at +25°C Free-Air Temperature

Output Voltage, V_{CE}	80V
Supply Voltage, V_{DD}	15V
Input Voltage Range, V_{IN}	−0.3V to V_{DD} + 0.3V
Package Power Dissipation:	
MIC58P01BN	2.25W
Derate above T_A = +25°C	22.5mW/°C
MIC58P01AJ/AJB	2.0W
Derate above T_A = +25°C	20mW/°C
MIC58P01BV	1.6W
Derate above T_A = +25°C	16mW/°C
MIC58P01BWM	1.4W
Derate above T_A = +25°C	14mW/°C
Operating Temperature Range, T_A	−55°C to +125°C
Storage Temperature Range, T_S	−65°C to +125°C

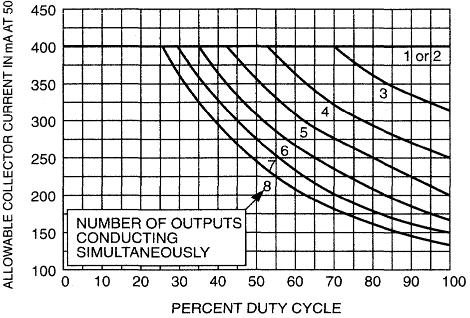
Note 1: Micrel CMOS devices have input-static protection but are susceptible to damage when exposed to extremely high static electrical charges.

Typical Input



Allowable Output Current As A Function of Duty Cycle

MIC58P01BN



Pin Description

Pin (DIP)	Name	Description
1	CLEAR	Resets all Latches and turns all outputs OFF (open).
2	STROBE	Input Strobe Pin. Loads output latches when High.
3–10	INPUT	Parallel Inputs, 1 through 8
11	GROUND	Logic and Output Ground pin.
12	COMMON	Transient suppression diode common cathode pin.
13–20	OUTPUT	Parallel Outputs, 8 through 1.
21	V_{DD}	Logic Supply voltage.
22	$\overline{\text{OUTPUT ENABLE}}$/RESET	When Low, Outputs are active. When High, outputs are inactive and device is reset from a fault condition. An undervoltage condition emulates a high $\overline{\text{OE}}$ input.

Electrical Characteristics: at T_A = +25°C, V_{DD} = 5V (unless otherwise noted)

Characteristic	Symbol	Test Conditions	Limits			Units
			Min.	**Typ.**	**Max.**	
Output Leakage Current	I_{CEX}	V_{CE} = 80V, T_A = +25°C			50	µA
		V_{CE} = 80V, T_A = +70°C			100	
Collector-Emitter Saturation Voltage	$V_{CE(SAT)}$	I_C = 100mA		0.9	1.1	V
		I_C = 200mA		1.1	1.3	
		I_C = 350mA		1.3	1.6	
Input Voltage	$V_{IN(0)}$				1.0	V
	$V_{IN(1)}$	V_{DD} = 12V	10.5			
		V_{DD} = 10V	8.5			
		V_{DD} = 5.0V (See Note)	3.5			
Input Resistance	R_{IN}	V_{DD} = 12V	50	200		kΩ
		V_{DD} = 10V	50	300		
		V_{DD} = 5.0V	50	600		
Supply Current	$I_{DD(ON)}$ (One output active)	V_{DD} = 12V, Outputs Open		3.3	4.5	mA
		V_{DD} = 10V, Outputs Open		3.1	4.5	
		V_{DD} = 5.0V, Outputs Open		2.4	3.6	
	$I_{DD(ON)}$ (All outputs active)	V_{DD} = 12V, Outputs Open		6.4	10.0	mA
		V_{DD} = 10V, Outputs Open		6.0	9.0	
		V_{DD} = 5.0V, Outputs Open		4.7	7.5	
	$I_{DD(OFF)}$ (Total)	V_{DD} = 12V, Outputs Open, Inputs = 0V		3.0	4.5	mA
		V_{DD} = 5.0V, Outputs Open, Inputs = 0V		2.2	3.6	
Clamp Diode Leakage Current	I_R	V_R = 80V, T_A = +25°C			50	µA
		V_R = 80V, T_A = +70°C			100	
Overcurrent Threshold	I_{LIM}	Per Output		500		mA
Start-Up Voltage	V_{SU}	Note 2.	3.5	4.0	4.5	V
Minimum Operating V_{DD}	$V_{DD\ MIN}$		3.0	3.5	4.0	V
Clamp Diode Forward Voltage	V_F	I_F = 350mA		1.7	2.0	V
Thermal Shutdown				165		°C
Thermal Shutdown Hysteresis				10		°C

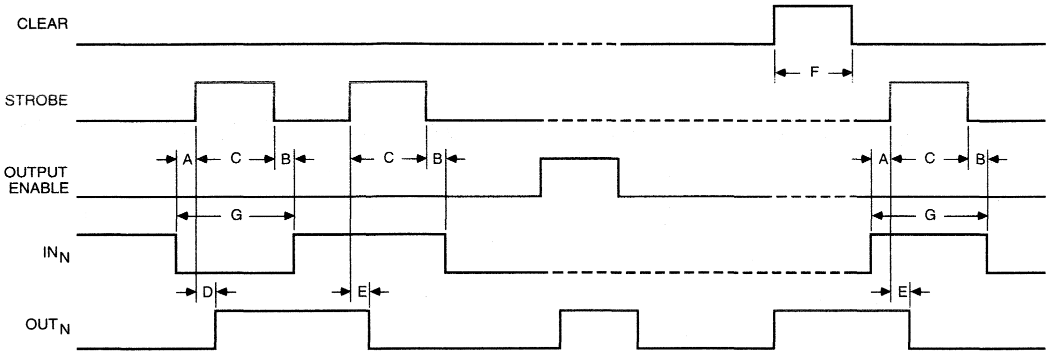
NOTE 1: Operation of these devices with standard TTL or DTL may require the use of appropriate pull-up resistors to insure a minimum logic "1".
NOTE 2: Under-Voltage Lockout is guaranteed to release device at no more than 4.5V, and disable the device at no less than 3.0V.

Truth Table

IN_N	Strobe	Clear	$\overline{\text{Output}}$ Enable	OUT_N	
				t–1	t
0	1	0	0	X	OFF
1	1	0	0	X	ON
X	X	1	X	X	OFF
X	X	X	1	X	OFF
X	0	0	0	ON	ON
X	0	0	0	OFF	OFF

X = Irrelevant
t–1 = previous output state
t = present output state

Information present at an input is transferred to its latch when the STROBE is high. A high CLEAR input will set all latches to the output OFF condition regardless of the Data or STROBE input levels. A high $\overline{\text{OUTPUT ENABLE}}$ will set all outputs to the OFF condition, regardless of any other input conditions. When the $\overline{\text{OUTPUT ENABLE}}$ is low, the outputs depend on the state of their respective latches. If current shutdown is activated, the $\overline{\text{OUTPUT ENABLE}}$ must be pulsed high to restore operation. Over temperature faults are not latched and require no reset pulse.



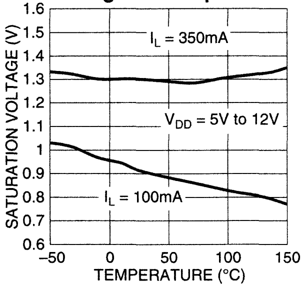
Timing Conditions

(T_A = +25°C, Logic Levels are V_{DD} and Ground, V_{DD} = 5V)

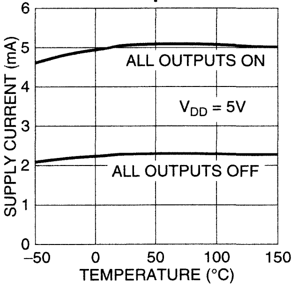
A.	Minimum data active time before strobe enabled (data set-up time)	50ns
B.	Minimum data active time after strobe disabled (data hold time)	50ns
C.	Minimum strobe pulse width	125 ns
D.	Typical time between strobe activation and output on to off transition	500ns
E.	Typical time between strobe activation and output off to on transition	500ns
F.	Minimum clear pulse width	300ns
G.	Minimum data pulse width	225 ns

Typical Characteristic Curves

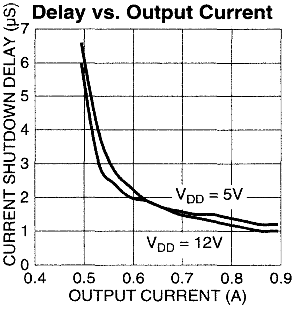
Output Saturation Voltage vs. Temperature



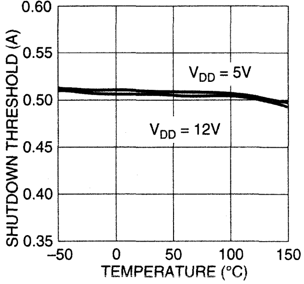
Supply Current vs. Temperature



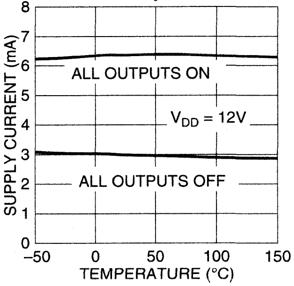
Current Shutdown Delay vs. Output Current



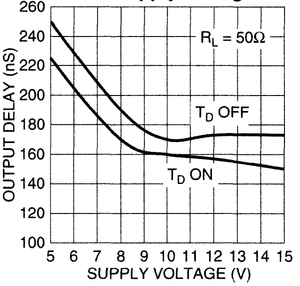
Current Shutdown Threshold vs. Temperature



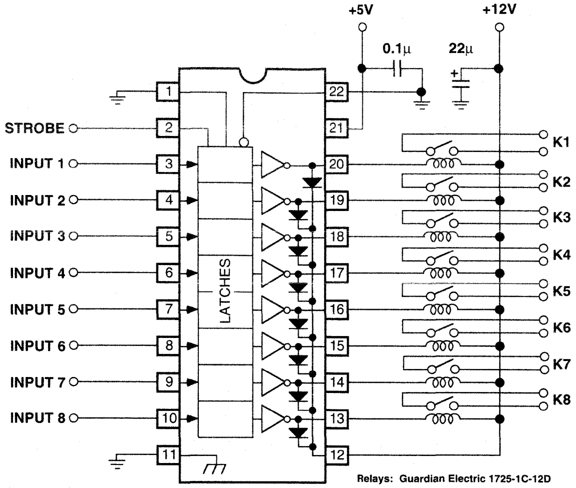
Supply Current vs. Temperature



Output Delay vs. Supply Voltage



Typical Application



MIC58P01 Protected Relay Driver

MIC5821/5822

8-Bit Serial-Input Latched Drivers

General Description

BiCMOS technology gives the MIC5821/5822 family flexibility beyond the reach of standard logic buffers and power driver arrays. These devices each have an eight-bit CMOS shift register, CMOS control circuitry, eight CMOS data latches, and eight bipolar current-sink Darlington output drivers. The 500mA outputs are suitable for use with incandescent bulbs and other moderate to high current loads. The drivers can be operated with a split supply where the negative supply is down to –20V. Except for maximum driver output voltage ratings, the MIC5821 and MIC5822 are identical.

These devices have greatly improved data-input rates. With a 5V logic supply they will typically operate faster than 5 MHz. With a 12V supply significantly higher speeds are obtained. The CMOS inputs are compatible with standard CMOS, PMOS, and NMOS logic levels. TTL and DTL circuits may require the use of appropriate pull-up resistors. By using the serial data output, the drivers can be cascaded for interface applications requiring additional drive lines.

Features

- 3.3 MHz Minimum Data-Input Rate
- CMOS, PMOS, NMOS, TTL Compatible
- Internal Pull-Down or Pull-Up Resistors
- Low-Power CMOS Logic and Latches
- High-Voltage Current-Sink Outputs
- Single or Split Supply Operation

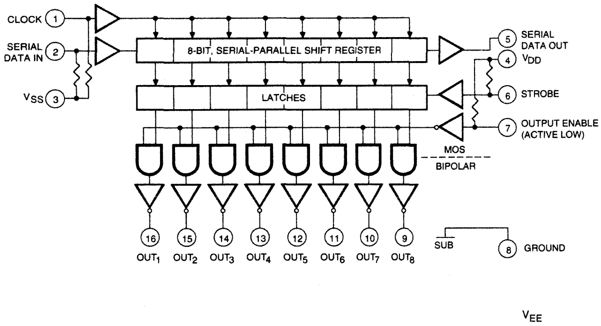
Ordering Information

Part Number	Temperature Range	Package
MIC5821CN*	0°C to +70°C	16-Pin Plastic DIP
MIC5821BN	–40°C to +85°C	16-Pin Plastic DIP
MIC5822BN	–40°C to +85°C	16-Pin Plastic DIP
MIC5822AJ	–55°C to +125°C	16-Pin Ceramic DIP
5962-8764101EA†	–55°C to +125°C	16-Pin Ceramic DIP

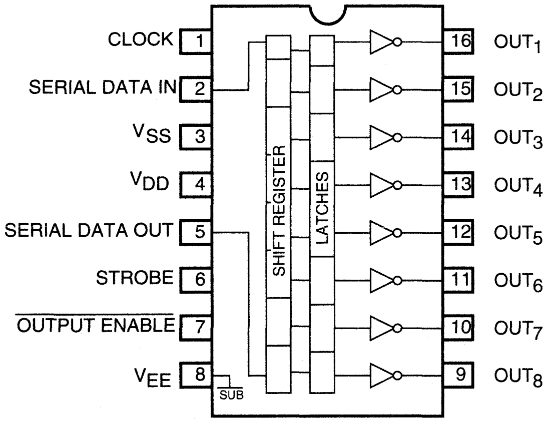
* Micrel reserves the right to substitute MIC5821BN grade devices for the MIC5821CN

† Standard Military Drawing number for MIC5822AJBQ

Functional Diagram

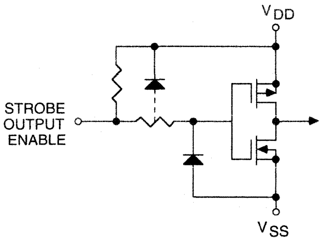


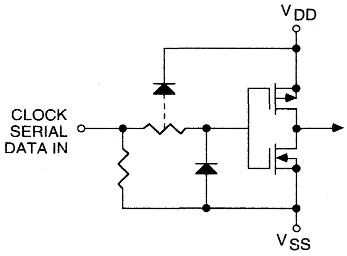
Pin Configuration



(Plastic and Ceramic DIP)

Typical Input Circuits





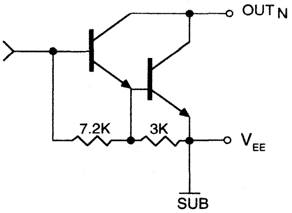
Absolute Maximum Ratings (Note 1)

at 25°C Free-Air Temperature and V_{SS} = 0V

Output Voltage, V_{CE}	(MIC5821)	50V
	(MIC5822)	80V
Output Voltage, $V_{CE\ SUS}$	(MIC5821)(Note 3)	35V
	(MIC5822)(Note 3)	50V
Logic Supply Voltage, V_{DD}		15V
Input Voltage Range, V_{IN}		–0.3V to V_{DD} + 0.3V
$V_{DD} - V_{EE}$		25V
Emitter Supply Voltage, V_{EE}		–20V
Continuous Output Current, I_{OUT}		500mA
Package Power Dissipation, P_{D} (Note 1)		1.67W
Operating Temperature Range, T_A		–55°C to +125°C
Storage Temperature Range, T_S		–65°C to +150°C

Note 1: Derate at the rate of 16.7mW/°C above T_A = 25°C (Plastic DIP).
Note 2: CMOS devices have input static protection but are susceptible to damage when exposed to extremely high static electrical charges.
Note 3: For inductive load applications.

Typical Output Driver



Maximum Allowable Duty Cycle (Plastic DIP)

Number of Outputs ON (I_{OUT} = 200mA V_{DD} = 12V)	Maximum Allowable Duty Cycle at Ambient Temperature of 25°C	40°C	50°C	60°C	70°C
8	73%	62%	55%	47%	40%
7	83%	71%	62%	54%	46%
6	97%	82%	72%	63%	53%
5	100%	98%	87%	75%	63%
4	100%	100%	100%	93%	79%
3	100%	100%	100%	100%	100%
2	100%	100%	100%	100%	100%
1	100%	100%	100%	100%	100%

Electrical Characteristics at $T_A = 25°C$ $V_{DD} = 5V$, $V_{EE} = V_{SS} = 0V$ (unless otherwise specified)

Characteristic	**Symbol**	**Applicable Devices**	**Test Conditions**	**Limits Min.**	**Limits Max.**	**Unit**
Output Leakage Current	I_{CEX}	MIC5821	$V_{OUT} = 50V$		50	μA
			$V_{OUT} = 50V$, $T_A = +70°C$		100	
		MIC5822	$V_{OUT} = 80V$		50	
			$V_{OUT} = 80V$, $T_A = +70°C$		100	
Collector-Emitter Saturation Voltage	$V_{CE(SAT)}$	Both	$I_{OUT} = 100mA$		1.1	V
			$I_{OUT} = 200mA$		1.3	
			$I_{OUT} = 350mA$, $V_{DD} = 7.0V$		1.6	
Input Voltage	$V_{IN(0)}$	Both			0.8	V
	$V_{IN(1)}$	Both	$V_{DD} = 12V$	10.5		
			$V_{DD} = 10V$	8.5		
			$V_{DD} = 5.0V$	3.5		
Input Resistance	R_{IN}	Both	$V_{DD} = 12V$	50		kΩ
			$V_{DD} = 10V$	50		
			$V_{DD} = 5.0V$	50		
Supply Current	$I_{DD(ON)}$	Both	One Driver ON, $V_{DD} = 12V$		4.5	mA
			One Driver ON, $V_{DD} = 10V$		3.9	
			One Driver ON, $V_{DD} = 5.0V$		2.4	
			All Drivers ON, $V_{DD} = 12V$		16	
			All Drivers ON, $V_{DD} = 10V$		14	
			All Drivers ON, $V_{DD} = 5.0V$		8	
	$I_{DD(OFF)}$	Both	All Drivers OFF, $V_{DD} = 5.0V$, All Inputs = 0V		1.6	
			All Drivers OFF, $V_{DD} = 12V$, All Inputs= 0V		2.9	

Electrical Characteristics MIC5822AJ/AJB at $T_A = -55°C$, $V_{DD} = 5V$, $V_{SS} = V_{EE} = 0V$ (unless otherwise noted)

Characteristic	**Symbol**	**Test Conditions**	**Limits Min.**	**Limits Max.**	**Unit**
Output Leakage Current	I_{CEX}	$V_{OUT} = 80V$		50	μA
Collector-Emitter Saturation Voltage	$V_{CE(SAT)}$	$I_{OUT} = 100mA$		1.3	V
		$I_{OUT} = 200mA$		1.5	
		$I_{OUT} = 350mA$, $V_{DD} = 7.0V$		1.8	
Input Voltage	$V_{IN0)}$			0.8	V
	$V_{IN(1)}$	$V_{DD} = 12V$	10.5		
		$V_{DD} = 5.0V$	3.5		
Input Resistance	RIN	$V_{DD} = 12V$	35		kΩ
		$V_{DD} = 10V$	35		
		$V_{DD} = 5.0V$	35		
Supply Current	$I_{DD(ON)}$	One Driver ON, $V_{DD} = 12V$		5.5	mA
		One Driver ON, $V_{DD} = 10V$		4.5	
		One Driver ON, $V_{DD} = 5.0V$		3.0	
		All Drivers ON, $V_{DD} = 12V$		16	
		All Drivers ON, $V_{DD} = 10V$		14	
		All Drivers ON, $V_{DD} = 5.0V$		10	
	$I_{DD(OFF)}$	All Drivers OFF, $V_{DD} = 12V$		3.5	
		All Drivers OFF, $V_{DD} = 5.0V$		2.0	

Electrical Characteristics MIC5822AJ/AJB at T_A = +125°C, V_{DD} = 5V, V_{SS} = V_{EE} = 0V (unless otherwise noted)

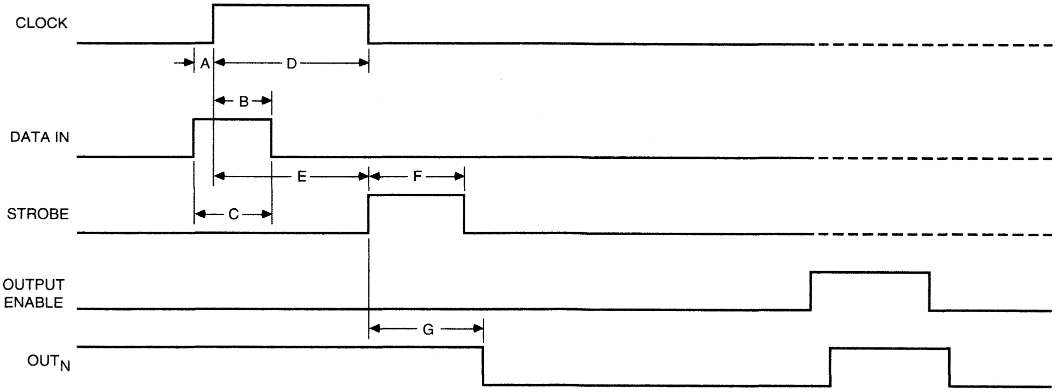
			Limits		
Characteristic	**Symbol**	**Test Conditions**	**Min.**	**Max.**	**Unit**
Output Leakage Current	I_{CEX}	V_{OUT} = 80V		500	µA
Collector-Emitter Saturation Voltage	$V_{CE(SAT)}$	I_{OUT} = 100mA		1.3	V
		I_{OUT} = 200mA		1.5	
		I_{OUT} = 350mA, V_{DD} = 7.0V		1.8	
Input Voltage	$V_{IN(0)}$			0.8	V
	$V_{IN(1)}$	V_{DD} = 12V	10.5		
		V_{DD} = 5.0V	3.5		
Input Resistance	R_{IN}	V_{DD} = 12V	50		kΩ
		V_{DD} = 10V	50		
		V_{DD} = 5.0V	50		
Supply Current	$I_{DD(ON)}$	One Driver ON, V_{DD} = 12V		4.5	mA
		One Driver ON, V_{DD} = 10V		3.9	
		One Driver ON, V_{DD} = 5.0V		2.4	
		All Drivers ON, V_{DD} = 12V		16	
		All Drivers ON, V_{DD} = 10V		14	
		All Drivers ON, V_{DD} = 5.0V		8	
	$I_{DD(OFF)}$	All Drivers OFF, V_{DD} = 12V		2.9	
		All Drivers OFF, V_{DD} = 5.0V		1.6	

MIC5821/5822 Family Truth Table

Serial Data Input	Clock Input	Shift Register Contents					Serial Data Output	Strobe Input	Latch Contents					Output Enable	Output Contents				
		I_1	I_2	I_3	......	I_8			I_1	I_2	I_3	......	I_8		I_1	I_2	I_3	......	I_8
H	↑	H	R_1	R_2	......	R_7	R_7												
L	↑	L	R_1	R_2	......	R_7	R_7												
X	↓	R_1	R_2	R_3	......	R_8	R_8												
		X	X	X	......	X	X	L	R_1	R_2	R_3	......	R_8						
		P_1	P_2	P_3	......	P_8	P_8	H	P_1	P_2	P_3	......	P_8	L	P_1	P_2	P_3	......	P_8
									X	X	X	......	X	H	H	H	H	......	H

L = Low Logic Level H = High Logic Level X = Irrelevant P = Present State R = Previous State

Timing Diagram



Timing Conditions

(T_A = +25°C, Logic Levels are V_{DD} and V_{SS})

	V_{DD} = 5.0V
A. Minimum Data Active Time Before Clock Pulse (Data Set-Up Time)	75 ns
B. Minimum Data Active Time After Clock Pulse (Data Hold Time)	75 ns
C. Minimum Data Pulse Width	150 ns
D. Minimum Clock Pulse Width	150 ns
E. Minimum Time Between Clock Activation and Strobe	300 ns
F. Minimum Strobe Pulse Width	100 ns
G. Typical Time Between Strobe Activation and Output Transition	500 ns

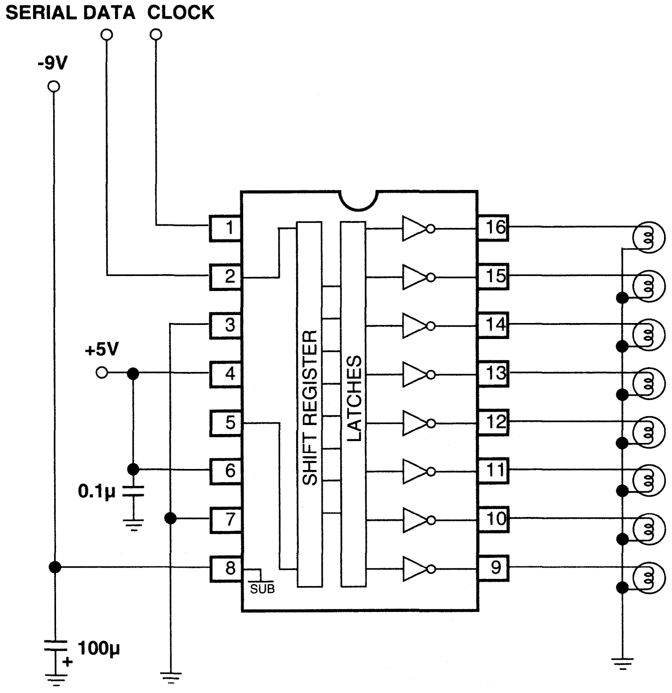
SERIAL DATA present at the input is transferred to the shift register on the logic "0" to logic "1" transition of the CLOCK input pulse. On succeeding CLOCK pulses, the registers shift data information towards the SERIAL DATA OUTPUT. The SERIAL DATA must appear at the input prior to the rising edge of the CLOCK input waveform.

Information present at any register is transferred to its respective latch when the STROBE is high (serial-to-parallel conversion). The latches will continue to accept new data as long as the STROBE is held high. Applications where the latches are bypassed (STROBE tied high) will require that the ENABLE input be high during serial entry.

When the ENABLE input is high, all of the output buffers are disabled (OFF) without affecting the information stored in the latches or shift register. With the ENABLE input low, the outputs are controlled by the state of the latches.

Typical Applications

MIC5822 Level Shifting Lamp Driver with Darlington Emitters Tied to a Negative Supply



MIC5841/5842

8-Bit Serial-Input Latched Drivers

General Description

Using BiCMOS technology, the MIC5841/5842 integrated circuits were fabricated to be used in a wide variety of peripheral power driver applications. The devices each have an eight-bit CMOS shift register, CMOS control circuitry, eight CMOS data latches, and eight bipolar current-sink Darlington output drivers.

These two devices differ only in maximum voltage ratings. The MIC5842 offers premium performance with a minimum output breakdown voltage rating of 80V (50V sustaining). The drivers can be operated with a split supply where the negative supply is down to –20V.

The 500 mA outputs, with integral transient-suppression diodes, are suitable for use with lamps, relays, solenoids and other inductive loads.

These devices have improved speed characteristics. With a 5V logic supply, they will typically operate faster than 5 MHz. With a 12V supply, significantly higher speeds are obtained. The CMOS inputs are compatible with standard CMOS, PMOS, and NMOS logic levels. TTL or DTL circuits may require the use of appropriate pull-up resistors. By using the serial data output, the drivers can be cascaded for interface applications requiring additional drive lines.

The MIC5840 family is available in DIP, PLCC, and SOIC packages. Because of limitations on package power dissipation, the simultaneous operation of all drivers at maximum rated current might require a reduction in duty cycle. A copper-alloy lead frame provides for maximum package power dissipation.

Features

- 3.3 MHz Minimum Data-Input Rate
- CMOS, PMOS, NMOS, TTL Compatible
- Internal Pull-Up/Pull-Down Resistors
- Low-Power CMOS Logic and Latches
- High-Voltage Current-Sink Outputs
- Output Transient-Protection Diodes
- Single or Split Supply Operation

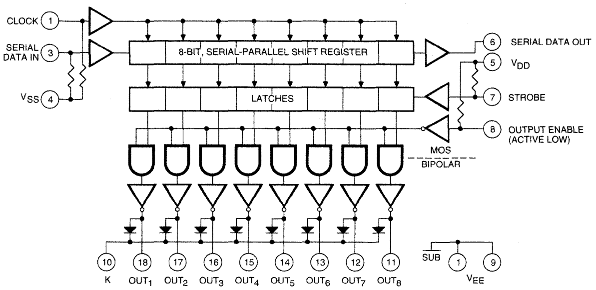
Ordering Information

Part Number	Temperature Range	Package
MIC5841BN	–40°C to +85°C	18-Pin Plastic DIP
MIC5841BV	–40°C to +85°C	20-Pin PLCC
MIC5841BWM	–40°C to +85°C	18-Pin Wide SOIC
MIC5842BN	–40°C to +85°C	18-Pin Plastic DIP
MIC5842BV	–40°C to +85°C	20-Pin PLCC
MIC5842BWM	–40°C to +85°C	18-Pin Wide SOIC
MIC5842AJ	–55°C to +125°C	18-Pin Ceramic DIP
MIC5842AJB*	–55°C to +125°C	18-Pin Ceramic DIP

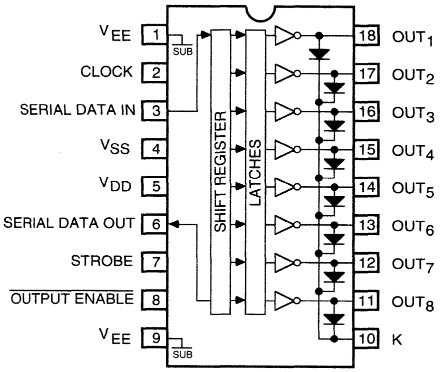
* AJB indicates units screened to MIL-STD 883, Method 5004, condition B, and burned-in for 1-week.

8

Functional Diagram



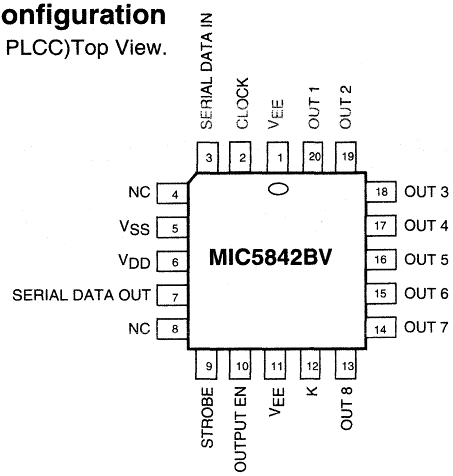
Pin Configuration



(Plastic and Ceramic DIP, SOIC)

Pin Configuration

(20-Pin PLCC)Top View.



Absolute Maximum Ratings (Note 1, 2, 3)

at 25°C Free-Air Temperature and V_{SS} = 0V

Output Voltage, V_{CE} (MIC5841)	50V
(MIC5842)	80V
Output Voltage, $V_{CE(SUS)}$ (MIC5841) (Note 1)	35V
(MIC5842)	50V
Logic Supply Voltage, V_{DD}	15V
V_{DD} with Reference to V_{EE}	25V
Emitter Supply Voltage, V_{EE}	–20V
Input Voltage Range, V_{IN}	–0.3V to V_{DD} + 0.3V
Continuous Output Current, I_{OUT}	500mA
Package Power Dissipation, P_D (Note 2)	1.82W
Operating Temperature Range, T_A	–55°C to +125°C
Storage Temperature Range, T_S	–65°C to +150°C

Note 1: For Inductive load applications.
Note 2: Derate at the rate of 18.2mW/°C above T_A = 25°C (Plastic DIP)
Note 3: CMOS devices have input-static protection but are susceptible to damage when exposed to extremely high static electrical charges.

Electrical Characteristics at T_A = 25°C V_{DD} = 5V, V_{SS} = V_{EE} = 0V (unless otherwise noted)

Characteristic	Symbol	Applicable Devices	Test Conditions	Limits Min.	Limits Max.	Unit
Output Leakage Current	I_{CEX}	MIC5841	V_{OUT} = 50V		50	µA
			V_{OUT} = 50V, T_A = +70°C		100	
		MIC5842	V_{OUT} = 80V		50	
			V_{OUT} = 80V, T_A = +70°C		100	
Collector-Emitter Saturation Voltage	$V_{CE(SAT)}$	Both	I_{OUT} = 100mA		1.1	V
			I_{OUT} = 200mA		1.3	
			I_{OUT} = 350mA, V_{DD} = 7.0V		1.6	
Collector-Emitter Sustaining Voltage	$V_{CE(SUS)}$ (Note 5)	MIC5841	I_{OUT} = 350mA, L = 2mH	35		V
		MIC5842	I_{OUT} = 350mA, L = 2mH	50		
Input Voltage	$V_{IN(0)}$	Both			0.8	V
	$V_{IN(1)}$	Both	V_{DD} = 12V	10.5		
			V_{DD} = 10V	8.5		
			V_{DD} = 5.0V (See Note 4)	3.5		
Input Resistance	R_{IN}	Both	V_{DD} = 12V	50		kΩ
			V_{DD} = 10V	50		
			V_{DD} = 5.0V	50		
Supply Current	$I_{DD(ON)}$	Both	All Drivers ON, V_{DD} = 12V		16	mA
			All Drivers ON, V_{DD} = 10V		14	
			All Drivers ON, V_{DD} = 5.0V		8.0	
	$I_{DD(OFF)}$	Both	All Drivers OFF, V_{DD} = 12V		2.9	
			All Drivers OFF, V_{DD} = 10V		2.5	
			All Drivers OFF, V_{DD} = 5.0V		1.6	
Clamp Diode Leakage Current	I_R	MIC5841	V_R = 50V		50	µA
		MIC5842	V_R = 80V		50	
Clamp Diode Forward Voltage	V_F	Both	I_F = 350mA		2.0	V

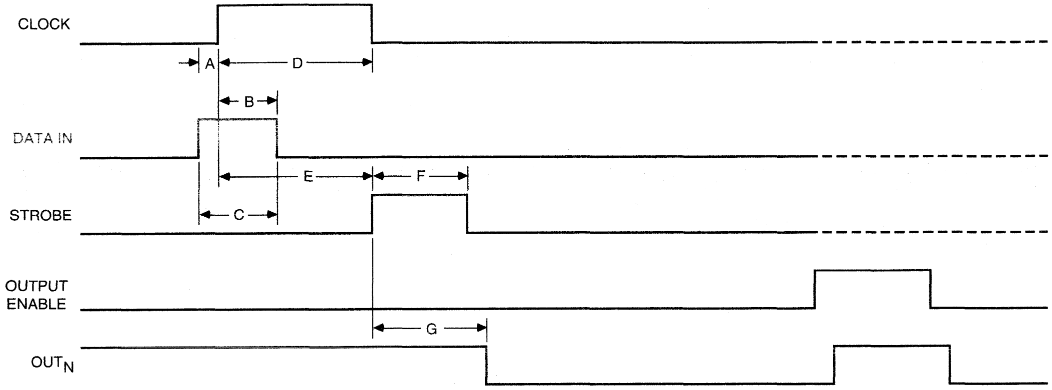
Note 4: Operation of these devices with standard TTL may require the use of appropriate pull-up resistors to insure an input logic HIGH.
Note 5: Not 100% tested. Guaranteed by design.

Electrical Characteristics MIC5841AJ/AJB and MIC5842AJ/AJB at $T_A = -55°C$, $V_{DD} = 5V$, $V_{SS} = V_{EE} = 0V$ (unless otherwise noted)

Characteristic	Symbol	Test Conditions	Limits Min.	Limits Max.	Unit
Output Leakage Current	I_{CEX}	$V_{OUT} = 80V$		50	µA
Collector-Emitter Saturation Voltage	$V_{CE(SAT)}$	$I_{OUT} = 100mA$		1.3	V
		$I_{OUT} = 200mA$		1.5	
		$I_{OUT} = 350mA$, $V_{DD} = 7.0V$		1.8	
Input Voltage	$V_{IN(0)}$			0.8	V
	$V_{IN(1)}$	$V_{DD} = 12V$	10.5		
		$V_{DD} = 5.0V$	3.5		
Input Resistance	R_{IN}	$V_{DD} = 12V$	35		kΩ
		$V_{DD} = 10V$	35		
		$V_{DD} = 5.0V$	35		
Supply Current	$I_{DD(ON)}$	All Drivers ON, $V_{DD} = 12V$		16	mA
		All Drivers ON, $V_{DD} = 10V$		14	
		All Drivers ON, $V_{DD} = 5.0V$		10	
	$I_{DD(OFF)}$	All Drivers OFF, $V_{DD} = 12V$		3.5	
		All Drivers OFF, $V_{DD} = 5.0V$		2.0	

Electrical Characteristics MIC5841AJ/AJB and MIC5842AJ/AJB at $T_A = +125°C$, $V_{DD} = 5V$, $V_{SS} = V_{EE} = 0V$ (unless otherwise noted)

Characteristic	Symbol	Test Conditions	Limits Min.	Limits Max.	Unit
Output Leakage Current	I_{CEX}	$V_{OUT} = 80V$		500	µA
Collector-Emitter Saturation Voltage	$V_{CE(SAT)}$	$I_{OUT} = 100mA$		1.3	V
		$I_{OUT} = 200mA$		1.5	
		$I_{OUT} = 350mA$, $V_{DD} = 7.0V$		1.8	
Input Voltage	$V_{IN(0)}$			0.8	V
	$V_{IN(1)}$	$V_{DD} = 12V$	10.5		
		$V_{DD} = 5.0V$	3.5		
Input Resistance	R_{IN}	$V_{DD} = 12V$	50		kΩ
		$V_{DD} = 10V$	50		
		$V_{DD} = 5.0V$	50		
Supply Current	$I_{DD(ON)}$	All Drivers ON, $V_{DD} = 12V$		16	mA
		All Drivers ON, $V_{DD} = 10V$		14	
		All Drivers ON, $V_{DD} = 5.0V$		8	
	$I_{DD(OFF)}$	All Drivers OFF, $V_{DD} = 12V$		2.9	
		All Drivers OFF, $V_{DD} = 5.0V$		1.6	
Clamp Diode Leakage Current	I_R	MIC5841A $V_R = 50V$		100	µA
		MIC5842A $V_R = 80V$		100	



Timing Conditions

(T_A = 25°C Logic Levels are V_{DD} and V_{SS})

	V_{DD} = 5V
A. Minimum Data Active Time Before Clock Pulse (Data Set-Up Time)	75 ns
B. Minimum Data Active Time After Clock Pulse (Data Hold Time)	75 ns
C. Minimum Data Pulse Width	150 ns
D. Minimum Clock Pulse Width	150 ns
E. Minimum Time Between Clock Activation and Strobe	300 ns
F. Minimum Strobe Pulse Width	100 ns
G. Typical Time Between Strobe Activation and Output Transition	500 ns

SERIAL DATA present at the input is transferred to the shift register on the logic "0" to logic "1" transition of the CLOCK input pulse. On succeeding CLOCK pulses, the registers shift data information towards the SERIAL DATA OUTPUT. The SERIAL DATA must appear at the input prior to the rising edge of the CLOCK input waveform.

Information present at any register is transferred to its respective latch when the STROBE is high (serial-to-parallel conversion). The latches will continue to accept new data as long as the STROBE is held high. Applications where the latches are bypassed (STROBE tied high) will require that the ENABLE input be high during serial data entry.

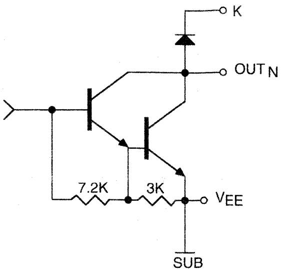
When the ENABLE input is high, all of the output buffers are disabled (OFF) without affecting information stored in the latches or shift register. With the ENABLE input low, the outputs are controlled by the state of the latches.

MIC5840 Family Truth Table

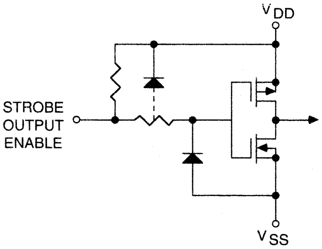
Serial Data Input	Clock Input	Shift Register Contents					Serial Data Output	Strobe Input	Latch Contents					Output Enable	Output Contents				
		I_1	I_2	I_3	......	I_8			I_1	I_2	I_3	......	I_8		I_1	I_2	I_3	......	I_8
H	↑	H	R_1	R_2	......	R_7	R_7												
L	↑	L	R_1	R_2	......	R_7	R_7												
X	↓	R_1	R_2	R_3	......	R_8	R_8												
		X	X	X	......	X	X	L	R_1	R_2	R_3	......	R_8						
		P_1	P_2	P_3	......	P_8	P_8	H	P_1	P_2	P_3	......	P_8	L	P_1	P_2	P_3	......	P_8
									X	X	X	......	X	H	H	H	H	......	H

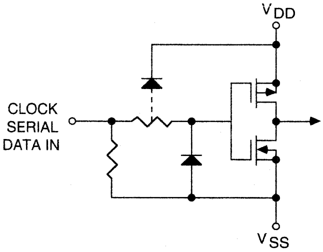
L = Low Logic Level
H = High Logic Level
X = Irrelevant
P = Present State
R = Previous State

Typical Output Driver



Typical Input Circuits





Maximum Allowable Duty Cycle (Plastic DIP)

V_{DD} = 5.0V

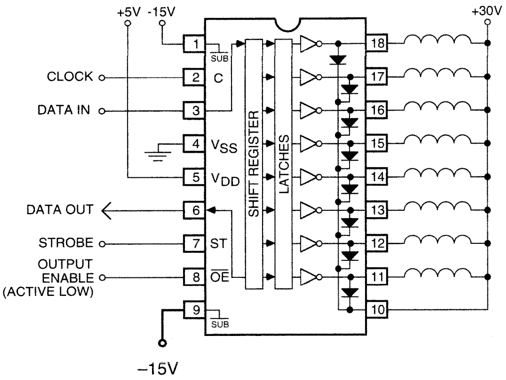
Number of Outputs ON (I_{OUT} = 200mA V_{DD} = 5.0V)	Max. Allowable Duty Cycle at Ambient Temperature of				
	25°C	**40°C**	**50°C**	**60°C**	**70°C**
8	85%	72%	64%	55%	46%
7	97%	82%	73%	63%	53%
6	100%	96%	85%	73%	62%
5	100%	100%	100%	88%	75%
4	100%	100%	100%	100%	93%
3	100%	100%	100%	100%	100%
2	100%	100%	100%	100%	100%
1	100%	100%	100%	100%	100%

V_{DD} = 12V

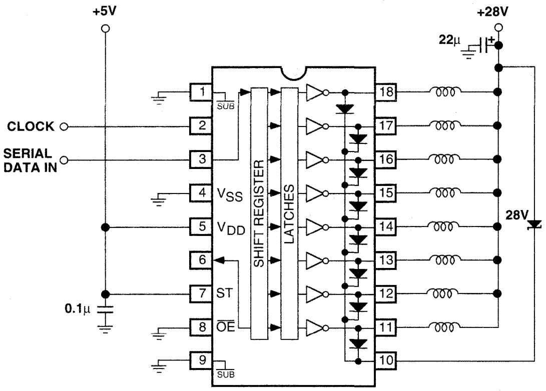
Number of Outputs ON (I_{OUT} = 200mA V_{DD} = 12V)	Max. Allowable Duty Cycle at Ambient Temperature of				
	25°C	**40°C**	**50°C**	**60°C**	**70°C**
8	80%	68%	60%	52%	44%
7	91%	77%	68%	59%	50%
6	100%	90%	79%	69%	58%
5	100%	100%	95%	82%	69%
4	100%	100%	100%	100%	86%
3	100%	100%	100%	100%	100%
2	100%	100%	100%	100%	100%
1	100%	100%	100%	100%	100%

Typical Applications

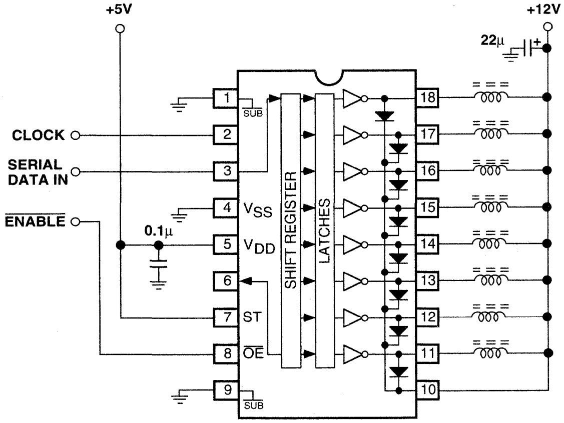
Relay/Solenoid Driver MIC5842



MIC5841 Hammer Driver

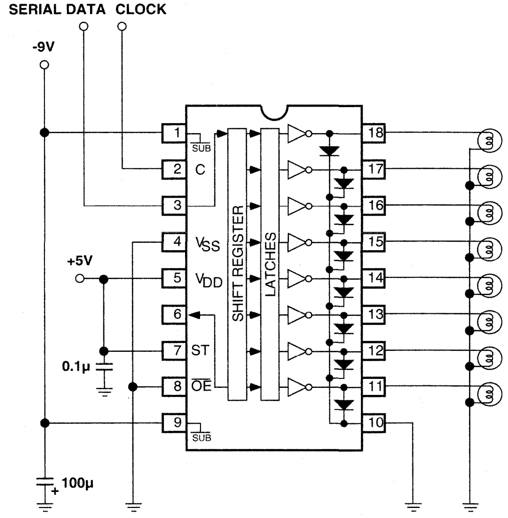


MIC5841 Solenoid Driver with Output Enable



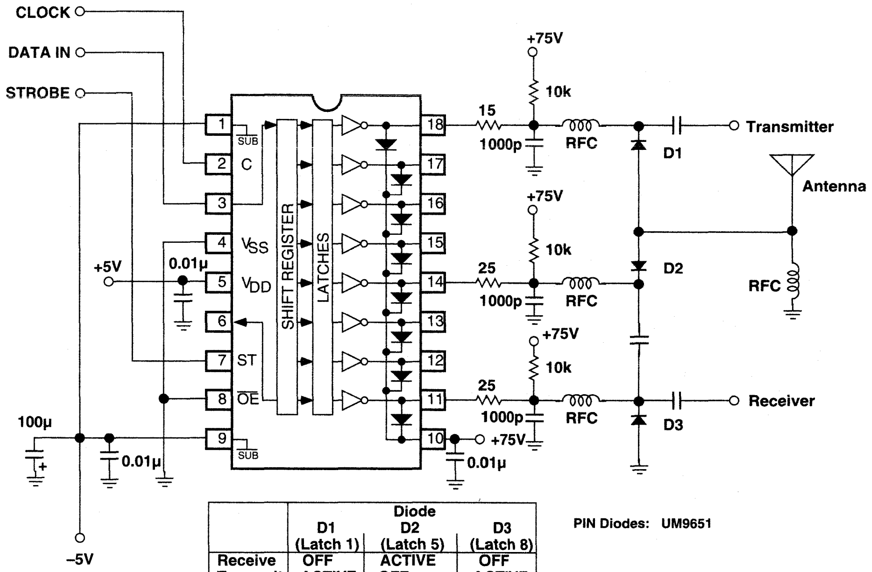
Solenoids: Guardian Electric LT4X7-C-12V

MIC5841 Level Shifting Lamp Driver with Darlington Emitters Tied to a Negative Supply



Typical Applications, Continued

MIC5842 Negative/Positive Supply PIN Diode Driver Transmit/Receive Switch



	Diode		
	D1 (Latch 1)	D2 (Latch 5)	D3 (Latch 8)
Receive	OFF	ACTIVE	OFF
Transmit	ACTIVE	OFF	ACTIVE

PIN Diodes: UM9651

MIC58P42

8-Bit Serial-Input Protected Latched Driver

General Description

The MIC58P42 serial-input latched driver is a high-voltage (80V), high-current (500mA) integrated circuit comprised of eight CMOS data latches, a bipolar Darlington transistor driver for each latch, and CMOS control circuitry for the common STROBE, CLOCK, SERIAL DATA INPUT, and OUTPUT ENABLE functions. Similar to the MIC5842, additional protection circuitry supplied on this device includes thermal shutdown, under voltage lockout (UVLO), and over-current shutdown.

The bipolar/CMOS combination provides an extremely low-power latch with maximum interface flexibility. The MIC58P42 has open-collector outputs capable of sinking 500 mA and integral diodes for inductive load transient suppression with a minimum output breakdown voltage rating of 80V (50V sustaining). The drivers can be operated with a split supply, where the negative supply is down to –20V and may be paralleled for higher load current capability.

With a 5V logic supply, the MIC58P42 will typically operate at better than 5MHz. With a 12V logic supply, significantly higher speeds are obtained. The CMOS inputs are compatible with standard CMOS, PMOS, and NMOS circuits. TTL circuits may require pull-up resistors. By using the serial data output, drivers may be cascaded for interface applications requiring additional drive lines.

Each of these eight outputs has an independent over current shutdown of 500 mA. Upon over-current detection, the affected channel will turn OFF until V_{DD} is cycled or the ENABLE/RESET pin is pulsed high. Current pulses less than 2µs will not activate current shutdown. Temperatures above 165°C will shut down the device. The UVLO circuit prevents operation at low V_{DD}; hysteresis of 0.5V is provided. See the MIC59P60 for a similar device that additionally provides an error flag output.

Features

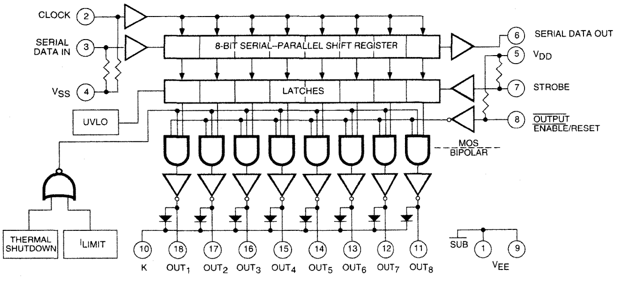
- 3.3 MHz Minimum Data-Input Rate
- CMOS, PMOS, NMOS, and TTL Compatible
- Internal Pull-Up/Pull-Down Resistors
- Low Power CMOS Logic and Latches
- High Voltage (80V) Current-Sink Outputs
- Output Transient-Protection Diodes
- Single or Split Supply Operation
- Thermal Shutdown
- Under-Voltage Lockout
- Per-Output Over-Current Shutdown (500mA typical)

Ordering Information

Part Number	Temperature Range	Package
MIC58P42AJ	–55°C to +125°C	18-Pin Ceramic DIP
MIC58P42AJB†	–55°C to +125°C	18-Pin Ceramic DIP
MIC58P42BN	–40°C to +85°C	18-Pin Plastic DIP
MIC58P42BV	–40°C to +85°C	20-Pin PLCC
MIC58P42BWM	–40°C to +85°C	18-Pin Wide SOIC

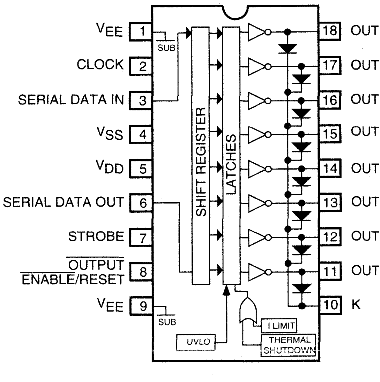
† AJB indicates units screened to MIL-STD 883, Method 5004, condition B, and burned-in for 1 week.

Functional Diagram

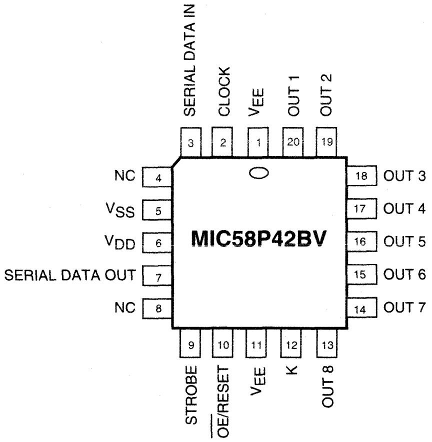


Pin Configuration

(Ceramic and Plastic DIP and SOIC)



PLCC Pin Configuration



Absolute Maximum Ratings (Note 1, 2)

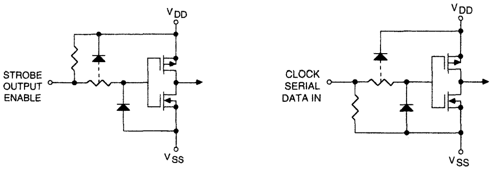
at 25°C Free-Air Temperature and V_{SS} = 0V

Output Voltage	80V
Output Voltage, $V_{CE(SUS)}$ (Note 1)	50V
Logic Supply Voltage Range, V_{DD}	4.5V to 15V
V_{DD} with Reference to V_{EE}	25V
Emitter Supply Voltage (Substrate), V_{EE}	–20V
Input Voltage Range, V_{IN}	–0.3V to V_{DD} + 0.3V
Package Power Dissipation, P_D	
MIC58P42BN	1.82W
Derate above T_A = +25°C	18mW/°C
MIC58P42AJ/AJB	1.6W
Derate above T_A = +25°C	16mW/°C
MIC58P42BV	1.4W
Derate above T_A = +25°C	14mW/°C
MIC58P42BWM	1.2W
Derate above T_A = +25°C	12mW/°C
Operating Temperature Range, T_A	–55°C to +125°C
Storage Temperature Range, T_S	–65°C to +150°C

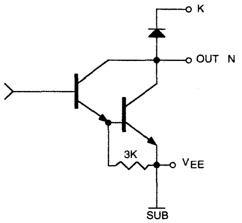
Note 1: For Inductive load applications.

Note 2: CMOS devices have input-static protection but are susceptible to damage when exposed to extremely high static electrical charges.

Typical Input Circuits



Typical Output Driver



Pin Description

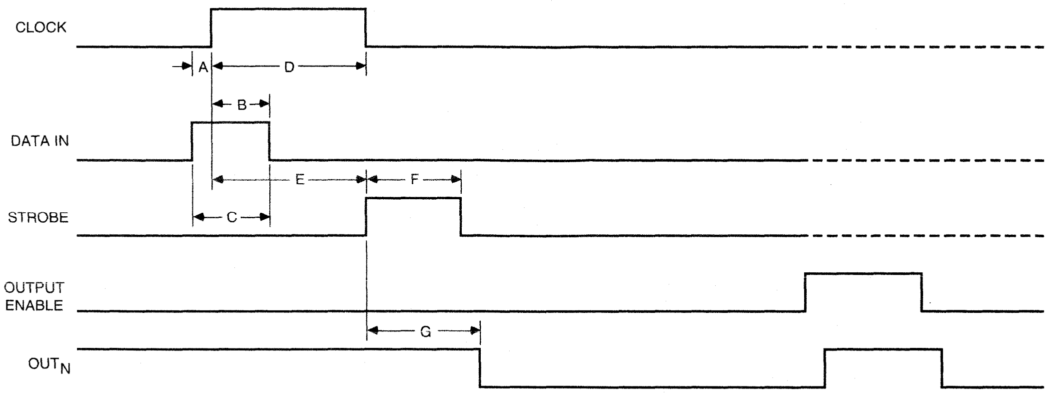
Pin (DIP & S.O.)	Name	Description
1,9	V_{EE}	Substrate. Most Negative voltage in the system connects here.
2	CLOCK	Serial Data Clock. A CLEAR input must also be clocked into the latches.
3	SERIAL DATA IN	Serial Data Input pin.
4	V_{SS}	Logic reference (Ground) pin.
5	V_{DD}	Logic Positive Supply voltage.
6	SERIAL DATA OUT	Serial Data Output pin. (Flow–through).
7	STROBE	Output Strobe pin. Loads output latches when high. Strobe is needed to clear latch.
8	$\overline{\text{OUTPUT ENABLE}}$/RESET	When Low, Outputs are active. When High, device is reset from a fault condition.
10	K	Transient suppression diode's cathode common pin.
11—18	OUTPUT N	Open Collector outputs 8 through 1.

Electrical Characteristics at $T_A = +25°C$, $V_{DD} = 5V$, $V_{SS} = V_{EE} = 0V$ (unless otherwise noted)

			Limits			
Characteristic	**Symbol**	**Test Conditions**	**Min.**	**Typ.**	**Max.**	**Unit**
Output Leakage Current	I_{CEX}	$V_{OUT} = 80V$			50	µA
		$V_{OUT} = 80V$, $T_A = +70°C$			100	
Collector-Emitter Saturation Voltage	$V_{CE(SAT)}$	$I_{OUT} = 100mA$ $I_{OUT} = 200mA$ $I_{OUT} = 350mA$		0.9 1.1 1.3	1.1 1.3 1.6	V
Collector-Emitter Sustaining Voltage	$V_{CE(SUS)}$	$I_{OUT} = 350mA$, $L = 2mH$	50			V
Input Voltage	$V_{IN(0)}$				1.0	V
	$V_{IN(1)}$	$V_{DD} = 12V$ $V_{DD} = 10V$ $V_{DD} = 5.0V$, **Note 1**		10.5 8.5 3.5		
Input Resistance	R_{IN}	$V_{DD} = 12V$ $V_{DD} = 10V$ $V_{DD} = 5.0V$	50 50 50	200 300 600		kΩ
Supply Current	$I_{DD(ON)}$	All Drivers ON, $V_{DD} = 12V$ All Drivers ON, $V_{DD} = 10V$ All Drivers ON, $V_{DD} = 5.0V$		6.4 6.0 4.6	10.0 9.0 7.5	mA
	$I_{DD\ (1\ ON)}$	One Driver ON, All others OFF, $V_{DD} = 12V$ One Driver ON, All others OFF, $V_{DD} = 10V$ One Driver ON, All others OFF, $V_{DD} = 5V$		3.1 2.9 2.3	4.5 4.5 3.6	
	$I_{DD(OFF)}$	All Drivers OFF, $V_{DD} = 12V$ All Drivers OFF, $V_{DD} = 10V$ All Drivers OFF, $V_{DD} = 5.0V$		2.6 2.4 1.9	4.2 3.6 3.0	
Clamp Diode Leakage Current	I_R	$V_R = 80V$			50	µA
Clamp Diode Forward Voltage	V_F	$I_F = 350mA$		1.7	2.0	V
Output Current Shutdown Threshold	I_{LIM}			500		mA
Start Up Voltage	V_{SU}	**Note 2**	3.5	4.0	4.5	V
Minimum Supply (V_{DD})	$V_{DD\ MIN}$		3.0	3.5	4.0	V
Thermal Shutdown				165		°C
Thermal Shutdown Hysteresis				10		°C

Note 1: Operation of these devices with standard TTL or DTL may require the use of appropriate pull-up resistors to insure a minimum logic "1".

Note 2: Undervoltage Lockout is guaranteed to release device at no more than 4.5V, and disable the device at no less than 3.0V.



Timing Conditions

(T_A = +25°C, Logic Levels are V_{DD} and V_{SS}), V_{DD} = 5V

A. Typical Data Active Time Before Clock Pulse (Data Set-Up Time)	75 ns
B. Minimum Data Active Time After Clock Pulse (Data Hold Time)	75 ns
C. Minimum Data Pulse Width	150 ns
D. Minimum Clock Pulse Width	150 ns
E. Minimum Time Between Clock Activation and Strobe	300 ns
F. Minimum Strobe Pulse Width	100 ns
G. Typical Time Between Strobe Activation and Output Transition	500 ns

SERIAL DATA present at the input is transferred to the shift register on the logic "0" to logic "1" transition of the CLOCK input pulse. On succeeding CLOCK pulses, the registers shift data information towards the SERIAL DATA OUTPUT. The SERIAL DATA must appear at the input prior to the rising edge of the CLOCK input waveform.

Information present at any register is transferred to its respective latch when the STROBE is high (serial-to-parallel conversion). The latches will continue to accept new data as long as the STROBE is held high. Applications where the latches are bypassed (STROBE tied high) will require that the ENABLE input be high to prevent invalid output states.

When the ENABLE input is high, all of the output buffers are disabled (OFF) without affecting information stored in the latches or shift register. With the ENABLE input low, the outputs are controlled by the state of the latches. A positive OUTPUT ENABLE/ RESET pulse resets the output after a current shutdown fault. Thermal limit faults are not latched and require no reset pulse.

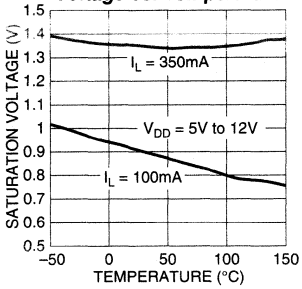
MIC58P42 Truth Table

Serial Data Input	Clock Input	Shift Register Contents				Serial Data Output	Strobe Input	Latch Contents				Output Enable	Output Contents			
		I_1	I_2	I_3	I_8			I_1	I_2	I_3	I_8		I_1	I_2	I_3	I_8
H	↑	H	R_1	R_2	R_7	R_7										
L	↑	L	R_1	R_2	R_7	R_7										
X	↓	R1	R2	R_3	R_8	R_8										
	↑	O	O	O	O	L										
		X	X	X	X	X	L	R_1	R_2	R_3	R_8					
		P_1	P_2	P_3	P_8	P_8	H	P_1	P_2	P_3	P_8	L	P_1	P_2	P_3	P_8
								X	X	X	X	H	H	H	H	H

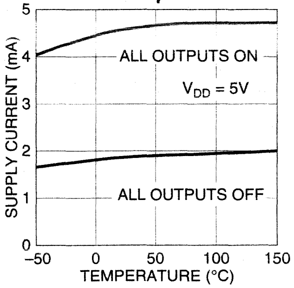
L = Low Logic Level
H = High Logic Level
X = Irrelevant
P = Present State
R = Previous State
O = Output OFF

Typical Characteristic Curves

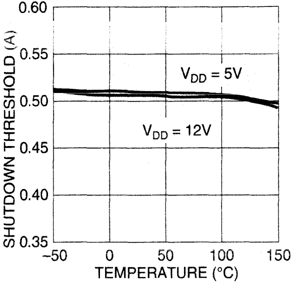
Output Saturation Voltage vs. Temperature



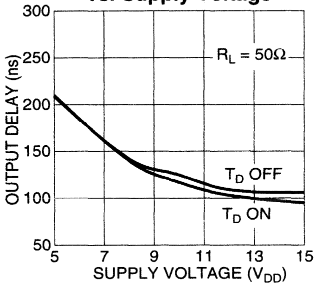
Supply Current vs. Temperature



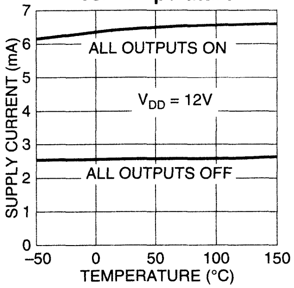
Current Shutdown Threshold vs. Temperature



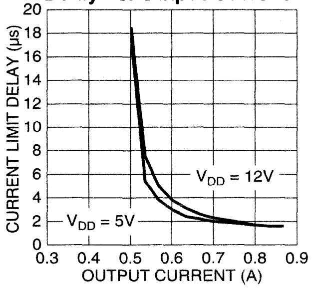
Output Delay vs. Supply Voltage



Supply Current vs. Temperature



Current Shutdown Delay vs. Output Current



Maximum Allowable Duty Cycle, Plastic DIP

V_{DD} = 5.0V

Number of Outputs ON (I_{OUT} = 200mA V_{DD} = 5.0V)	Max. Allowable Duty Cycle at Ambient Temperature of:				
	25°C	40°C	50°C	60°C	70°C
8	85%	72%	64%	55%	46%
7	97%	82%	73%	63%	53%
6	100%	96%	85%	73%	62%
5	100%	100%	100%	88%	75%
4	100%	100%	100%	100%	93%
3	100%	100%	100%	100%	100%
2	100%	100%	100%	100%	100%
1	100%	100%	100%	100%	100%

V_{DD} = 12V

Number of Outputs ON (I_{OUT} = 200mA V_{DD} = 12V)	Max. Allowable Duty Cycle at Ambient Temperature of:				
	25°C	40°C	50°C	60°C	70°C
8	80%	68%	60%	52%	44%
7	91%	77%	68%	59%	50%
6	100%	90%	79%	69%	58%
5	100%	100%	95%	82%	69%
4	100%	100%	100%	100%	86%
3	100%	100%	100%	100%	100%
2	100%	100%	100%	100%	100%
1	100%	100%	100%	100%	100%

MIC5891

8-Bit Serial-Input Latched Source Driver

Preliminary Information

General Description

The MIC5891 latched driver is a high-voltage, high current integrated circuits comprised of eight CMOS data latches, CMOS control circuitry for the common STROBE and OUTPUT ENABLE, and bipolar Darlington transistor drivers for each latch.

Bipolar/MOS construction provides extremely low power latches with maximum interface flexibility.

The MIC5891 will typically operate at better than 5MHz with a 5V logic supply.

The CMOS inputs are compatible with standard CMOS, PMOS and NMOS logic levels. TTL circuits may be used with appropriate pull-up resistors to ensure a proper logic-high input.

A CMOS serial data output allows additional drivers to be cascaded when more than 8 bits are required.

The MIC5891 has open-emitter outputs with suppression diodes for protection against inductive load transients. The output transistors are capable of sourcing 500mA and will sustain at least 35V in the ON state.

Simultaneous operation of all drivers at maximum rated current requires a reduction in duty cycle due to package power limitations. Outputs may be paralleled for higher load current capability.

The MIC5891 is available in a 16-pin plastic DIP package (N), 16-pin CerDIP package (J), and 16-pin wide SOIC package (WM).

Features

- High-Voltage, High-Current Outputs
- Output Transient Protection Diodes
- CMOS, PMOS, NMOS, TTL Compatible Inputs
- 10MHz Minimum Data Input Rate
- Low-Power CMOS Latches

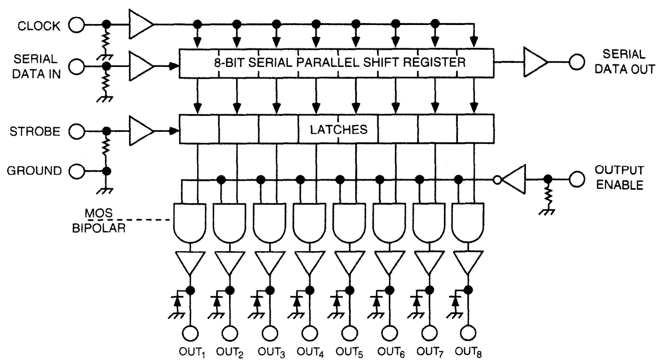
Applications

- Alphanumeric and Bar Graph Displays
- LED and Incandescent Displays
- Relay and Solenoid Drivers
- Other High Power Loads

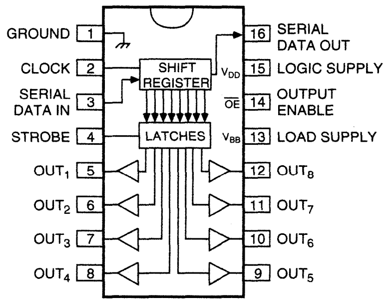
Ordering Information

Part Number	Temperature Range	Package
MIC5891BN	–40°C to +85°C	16-Pin Plastic DIP
MIC5891BWM	–40°C to +85°C	16-pin Wide SOIC

Functional Diagram

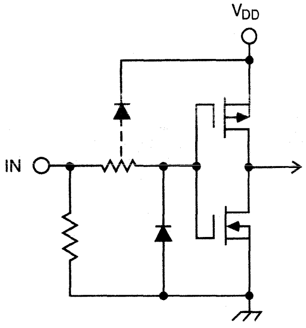


Pin Configurations

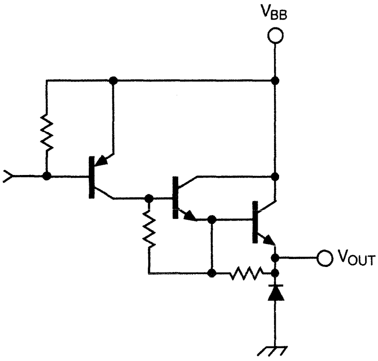


MIC5891

Typical Circuits

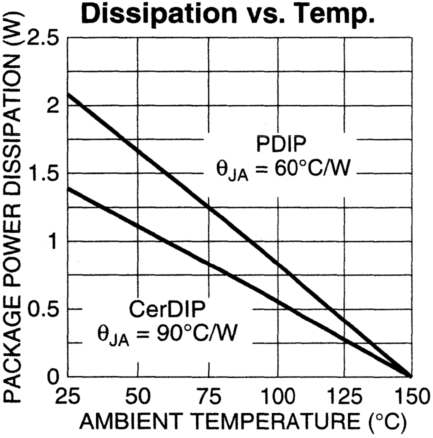


Typical Input Circuit



Typical Output Circuit

Allowable Package Power Dissipation vs. Temp.



Absolute Maximum Ratings: (Notes 1, 2)

at T_A = +25°C

Output Voltage, V_{OUT}	50V
Logic Supply Voltage Range, V_{DD}	4.5V to 15V
Load Supply Voltage Range, V_{BB}	5.0V to 50V
Input Voltage Range, V_{IN}	–0.3 V to V_{DD} + 0.3 V
Continuous Collector Current, I_C	500mA
Package Power Dissipation	See graph
Operating Temperature Range, T_A	–55°C to +125°C
Storage Temperature Range, T_S	–65°C to +150°C

Note 1: Derate at the rate of 20 mW/°C above T_A = 25°C

Note 2: Micrel CMOS devices have input-static protection but are susceptible to damage when exposed to extremely high static electrical charges

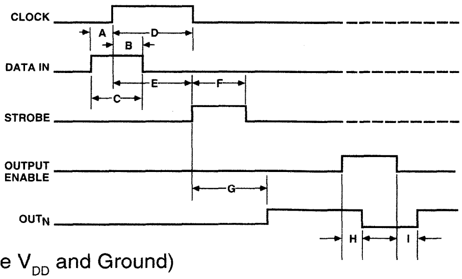
Allowable Duty Cycles

Number of Outputs ON at I_{OUT} = –200 mA	Max. Allowable Duty Cycles at T_A of:		
	50°C	60°C	70°C
8	53%	47%	41%
7	60%	54%	48%
6	70%	64%	56%
5	83%	75%	67%
4	100%	94%	84%
3	100%	100%	100%
2	100%	100%	100%
1	100%	100%	100%

Electrical Characteristics: at T_A = +25°C, V_{BB} = 50V, V_{DD} = 5V to 12V (unless otherwise noted).

				Limits		
Characteristic	**Symbol**	**V_{BB}**	**Test Conditions**	**Min.**	**Max.**	**Units**
Output Leakage Current	I_{CEX}	50V	T_A = +25°C		–50	µA
			T_A = +70°C		–100	µA
Output Saturation Voltage	$V_{CE(SAT)}$	50V	I_{OUT} = –100mA		1.8	V
			I_{OUT} = –225mA		1.9	V
			I_{OUT} = –350mA,		2.0	V
Output Sustaining Voltage	$V_{CE(SUS)}$	50V	I_{OUT} = –350mA, L = 2mH	35		V
Input Voltage	$V_{IN(1)}$	50V	V_{DD} = 5.0V	3.5	V_{DD}+0.3	V
			V_{DD} = 12V	10.5	V_{DD}+0.3	V
	$V_{IN(0)}$	50V	V_{DD} = 5V to 12V	V_{SS}–0.3	0.8	V
Input Current	$I_{IN(1)}$	50V	V_{DD} = V_{IN} = 5.0V		50	µA
			V_{DD} = 12V		240	µA
Input Impedance	Z_{IN}	50V	V_{DD} = 5.0V	100		kΩ
			V_{DD} = 12V	50		kΩ
Maximum Clock Frequency	f_c	50V		10		MHz
Serial Data Output Resistance	R_{OUT}	50V	V_{DD} = 5.0V		20	kΩ
			V_{DD} = 12V		6.0	kΩ
Turn-ON Delay	t_{PLH}	50V	Output Enable to Output, I_{OUT} = –350mA		2.0	µs
Turn-OFF Delay	t_{PHL}	50V	Output Enable to Output, I_{OUT} = –350mA		10	µs
Supply Current	I_{BB}	50V	All outputs ON, All outputs open		10	mA
			All outputs OFF		200	µA
	I_{DD}	50V	V_{DD} = 5V, All outputs OFF, Inputs = 0V		100	µA
			V_{DD} = 12V, All outputs OFF, Inputs = 0V		200	µA
			V_{DD} = 5V, One output ON, All Inputs = 0V		1.0	mA
			V_{DD} = 12V, One output ON, All Inputs = 0V		3.0	mA
Diode Leakage Current	I_H	Max	T_A = +25°C		50	µA
			T_A = +70°C		100	µA
Diode Forward Voltage	V_F	Open	I_F = 350mA		2.0	V

NOTE 1: Positive (negative) current is defined as going into (coming out of) the specified device pin.
NOTE 2: Operation of these devices with standard TTL may require the use of appropriate pull-up resistors.



Timing Conditions

(V_{DD} = 5.0V, Logic Levels are V_{DD} and Ground)

A. Minimum data active time before clock pulse (data set-up time) 75ns
B. Minimum data active time after clock pulse (data hold time) 75ns
C. Minimum data pulse width 150ns
D. Minimum clock pulse width 150ns
E. Minimum time between clock activation and strobe 300ns
F. Minimum strobe pulse width 100ns
G. Typical time between strobe activation and output transition 1.0µs
H. Turn-OFF Delay .... see Electrical Characteristics
I Turn-ON Delay .... see Electrical Characteristics

Serial data present at the input is transferred into the shift register on the rising edge of the CLOCK input pulse. Additional CLOCK pulses shift data information towards the SERIAL DATA OUTPUT. The serial data must appear at the input prior to the rising edge of the CLOCK input waveform.

The 8 bits present in the shift register are transferred to the respective latches when the STROBE is high (serial-to-parallel conversion). The latches will continue to accept new data as long as the STROBE is held high. Most applications where the latching feature is not used (STROBE tied high) require the OUTPUT ENABLE input to be high during serial data entry.

Outputs are active (controlled by the latch state) when the OUTPUT ENABLE is low. All Outputs are low (disabled) when the OUTPUT ENABLE is high. OUTPUT ENABLE does not affect the data in the shift register or latch.

Truth Table

Serial Data Input	Clock Input	Shift Register Contents						Serial Data Output	Strobe Input	Latch Contents						Output Enable	Output Content					
		I_1	I_2	I_3	...	I_{N-1}	I_N			I_1	I_2	I_3	...	I_{N-1}	I_n		I_1	I_2	I_3	...	I_{N-1}	I_n
H	_|‾	H	R_1	R_2	...	R_{N-2}	R_{N-1}	R_{N-1}														
L	_|‾	L	R_1	R_2	...	R_{N-2}	R_{N-1}	R_{N-1}														
X	‾|_	R_1	R_2	R_3	...	R_{N-1}	R_N	R_N														
		X	X	X	...	X	X	X	L	R_1	R_2	R_3	...	R_{N-1}	R_N							
		P_1	P_2	P_3	...	P_{N-1}	P_N	P_N	H	P_1	P_2	P_3	...	P_{N-1}	P_N	L	P_1	P_2	P_3	...	P_{N-1}	P_N
										X	X	X	...	X	X	H	L	L	L	...	L	L

L = Low Logic Level
H = High Logic Level
X = Irrelevant
P = Present State
R = Previous State

MICREL

MIC59P50

8-Bit Parallel-Input Protected Latched Driver

General Description

The MIC59P50 parallel-input latched driver is a high-voltage (80V), high-current (500mA) integrated circuit comprised of eight CMOS data latches, a bipolar Darlington transistor driver for each latch, and CMOS control circuitry for the common CLEAR, STROBE, and OUTPUT ENABLE functions. Similar to the MIC5801, additional protection circuitry supplied on this device includes thermal shutdown, under voltage lockout (UVLO), and over-current shutdown.

The bipolar/MOS combination provides an extremely low-power latch with maximum interface flexibility. The MIC59P50 has open-collector outputs capable of sinking 500mA and integral diodes for inductive load transient suppression with a minimum output breakdown voltage rating of 80V above V_{EE} (50V sustaining). The drivers can be operated with a split supply, where the negative supply is down to –20V and may be paralleled for higher load current capability.

With a 5V logic supply, the MIC59P50 will typically operate at better than 5MHz. With a 12V logic supply, significantly higher speeds are obtained. The CMOS inputs are compatible with standard CMOS, PMOS, and NMOS circuits. TTL circuits may require pull-up resistors.

Each of these eight outputs has an independent over-current shutdown at 500 mA. Upon current shutdown, the affected channel will turn OFF and the flag will go low until V_{DD} is cycled or the $\overline{\text{ENABLE}}$/RESET pin is pulsed high. Current pulses less than 2µs will not activate over-current shutdown. Temperatures above 165°C will shut down the device and activate the open collector FLAG output at pin 1. The UVLO circuit disables the outputs at low V_{DD}; hysteresis of 0.5V is provided.

Features

- 4.4 MHz Minimum Data Input Rate
- High-Voltage, High-Current Outputs
- Per-Output Over-Current Shutdown (500mA Typical)
- Undervoltage Lockout
- Thermal Shutdown
- Output Fault Flag
- Output Transient Protection Diodes
- CMOS, PMOS, NMOS, and TTL Compatible Inputs
- Internal Pull-Down Resistors
- Low-Power CMOS Latches
- Single or Split Supply Operation

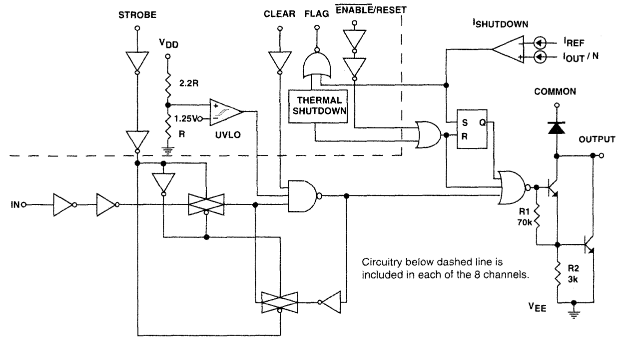
Ordering Information

Part Number	Temperature Range	Package
MIC59P50AJ	–55°C to +125°C	24-Pin Ceramic DIP*
MIC59P50AJB†	–55°C to +125°C	24-Pin Ceramic DIP*
MIC59P50BN	–40°C to +85°C	24-Pin Plastic DIP*
MIC59P50BV	–40°C to +85°C	28-Pin PLCC
MIC59P50BWM	–40°C to +85°C	24-Pin Wide SOIC

* 300-mil "skinny-DIP"

† AJB indicates units screened to MIL-STD 883, Method 5004, condition B, and burned-in for 1-week.

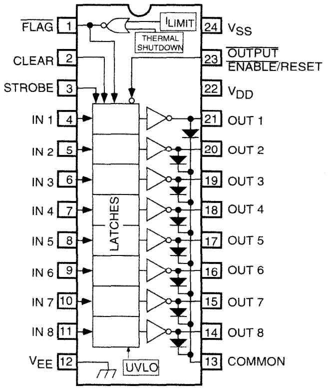
Functional Diagram



Circuitry below dashed line is included in each of the 8 channels.

Pin Configuration

(Ceramic and Plastic DIP and SOIC)



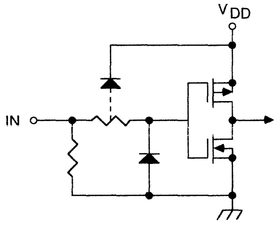
Absolute Maximum Ratings: (Note 1)

at +25°C Free-Air Temperature

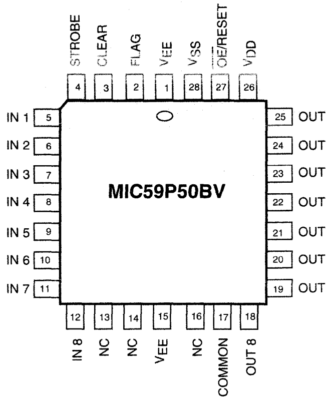
Output Voltage, V_{CE}	80V
Supply Voltage, V_{DD}	15V
$V_{DD} - V_{EE}$	25V
Input Voltage Range, V_{IN}	–0.3V to V_{DD} + 0.3V
Continuous Collector Current, I_C	500mA
Package Power Dissipation	
MIC59P50BN	2.4W
Derate above T_A = +25°C	24mW/°C
MIC59P50AJ	2.2W
Derate above T_A = +25°C	22mW/°C
MIC59P50BV	1.6W
Derate above T_A = +25°C	16mW/°C
MIC59P50BWM	1.4W
Derate above T_A = +25°C	14mW/°C
Operating Temperature Range, T_A	–40°C to +85°C
Storage Temperature Range, T_S	–65°C to +125°C

Note 1: Micrel CMOS devices have input-static protection but are susceptible to damage when exposed to extremely high static electrical charges.

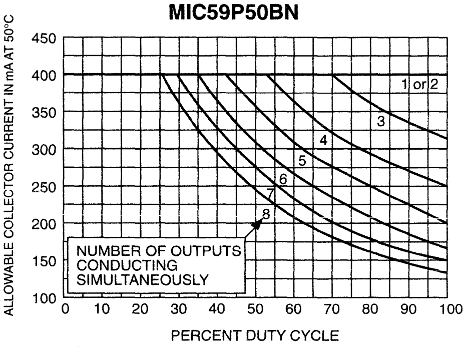
Typical Input



PLCC Pin Configuration



Allowable Output Current As A Function of Duty Cycle



Pin Description

Pin	Name	Description
1	FLAG	Error Flag. Open Collector Output is Low upon Overcurrent Fault or Overtemperature Fault. $\overline{\text{OUTPUT ENABLE}}$/RESET must be pulled high to reset the flag and fault condition.
2	CLEAR	Sets All Latches OFF (open).
3	STROBE	Input Strobe Pin. Loads output latches when High.
4–11	INPUT	Parallel Inputs, 1 through 8
12	V_{EE}	Output Ground (Substrate). Most negative voltage in the system connects here.
13	COMMON	Transient suppression diodes cathode common pin.
14–21	OUTPUT	Parallel Outputs, 8 through 1.
22	V_{DD}	Logic Positive Supply voltage.
23	$\overline{\text{OUTPUT ENABLE RESET}}$	Output Enable Reset. When Low, Outputs are active. When High, outputs are inactive and the Flag and outputs are reset from a fault condition. An undervoltage condition emulates a high $\overline{\text{OE}}$ input.
24	V_{SS}	Logic reference (Ground) pin.

Electrical Characteristics: at T_A = +25°C, V_{DD} = 5V (unless otherwise noted)

			Limits			
Characteristic	**Symbol**	**Test Conditions**	**Min.**	**Typ.**	**Max.**	**Units**
Output Leakage Current	I_{CEX}	V_{CE} = 80V, T_A = +25°C V_{CE} = 80V, T_A = +70°C			50 100	µA
Collector-Emitter	$V_{CE(SAT)}$	I_C = 100 mA		0.9	1.1	V
Saturation Voltage		I_C = 200 mA I_C = 350 mA		1.1 1.3	1.3 1.6	
Input Voltage	$V_{IN(0)}$				1.0	V
	$V_{IN(1)}$	V_{DD} = 12V V_{DD} = 10V V_{DD} = 5.0V **Note 1**	10.5 8.5 3.5			
Input Resistance	R_{IN}	V_{DD} = 12V V_{DD} = 10V V_{DD} = 5.0V	50 50 50	200 300 600		kΩ
$\overline{\text{Flag}}$ Output Current	I_{OL}	V_{OL} = 0.4V		15		mA
$\overline{\text{Flag}}$ Output Leakage	I_{OH}	V_{OH} = 12.0V		50		nA
Supply Current	$I_{DD(ON)}$ (One output active)	V_{DD} = 12V, Outputs Open V_{DD} = 10V, Outputs Open V_{DD} = 5.0V, Outputs Open		3.3 3.1 2.4	4.5 4.5 3.6	mA
	$I_{DD(ON)}$ (All outputs active)	V_{DD} = 12V, Outputs Open V_{DD} = 10V, Outputs Open V_{DD} = 5.0V, Outputs Open		6.4 6.0 4.7	10.0 9.0 7.5	mA
	$I_{DD(OFF)}$ (Total)	V_{DD} = 12V, Outputs Open, Inputs = 0V V_{DD} = 5.0V, Outputs Open, Inputs = 0V		3.0 2.2	4.5 3.6	mA
Clamp Diode Leakage Current	I_R	V_R = 80V, T_A = +25°C V_R = 80V, T_A = +70°C			50 100	µA
Over-Current Threshold	I_{LIM}	Each Output		500		mA
Start-Up Voltage	V_{SU}	**Note 2**	3.5	4.0	4.5	V
Minimum Operating V_{DD}	$V_{DD\ MIN}$		3.0	3.5	4.0	V
Clamp Diode Forward Voltage	V_F	I_F = 350 mA		1.7	2.0	V
Thermal Shutdown				165		°C
Thermal Shutdown Hysteresis				10		

NOTE 1: Operation of these devices with standard TTL or DTL may require the use of appropriate pull-up resistors to insure a minimum logic "1".

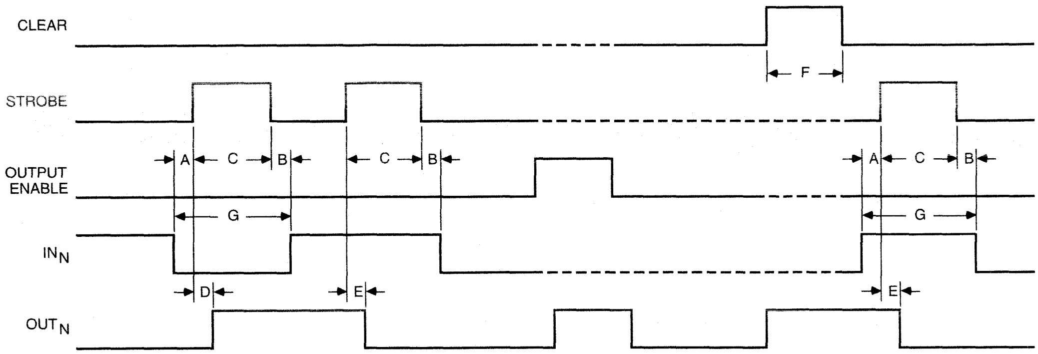
NOTE 2: Undervoltage Lockout is guaranteed to release device at no more than 4.5V, and disable the device at no less than 3.0V.Input Logic Voltage.

Truth Table

			Output	OUT_N	
IN_N	Strobe	Clear	Enable	t–1	t
0	1	0	0	X	OFF
1	1	0	0	X	ON
X	X	1	X	X	OFF
X	X	X	1	X	OFF
X	0	0	0	ON	ON
X	0	0	0	OFF	OFF

‹ = Irrelevant
–1 = previous output state
= present output state

Information present at an input is transferred to its latch when the STROBE is high. A high CLEAR input will set all latches to the output OFF condition regardless of the data or STROBE input levels. A high OUTPUT ENABLE will set all outputs to the off condition, regardless of any other input conditions. When the OUTPUT ENABLE is low, the outputs depend on the state of their respective latches. If current shutdown is activated, the OUTPUT ENABLE must be pulsed high to restore operation and reset the Flag. Over temperature faults are not latched and require no reset pulse.

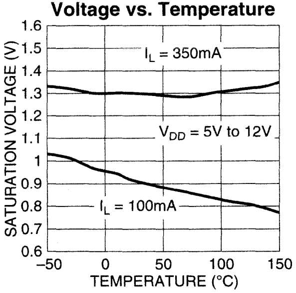


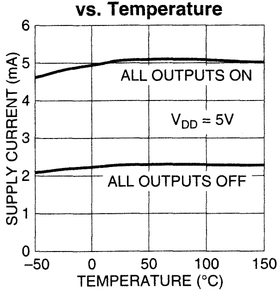
Timing Conditions

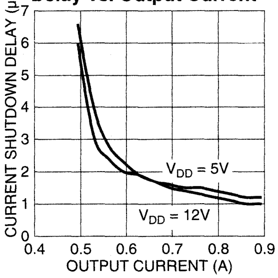
(T_A = +25°C, Logic Levels are V_{DD} and V_{SS}, V_{DD} = 5V).

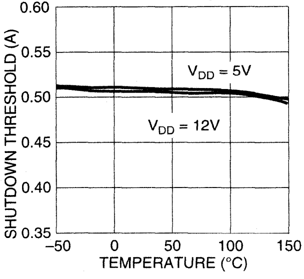
A.	Minimum data active time before strobe enabled (data set-up time)	50 ns
B.	Minimum data active time after strobe disabled (data hold time)	50 ns
C.	Minimum strobe pulse width	125 ns
D.	Typical time between strobe activation and output on to off transition	500 ns
E.	Typical time between strobe activation and output off to on transition	500 ns
F.	Minimum clear pulse width	300 ns
G.	Minimum data pulse width	225 ns

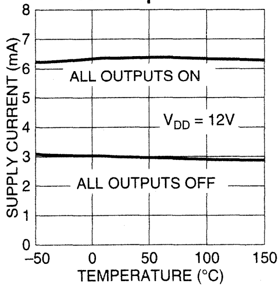
Typical Characteristic Curves

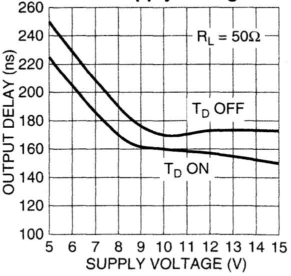

Output Saturation Voltage vs. Temperature


Supply Current vs. Temperature


Current Shutdown Delay vs. Output Current

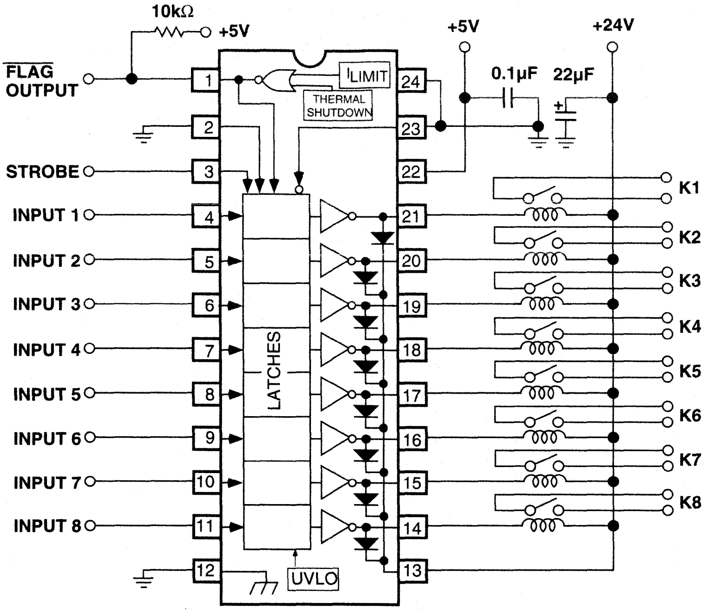

Current Shutdown Threshold vs. Temperature


Supply Current vs. Temperature


Output Enable Delay vs. Supply Voltage

Typical Applications

MIC59P50 Protected Relay Driver



MIC59P60

8-Bit Serial-Input Protected Latched Driver

General Description

The MIC59P60 serial-input latched driver is a high-voltage (80V), high-current (500mA) integrated circuit comprised of eight CMOS data latches, a bipolar Darlington transistor driver for each latch, and CMOS control circuitry for the common CLEAR, STROBE, CLOCK, SERIAL DATA INPUT, and OUTPUT ENABLE functions. Similar to the MIC5842, additional protection circuitry supplied on this device includes thermal shutdown, under voltage lockout (UVLO), and over-current shutdown.

The bipolar/CMOS combination provides an extremely low-power latch with maximum interface flexibility. The MIC59P60 has open-collector outputs capable of sinking 500mA and integral diodes for inductive load transient suppression with a minimum output breakdown voltage rating of 80V (50V sustaining). The drivers can be operated with a split supply, where the negative supply is down to –20V and may be paralleled for higher load current capability.

Using a 5V logic supply, the MIC59P60 will typically operate at better than 5MHz. With a 12V logic supply, significantly higher speeds are obtained. The CMOS inputs are compatible with standard CMOS, PMOS, and NMOS circuits. TTL circuits may require pull-up resistors. By using the serial data output, drivers may be cascaded for interface applications requiring additional drive lines.

Each of these eight outputs has an independent over current shutdown of 500 mA. Upon over-current shutdown, the affected channel will turn OFF and the flag will go low until V_{DD} is cycled or the ENABLE/RESET pin is pulsed high. Current pulses less than 2µs will not activate current shutdown. Temperatures above 165°C will shut down the device and activate the error flag. The UVLO circuit prevents operation at low V_{DD}; hysteresis of 0.5V is provided.

Features

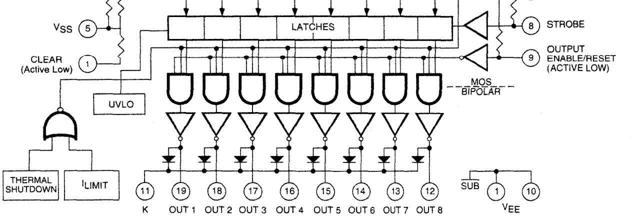
- 3.3 MHz Minimum Data-Input Rate
- Output Current Shutdown (500mA Typical)
- Under Voltage Lockout
- Thermal Shutdown
- Output Fault Flag
- CMOS, PMOS, NMOS, and TTL Compatible
- Internal Pull-Up/Pull-Down Resistors
- Low Power CMOS Logic and Latches
- High Voltage Current Sink Outputs
- Output Transient-Protection Diodes
- Single or Split Supply Operation

Ordering Information

Part Number	Temperature Range	Package
MIC59P60AJ	–55°C to +125°C	20-Pin Ceramic DIP
MIC59P60AJB†	–55°C to +125°C	20-Pin Ceramic DIP
MIC59P60BN	–40°C to +85°C	20-Pin Plastic DIP
MIC59P60BV	–40°C to +85°C	20-Pin PLCC
MIC59P60BWM	–40°C to +85°C	20-Pin Wide SOIC

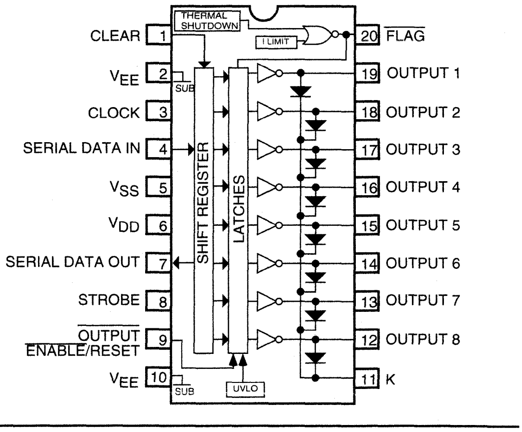
† AJB indicates units screened to MIL-STD 883, Method 5004, condition B, and burned-in for 1 week.

Functional Diagram

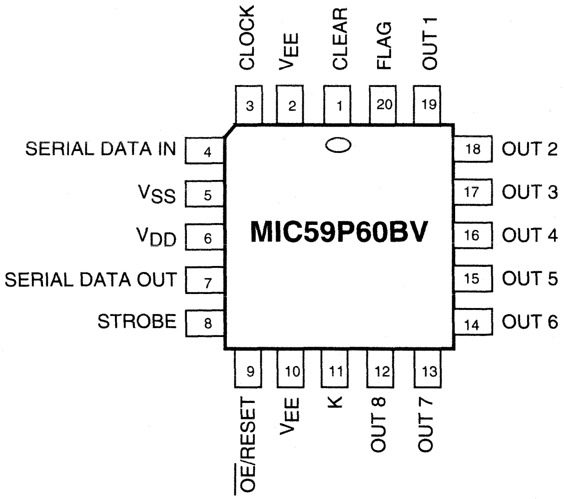


Pin Configuration

(Ceramic and Plastic DIP and SOIC)



PLCC Pin Configuration



Absolute Maximum Ratings (Note 1, 2)

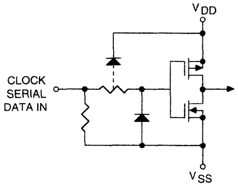
at 25°C Free-Air Temperature and V_{SS} = 0V

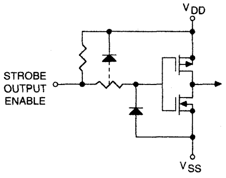
Output Voltage, V_{CE}	80V
Output Voltage, $V_{CE(SUS)}$ (Note 1)	50V
V_{DD} with Reference to V_{SS}	15V
V_{DD} with Reference to V_{EE}	25V
Emitter Supply Voltage, V_{EE}	–20V
Input Voltage Range, V_{IN}	–0.3V to V_{DD} + 0.3V
Package Power Dissipation:	
MIC59P60BN	2.0W
Derate above T_A = +25°C	20mW/°C
MIC59P60AJ/AJB	1.8W
Derate above T_A = +25°C	18mW/°C
MIC59P60BV	1.4W
Derate above T_A = +25°C	14mW/°C
MIC59P60BWM	1.2W
Derate above T_A = +25°C	12mW/°C
Operating Temperature Range, T_A	–55°C to +125°C
Storage Temperature Range, T_S	–65°C to +125°C

Note 1: For Inductive load applications.

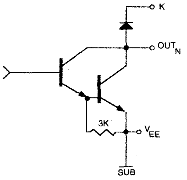
Note 2: CMOS devices have input-static protection but are susceptible to damage when exposed to extremely high static electrical charges.

Typical Input Circuits





Typical Output Driver



Pin Description

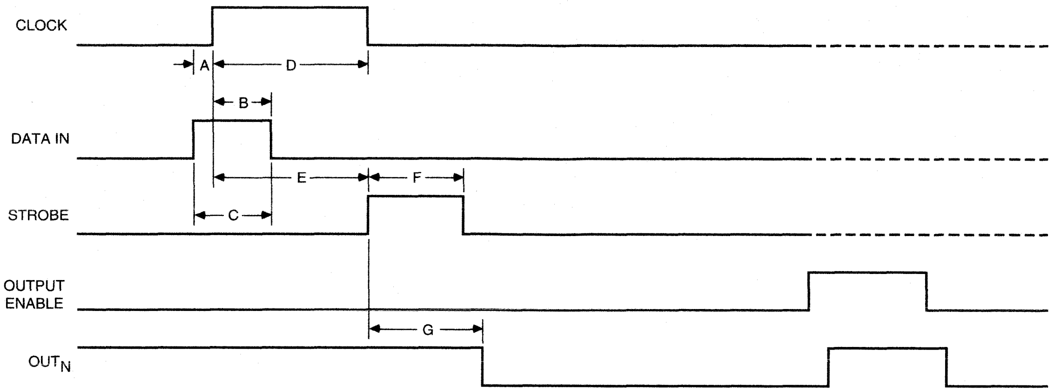
Pin	Name	Description
1	CLEAR	Sets All Latches OFF (open).
2,10	V_{EE}	Output Ground (Substrate). Most negative voltage in the system connects here.
3	CLOCK	Serial Data Clock. A CLEAR must also be clocked into the latches.
4	SERIAL DATA IN	Serial Data Input pin.
5	V_{SS}	Logic reference (Ground) pin.
6	V_{DD}	Logic Positive Supply voltage.
7	SERIAL DATA OUT	Serial Data Output pin. (Flow through).
8	STROBE	Output Strobe pin. Loads output latches when High. A STROBE is needed to CLEAR latches.
9	$\overline{\text{OUTPUT ENABLE}}$/RESET	When Low, Outputs are active. When High, device is inactive and reset from a fault condition. An under voltage condition emulates a high $\overline{\text{OE}}$/RESET input.
11	K	Transient suppression diode's cathode common pin.
12—19	OUTPUT N	Open Collector outputs 8 through 1.
20	$\overline{\text{FLAG}}$	Error Flag. Flag is Low upon Overcurrent Fault or Overtemperature fault. $\overline{\text{OUTPUT ENABLE}}$/RESET must be pulled high to reset the flag and fault condition.

Electrical Characteristics: at T_A = +25°C, V_{DD} = 5V, V_{SS} = V_{EE} = 0V (unless otherwise noted)

			Limits			
Characteristic	**Symbol**	**Test Conditions**	**Min.**	**Typ.**	**Max.**	**Unit**
Output Leakage Current	I_{CEX}	V_{OUT} = 80V V_{OUT} = 80V, T_A = +70°C		 100	50	µA
Collector-Emitter Saturation Voltage	$V_{CE(SAT)}$	I_{OUT} = 100mA I_{OUT} = 200mA I_{OUT} = 350mA		0.9 1.1 1.3	1.1 1.3 1.6	V
Collector-Emitter Sustaining Voltage	$V_{CE(SUS)}$	I_{OUT} = 350mA, L = 2mH	50			V
Input Voltage	$V_{IN(0)}$				1.0	V
	$V_{IN(1)}$	V_{DD} = 12V V_{DD} = 10V V_{DD} = 5.0V, **Note 1**	10.5 8.5 3.5			V
Input Resistance	R_{IN}	V_{DD} = 12V V_{DD} = 10V V_{DD} = 5.0V	50 50 50	200 300 600		kΩ
$\overline{\text{Flag}}$ Output Current	I_{OL}	V_{OL} = 0.4V		15		mA
$\overline{\text{Flag}}$ Output Leakage	I_{OH}	V_{OH} = 12.0V		50		nA
Supply Current	$I_{DD(ON)}$	All Drivers ON, V_{DD} = 12V All Drivers ON, V_{DD} = 10V All Drivers ON, V_{DD} = 5.0V		6.4 6.0 4.6	10.0 9.0 7.5	mA
	$I_{DD\ (1\ OUTPUT)}$	One Driver ON, All others OFF, V_{DD} = 12V One Driver ON, All others OFF, V_{DD} = 10V One Driver ON, All others OFF, V_{DD} = 5V		3.1 2.9 2.3	4.5 4.5 3.6	mA
	$I_{DD(OFF)}$	All Drivers OFF, V_{DD} = 12V All Drivers OFF, V_{DD} = 10V All Drivers OFF, V_{DD} = 5.0V		2.6 2.4 1.9	4.2 3.6 3.0	mA
Clamp Diode Leakage Current	I_R	V_R = 80V			50	µA
Clamp Diode Forward Voltage	V_F	I_F = 350mA		1.7	2.0	V
Over Current Shutdown Threshold	I_{LIM}			500		mA
Start Up Voltage	V_{SU}	**Note 2**	3.5	4.0	4.5	V
Minimum Supply (V_{DD})	$V_{DD\ MIN}$		3.0	3.5	4.0	V
Thermal Shutdown				165		°C
Thermal Shutdown Hysteresis				10		°C

Note 1: Operation of these devices with standard TTL or DTL may require the use of appropriate pull-up resistors to insure a minimum logic "1".

Note 2: Undervoltage lockout is guaranteed to release device at no more than 4.5V, and disable the device at no less than 3.0V



Timing Conditions

(T_A = +25°C, Logic Levels are V_{DD} and V_{SS}, V_{DD} = 5V)

A. Typical Data Active Time Before Clock Pulse (Data Set-Up Time)	75 ns
B. Minimum Data Active Time After Clock Pulse (Data Hold Time)	75 ns
C. Minimum Data Pulse Width	150 ns
D. Minimum Clock Pulse Width	150 ns
E. Minimum Time Between Clock Activation and Strobe	300 ns
F. Minimum Strobe Pulse Width	100 ns
G. Typical Time Between Strobe Activation and Output Transition	500 ns

SERIAL DATA present at the input is transferred to the shift register on the logic "0" to logic "1" transition of the CLOCK input pulse. On succeeding CLOCK pulses, the registers shift data information towards the SERIAL DATA OUTPUT. The SERIAL DATA must appear at the input prior to the rising edge of the CLOCK input waveform. Holding CLEAR high results in a data logic "0" being clocked into the shift register, turning off respective channels.

Information present at any register is transferred to its respective latch when the STROBE is high (serial-to-parallel conversion). The latches will continue to accept new data as long as the STROBE is held high. Applications where the latches are bypassed (STROBE tied high) will require that the ENABLE input be high to prevent invalid output states.

When the ENABLE input is high, all of the output buffers are disabled (OFF) without affecting information stored in the latches or shift register. With the ENABLE input low, the outputs are controlled by the state of the latches. A positive OE/RESET pulse resets the FLAG and the output after a current shutdown fault. Over-temperature faults are not latched and require no reset pulse.

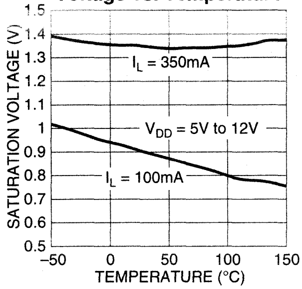
MIC59P60 Truth Table

Serial Data Input	Clear Input	Clock Input	Shift Register Contents				Serial Data Output	Strobe Input	Latch Contents				Output Enable	Output Contents			
			I_1	I_2	I_3	I_8			I_1	I_2	I_3	I_8		I_1	I_2	I_3	...... I_8
H		↑	H	R_1	R_2	R_7	R_7										
L		↑	L	R_1	R_2	R_7	R_7										
X		↓	R1	R2	R_3	R_8	R_8										
	H	↑	O	O	O	O	L										
			X	X	X	X	X	L	R_1	R_2	R_3	R_8					
			P_1	P_2	P_3	P_8	P_8	H	P_1	P_2	P_3	P_8	L	P_1	P_2	P_3	......P_8
									X	X	X	X	H	H	H	H	...... H

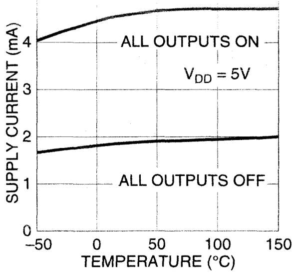
L = Low Logic Level
H = High Logic Level
X = Irrelevant
P = Present State
R = Previous State
O = Output OFF

Typical Characteristic Curves

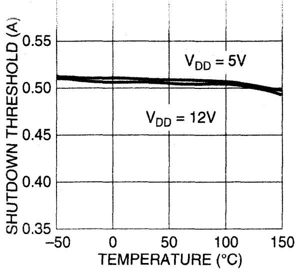
Output Saturation Voltage vs. Temperature



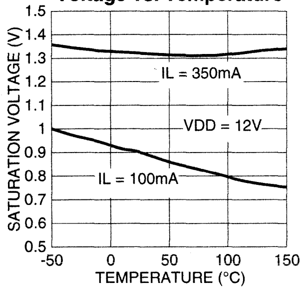
Supply Current vs. Temperature



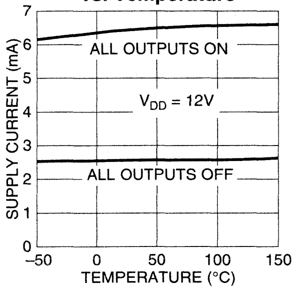
Current Shutdown Threshold vs. Temperature



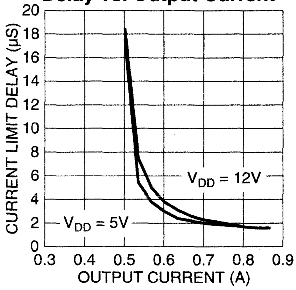
Output Saturation Voltage vs. Temperature



Supply Current vs. Temperature



Current Shutdown Delay vs. Output Current



Maximum Allowable Duty Cycle (Plastic DIP)

V_{DD} = 5.0V

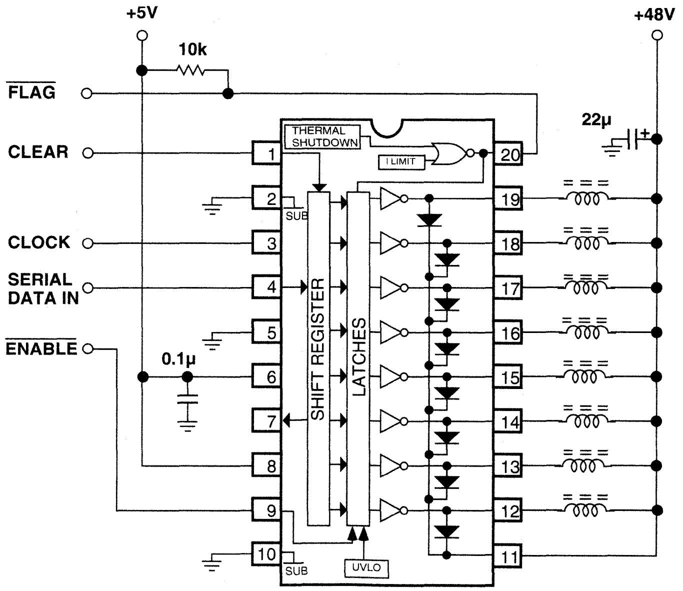
Number of Outputs ON (I_{OUT} = 200mA V_{DD} = 5.0V)	Max. Allowable Duty Cycle at Ambient Temperature of				
	25°C	**40°C**	**50°C**	**60°C**	**70°C**
8	85%	72%	64%	55%	46%
7	97%	82%	73%	63%	53%
6	100%	96%	85%	73%	62%
5	100%	100%	100%	88%	75%
4	100%	100%	100%	100%	93%
3	100%	100%	100%	100%	100%
2	100%	100%	100%	100%	100%
1	100%	100%	100%	100%	100%

V_{DD} = 12V

Number of Outputs ON (I_{OUT} = 200mA V_{DD} = 12V)	Max. Allowable Duty Cycle at Ambient Temperature of				
	25°C	**40°C**	**50°C**	**60°C**	**70°C**
8	80%	68%	60%	52%	44%
7	91%	77%	68%	59%	50%
6	100%	90%	79%	69%	58%
5	100%	100%	95%	82%	69%
4	100%	100%	100%	100%	86%
3	100%	100%	100%	100%	100%
2	100%	100%	100%	100%	100%
1	100%	100%	100%	100%	100%

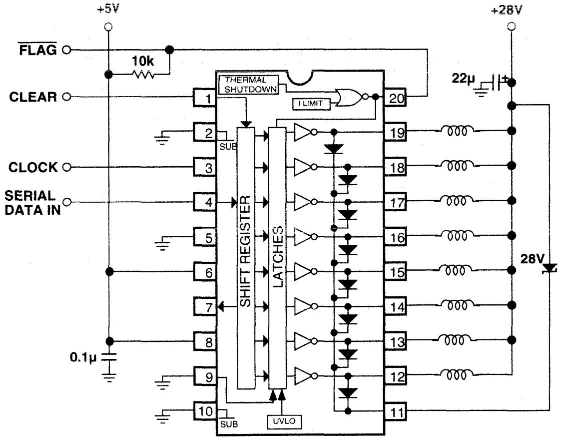
Typical Applications

Protected Solenoid Driver with Output Enable

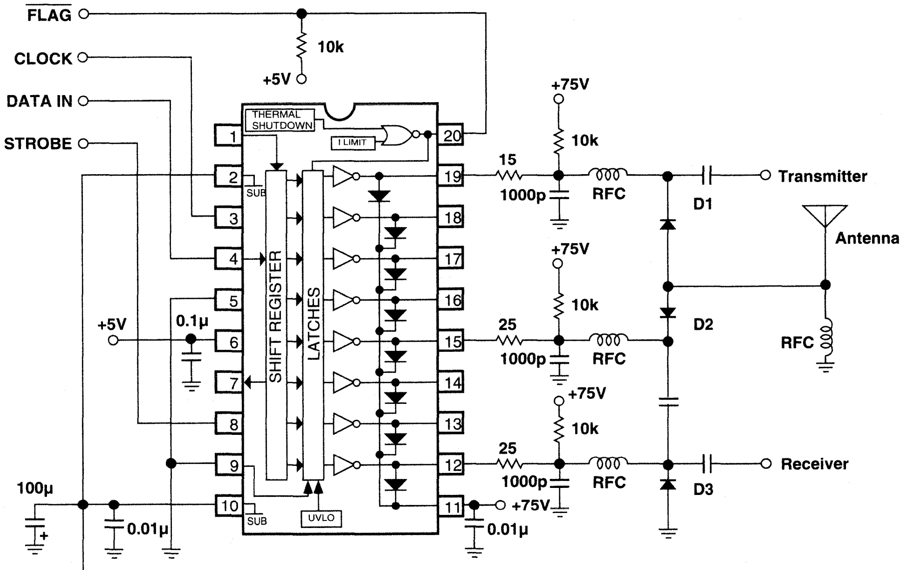


Typical Applications, continued

Hammer Driver



Protected Negative/Positive PIN Diode Driver Transmit/Receive Switch



−5V

	Diode		
	D1 (Latch 1)	D2 (Latch 5)	D3 (Latch 8)
Receive	OFF	ACTIVE	OFF
Transmit	ACTIVE	OFF	ACTIVE

PIN Diodes: UM9651

Application Note 2

MIC4807 Display Dimmer

by Mitchell Lee

Abstract

The MIC4807 is an 8 channel, addressable low side driver and is guaranteed to deliver 100mA minimum at up to 80V per channel. This note discusses the operation of the MIC4807 and shows how it can be used as a display driver with dimming for incandescent indicators.

Introduction

The MIC4807 contains 8 low side drivers that are controlled by addressable latches (see Figure 1). Open-drain, N-channel MOSFETs of approximately 5.1Ω "on" resistance are used as output devices. The MOSFETs are designed for operation to 80V.

Each output is controlled by its own addressable latch; the latches are selected by a 3-bit parallel address (A_{in}, B_{in}, and C_{in}). A "1" at the data input turns the corresponding MOSFET on.

Power ICs demand protection from excessive current and dissipation, and to this end the MIC4807 includes short-circuit current limiting and thermal shutdown. In fact, the chip can withstand a dead short to 80V without damage. The output limits at typically 200mA, and the chip is guaranteed to deliver 100mA minimum over temperature. While current limiting provides short-term protection from load faults, thermal shutdown protects against sustained fault conditions by shutting off all outputs when the die temperature exceeds 150°C. Current limiting and thermal shutdown are indispensable, yet they are sorely lacking in many other functionally similar ICs where the implementation of protection circuits is left as an exercise for the user.

Incandescent Lamp Characteristics

Owing to their superior light output, incandescent lamps are preferred over other display devices for use in bright environments. Unfortunately, incandescent lamps have a number of characteristics that make them difficult to work with in practical applications. For example, lamps do not lend themselves to multiplexing. It is technically possible to multiplex lamps by a higher-than-rated supply voltage in conjunction with PWM techniques to control filament power dissipation.

A major pitfall of multiplexing is reliability. If the multiplex circuit fails to advance for any reason (power-up phenomenon, slow or stuck oscillator, etc.) the lamps will burn out instantly. In addition, the switched current increases proportionally with the supply voltage, necessitating larger switches.

Since multiplexing is impractical, each lamp must have its own dedicated driver. This adds circuit overhead not only in the number of drivers, but also in terms of communicating with the drivers.

The brightness of an incandescent lamp is an asset in brightly illuminated environments, but what happens at night? Under contrasting conditions of low ambient light levels, the bright display can temporarily blind persons viewing it. Examples of environments with wide-ranging light levels include the cockpit of an airplane, or the operator's cab on farm or construction machinery. A dimming feature is highly desirable for any incandescent display.

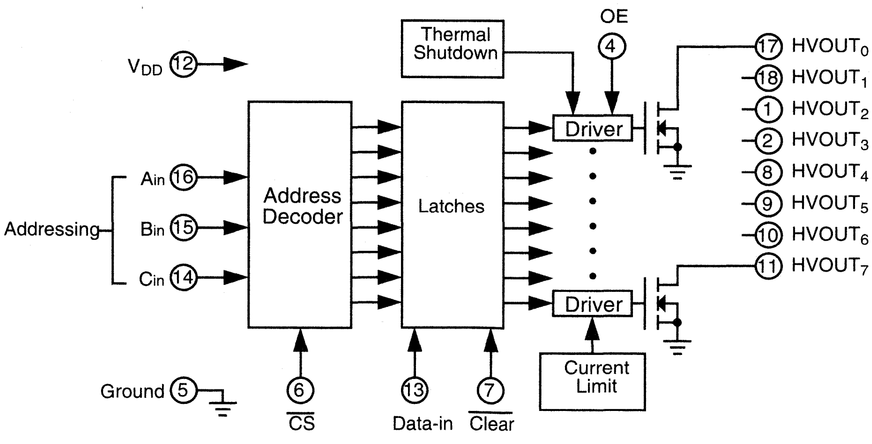


Figure 1. MIC4807 Block Diagram

Unlike LEDs, incandescent lamps require more current and voltage than 5V digital logic circuits can deliver. In particular, lamps draw an appreciable inrush current because the filament resistance is much lower when cold than when hot. Inrush currents of 10 times rated operating current are not uncommon. This impacts both the current rating of the driver and the lifetime of the lamp. Among other contributing factors, lamp lifetime is limited by the severe thermal shock experienced at turn-on.

Display Driver

Figure 2 shows a practical display driver circuit using the MIC4807. #1835 miniature lamps were selected for use on a loosely regulated "48V" system supply, which normally ran about 110% rated voltage. The #1835 lamp is specified at 55V and 50mA, and it can easily withstand ±15% variations in a 48V supply without loss of rated life. The lamps are housed in #31099 (GTE/Sylvania) indicator assemblies. Output current limit precludes the possibility of chip destruction from short circuit conditions such as arise when a lamp socket is "tested" for power with the conductive end of a screwdriver. Long-term short circuits (wiring faults) are handled by the MIC4807's thermal shutdown circuit.

When the MIC4807 cold-starts a #1835 lamp, the output is immediately driven into current limit since it cannot deliver the full inrush current. The cold resistance of a #1835 lamp is approximately 94Ω; an initial current of 585mA would flow if connected directly to 55V. The MIC4807 current limit is typically 200mA at room temperature, which reduces the thermal shock at turn-on and increases lamp lifetime. Note that applying 200mA to the cold filament is equivalent to an initial lamp voltage of only 18.8V.

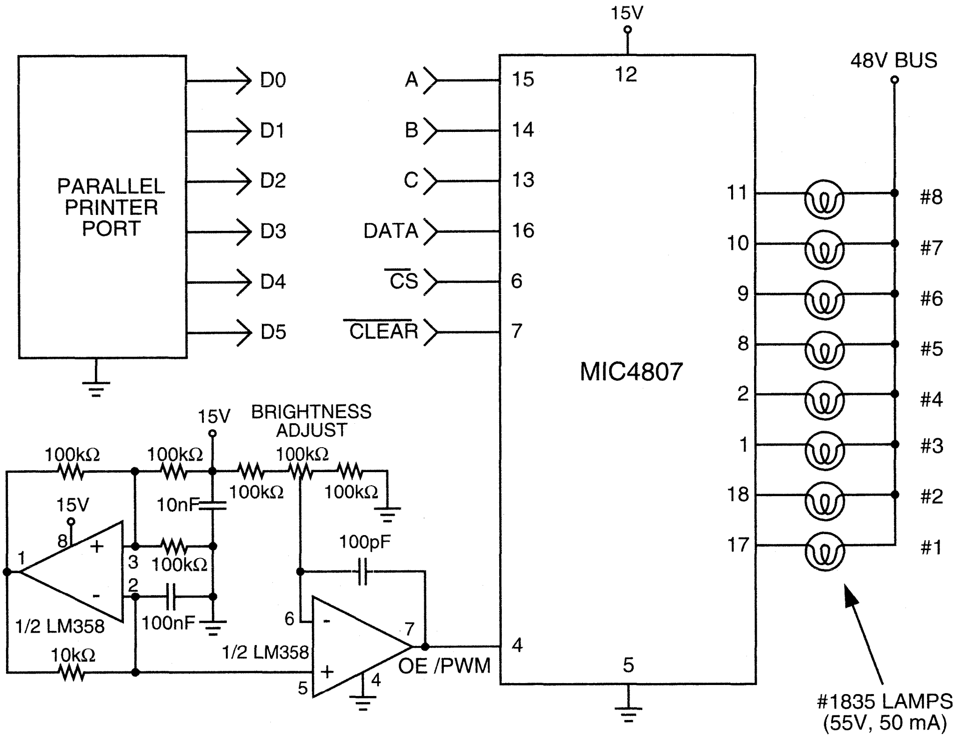


Figure 2. MIC4807 Display Controller with PWM Dimming

Display Dimming

Dimming is achieved by pulse-width modulation applied to the OUTPUT ENABLE (OE) pin. Since OUTPUT ENABLE acts on all 8 channels, the lamps are simultaneously dimmed by one control signal and maintain equal brightness, regardless of the dimming level.

An LM358 dual op-amp forms the basis of a variable PWM. The control range extends from completely off to completely on, and to any intermediate brightness level.

The PWM frequency (400Hz) is considerably higher than the filament's thermal time constant, so the filament's resistance (and temperature) changes very little between "on" and "off" periods. Figure 3 shows the pulsed filament current in a PWM application for a single #1835 lamp as a function of duty cycle. Lamp manufacturers recommend a PWM frequency of at least 400Hz to eliminate aging effects associated with thermal cycling. At an extremely dim 10% duty cycle, a #1835 lamp accepts current pulses of 90mA on a 55V supply, exhibiting a filament resistance of 611Ω. At 100% duty cycle the current falls to 50mA, at a resistance of 1100Ω. In any dimming circuit the driver circuitry must be sized to deliver the pulsed, low duty cycle current required by the relatively cool filament. This is typically twice the rated (100% duty cycle) lamp current.

MIC4807 Programming

The MIC4807 programming interface consists of a 3-bit address, a data line, and two control lines (see Figure 2). CLEAR is straightforward; a low on this pin asynchronously clears the internal latches to turn all outputs off. Programming is accomplished by addressing an output, presenting the desired data (1 = ON, 0 = OFF), and strobing CHIP SELECT with a logic low. DATA is transferred to the addressed output on the falling edge of CHIP SELECT, and is latched in place when CHIP SELECT returns to a high state. In larger displays, CHIP SELECT serves as a means of controlling several MIC4807s while the address, OUTPUT ENABLE, CLEAR, and DATA lines are paralleled.

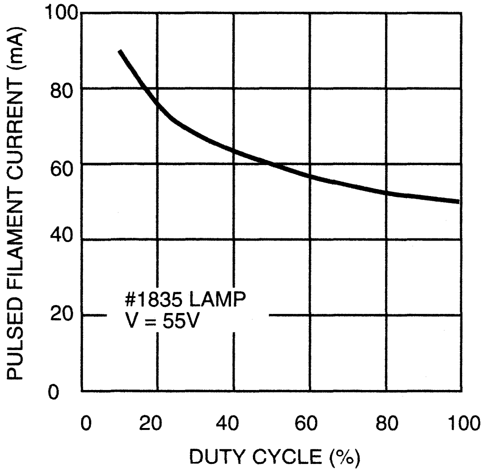


Figure 3. Pulsed Filament Current vs. Duty Cycle

For bench testing purposes a personal or laptop/portable computer is quite useful. A parallel printer port is commonly available and serves as a convenient means of programming one or more MIC4807s. Software changes can be made quickly and easily and, depending on the programming language used, the program can be stepped manually so that each bit can be checked "on the fly." This presents no problems because the MIC4807 is fully static.

An evaluation program written in BASIC is listed in Figure 4. The program consists of 5 parts. The control/input section is lines 100 through 130. This portion scans the keyboard, and branches to other parts of the program depending on which key is pressed. A "line return" branches to lines 3000 through 3030 where the MIC4807 is cleared and the computer's record of the MIC4807 latch states [8-element array D(A)] is cleared. Execution then returns to lines 100 through 130. A "?" invokes a lamp test function—all of the outputs are turned on by lines 2000 through 2060. Pressing any other key reprograms the MIC4807 with the original data, and returns execution to lines 100 through 130. Pressing any number from 1 to 8 toggles the associated output on or off (lines 1000 through 1020). Lines 4000 through 4020 are accessed from several points in the program; these lines write data to a given address by toggling CHIP SELECT.

The parallel output word is given a value according to which MIC4807 pins should be high or low at any given time. A_{in} has a numeric (decimal) value of 1, $B_{in} = 2$, $C_{in} = 4$, DATA = 8, CHIP SELECT = 16, and CLEAR = 32 to represent a logical "1" at each pin. The port number (8) specified in the "OUT" statements will vary from computer to computer. While final evaluation of data communications must be carried out with the actual host processor, using a computer during the debugging phase of the display design is most helpful.

An equivalent block diagram of the MIC4807 logic circuitry is shown in Figure 5. Note that CHIP SELECT, DATA, CLEAR, AND OUTPUT ENABLE operate on all channels in parallel. The address decoder determines to which latch CHIP SELECT is directed. DATA has no effect on the other latches as their clocking signals remain low.

```
10 REM  MIC4807 CONTROL PROGRAM
20 GOSUB 3000
30 REM A=1,B=2,C=4,DATA=8,CS=16,CLR=32
100 A$=INKEY$:IF A$="" THEN GOTO 100 ELSE
    LET A=ASC(A$)-49
110 IF A=-36 THEN GOSUB 3000
120 IF A=14 THEN GOSUB 2000
130 IF A<0 OR A>7 THEN GOTO 100
1000 D(A)=8-D(A)+2*A+96:REM TOGGLE OUTPUT
1010 GOSUB 4000
1020 GOTO 100
2000 REM "?" TURNS ON ALL OUTPUTS FOR TEST
2010 FOR A=0 TO 7
2020 OUT 8,A+56:OUT 8,A+40:OUT 8,A+56
2030 NEXT A
2040 IF INKEY$="" THEN GOTO 2040
2050 FOR A=0 TO 7:GOSUB 4000:NEXT A
2060 RETURN
3000 REM  CLEAR DISPLAY AND MEMORY
3010 OUT 8,16:OUT 8,48
3020 FOR A=0 TO 7:D(A)=A+48:NEXT A
3030 RETURN
4000 REM  COMMUNICATIONS DRIVER
4010 OUT 8,D(A):OUT 8,D(A)-16:OUT 8,D(A)
4020 RETURN
9999 END
```

Figure 4. MIC4807 Control Program Listing

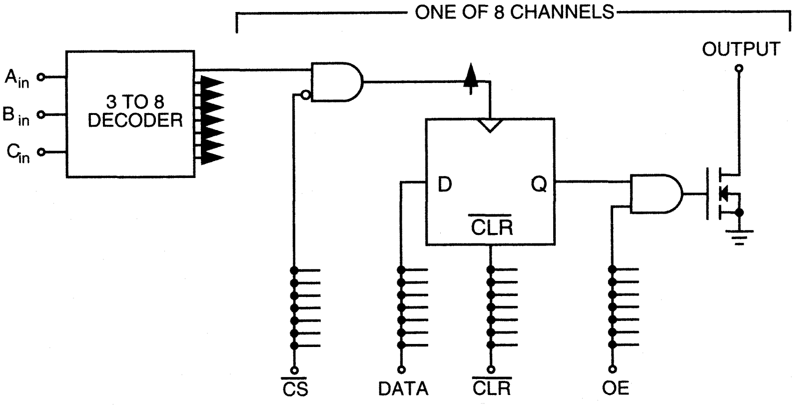


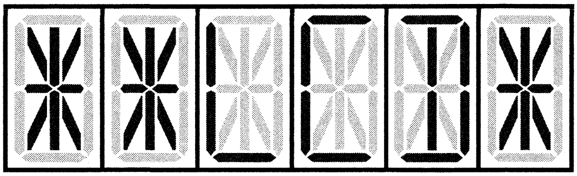
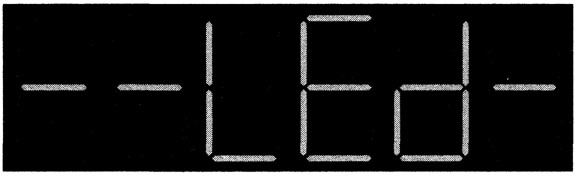
Figure 5. Block Diagram of Logic Circuitry

Table of Contents

Section 9: Display Drivers

* Summary information. For full details, contact Micrel.

Display Driver Selection Guide

If your product's display is:	*Consider:*
	**MIC8030** **MIC8031**
	**MIC50397** **MIC50398** **MIC50399** **MM5450** **MM5451** **MIC50396** **MIC50395**
Vacuum Fluorescent	**MIC8030** **MIC8031** **MIC10937/10957** **MIC10938/10939** **MIC10939/10942/10943** **MIC10951** **MIC10955**

NUMERICAL	ALPHANUMERIC	DOT MATRIX
MIC50395	MIC8030	MIC8030
MIC50396	MIC8031	MIC8031
MIC50397	MM5450	MM5450
MIC50398	MM5451	MM5451
MIC50399	MIC10937/10957	MIC10938/10939
MIC10951	MIC10938/10939	MIC10939/10942/10943
	MIC10939/10942/10943	
	MIC10941/10939	
	MIC10955	

Display Driver Selection Guide

All Micrel Display Drivers are available in die form. Special package options are available on most display drivers: please contact factory for details.

DEVICE	Number of Segments	Serial Input/Latched Output	Counter	7 Segment Decoder	BCD Output	LED Driver	LCD Driver	Vacuum Fluorescent Driver	Single Supply Capability	Multiple Supply Capability	PACKAGE
MIC50395 6 Decade Counter Decoder to 9999.99	6x7	•	•	•	•	•			•		40-pin PDIP
MIC50396 6 Decade Counter Decoder to 99:59:59	6x7	•	•	•	•	•			•		40-pin PDIP
MIC50397 6 Decade Counter Decoder to 59:59.99	6x7	•	•	•	•	•			•		40-pin PDIP
MIC50398 6 Decade Counter Decoder	6x7		•	•		•			•		28-pin PDIP
MIC50399 6 Decade Counter Decoder	6x7		•		•	•			•		28-pin PDIP
MIC8030 50V LCD Driver	32	•					•	•		•	44-pin LCC/PLCC
	38	•					•	•		•	48-pin PDIP
MIC8031 100V LCD Driver	32	•					•	•		•	44-pin LCC/PLCC
	38	•					•	•		•	48-pin PDIP
MM5450 LED Display Driver	34	•				•			•		40-pin PDIP
	34	•				•			•		44-pin PLCC
MM5451 LED Display Driver	35	•				•			•		40-pin PDIP
	35	•				•			•		44-pin PLCC

Display Driver Selection Guide

Micrel Intelligent Vacuum Fluorescent Display Controllers
(formerly from Rockwell International)

MIC10937	**Display Controller-Alphanumeric**
MIC10938	**Display Controller-Anode Drive (5x7)**
MIC10939	**Display Controller-Grid Drive**
MIC10941	**Display Controller-Anode Drive (16 segment)**
MIC10942	**Display Controller-Anode Drive**
MIC10943	**Display Controller-Anode Drive**
MIC10951	**Display Controller-Numeric/Bargraph**
MIC10955	**Segmented Display Controller/Driver**
MIC10957	**Display Controller-Alphanumeric**

Ordering Information

Micrel Intelligent Display Controller Driver Configuration

MIC 109 *ww* *x* *y* - *zz*

MIC = Micrel

Configuration (*ww*)

Package (*x*):		P =	Plastic DIP
		J =	44 Pin PLCC
Temperature (*y*):	Commercial	(no letter)	0°C to +70°C
	Extended	E =	–40°C to +85°C
Voltage Drive (*zz*):		40 =	40V
		50 =	50V

Typical applications require one or more MIC10939 with each MIC10938, MIC10941, or MIC10942/10943 set.

For full datasheets, please call Micrel Semiconductor, (408) 944-0800.

MIC50395/50396/50397

Six Decade Counter / Display Decoder

General Description

The MIC50395 is an ion-implanted, P-channel MOS six-decade synchronous up/down-counter/display driver with compare-register and storage-latches. The counter as well as the register can be loaded digit-by-digit with BCD data. The counter has an asynchronous-clear function.

Scanning is controlled by the scan oscillator input which is self-oscillating or can be driven by an external signal. The six-decade register is constantly compared to the state of the six-decade counter and when both the register and the counter have the same content, an EQUAL signal is generated. The contents of the counter can be transferred into the 6-digit latch which is then multiplexed from MSD to LSD in BCD and 7-segment format to the output. The seven-segment decoder incorporates a leading-zero blanking circuit which can be disabled by an external signal. This device is intended to interface directly with the standard CMOS logic families.

The MIC50396 and MIC50397 operate identically to the MIC50395 except that two digits in each were reprogrammed to provide divide by six circuitry instead of divide by ten. The MIC50396 is well suited for industrial timer applications while the MIC50397 is best suited for stop watch or real time computer clock applications.

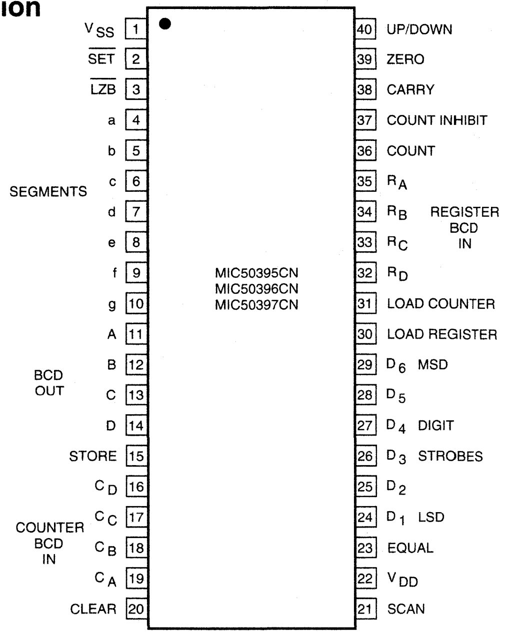
Features

- Single power supply
- Schmitt-Trigger on the count-input
- Drives common anode or cathode displays (CA with buffer)
- Six decades of synchronous up/down counting
- Look-ahead carry or borrow
- Loadable counter
- Loadable compare-register with comparator output
- Multiplexed BCD and seven-segment outputs
- Internal scan oscillator
- Direct LED segment drive
- Interfaces directly with CMOS logic
- Leading zero blanking
- MIC50396 programmed to count time:
  - 99 hrs. 59 min. 59 sec.
- MIC50397 programmed to count time:
  - 59 hrs. 59 min. 99/100 min.

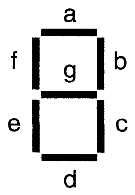
Ordering Information

Part Number	Temp. Range	Package
MIC50395CN	0°C to 70°C	40-pin Plastic DIP
MIC50396CN	0°C to 70°C	40-pin Plastic DIP
MIC50397CN	0°C to 70°C	40-pin Plastic DIP

Pin Connection



Segment Identification



Operations:

Six Decade Counter, Latch

The six decade counter is synchronously incremented or decremented on the positive edge of the count input signal. A Schmitt trigger on this input provides hysteresis for protection against both a noisy environment and double triggering due to a slow rising edge at the count input.

The count inhibit can be changed in coincidence with the positive transition of the count input; the count input is inhibited when the count inhibit is high.

The counter will increment when up/down input is high (V_{SS}) and will decrement when up/down input is low. The up/down input can be changed 0.75 µs prior to the positive transition of the count input.

The clear input is asynchronous and will reset all decades to zero when brought high but does not affect the six digit latch or the scan counter.

As long as store input is low, data is continuously transferred from the counter to the display. Data in the counter will be latched and displayed when store input is high. Store can be changed in coincidence with the positive transition of the count input.

The counter is loaded digit by digit corresponding to the digit strobe outputs. BCD thumb wheel switches with four diodes per decade connected between the digit strobe outputs and the BCD inputs is one method to supply BCD data for loading the counter decades.

The load counter pulse must be at V_{SS} 2 µs prior to the positive transition of the digit strobe of the digit to be loaded. The load counter pulse may be removed after the positive transition of the digit strobe since the chip internally latches this signal. The BCD data to be loaded must be valid through the negative transition of the digit strobe.

Inputs, Outputs

The seven segment outputs are open drain capable of sourcing 10mA average current per segment over one digit cycle. Segments are on when at V_{SS}. The Carry, Equal, Zero, BCD and digit strobe outputs are push pull and are on when at V_{SS}. All inputs except Counter BCD, Register BCD, and SCAN inputs are high impedance CMOS compatible.

Three basic outputs originate from the counter: zero output, equal output, and carry output. Each output goes high on the positive (V_{SS}) going edge of the count input under the following conditions:

Zero output goes high for one count period when all decades contain zero. During a load counter operation the zero output is inhibited.

Equal output goes high for one count period when the contents of the counter and compare register are equal. The equal output is inhibited by a load counter or load register operation, which lasts until the next interdigit blanking period following a negative transition of Load Counter or Load Register.

The carry output goes high with the leading edge of the count input at the count of 000000 when counting up or at 999999* when counting down and goes low with the negative going edge of the same count input.

A count frequency of 1 MHz can be achieved if the equal output, zero output and carry output are not used. These outputs do not respond at this frequency due to their output delay illustrated on the timing diagram.

Six Decade Compare Register

The register is loaded identically to the load counter paragraph described previously. The register may be loaded independently of the counter, however, the clear input will not remove the register contents. Contents of the register are not displayed by the BCD or seven segment outputs.

BCD Seven Segment Outputs

BCD or seven segment outputs are available. Digit strobes are decoded internally by a divide by six Johnson counter. This counter scans from MSD to LSD. By bringing the $\overline{\text{SET}}$ input low, this counter will be forced to the MSD decade count. During this time the segment outputs are blanked to protect against display burn out.

BCD outputs are valid for MSD when $\overline{\text{SET}}$ is low. Applying V_{SS} to $\overline{\text{SET}}$ allows normal scan to resume. Digit 6 output is active (V_{SS}) until the next scan clock pulse brings up digit 5 output.

The segment outputs and digit strobes are blanked during the interdigit blanking time. Leading zero blanking affects only the segment outputs. This option is disabled by bringing the $\overline{\text{LZB}}$ input high. Typically the interdigit blanking time is 5 to 25 µs when using the internal scan oscillator.

BCD output data changes at the beginning of the interdigit blanking time. Therefore the BCD output data is valid when the positive transition of a digit output occurs.

Scan Oscillator

The MIC50395 has an internal scan oscillator. The frequency of the scan oscillator is determined by an external capacitor between V_{SS} or V_{DD} and scan input. The wave form present on the scan oscillator input is triangular in the self oscillate mode.

An external oscillator may also be used to drive the scan input. In either case, external capacitors of 150pF each will be required from V_{SS} to Counter BCD inputs and register BCD inputs. This will allow asynchronous loading of the BCD inputs.

In the internal drive mode the interdigit blanking time will be the sum of the negative dwell period of the external oscillator and the normal self oscillate blanking time. (5→25 µs). Display brightness can be controlled by the duty cycle of the external scan oscillator.

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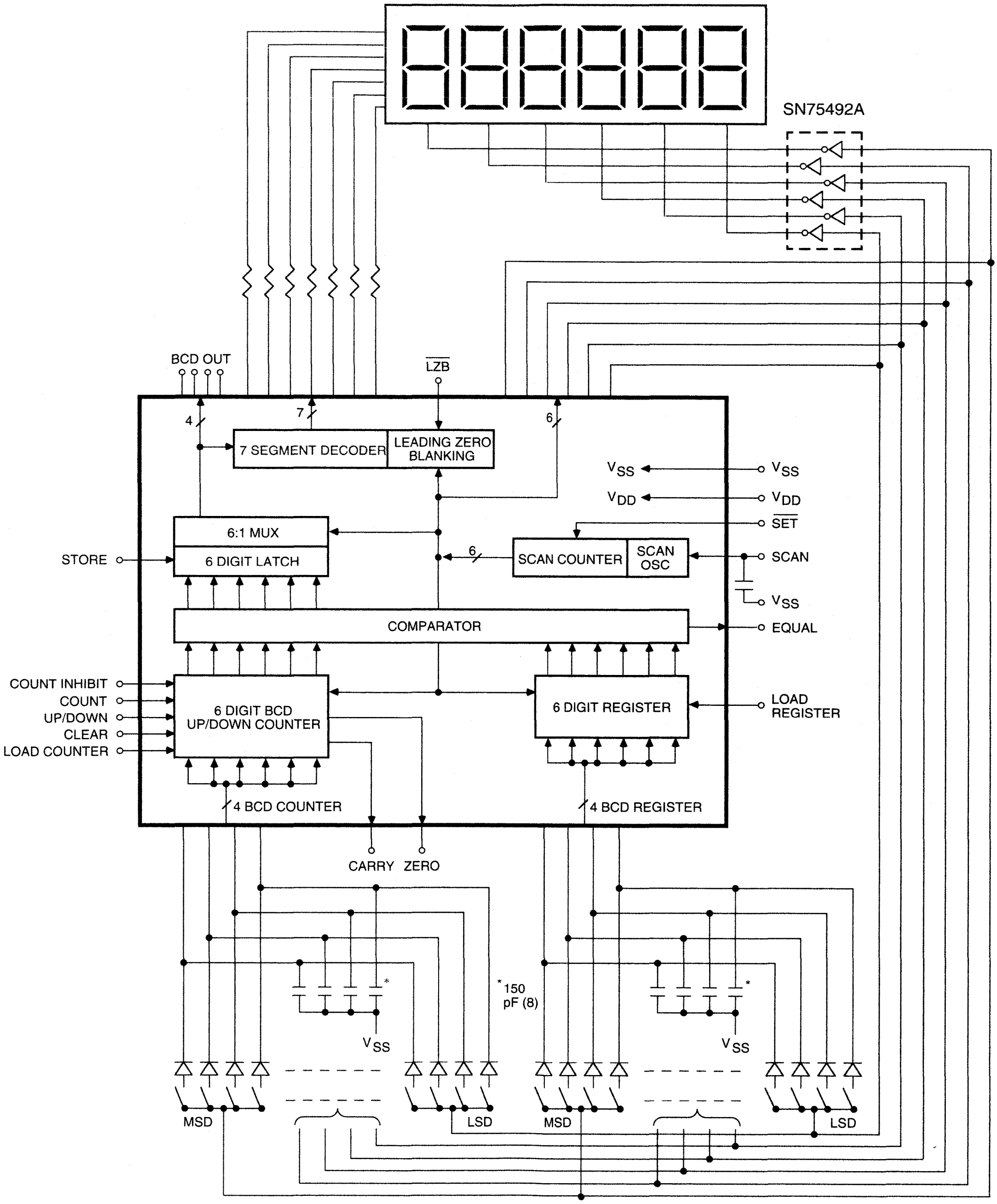
*Carry occurs at 99:59:59 for the 50396 and 59:59:99 for the 50397

If external capacitors on the BCD inputs are undesirable, it will be necessary to synchronize the negative going edge of the load register and/or load counter command to coincide with the positive going edge of the scan input signal. Also the V_{SS} range should be limited from 10.8 to 13.2 Volts.

Typically, the scan oscillator will oscillate at the following frequencies with these nominal capacitor values from V_{SS} to scan input.

C_{IN}	Min	Max
820 pF	1.4 kHz	4.8 kHz
470 pF	2.0 kHz	6.8 kHz
120 pF	7.0 kHz	20 kHz

Functional Diagram



Absolute Maximum Ratings

Voltage on Any Terminal Relative to V_{SS}	+0.3V to –20V
Operating Temperature Range (Ambient)	0°C to +70°C
Storage Temperature Range (Ambient)	–40°C to +100°C

Maximum Operating Conditions

Symbol	Parameter	Min	Max	Units	Notes
T_A	Operating Temperature	0	70	°C	
V_{SS}	Supply voltage (V_{DD} = 0V)	10	15	V	1
I_{SS}	Supply Current		35	mA	2
B_V	Break Down Voltage (Segment only @ 10 µA)		V_{SS} – 26	V	
P_D	Power Dissipation		670	mW	3

Electrical Characteristics

(V_{DD} = 0V, V_{SS} = +10.0V to +15.0, 0°C ≤ T_A ≤ 70°C)

Static Operating Conditions

Symbol	Parameter	Min	Max	Units	Notes
V_{IL}	Input Low Voltage, "0"	V_{DD}	0.2 V_{SS}	V	
V_{IH}	Input High Voltage, "1"	V_{SS} – 1	V_{SS}	V	4
V_{OL}	Output Voltage "0" @ 30 µA		0.2 V_{SS}	V	5
V_{OH}	Output Voltage "1" @ 1.5 mA	0.8 V_{SS}		V	5
I_{OH}	Output Current "1"				
	Digit strobes	3.0		mA	6
	Segment outputs	10.0		mA	7
I_{SCAN}	Scan Input Pullup Current @ 0 V		5.5	mA	
I_{SCAN}	Scan Input Pulldown Current @ 15 V	2	40	µA	
$I_{\overline{SET}}$	$\overline{\text{SET}}$ Input Pullup Current @ 0V	5	60	µA	

Note 1: With 150 pF capacitor to V_{SS} from counter BCD and register BCD inputs.

Note 2: I_{SS} with inputs and outputs open at 0°C. 33 mA at 25°C and 28 mA at 70°C. This does not include segment current. Total power per segment must be limited not to exceed power dissipation of package. (θ_{JA} = 100°C/Watt)

Note 3: All outputs loaded.

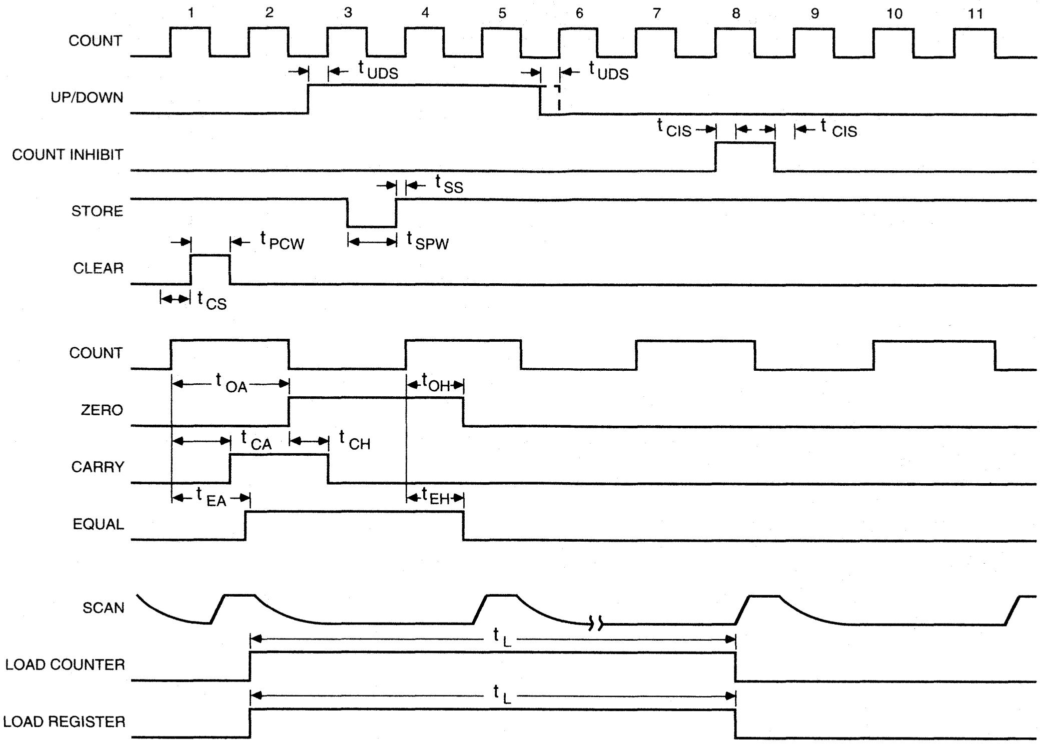
Note 4: MIN V_{IH} from R_A R_B R_C R_D C_A C_B C_C C_D inputs is V_{SS} – 2.5 V. Those inputs have internal pulldown resistors to V_{DD}.

Note 5: This applied to the push pull CMOS compatible outputs. Does not include digit strobes or segment outputs.

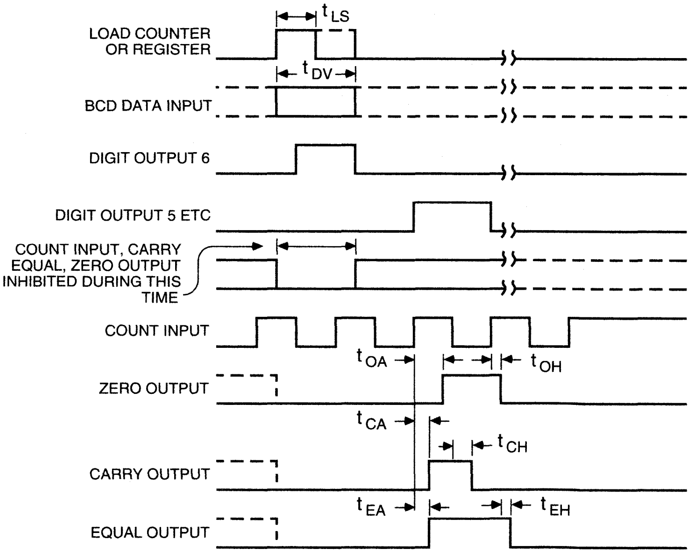
Note 6: For V_{OUT} = V_{SS} – 2.0 Volts. Average value over one digit cycle.

Note 7: For V_{OUT} = V_{SS} – 3.0 Volts. Average value over one digit cycle.

Timing



Loading Counter, Register (1 Digit)



t_{LS} 2.0 µs min NOTE: REF. TO POSITIVE TRANSITION OF DIGIT OUTPUT

t_{DV} 2.0 µs min NOTE: REF. TO NEGATIVE EDGE OF DIGIT OUTPUT

NOTE:
The inhibit function of the zero or equal outputs does not end when the Load Counter input goes to a “0” unless that transition occurs during interdigit blanking period at least 2.0 µs prior to a positive transition of a digit output. This same timing restriction holds for Equal and Load Register.

Dynamic Operating Conditions

Symbol	Parameter	Min	Max	Units	Notes
f_{CI}	Count Input Frequency	0	1.00	MHz	8,9
f_{SI}	Scan Input Frequency	0	20	kHz	
t_{CPW}	Count Pulse Width	400		ns	10
t_{SPW}	Store Pulse Width	2.0		µs	
t_{SS}	Store Setup Time	0		µs	11
t_{CIS}	Count Inhibit Setup Time	0		µs	11
t_{UDS}	Up/Down Setup Time	–0.75		µs	11
t_{CPW}	Clear Pulse Width	2.0		µs	11
t_{CS}	Clear Setup Time	–0.5		µs	11
t_{OA}	Zero Access Time		3.0	µs	11
t_{OH}	Zero Hold Time		1.5	µs	11
t_{CA}	Carry Access Time		1.5	µs	11
t_{CH}	Carry Hold Time	0.9		µs	12
t_{EA}	Equal Access Time	2.0		µs	11
t_{EH}	Equal Hold Time	1.5		µs	11
t_L	Load Time	1/6 f_{SI}			

Note 8: Measured at 50% duty cycle.

Note 9: If carry, equal, or zero outputs are used, the count frequency will be limited by their respective output times.

Note 10: The count pulse width must be greater than the carry access time when using the carry output.

Note 11: The positive edge of the count input is the t = 0 reference.

Note 12: Measured from negative edge of count input.

MIC50398/MIC50399

Six Decade Counter / Display Decoder

General Description

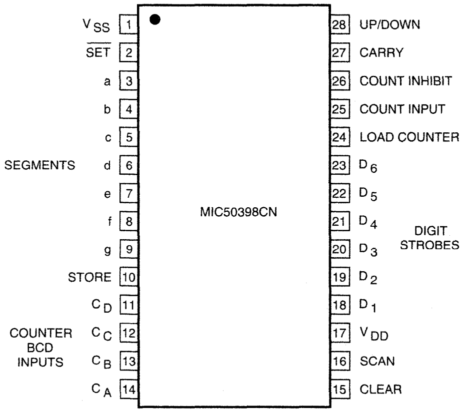
The MIC50398/9 is an ion-implanted, P-channel MOS six-decade synchronous up/down-counter/display driver with storage latches. The counter can be loaded digit-by-digit with BCD data. The counter has an asynchronous-clear function.

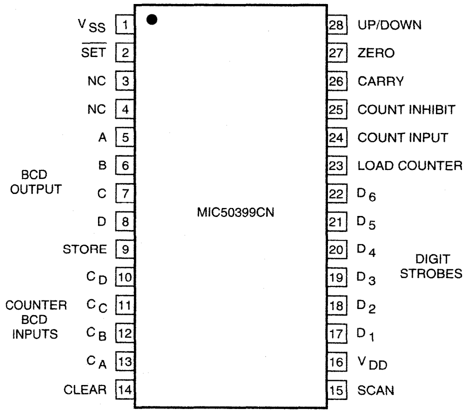
Scanning is controlled by the scan oscillator input which is self-oscillating or can be driven by an external signal. The contents of the counter can be transferred into the 6-digit latch which is then multiplexed from MSD to LSD in BCD or 7-segment format to the output. These devices are intended to interface directly with the standard CMOS logic families.

Features

- Single power supply
- Schmitt-Trigger on the count-input
- Six decades of synchronous up/down counting
- Look-ahead carry or borrow
- Loadable counter
- Multiplexed seven-segment outputs MIC50398N
- Multiplexed BCD outputs, MIC50399N
- Internal scan oscillator

Pin Connection

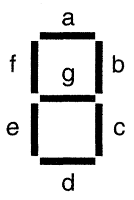




Ordering Information

Part Number	Temp. Range	Package
MIC50398CN	0°C to 70°C	28-pin Plastic DIP
MIC50399CN	0°C to 70°C	28-pin Plastic DIP

Segment Identification



Operations:

Six Decade Counter, Latch

The six decade counter is synchronously incremented or decremented on the positive edge of the count input signal. A Schmitt trigger on this input provides hysteresis for protection against both a noisy environment and double triggering due to a slow rising edge at the count input.

The count inhibit can be changed in coincidence with the positive transition of the count input. Count inhibit must remain high while the count input is high to inhibit counting.

The counter will increment when up/down input is high (V_{SS}) and will decrement when up/down input is low. The up/down input can be changed 0.75 μs prior to the positive transition of the count input.

The clear input is asynchronous and will reset all decades to zero when brought high but does not affect the six digit latch or the scan counter.

As long as store input is low, data is continuously transferred from the counter to the display. Data in the counter will be latched and displayed when store input is high. Store can be changed in coincidence with the positive transition of the count input.

The counter is loaded digit by digit corresponding to the digit strobe outputs. BCD thumb wheel switches with four diodes per decade connected between the digit strobe outputs and the BCD inputs is one method to supply BCD data for loading the counter decades.

The load counter pulse must be at V_{SS} 2 μs prior to the positive transition of the digit strobe of the digit to be loaded. The load counter pulse may be removed after the positive transition of the digit strobe since the chip internally latches this signal. The BCD data to be loaded must be valid through the negative transition of the digit strobe.

Inputs, Outputs

The seven segment outputs are open drain capable of sourcing 10mA average current per segment over one digit cycle. Segments are on when at V_{SS}. The Carry, Zero, BCD and digit strobe outputs are push pull and are on when at V_{SS}. All inputs except Counter BCD and SCAN inputs are high impedance CMOS compatible.

Two basic outputs originate from the counter: zero output, and carry output. Each output goes high on the positive (V_{SS}) going edge of the count input under the following conditions:

Zero output goes high for one count period when all decades contain zero. During a load counter operation the zero output is inhibited. Zero output is on the MIC50399 only.

The carry output goes high with the leading edge of the count input at the count of 000000 when counting up or at 999999 when counting down and goes low with the negative going edge of the same count input. During a load counter operation the carry output is inhibited.

A count frequency of 1.5 MHz can be achieved if the zero output and carry output are not used. These outputs do not respond at this frequency due to their output delay illustrated on the timing diagram.

BCD & Seven Segment Outputs

BCD or seven segment outputs are available. Digit strobes are decoded internally by a divide by six Johnson counter. This counter scans from MSD to LSD. By bringing the $\overline{SET}$ input low, this counter will be forced to the MSD decade count. During this time the segment outputs are blanked to protect against display burn out.

BCD outputs are valid for MSD when $\overline{SET}$ is low. Applying V_{SS} to $\overline{SET}$ allows normal scan to resume. Digit 6 output is active (V_{SS}) until the next scan clock pulse brings up digit 5 output.

The segment outputs and digit strobes are blanked during the interdigit blanking time. Typically the interdigit blanking time is 3 to 10 microseconds when using the internal scan oscillator.

BCD output data changes at the beginning of the interdigit blanking time. Therefore the BCD output data is valid when the positive transition of a digit output occurs. BCD outputs are on MIC50399 only.

Scan Oscillator

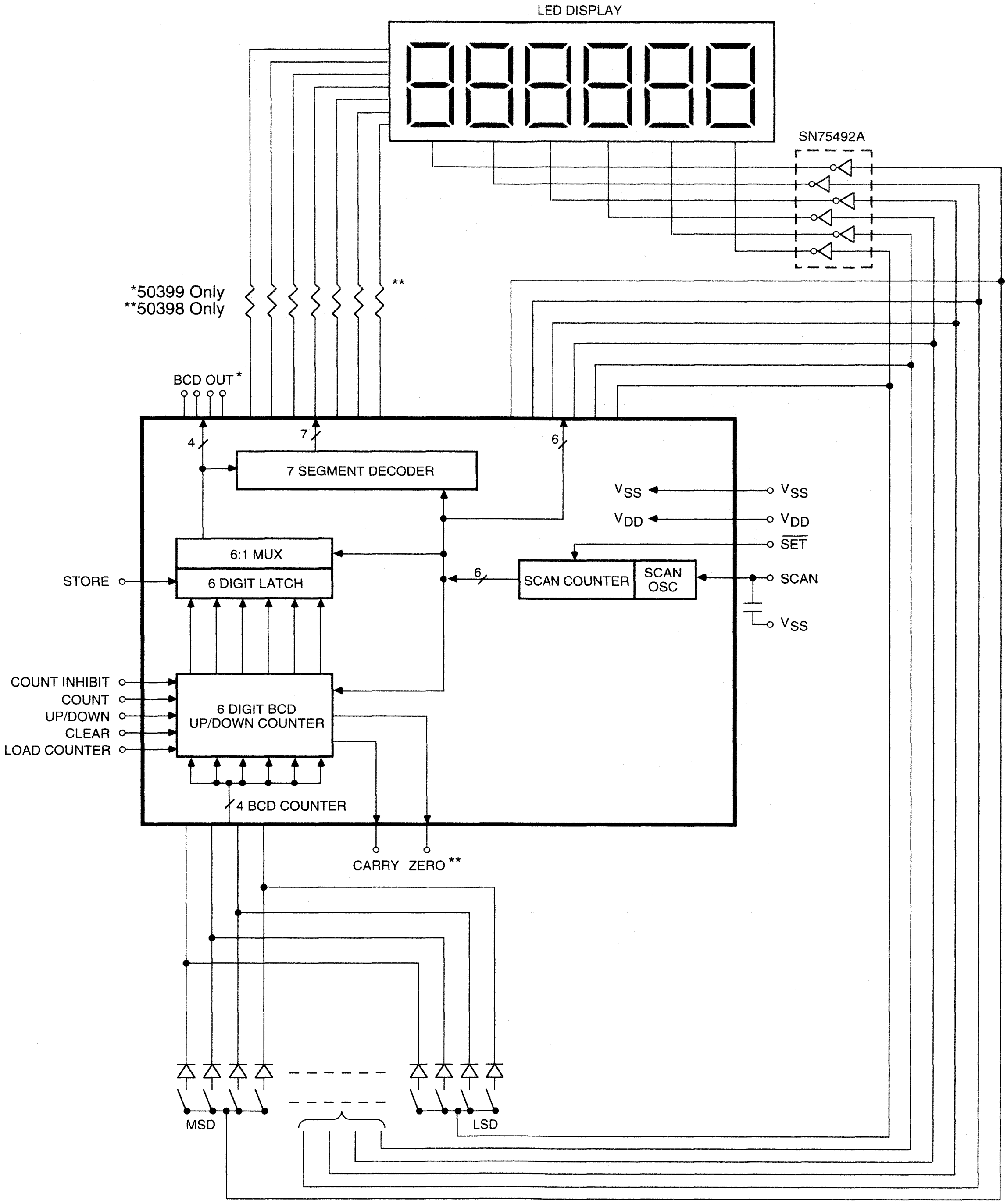
The counters have an internal scan oscillator. The frequency of the scan oscillator is determined by an external capacitor between V_{SS} or V_{DD} and scan input. The wave form present on the scan oscillator input is triangular in the self oscillate mode. An external oscillator may also be used to drive the scan input.

In the external drive mode the interdigit blanking time will be the sum of the negative dwell period of the external oscillator and the normal self oscillate blanking time. (3→10 μs). Display brightness can be controlled by the duty cycle of the external scan oscillator.

Typically, the scan oscillator will oscillate at the following frequencies with these nominal capacitor values from V_{SS} to scan input.

C_{IN}	Min	Max
820 pF	1.4 kHz	4.8 kHz
470 pF	2.0 kHz	6.8 kHz
120 pF	7.0 kHz	20 kHz

Functional Diagram



Absolute Maximum Ratings*

Voltage on Any Terminal Relative to V_{SS}	+0.3V to −20V
Operating Temperature Range (Ambient)	0°C to +70°C
Storage Temperature Range (Ambient)	−40°C to +100°C

*Operating above absolute maximum ratings may damage the device.

Maximum Operating Conditions

Symbol	Parameter	Min	Max	Units	Notes
T_A	Operating Temperature	0	70	°C	
V_{SS}	Supply voltage (V_{DD} = 0V)	10	15	V	
I_{SS}	Supply Current		40	mA	1
B_V	Break Down Voltage (Segment only @ 10 µA)		V_{SS} – 26	V	MIC50398 only
P_D	Power Dissipation		670	mW	2

Electrical Characteristics

(V_{DD} = 0V, V_{SS} = +10.0V to +15.0, 0°C ≤ T_A ≤ 70°C)

Static Operating Conditions

Symbol	Parameter	Min	Max	Units	Notes
V_{IL}	Input Low Voltage, "0"	V_{DD}	0.2 V_{SS}	V	
V_{IH}	Input High Voltage, "1"	V_{SS} – 1	V_{SS}	V	3
V_{OL}	Output Voltage "0" @ 30 µA		0.2 V_{SS}	V	4
V_{OH}	Output Voltage "1" @ 1.5 mA	0.8 V_{SS}		V	4
I_{OH}	Output Current "1"				
	Digit strobes	3.0		mA	5
	Segment outputs	10.0		mA	6
I_{SCAN}	Scan Input Pullup Current @ 0 V		5.5	mA	
I_{SCAN}	Scan Input Pulldown Current @ 15 V	2	40	µA	
$I_{\overline{SET}}$	$\overline{\text{SET}}$ Input Pullup Current @ 0V	5	60	µA	

Note 1: I_{SS} with inputs and outputs open at 0°C. 33 mA at 25°C and 28 mA at 70°C. This does not include segment current. Total power per segment must be limited not to exceed power dissipation of package. (θ_{JA} = 100°C/Watt)

Note 2: All outputs loaded.

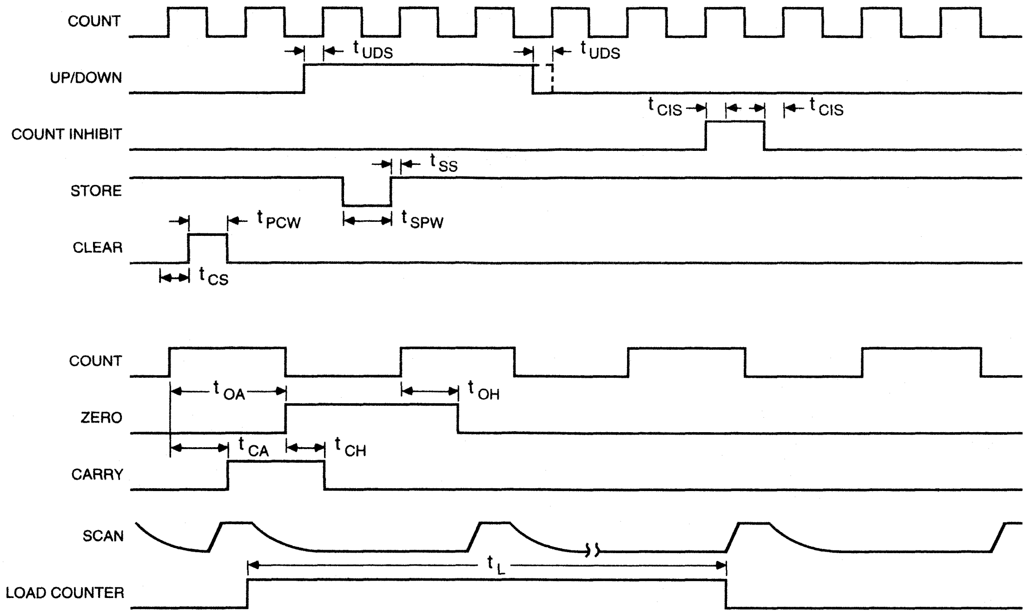
Note 3: MIN V_{IH} from C_A C_B C_C C_D inputs is V_{SS} – 3.5 V. Those inputs have internal pulldown resistors to V_{DD}.

Note 4: This applied to the push pull CMOS compatible outputs. Does not include digit strobes on segment outputs.

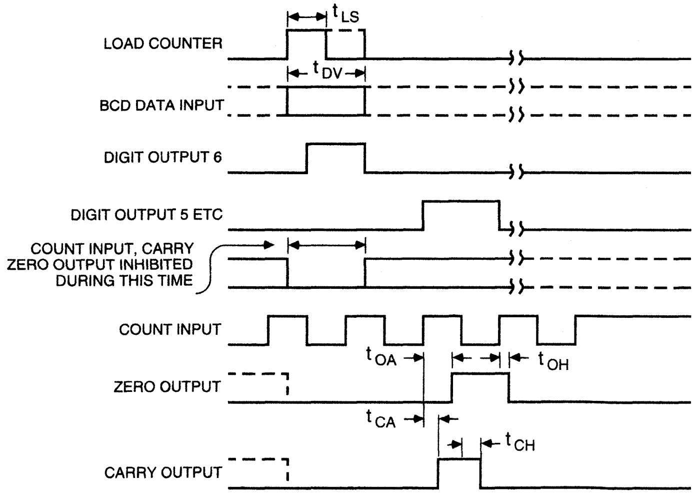
Note 5: For V_{OUT} = V_{SS} – 2.0 Volts. Average value over one digit cycle.

Note 6: For V_{OUT} = V_{SS} – 3.0 Volts. Average value over one digit cycle.

Timing



Loading Counter, Register (1 Digit)



t_{LS} 2.0 µs min NOTE: REF. TO POSITIVE TRANSITION OF DIGIT OUTPUT

t_{DV} 2.0 µS min NOTE: REF. TO NEGATIVE EDGE OF DIGIT OUTPUT

NOTE:
The inhibit function of the zero or carry outputs does not end when the Load Counter input goes to a “0” unless that transition occurs during interdigit blanking period at least 2.0 µs prior to a positive transition of a digit output.

Dynamic Operating Conditions

Symbol	Parameter	Min	Max	Units	Notes
f_{CI}	Count Input Frequency	0	1.5	MHz	7,8
f_{SI}	Scan Input Frequency	0	20	kHz	
t_{CPW}	Count Pulse Width	325		ns	9
t_{SPW}	Store Pulse Width	2.0		µs	
t_{SS}	Store Setup Time	0		µs	10
t_{CIS}	Count Inhibit Setup Time	0		µs	10
t_{UDS}	Up/Down setup Time	–0.75		µs	10
t_{CPW}	Clear Pulse Width	2.0		µs	10
t_{CS}	Clear Setup Time	–0.5		µs	10
t_{OA}	Zero Access Time		3.0	µs	10 MIC50399 only
t_{OH}	Zero Hold Time		1.5	µs	10 MIC50399 only
t_{CA}	Carry Access Time		1.5	µs	10
t_{CH}	Carry Hold Time		0.9	µs	11
t_L	Load Time	1/6 f_{SI}			12

Note 7: Measured at 50% duty cycle.

Note 8: If carry or zero outputs are used, the count frequency will be limited by their respective output times.

Note 9: The count pulse width must be greater than the carry access time when using the carry output.

Note 10: The positive edge of the count input is the t = 0 reference.

Note 11: Measured from negative edge of count input.

Note 12: Time to load one digit.

MIC8030/8031

High-Voltage Display Driver

General Description

The MIC8030/MIC8031 is a CMOS high voltage liquid crystal display driver. Up to 38 segments can be driven from four CMOS level inputs (CLOCK, DATA IN, LOAD and $\overline{\text{CHIP SELECT}}$). The MIC8031 is rated at 100V and the MIC8030 is rated at 50V. Data is loaded serially into a shift register, and transferred to latches which hold the data until new data is received.

The backplane can be driven from external source, or the internal oscillator can be used. If the internal oscillator is used, the frequency of the backplane will be determined by an external resistor and capacitor. The oscillator need not be used if a DC output is desired.

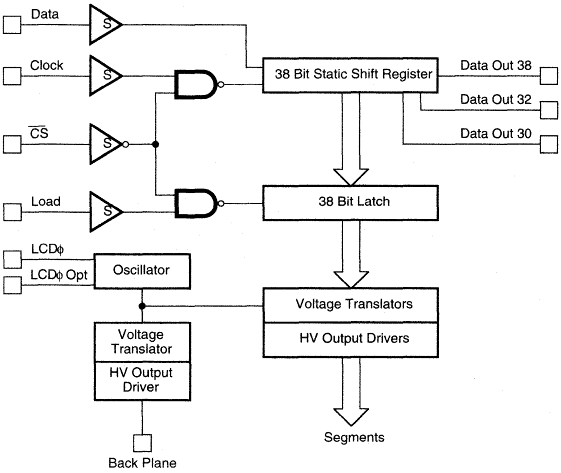
Features

- High Voltage Outputs capable of a driving up to 100 volt outputs from 5 to 15 volt logic
- Drives 30, 32, or 38 segments
- Cascadable
- On chip Oscillator or External Backplane Input
- CMOS construction for wide supply range and low power consumption
- Schmitt Triggers on all inputs
- CMOS, PMOS, and NMOS compatible

Applications

- Dichroic and Standard Liquid Crystal Displays
- Flat Panel Displays
- Print Head Drives
- Vacuum Fluorescent Displays

Functional Diagram

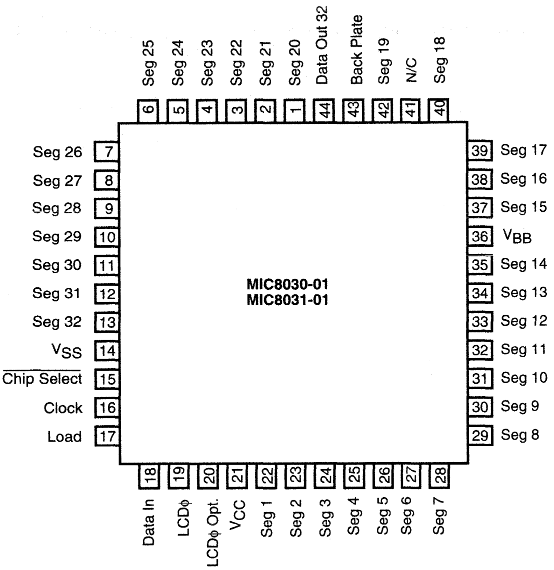


Ordering Information

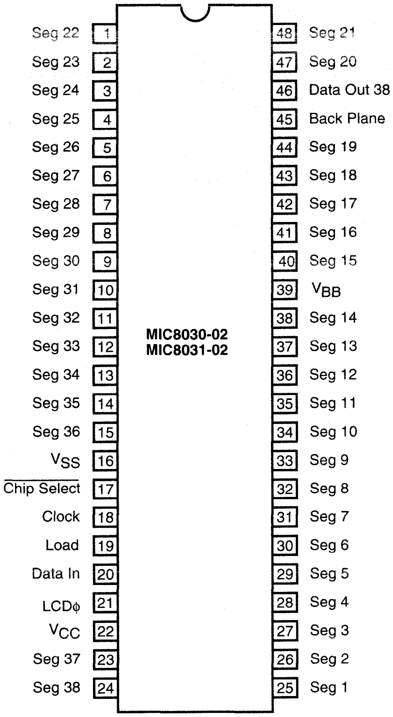
Part Number	Temperature Range	Package
MIC8030-01AEB	–55°C to +125°C	44-lead CER QUAD
MIC8030-01CV	0°C to +70°C	44-pin PLCC
MIC8030-02CN	0°C to +70°C	48-pin Plastic DIP

* AEB indicates units screened to MIL-STD 883, Method 5004, condition B, and burned-in for 1-week.

Pin Configuration 44-Pin CER QUAD - E
44-Pin LCC -L
44-Pin PLCC -V



Pin Configuration 48-Pin Plastic DIP - N



Functional Description

With CHIP SELECT tied low, serial data is clocked into the shift register at each falling edge of the CLOCK input. Pulling LOAD high will cause a parallel loading of the shift register contents into the latches. If load is left high, the latches are transparent.

A logic "1" clocked into the shift register corresponds to that segment being on, and that segment is out of phase with the backplane.

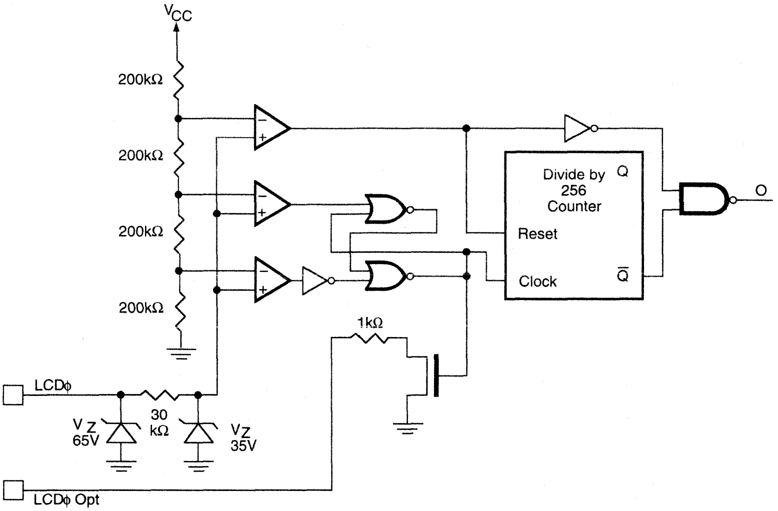
The backplane may be externally driven or the internal oscillator can be used. If LCDϕ is externally driven, the backplane will be in phase with the input; LCDϕ OPT is not connected. The internal oscillator is used by shorting LCDϕ OPT to LCDϕ, connecting a capacitor to ground, and a resistor to V_{CC}. The frequency of the backplane will be 1/256 of the input frequency, and is given as: f = 10/[R(C + .0002)] at V_{DD} = 5V, R in kΩ, C in µF.

Example: R = 150 kΩ, C = 420 pF: f = 108 Hz

For displays with more than 38 segments, two or more MIC8030/MIC8031 may be cascaded by connecting DATA OUT of the previous stage with DATA IN of the next stage; CLOCK, LOAD and CHIP SELECT of all following stages should be tied to the control lines of the first MIC8030/MIC8031. The backplane output of the first stage should be tied to LCDϕ of all following stages, the LCDϕ OPT must be left unconnected on those stages. If the internal oscillator is used, and V_{BB} > 50V then an external 330 kΩ resistor must be used between the BACKPLANE of the first stage and LCDϕ of all following stages.

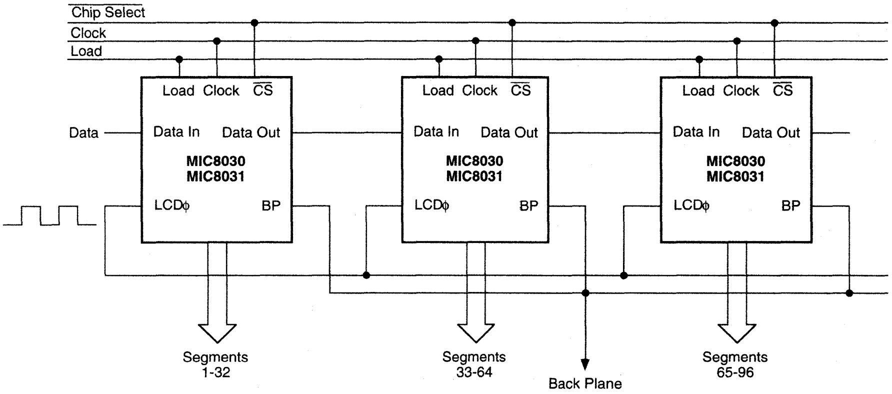
Packaging options available include DATA OUT 30, 32 or 38 with the corresponding number of segments, and the availability of LCDϕ OPT. Types of packages include plastic and ceramic DIPs, surface mount packages, plastic and ceramic Leadless Chip Carriers and custom packaging.

Internal Oscillator Circuit

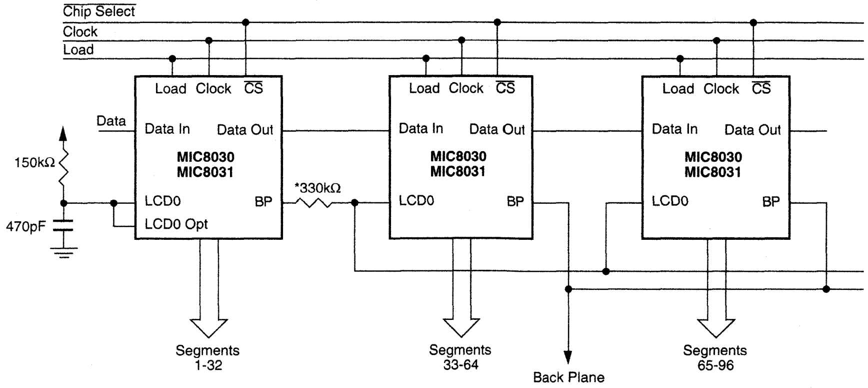


Typical Application

External Oscillator



Internal Oscillator



*Required if using MIC8031 with V_{BB} > 50

Absolute Maximum Ratings

V_{CC}	18V
V_{BB} (MIC8030)	75V
V_{BB} (MIC8031)	110V
Inputs (CLK, DATA IN, LOAD, $\overline{CS}$)	–0.5V to 18V
Inputs (LCD0)	–0.5V to 50V
Storage Temperature	–65°C to +150°C
Operating Temperature	–55°C to +125°C
Maximum Current into and out of any segment	20 mA
Maximum Power Dissipation, any segment	50 mW
Maximum Total power dissipation	600 mW

DC Electrical Characteristics: V_{CC} = 5V, V_{SS} = 0V, V_{BB} = 50V (MIC3830), V_{BB} = 100V (MIC3831), –55°C ≤ T_A ≤ +125°C, unless otherwise noted.

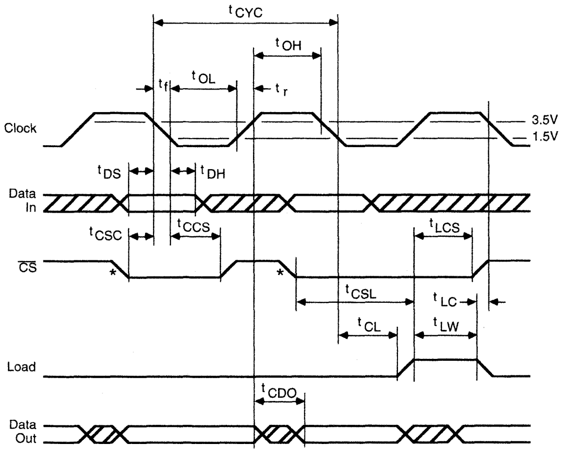
Symbol	Parameter	Test Conditions	Min	Typ	Max	Units
POWER SUPPLY						
V_{CC}	Logic Supply Voltage	MIC8030	4.5	5	5.5	V
V_{CC}	Logic Supply Voltage	MIC8031	4.5	5	16.5	V
V_{BB}	Display Supply Voltage	MIC8030	20	35	50	V
V_{BB}	Display Supply Voltage	MIC8031	20	35	100	V
I_{CC}	Supply Current (external oscillator)	Note 1		35	250	µA
	Supply Current (internal oscillator)	Note 1		35	250	
I_{BB}	Display Driver Current	F_{BP} = 100Hz No Loads		7	100	µA
I_{BB}	Display Driver Current	MIC8031, V_{BB} = 100V		20	200	µA
INPUTS (CLK, DATA IN, LOAD, $\overline{CS}$)						
V_{IH}	Input High Level		V_{CC} - 1.5	V_{CC} - 1.8	V_{CC}	V
V_{IL}	Input Low Level		0	2.5	2.0	V
I_L	Input Leakage Current			<1	5	µA
C_I	Input Capacitance	Note 2		5	10	pF
INPUT LCD0						
V_{IH}	LCD0 Input High Level	Externally driven	0.9V_{CC}	V_{CC}	50	V
V_{IL}	LCD0 Input Low Level	Externally driven	–0.5V	0	0.1V_{CC}	V
I_{LCD0}	LCD0 Leakage Current	V_{LCD0} = 15V		2	10	µA
I_{LCD0}	LCD0 Leakage Current	V_{LCD0} = 35V		6	100	µA
I_{LCD0}	LCD0 Leakage Current	V_{LCD0} = 50V			1	mA
CAPACITANCE LOADS (TYPICAL)						
C_{LSEG}	Segment Output	FBP < 100Hz			100	pF
C_{LBP}	Backplane Output	FBP < 100Hz			4000	pF
V_{OAVG}	DC Bias (Average) Any Segment	FBP < 100Hz, Note 2			+25	mV
OUTPUT TO BACKPLANE						
R_{SEG}	Segment Output Impedance	I_L = 100µA		1.4	10	kΩ
R_{BP}	Backplane Output Impedance	I_L = 100µA		170	312	Ω
$R_{DATA\ OUT}$	Data Out Output Impedance	I_L = 100µA		1.8	3	kΩ

Note 1: CMOS input levels. No loads.
Note 2: Guaranteed by design but not tested on a production basis.

AC Electrical Characteristics: V_{CC} = 5V, V_{SS} = 0V, V_{BB} = 50V (MIC3830), V_{BB} = 50V (MIC3831), –55°C ≤ T_A ≤ +125°C

Symbol	Parameter	Min	Typ	Max	Units
t_{CYC}	Cycle Time	500			ns
t_{OL}, tOH	Clock Pulse Width low/high	250			ns
t_r, t_f	Clock rise/fall			1	µs
t_{DS}	Data In Setup	100			ns
t_{CSC}	$\overline{CS}$ Setup to Clock	100			ns
t_{DH}	Data Hold	10			ns
t_{CCS}	$\overline{CS}$ Hold	220			ns
t_{CL}	Load Pulse Setup	250			ns
t_{LCS}	$\overline{CS}$ Hold (rising load to rising $\overline{CS}$)	200			ns
t_{LW}	Load Pulse Width	300			ns
t_{LC}	Load Pulse Delay (falling load to falling clock)	0			ns
t_{CDO}	Data Out Valid from Clock			220	ns
t_{CSL}	$\overline{CS}$ Setup to LOAD	0			ns
F_{BP}	Backplane Frequency	50	100	2000	Hz

Timing Diagram



* The $\overline{CS}$ high-to-low transition will generate a clock pulse.

Logic Truth Table

Data In	Clock	Chip Select	Load	$Q_{1(SR)}$	$Q_{N(SR)}$	$Q_{N(DRIVER)}$
X	X	1	X	NC	NC	$Q_{N(L)}$
0	↑	0	0	NC	NC	$Q_{N(L)}$
0	↑	0	1	NC	NC	$Q_{N(L)}$
0	↓	0	0	0	$Q_N - 1 \rightarrow Q_N$	$Q_{N(L)}$
0	↓	0	1	0	$Q_N - 1 \rightarrow Q_N$	$Q_{N(SR)}$
1	↑	0	0	NC	NC	$Q_{N(L)}$
1	↑	0	1	NC	NC	$Q_{N(L)}$
1	↓	0	0	1	$Q_N - 1 \rightarrow Q_N$	$Q_{N(L)}$
1	↓	0	1	1	$Q_N - 1 \rightarrow Q_N$	$Q_{N(SR)}$

↑ = Rising Edge, ↓ = Falling Edge

MIC10937/10957

V. F. Alphanumeric Display Controller

Summary Information*

General Description

The MIC10937 and MIC10957 Alphanumeric Display Controllers are MOS/LSI general purpose display controllers designed to interface to segmented displays (vacuum fluorescent or LED).

The MIC10937 and MIC10957 will drive displays with up to 16 characters with 14 or 16 segments plus a decimal point and comma tail. Segment decoding within each device provides for the ASCII character set (upper case only). No external driver circuitry is required for displays that operate on 20mA of drive current up to 50V. A 16 × 64-bit segment decoder provides internal ASCII character set decoding for the display.

The MIC10937 and MIC10957 are identical with the exception that the MIC10957 has two additional decodings for the decimal point and comma tail.

Micrel has received the rights from Rockwell International to manufacture and market this product and reproduce the specifications, including references to Rockwell.

Features

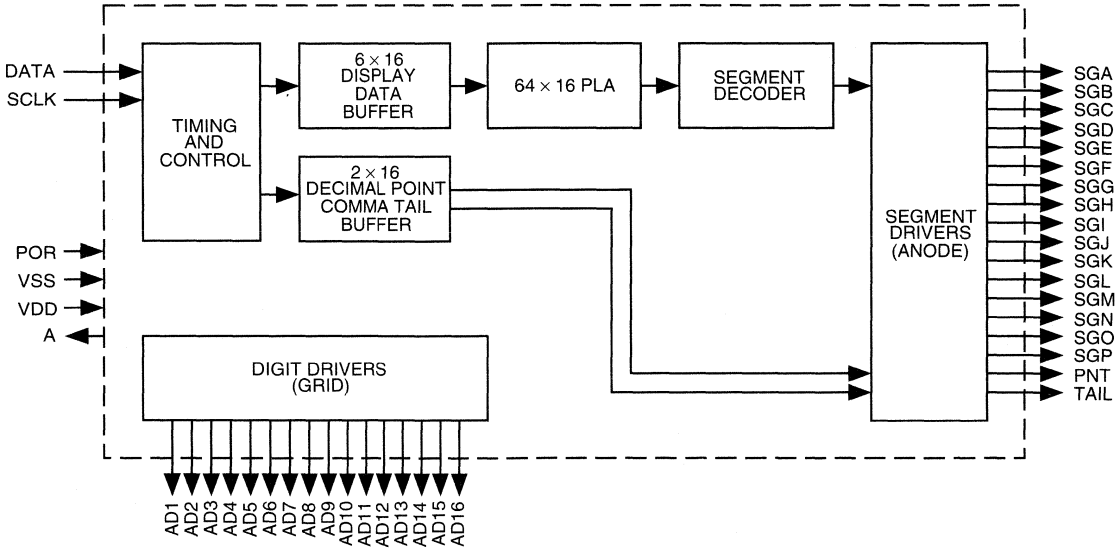
- 16-character display with decimal point and comma tail
- 14 or 16-segment drivers
- Up to 66kHz data rate
- Direct digit drive and 20mA at 50V
- Supports vacuum fluorescent or LED displays
- 64 × 16-bit PLA provides segment decoding for ASCII character set (all caps only)
- Serial data input for 8-bit display and control data words
- 40-pin DIP or 44-pin PLCC

Ordering Information

Part Number	Drive	Temp. Range	Package
MIC10937J-40	40V	0°C to +70°C	44-pin PLCC
MIC10937P-40/ MIC10937P-50†	50V	0°C to +70°C	40-pin P-DIP
MIC10937PE-40/ MIC10937PE-50†	50V	–40°C to +85°C	40-pin P-DIP
MIC10957J-40	40V	0°C to +70°C	44-pin PLCC
MIC10957P-40/ MIC10957P-50†	50V	0°C to +70°C	40-pin P-DIP
MIC10957PE-40/ MIC10957PE-50†	50V	–40°C to +85°C	40-pin P-DIP

† Dual-marked devices replace both 40V and 50V versions

Block Diagram



* Contact Micrel for more information.

MIC10938/10939

V. F. Dot Matrix Display Controller

Summary Information*

General Description

The MIC10938 and MIC10939 Dot Matrix Display Controller is a two-chip MOS/LSI general purpose display controller system designed to interface to dot matrix displays (vacuum fluorescent or LED).

The two-chip set will drive displays with up to 35 anodes (dots) and up to 20 grids (characters) plus a cursor. The chips can be cascaded to drive larger displays of as many as 80 characters.

An internal PLA-type decoder provides character decoding and dot pattern generation for the full 96-character ASCII set and an additional 32 special characters.

Micrel has received the rights from Rockwell International to manufacture and market this product and reproduce the specifications, including references to Rockwell.

Features

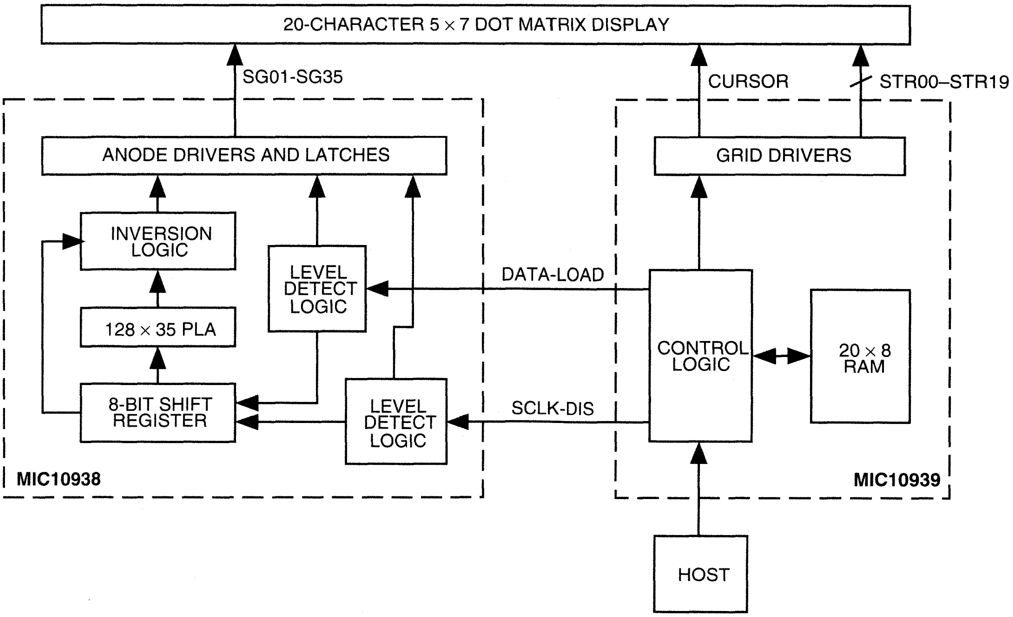
- 20-character display driver cascadable to 80 characters
- Standard 5 × 7 character font
- Separate cursor driver output
- Direct drive capability for vacuum-fluorescent displays
- 128 × 35 PLA provides segment decoding for full 96-character ASCII set, plus 32 special characters
- Serial or parallel data input for 8-bit display and control characters
- 40-pin DIP or 44-pin PLCC

Ordering Information

Part Number	Temperature Range	Package
MIC10938J-50	0°C to +70°C	44-pin PLCC
MIC10938P-50	0°C to +70°C	40-pin P-DIP
MIC10938PE-50	–40°C to +85°C	40-pin P-DIP
MIC10939J-50	0°C to +70°C	44-pin PLCC
MIC10939P-50	0°C to +70°C	40-pin P-DIP
MIC10939PE-50	–40°C to +85°C	40-pin P-DIP

‡ Dual-marked devices replace both 40V and 50V versions

Block Diagram



* Contact Micrel for more information.

MICREL

MIC10939/10942/10943

V. F. Dot Matrix Display Controller

Summary Information*

General Description

The MIC10939, MIC10942, and MIC10943 Dot Matrix Display Controller is a three-chip MOS/LSI general purpose display controller system designed to interface to dot matrix displays (vacuum fluorescent or LED).

The three-chip set will drive displays with up to 46 anodes (dots) and up to 20 grids (characters) plus a cursor. The chips can be cascaded to drive larger displays of up to 80 characters.

An internal PLA-type decoder provides character decoding and dot pattern generation for the full 96-character ASCII set and an additional 32 special characters.

Micrel has received the rights from Rockwell International to manufacture and market this product and reproduce the specifications, including references to Rockwell.

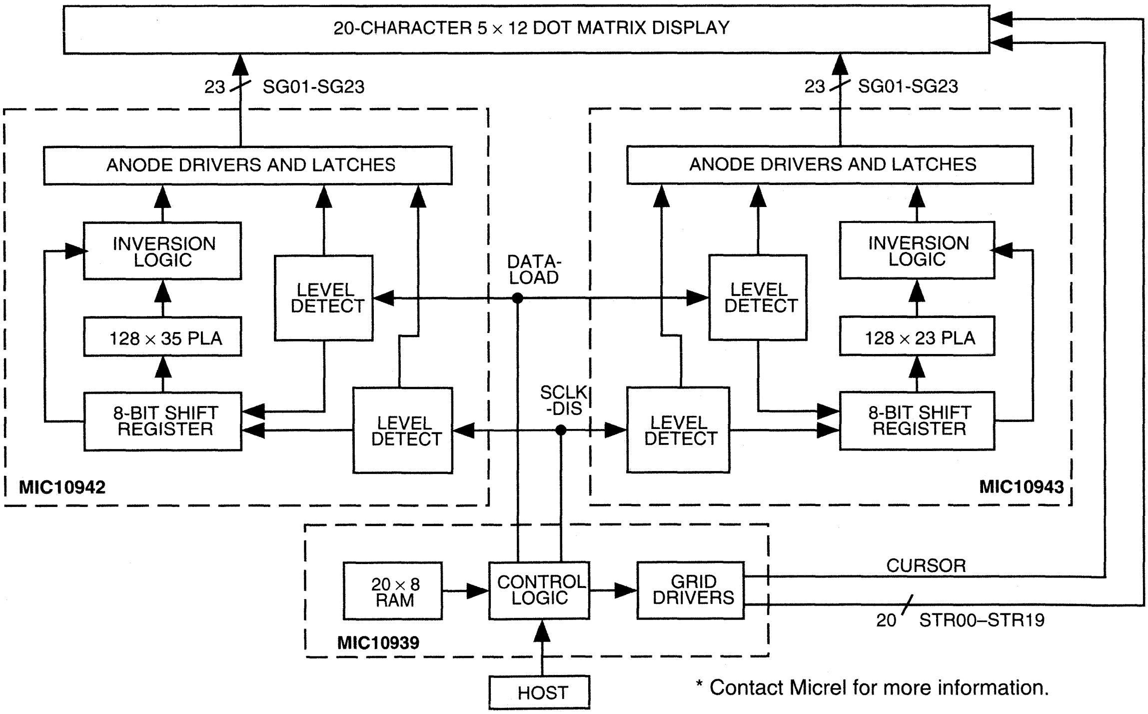
Features

- 20-character display driver cascadable to 80 characters
- Standard 5 × 12 character font
- Separate cursor driver output
- Two 128 × 23 PLAs provides segment decoding for full 96-character ASCII set, plus 32 special characters
- Serial or parallel data input for 8-bit display mode controls
- Brightness, refresh rate, and display mode controls
- 40-pin DIP or 44-pin PLCC (MIC10939)
- 28-pin DIP (MIC10942 and MIC10943)

Ordering Information

Part Number	Temperature Range	Package
MIC10939J-50	0°C to +70°C	44-Pin PLCC
MIC10939P-50	0°C to +70°C	40-pin P-DIP
MIC10939PE-50	–40°C to +85°C	40-pin P-DIP
MIC10942P-50	0°C to +70°C	40-pin P-DIP
MIC10942PE-50	–40°C to +85°C	40-pin P-DIP
MIC10943P-50	0°C to +70°C	40-pin P-DIP
MIC10943PE-50	–40°C to +85°C	40-pin P-DIP

Block Diagram



* Contact Micrel for more information.

MIC10941/10939

V. F. Alphanumeric and Bargraph Display Controller

Summary Information*

General Description

The MIC10941 and MIC10939 Alphanumeric and Bargraph Display Controller is a two-chip MOS/LSI general purpose display controller system designed to interface with bargraph and segmented displays (vacuum fluorescent or LED).

The two-chip set will drive displays with up to 16 segments (plus decimal point and comma tail) and up to 20 grids (characters) plus a cursor. The chips can be cascaded to drive larger displays of 80 characters. Segment decoding for ASCII characters and bargraph patterns is accomplished through an internal PLA.

Micrel has received the rights from Rockwell International to manufacture and market this product and reproduce the specifications, including references to Rockwell.

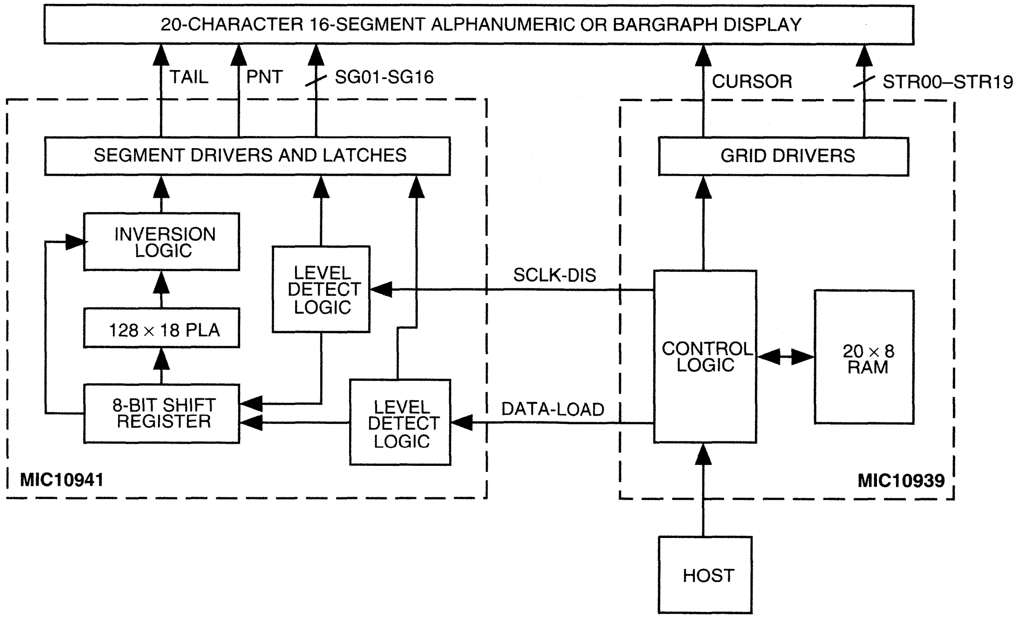
Features

- 20-character display driver cascadable to 80 characters
- Direct drive capability for vacuum-fluorescent displays
- 128 × 18 PLA provides segment decoding for ASCII characters (all caps only) and bargraph patterns
- Serial or parallel data input for 8-bit display and control characters
- Brightness, refresh rate, and display mode controls
- Separate cursor driver output
- 40-pin DIP or 44-pin PLCC (MIC10939)
- 24-pin DIP package (MIC10941)

Ordering Information

Part Number	Temperature Range	Package
MIC10941P-50	0°C to +70°C	24-pin P-DIP
MIC10941PE-50	–40°C to +85°C	24-pin P-DIP
MIC10939J-50	0°C to +70°C	44-pin PLCC
MIC10939P-50	0°C to +70°C	40-pin P-DIP
MIC10939PE-50	–40°C to +85°C	40-pin P-DIP

Block Diagram



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* Contact Micrel for more information.

MIC10951

V. F. Bargraph and Numeric Display Controller

Summary Information*

General Description

The MIC10951 Bargraph and Numeric Display Controller is an LSI general purpose display controller designed to interface to bargraph and numeric displays (vacuum fluorescent or LED).

The MIC10951 will drive 16-segment bargraph or 7-segment plus comma and decimal numeric displays with up to 16 display positions. The controller accepts command and data input words on a clocked serial input line. Commands control the on/off duty cycle, starting character position, and number of characters to display. Encoded data words display bargraph position (single segment or increasing bar length), numbers, comma, decimal, and selected upper and lower case letters. No external drive circuitry is required for displays that operate on 20mA of drive current up to 50V. A 64 × 16-bit segment decoder provides character set decoding for the display.

Micrel has received the rights from Rockwell International to manufacture and market this product and reproduce the specifications, including references to Rockwell.

Features

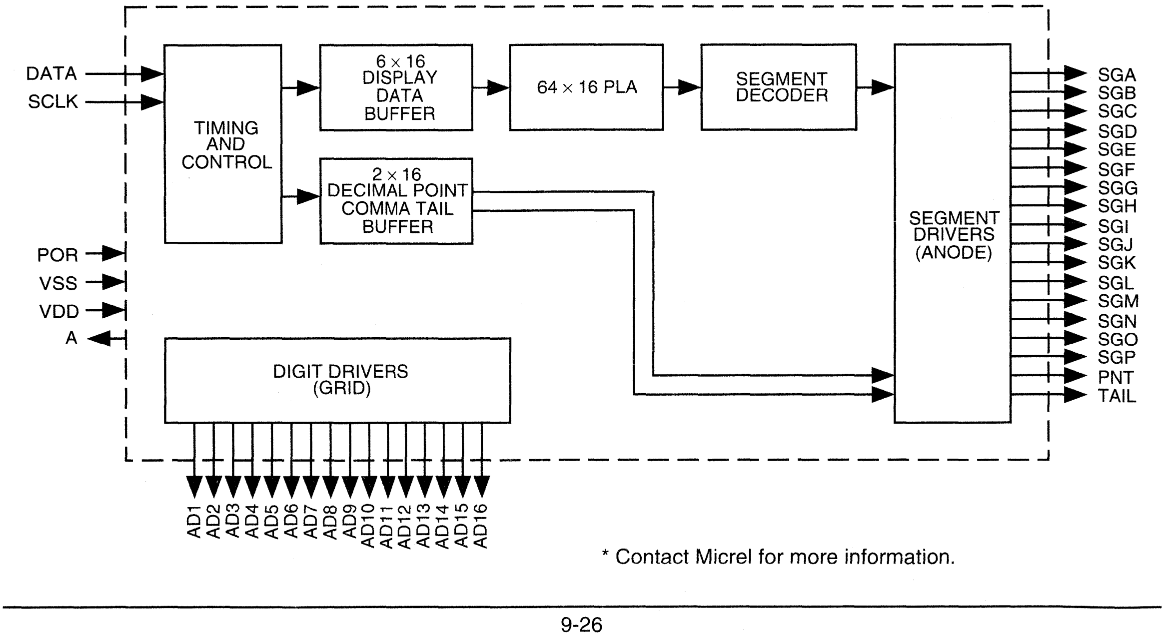
- 16 segment drivers plus decimal point and comma tail drivers
- 16 digit drivers
- Up to 66kHz data rate
- Direct digit drive of 20mA for up to 50V displays
- Supports vacuum fluorescent or LED displays
- Serial data input for 8-bit display and control data words
- 64 × 16-bit PLA provides segment decoding driving
    - Any 1 of 16 bargraphs segments
    - 1 to 16 bargraph segments
    - Ten 7-segment numeric characters (0 through 9)
    - Comma and decimal
    - 8 upper and lower case 7-segment characters
- Command functions
    - Duty cycle adjust
    - Character position select
    - Number of characters
- 40-pin DIP package

Ordering Information

Part Number	Drive	Temp. Range	Package
MIC10951P-40/ MIC10951P-50†	50V	0°C to +70°C	40-pin P-DIP
MIC10951PE-40/ MIC10951PE-50†	50V	–40°C to +85°C	40-pin P-DIP

† Dual-marked devices replace both 40V and 50V versions

Block Diagram



* Contact Micrel for more information.

MIC10955

V. F. Segmented Display Controller/Driver

Summary Information*

General Description

The MIC10955 Segmented Display/Driver is a MOS/LSI device capable of directly driving both the grids and anodes of multiplexed vacuum-fluorescent segmented displays. All timing circuits (including a clock generator) required to control the display drivers are contained within the device. The MIC10955 can drive segmented displays with 8 or 16 grids (characters) and 8, 16, or 24 anodes (segments). A serial interface allows for a host microprocessor to transmit commands and display data to the MIC10955 directly.

A 128 × 16-bit PLA provides coding for both 16-segment and 14-segment alphanumeric ASCII code character sets (all caps only). The PLA is divided into lower 64 and upper 64 code sets. Only one set can be selected at a time. In lower set mode the 16-segment display characters are selected. In upper set mode the 14-segment display characters are selected. The PLA can also be bypassed so that data words from the host microprocessor are loaded directly into segment drivers without decoding by the PLA. This mode is especially useful for creating special display patterns such as bar graph displays. Bypass mode is limited to eight drivers per data word.

Micrel has received the rights from Rockwell International to manufacture and market this product and reproduce the specifications, including references to Rockwell.

Features

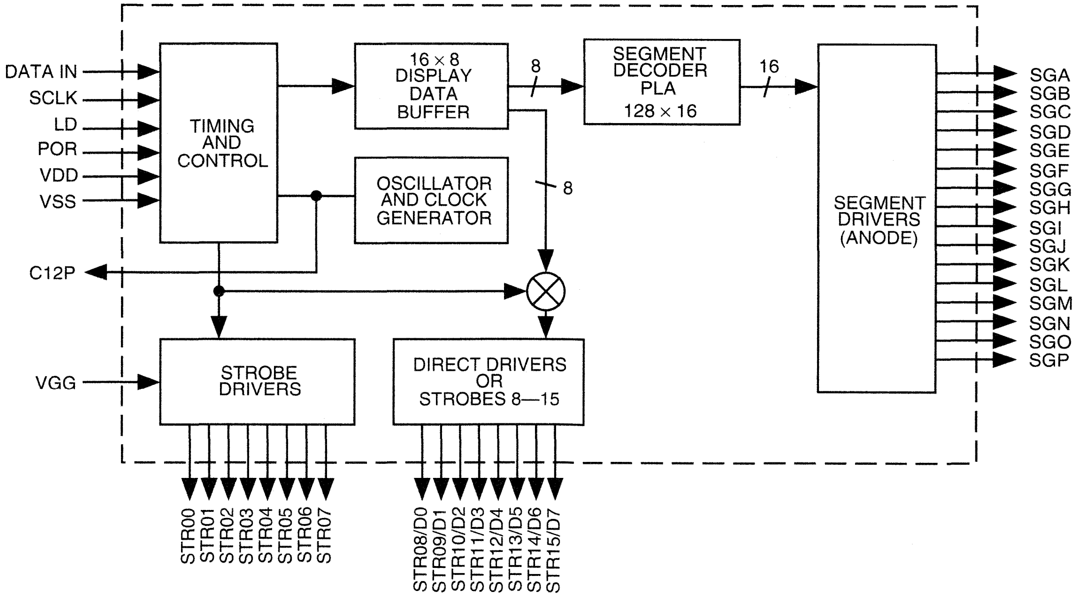
- 8 or 16-character display driver
- 8, 16, or 24-segment drivers
- Average data rate 66kHz
- Single character burst rate 500kHz
- Direct digit drive of 20mA for up to 40V or 50V vacuum fluorescent serial displays
- 128 × 16-bit PLA provides 16 or 14-segment alphanumeric characters set
- Internal clock generator circuit
- Serial host interface
- PLA bypass mode
- 40-pin DIP

Ordering Information

Part Number	Drive	Temp. Range	Package
MIC10955P-40/ MIC10955P-50†	50V	0°C to +70°C	40-pin P-DIP
MIC10955PE-40/ MIC10955PE-50†	50V	–40°C to +85°C	40-pin P-DIP

† Dual-marked devices replace both 40V and 50V versions

Block Diagram



* Contact Micrel for more information.

MM5450/5451

LED Display Driver

General Description

The MM5450 and MM5451 LED display drivers are monolithic MOS IC's fabricated in an N-Channel, metal-gate process. The technology produces low threshold, enhancement mode, and ion-implanted depletion mode devices. These devices are available in packaged or die form, suitable for conventional packaging, hybrid assembly or chip on board technology.

A single pin controls the LED display brightness by setting a reference current through a variable resistor connected to V_{DD}.

Applications

- Industrial control indicator
- Relay driver
- Digital clock, thermometer, counter, voltmeter
- Instrumentation readouts

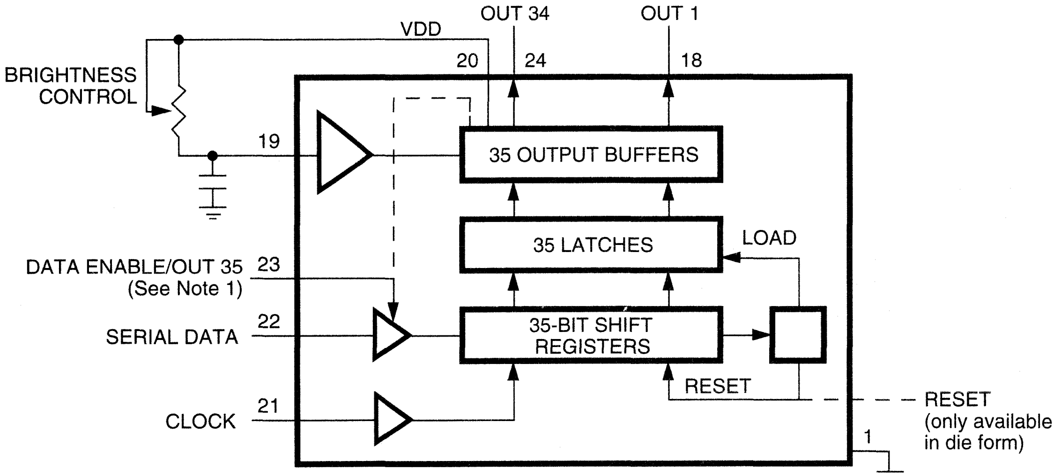
Features

- Continuous brightness control
- Serial data input
- No load signal requirement
- Enable (on MM5450)
- Wide power supply operation
- TTL compatibility
- 34 or 35 outputs, 15 mA capability
- Alphanumeric capability
- Available in die or packaged form

Ordering Information

Part Number	Temp. Range	Package
MM5450BN	–25 to +85°C	40-pin Plastic DIP
MM5451BN	–25 to +85°C	40-pin Plastic DIP
MM5450BV	–25 to +85°C	44-pin PLCC
MM5451BV	–25 to +85°C	44-pin PLCC
MM5450/51CY	0 to +70°C	(die form)

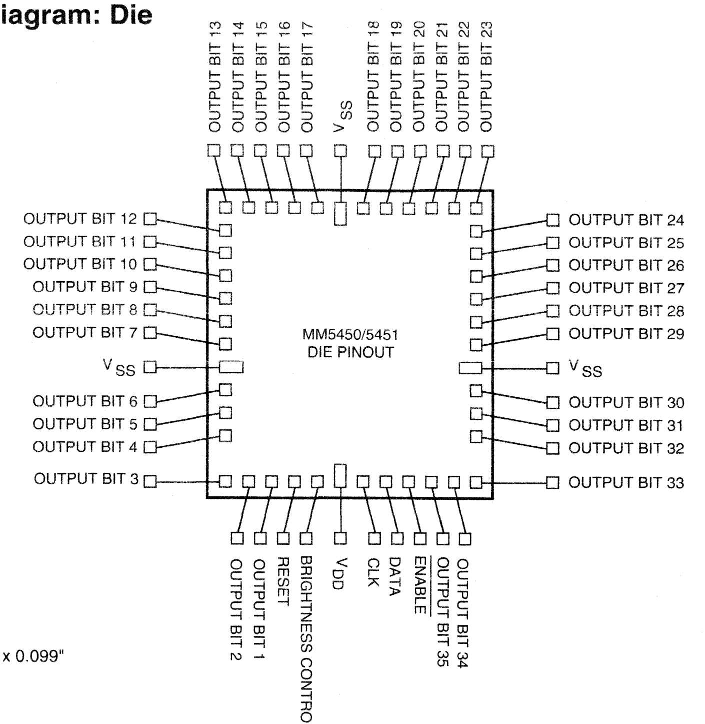
Block Diagram



Note 1: Pin 23 is Data Enable in MM5450
Pin 23 is Output 35 in MM5451

Figure 1.

Connection Diagram: Die



Note: Die size is 0.106" x 0.099"

Figure 2.

Connection Diagram: Dual-in-line Package

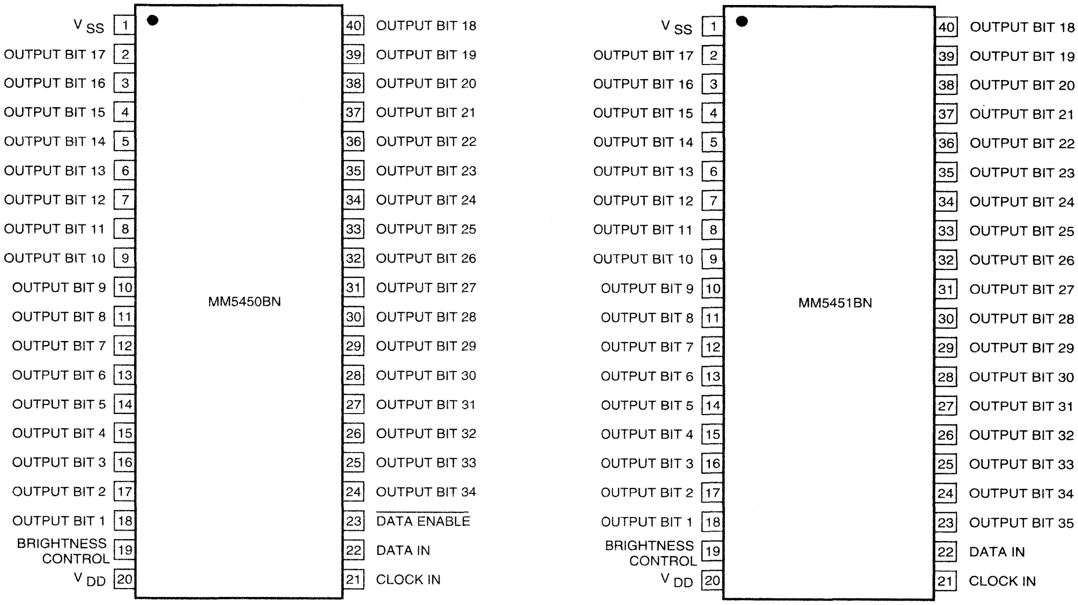


Figure 3a, 3b.

Connection Diagram: Plastic Leaded Chip Carrier

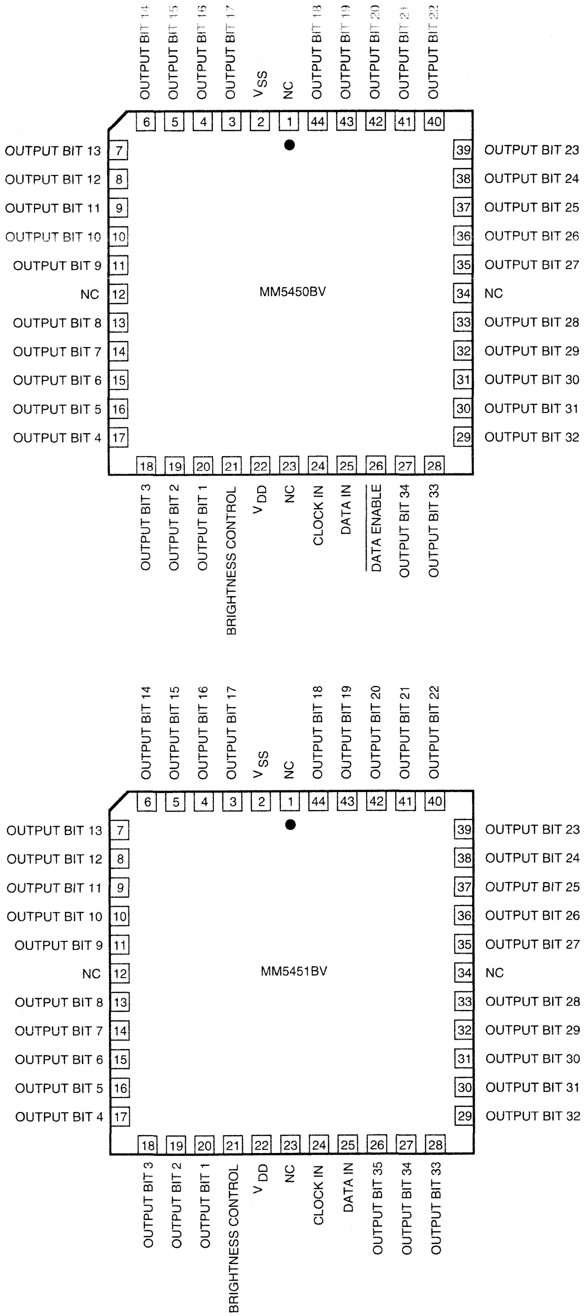


Figure 4a, 4b.

Absolute Maximum Ratings

Voltage at Any Pin	V_{SS} to V_{SS}+12V
Operating Temperature	–25°C to +85°C
Storage Temperature	–65°C to +150°C
Power Dissipation	560 mW at +85°C 1 W at +25°C
Junction Temperature	+150°C
Lead Temperature (max. soldering time is 10 seconds)	300°C

Electrical Characteristics

T_A within operating range, V_{DD} = 4.5 V to 11.0 V, V_{SS} = 0 V unless otherwise specified

Parameter	Conditions	Min	Typ	Max	Units
Power Supply		4.75		11	V
Power Supply Current	Excluding Output Loads			8.5	mA
Input Voltages					
Logical "0" Level (V_L)	±10 µA Input Bias	–0.3		0.8	V
Logical "1" Level (V_H)	$4.75 \le V_{DD} \le 5.25$	2.2		V_{DD}	V
	$V_{DD} > 5.25$	$V_{DD} - 2$		V_{DD}	V
Brightness Input (Note 2)		0		0.75	mA
Output Sink Current					
Segment OFF	$V_{OUT} = 3.0$ V			10	µA
Segment ON	$V_{OUT} = 1.0$ V (Note 3)	0		15	mA
	Brightness Input = 0 µA	0		10	µA
	Brightness Input = 100 µA	2.0	2.7	4	mA
	Brightness Input = 750 µA	15		25	mA
Brightness Input Voltage (Pin 19)	Input Current = 750 µA	3.0		4.3	V
Output Matching (Note 1)				±20	%
Clock input	(Notes 5 and 6)				
Frequency, f_C				500	kHz
High Time, t_H		950			ns
Low Time, t_L		950			ns
Data Input					
Set-Up Time, t_{DS}		300			ns
Hold Time, t_{DH}		300			ns
Data Enable Input Set-up Time, t_{DES}		100			ns
Reset Pad Current (Die Version)		8			µA

Note 1: Output matching is calculated as the percent variation $(I_{MAX} + I_{MIN}) / 2$.

Note 2: With a fixed resistor on the brightness input pin, some variation in brightness will occur from one device to another. Maximum brightness input current can be 2 mA as long as Note 3 and junction temperature equation are complied with.

Note 3: See Figures 7, 8 and 9 for Recommended Operating Conditions and limits. Absolute maximum for each output should be limited to 40 mA.

Note 4: The V_{OUT} voltage should be regulated by the user. See Figures 8 and 9 for allowable V_{OUT} vs. I_{OUT} operation.

Note 5: AC input waveform specification for test purpose: $t_r \le 20$ ns, $t_f \le 20$ ns, f = 500 kHz, 50% ±10% duty cycle.

Note 6: Clock input rise and fall times must not exceed 300 ns.

Functional Description

The MM5450 and MM5451 were designed to drive either 4 or 5 digit alphanumeric LED displays with the added benefit of requiring minimal interface with the display or data source.

Data is transferred serially via 2 signals; clock and serial data. Data transfer without the added inconvenience of an external load signal is accomplished by using a format of a leading "1" followed by the allowed 35 data bits. These 35 data bits are latched after the 36th has been transferred. This scheme provides non multiplexed, direct drive to the LED display. Characters currently displayed (thus, data output) changes only if the serial data bits differ from those previously transferred.

Control of the output current for LED displays provides for the display brightness. To prevent oscillations, a 1nF capacitor should be connected to pin 19, brightness control.

The block diagram is shown in Figure 1. For the MIC5450, the $\overline{\text{DATA ENABLE}}$ is a metal option and is used instead of the 35th output. The output current is typically 20 times greater that the current into pin 19, which is set by an external variable resistor. There is an external reset connection shown which is available on unpackaged (die) units only.

Figure 2 illustrates the die "pinout", or pad location for bonding in "chip on board" applications.

Figure 5 shows the input data format. A leading "1" is followed by 35 bits of data. After the 36th had been transferred, a LOAD signal is generated synchronously with the clock high state. This loads the 35 bits of data into the latches. The low side of the clock is used to generate a RESET signal which clears all shift registers for the next set of data. All shift registers are static master-slave, with no clear for the master portion of the first register, allowing continuous operation.

There must be a complete set of 36 clocks or the shift registers will not clear.

When the chip first powers ON an internal power ON reset signal is generated which resets all registers and all latches. The START bit and the first clock return the chip to its normal operation.

Figure 3 and 4 show the pin-out of the MIC5450 and MIC5451. Bit 1 is the first bit following the start bit and it will appear on pin 18. A logical "1" at the input will turn on the appropriate LED.

Figure 5 shows the timing relationships between data, clock and $\overline{\text{DATA ENABLE}}$. A max clock frequency of 0.5 MHz is assumed.

For applications where a lesser number of outputs are used, it is possible to either increase the current per output, or operate the part at higher than 1V V_{OUT}. The following equation can be used for calculations.

$$T_j = (V_{OUT})(I_{LED})(\text{No. of segments})(124°C/W) + T_A$$

where:

T_j = junction temperature + 150°C max

V_{OUT} = the voltage at the LED driver outputs

I_{LED} = the LED current

124°C/W = thermal resistance of the package

T_A = ambient temperature

The above equation was used to plot Figures 7–9.

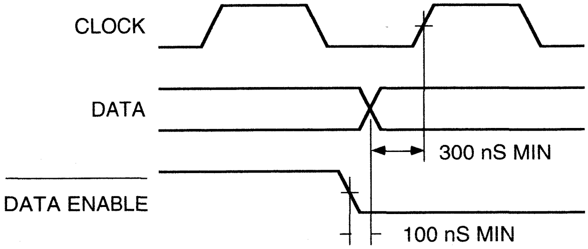


Figure 5.

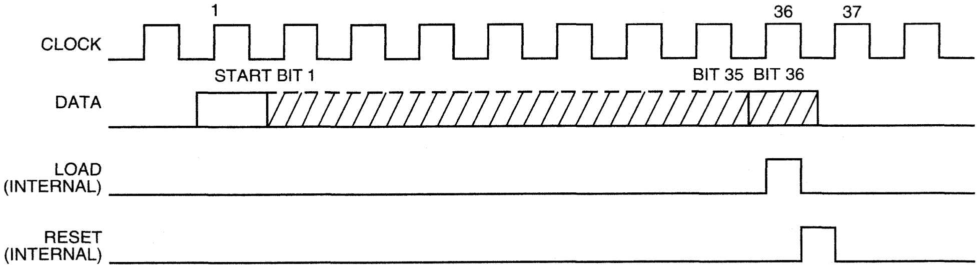


Figure 6. Input Data Format

Typical Performance Characteristics

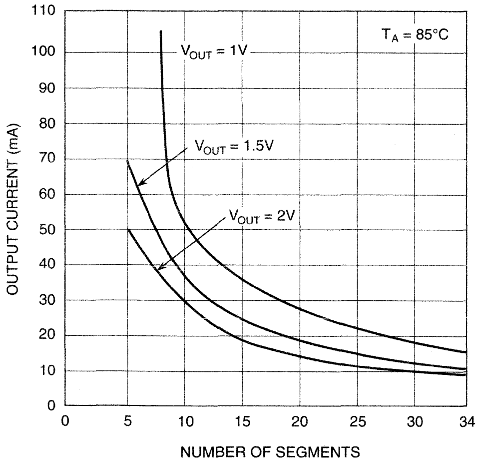


Figure 7.

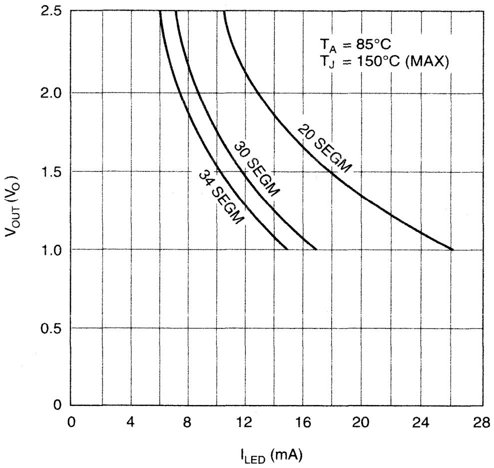


Figure 8.

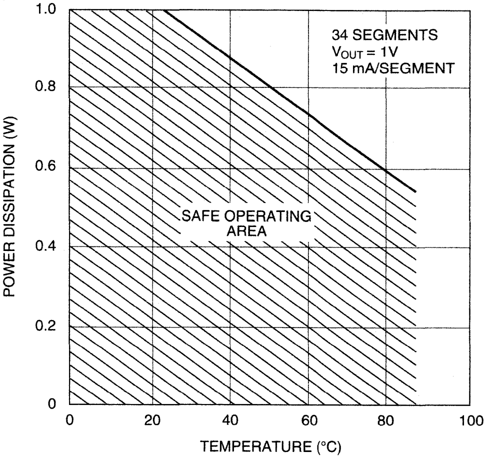


Figure 9.

Typical Applications

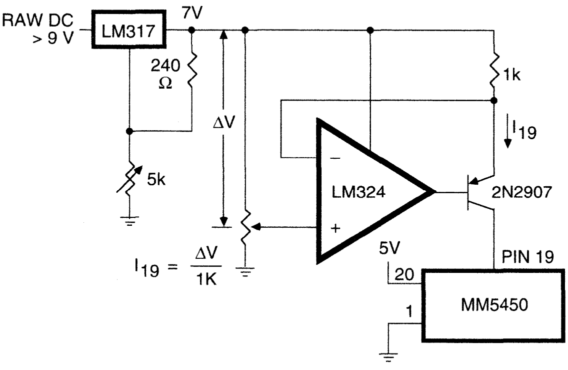


Figure 10. Typical Application of Constant Current Brightness Control

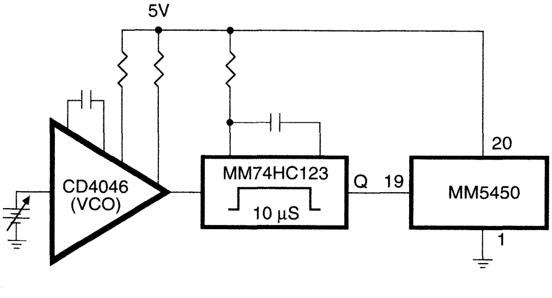


Figure 11. Brightness Control Varying the Duty Cycle

Typical Applications

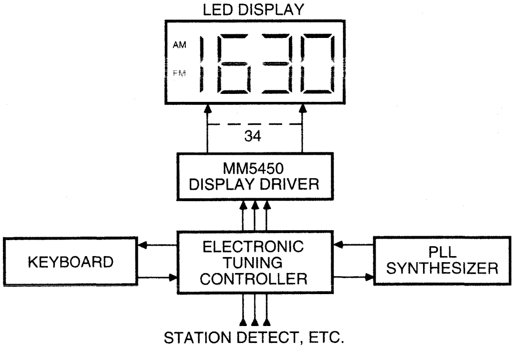


Figure 12. Basic Electronically Tuned Radio System

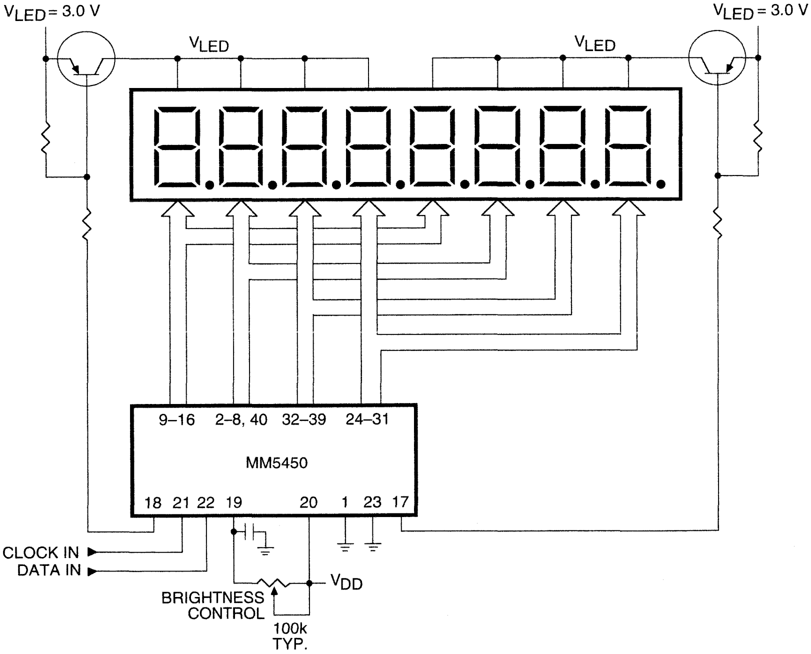


Figure 13. Duplexing 8 Digits with One MM5450.

Application Note 7

Six Decade Counter/Display Totalizer

Introduction

The Micrel MIC50395 was developed to provide counting system for most needs. This device consists of six, synchronous, up down decade counters with a data store and an auxiliary storage register that may be compared with the counter value. The circuit is relatively insensitive to power supply variation, and can interface with CMOS logic using power supplies in the 10 to 15 volt range. Counting speeds up to 1.0MHz are permissable and the circuits are readily cascaded.

The MIC50395 uses positive logic, i.e., logic 1 is the more positive level in the following description:

DESCRIPTION OF OPERATION

COUNTER

The positive going edges of a pulse train at the COUNT input (pin 36) are standardized by an internal monostable to a fixed pulse width thereby giving only a minimum value to the time for which the input pulse must stay high. This pulse is applied synchronously to the six decades and if the UP/DOWN input is a logic 1 the counters will be incremented, if at logic 0 then the counters will be decremented. At any time the value in the counter will be set back to zero if the CLEAR COUNTER input goes to a logic 1 for 2µs or longer. This resetting action occurs whether or not there is a counting input pulse train by forcing the counters directly to 0.

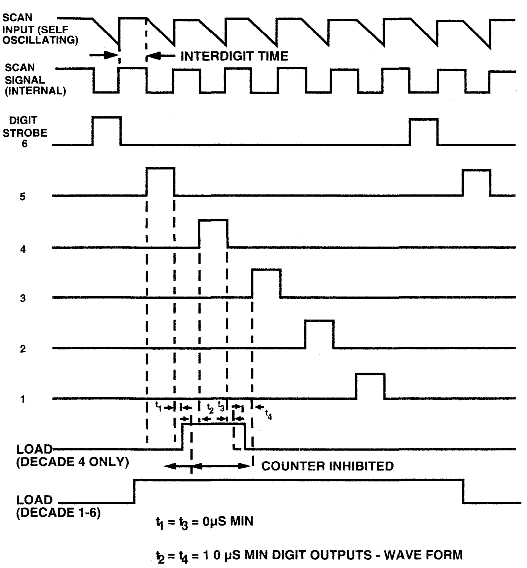


Figure 1: Load Counter, Register Timing

In addition to resetting it is also possible to preset any desired value into the counter. This is done sequentially decade by decade, under control of the LOAD COUNTER command in the following manner. If LOAD COUNTER is taken to logic one a minimum of 2µs prior to the positive transition of the digit output of the digit being loaded, the chip will latch this command and the BCD data presented to the counter will be loaded upon the negative transition of the digit strobe. It is thus possible to load each of the 6 counters individually if required. While the counter is being loaded the counting input is inhibited. Internally the load counter command is synchronized to the scan oscillator. Thus if LOAD COUNTER is brought to a logic zero in the middle of a digit strobe, the counter will remain inhibited until the next interdigit blanking time. A separate COUNT INHIBIT control is provided to stop the applied count inputs from being accepted while this signal is a logic 1.

The counter section has two control outputs, a CARRY from the most significant decade and a ZERO SIGNAL that indicates when the counter contents are zero. These signals are suppressed during LOAD COUNTER operations to avoid a spurious output being given during a counter presetting operation.

COMPARISON AND REGISTER

The six digit storage register may be preset to any value by bringing the LOAD REGISTER signal to logic 1. The presetting sequence is exactly the same as for the counter. The value on the REGISTER BCD INPUTS being loaded decade by decade by the six digit signals in the order "most significant" (digit 6) to "least significant" (digit 1). The outputs of this register are compared continuously with the value currently in the counter; this comparison is made in parallel and not decade by decade. When the two values are the same an EQUAL signal is given, however, during presetting of either the counter or the register, the CARRY, ZERO and EQUAL signals are inhibited so that no false intermediate comparison result is given. Since the counter and the register have separate BCD inputs, both may be preset simultaneously if desired. The value held in the register can only be altered by the BCD inputs. The Count Input is not inhibited during load register operations.

DIGIT SCANNING AND OUTPUT FUNCTIONS

The digit scan counter is timed from an internal oscillator which may be driven externally from the SCAN input. A capacitor attached from V_{SS} to this pin will determine the scan frequency when an external logic drive to this pin is not used. Internal circuitry gives a fixed delay to the DIGIT OUTPUT

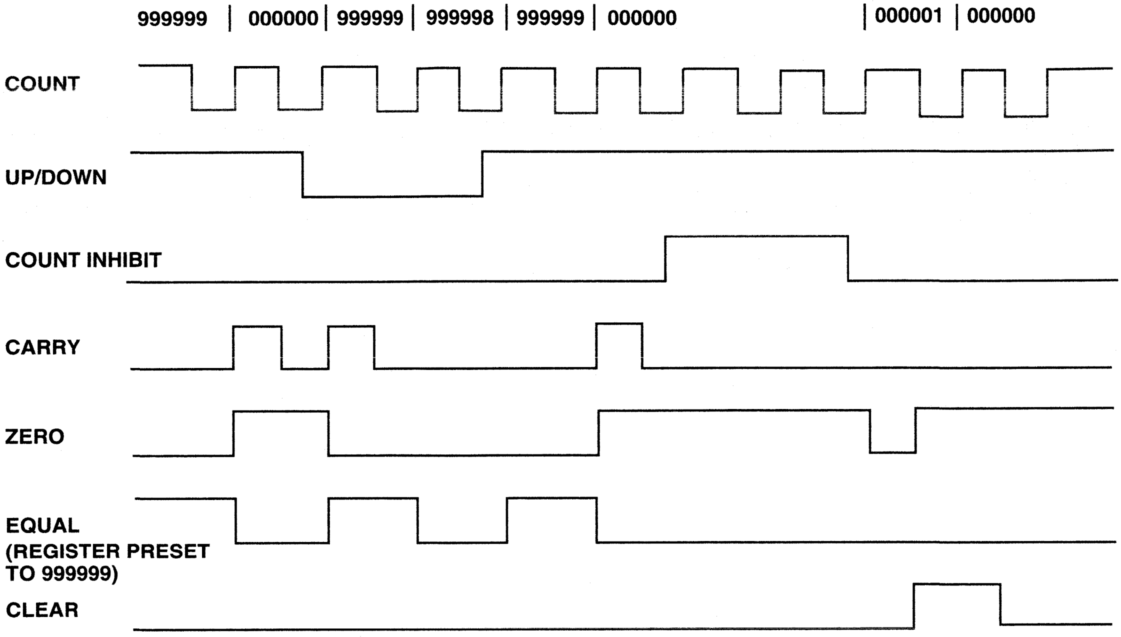


Figure 2: Up/Down Count Timing

signal to ensure that there is a gap between each digit strobe, thus a “ghosting” effect in a displayed output due to the storage time of external display driver transistors is eliminated. This is the interdigit blanking time. Typically this time can range from 3 to 10µs. SET input is used to force the digit strobe counter to the digit 6 position for purposes of synchronizing the counter output. The digit counter outputs are gated by the interdigit blanking period and appear as DIGIT STROBE OUTPUTS. The counter outputs are not directly multiplexed but are buffered by a 6 digit latch controlled by the STORE command. The outputs of the latch go directly to the output multiplexer, thus when the STORE signal is at logic 0 the counter contents are directly available, but as soon as STORE goes to logic 1 the value present as the signal changed is retained and subsequent changes in counter value are ignored. The contents of the store are read out, digit by digit — the scan counter again performs this function in the order most significant to least significant — and appear on BCD OUT pins. The four bits in each BCD digit are encoded simultaneously to seven segment code and appear as SEGMENTS OUT and can be used to drive a suitable 7 segment display. The $\overline{\text{SET}}$ operation will also turn off these seven outputs, blanking the display, as well as setting the digit counter to digit 6. This is to prevent possible destruction of an LED type display when $\overline{\text{SET}}$ is a prolonged signal. Frequently it is required to display only significant numbers, in which case taking the LZB control to a logic 0 will blank the leading zeros in the seven segment output.

INTERFACING WITH THE MIC50395

The wide range of power supply, 10.0 to 15.0V, makes the counting system particularly suitable for interfacing with CMOS logic.

A. Segment output — these transistors can source 10mA from the V_{SS} supply, there is no internal pull down to V_{DD} when the transistor is turned off. These transistors are capable of driving small LED displays directly via series resistors.

B. Digit outputs — a push pull configuration is used here as the most suitable arrangement for driving both external logic and display drivers. These outputs supply 3.0mA max from V_{SS} and sink 30µA to V_{DD}.

When higher power displays are used the segment outputs should be buffered by an emitter follower in order to provide the extra current.

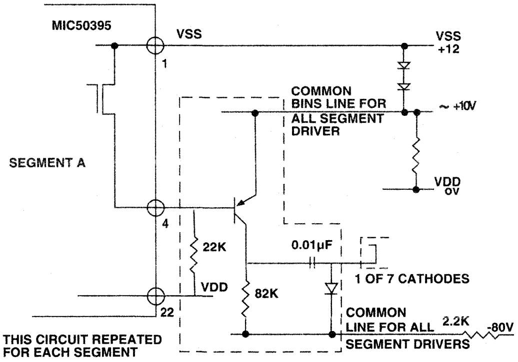


Figure 3: Segment Driver

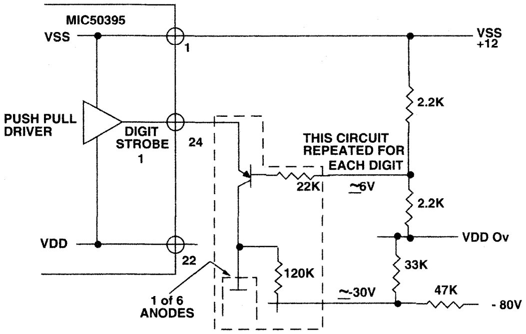


Figure 4: Digit Driver

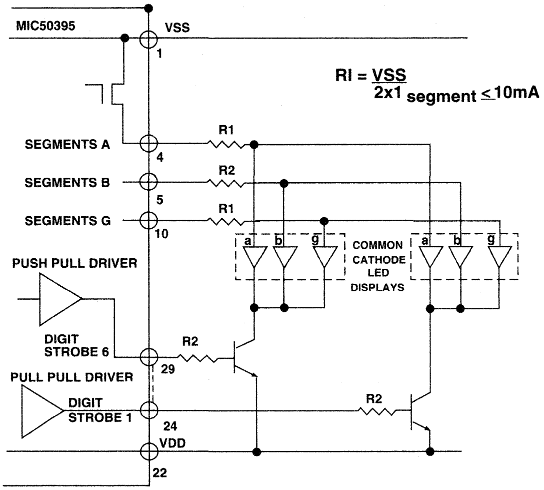
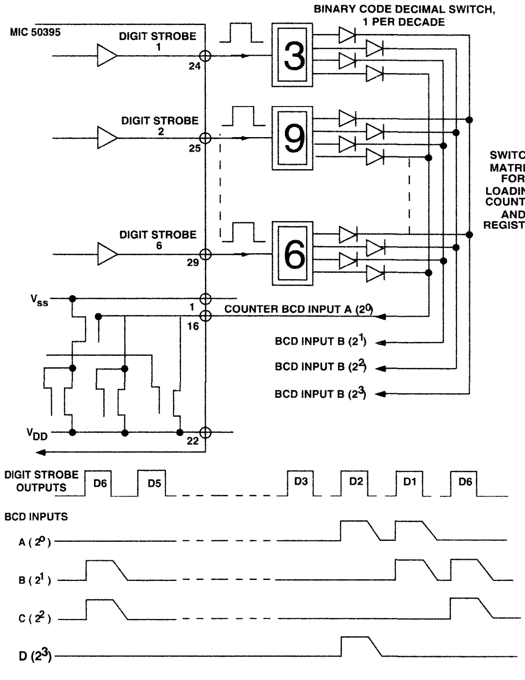


Figure 5: Driving LED Displays Directly

The BCD OUTPUTS, EQUAL, ZERO and CARRY are also push-pull. Output drive capabilities are listed in the following table:

	V_{OL}	V_{OH}
Segment Output (Pins 4-10)		V_{SS} – 3V at 10 mA (average over one digit cycle)
Digit Outputs (Pins 24 - 29)	V_{DD} at no load 0.2 V_{SS} at 30 μA	V_{SS} – 2V at 3.0 mA
Equal/Zero/Carry (Pins 23, 39,38)	V_{DD} at no load 0.2 V_{SS} at 30 μA	V_{SS} – 2V at 1.5 mA

The following inputs, COUNT, STORE, UP/DOWN, COUNT INHIBIT, CLEAR, LZB, and LOAD REGISTER have no internal current sources and must therefore be driven from sources that give correct logic 1 and 0 levels—open collector circuits, or switches without pull down resistors for example, may not be used. If any of the above functions are not required then those pins should be tied to the appropriate supply, that is to V_{SS} for logic 1 and V_{DD} for logic 0. $\overline{\text{SET}}$ has an internal transistor that pulls the pin to V_{SS}, if unconnected, thus the driving circuit should be able to sink this current, approximately 60μA, when pulling the input to logic 0. The COUNTER BCD and REGISTER BCD inputs have two internal transistors, one static and one switched as a precharge, that pull to



NOTE : THAT INPUT LINES ARE ALL PULLED TO V_{DD} DURING INTERDIGIT BLANKING

Figure 6: BCD Switch Matrix

V_{DD}. The static current is < 350μA to V_{DD} when the input is taken to Vss: the dynamic current from V_{SS} is 1mA while the transistor is on. The dynamic precharge ensures that even with the large capacitive loading and leakage current of a switch matrix at these pins, the correct data will be entered at the maximum digit scan frequency.

An example of a switch matrix input illustrates this operation. Six binary coded decimal switches are used, one for each decade, the switches being enabled by the corresponding DIGIT STROBE output, with the paralleled switch outputs connected to the COUNTER (or REGISTER) BCD inputs. The DIGIT STROBE outputs are separated by the interdigit blanking time and it is only during this time that the precharge transistors at the BCD inputs are all pulled to logic 0 (V_{DD}). After this blanking time the next DIGIT STROBE output will in its turn switch to logic 1 (only one out of six is ever on) and pull those BCD inputs selected by the switch and diode matrix to logic 1. This value is loaded into the corresponding register or counter stage, i.e. the switch matrix driven by DIGIT STROBE 6 will be loaded into MSB of the register or counter. As the DIGIT STROBE switches back to logic 0 the next interdigit blanking time begins and the inputs are all pulled back to logic 0 again by the internal precharge. It is possible for the DIGIT STROBE outputs to drive both the switch matrix and a display. If the COUNTER & REGISTER BCD inputs are connected in parallel they may still be driven directly from the DIGIT STROBE outputs.

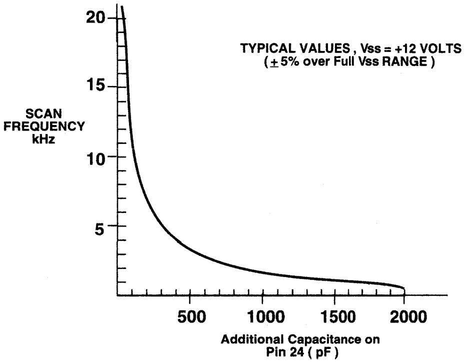


Figure 7: Scan Frequency vs. External

When the scan oscillator is free running the SCAN input may use an external capacitor to set the scanning frequency to a particular value. The signal seen at the pin is a ramp determined by the capacitance, followed by a period clamped at V_{SS}. This period clamped at V_{SS} is determined by the internal oscillator and is the interdigit blanking period. During this time the DIGIT STROBE outputs are all turned off.

When the SCAN input is driven externally this fixed interdigit period remains plus the time at which the synchronizing signal is at logic 0. Making the interdigit blanking time independent of the external synchronizing signal requires only the addition of a resistor and capacitor.

Time A is the interdigit blanking time, time B should be greater than 2μs—a range of 2 to 5μs is suitable and time C may be from infinity to 30μs. If time C is made too short then the interdigit blanking circuit never resets itself and will stay at logic 0 and no DIGIT STROBE outputs will appear.

TYPICAL MIC50395 APPLICATIONS

BATCH CONTROL

In many situations involving the metering of material, whether as a liquid, individual items or revolutions of a spindle, a two step operation is required for better efficiency. The flow is started at the maximum speed and at a preset point before the end of the operation a signal is required to slow down and eventually stop the equipment. Such applications could be as diverse as filling sacks with cement or controlling the turns on a transformer bobbin. A block diagram of such a system is presented. Pressing the start switch allows the input to the D flip flop to go to logic 1. This is clocked by the DIGIT STROBE 6 so that a synchronous signal at least one complete scan counter cycle long is obtained. This signal is used as LOAD COUNTER and LOAD REGISTER, the two controls being tied in parallel for simultaneous loading. It does not matter how long the load signal is as long as it is at least one scan cycle long and changes synchronously with the scan signal. The two values representing total quantity and "slow down"

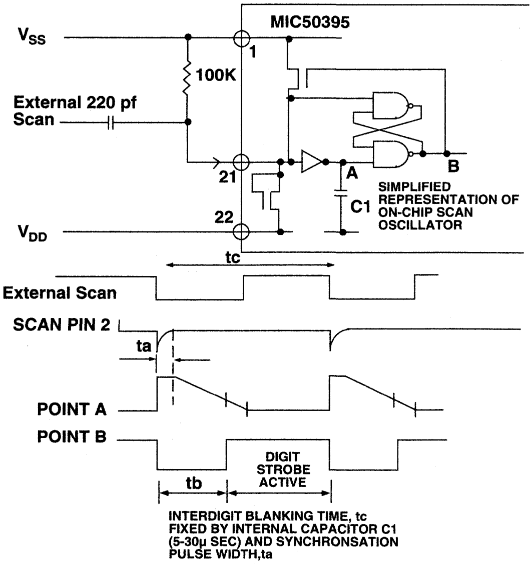


Figure 8: External Drive To Scan Input

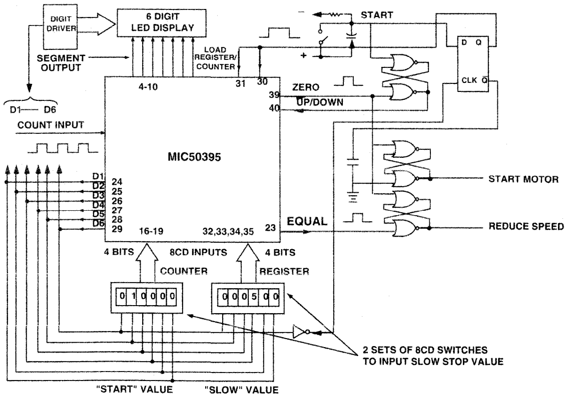


Figure 9: Batch Control

quantity are set on the digit switches and these values are loaded at the beginning of each cycle. Once the counter register loading is complete, a start signal is generated to set the equipment in operation. The train of pulses representing the measured quantity is counted, the UP/ DOWN control is in the down mode. Thus with two quantities at, for example, 10,000 and 500, the counter starts off with 10,000 loaded and counts toward zero. When the counter reaches 500 an EQUAL signal is generated and this sets the signal controlling the brake. A further 500 pulses and the counter reaches zero, an output on the ZERO pin resets the start flip flop and the equipment is brought to reset awaiting a new start signal. In such an operation the display outputs would probably not be used.

This application can be extended by using the ZERO output to control the UP/DOWN input. The operation is identical but the start signal also sets a latch into the count down state. As ZERO is detected this latch is reset so that the counter mode is now up. Even with a braking facility there may be an "overrun" and the value now held in the counter and displayed is the extra quantity. The operator may now decide if this extra quantity is within the tolerance allowed for the job and to take whatever action is necessary.

POSITIONAL MEASUREMENT

Positional measurement can readily be made using this circuit, the six decades gives considerable accuracy in one package. The two quadrature signals from a graticule type displacement measurement system must be converted to

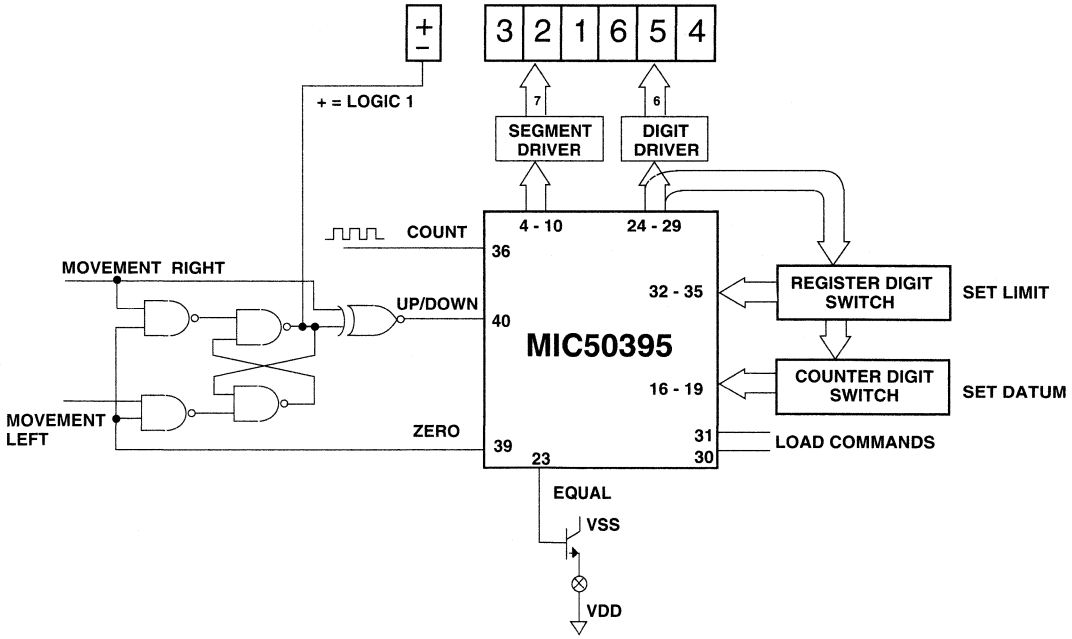


Figure 10: Positional Measurement

count impulses and an UP/DOWN signal. If the measurement zero datum is in the middle of the measurement area then the following counting conditions arise:

Direction of Movement	Displayed sign + or – Of Datum	Count Direction	
RIGHT	–	DOWN	ZERO DATUM CROSSED
RIGHT	+	UP	
LEFT	+	DOWN	ZERO DATUM CROSSED
LEFT	–	UP	

COUNT edge (Fig. 2) that ZERO has as much longer propagation delay than the EQUAL output. In the event that the register is not used it may be loaded with zeros—by giving a LOAD REGISTER command with the BCD inputs as zero — and the EQUAL output then used as zero detect. This has the advantage of increasing the system speed for although the counter can accept inputs up to 1.0MHz; the propagation delay of the outputs is too long to allow a control signal to be changed between clock pulses at this counting rate. In this example UP/DOWN has to be controlled and using the faster output enables a higher counting speed to be used; if necessary in this case, approximately 600kHz instead of 300kHz.

GREATER THAN—LESS THAN DETECTION

The availability of an EQUAL output facilitates the generation of greater than and less than signals. The only requirement is the circuit is set into the correct initial state. When the counter has the same value as the register, the generation of the "greater/less than" signal depends on the direction of count, i.e. from this EQUAL condition count up gives "greater than" and count down gives "less than". EQUAL is gated with UP and with DOWN and these are connected to the D inputs of two D flip flops that are both clocked by the counting pulse. As EQUAL is reached, the two flip flops are reset, but the next count pulse after the EQUAL condition will set one or the other flip flop, and thereby provide the appropriate signal.

AUTOMATIC STOP

The COUNT INHIBIT input may be used to stop the counter automatically when the EQUAL or ZERO outputs are connected directly to this input. As EQUAL, for example, goes to a logic 1, then further counting is inhibited when this signal is connected directly to COUNT INHIBIT. Since no more count inputs are accepted, the EQUAL value remains and blocks the counting action. The operation of CLEAR, LOAD REGISTER or LOAD COUNTER can be used to start the system counting again.

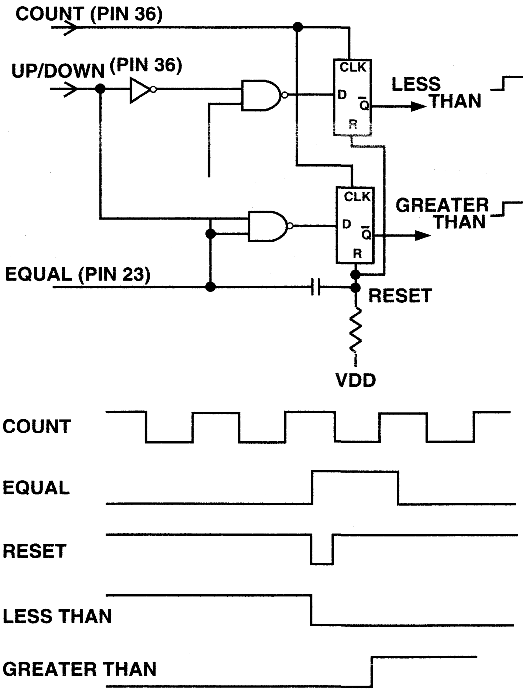


Figure 11: Less Than Greater Than

Application Hint 2

MIC8030/8031 Application Hints

MIC8030/MIC8031 Application Hints on Compatibility with Display Drivers Produced by AMI and HOLT

The MIC8030/MIC8031 can be made compatible with all bonding options of the Gould-AMI S4520 as well as all bonding options of the HOLT HI-8010. However, the high voltage supply must be positive with respect to ground for the MIC8030/MIC8031. Both AMI and HOLT use a negative High Voltage. See MIC8010/11/12/13 family for drop in replacements in existing sockets.

High Voltage Supply

Device	Vmin	Vmax	Absolute Max
MIC8031	20V	100V	110V
MIC8030	20V	50V	75V
HI-8010	Vlogic-35V	+0.3V	Vlogic-35V
S4520	Vlogic-32V	+0.3V	Vlogic-32V

Logic Power Supply

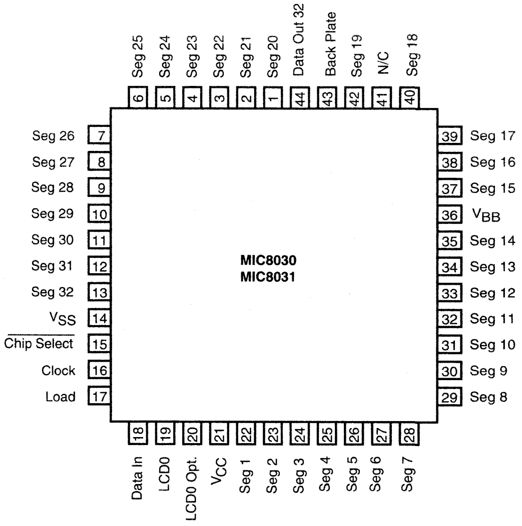
Device	Vmin	Vmax	Absolute Max
MIC8031	4.5V	16.5V	18V
MIC8030	4.5V	5.5V	18V
HI-8010	3.0V	18.0V	18V
S4520	3.0V	16.0V	17V

As can been seen above, the MIC8030/MIC8031 are superior to both AMI and HOLT in the voltage that can be applied to a Dichroic LCD display. Using the MIC8030/MIC8031 allows for a derating of 50%/70% if operated at 35V; the HI-8010 allows for no derating at 35V and the S4520 allows for no derating at 32V.

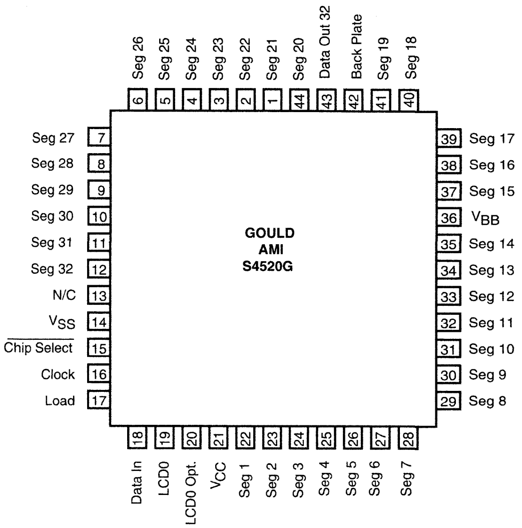
When placing the MIC8030/MIC8031 in a pin compatible configuration on a board which previously used a HOLT or AMI device, care must be taken before changing the polarity of the High Voltage Supply, to reverse the direction of any polarized filter capacitor on the High Voltage line, as well check any other circuit (like a zener diode, etc) which contacts the High Voltage line.

The pin out drawings match the MIC8030/MIC8031 to the S4520. By moving the No-Connect, from pin 41 to pin 13 and shifting the displaced signals clockwise, the pin out can be matched.

Other pin outs that can be matched are the S4520A, S4520B, S4520C, S4520S, S4520F, S4520G, HI-8010L5, HI-8010L6, HI-8010L7, HI-8010C5, HI-8010C6, and the HI-8010C7. Other packaging options are available, all options must use a positive V_{BB}.



MIC8030/MIC8031
Standard 44 Pin Quad Package



S4520G
AMI 44 Pin Quad Package

Table of Contents

Section 10: Special Purpose Products

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* Summary information. For full details, contact Micrel.

MIC1555/1557

IttyBitty™ RC Timer / Oscillator

Advance Information

General Description

The MIC1555 IttyBitty™ CMOS RC timer/oscillator and MIC1557 IttyBitty CMOS RC oscillator are designed to provide rail-to-rail pulses for precise time delay or frequency generation.

The devices are similar in function to the industry standard "555", without a frequency control (F_C) pin or an open-collector discharge (D) pin. The threshold pin (TH) has precedence over the trigger (TR) input, ensuring that the BiCMOS output is off when TR is high.

The MIC1555 may be used as an astable (oscillator) or monostable (one-shot) with separate threshold and trigger inputs. In the one-shot mode, the output pulse width is precisely controlled by an external resistor and a capacitor. Time delays may be accurately controlled from microseconds to hours. In the oscillator mode, the output is used to provide precise feedback, with a minimum of one resistor and one capacitor producing a 50% duty cycle square wave.

The MIC1557 is designed for astable (oscillator) operation only, with a chip select/reset (CS) input for low power shutdown. One resistor and one capacitor provide a 50% duty cycle square wave. Other duty-cycle ratios may be produced using two diodes and two resistors.

The MIC1555/7 is powered from a +2.7V to +18V supply voltage.

The MIC1555/7 is available in the SOT-23-5 5-lead package, and is rated for –40°C to +85°C ambient temperature range.

Features

- +2.7V to +18V operation
- Low current
  - <1µA typical shutdown mode (MIC1557)
  - 200µA typical (TRG and THR low) at 3V supply
- Timing from microseconds to hours
- TTL compatible inputs and output
- "Zero" leakage trigger and threshold inputs
- 50% square wave with one Resistor, one Capacitor
- Threshold precedence over trigger input
- <15Ω output on resistance
- No output cross-conduction current spikes
- <0.005%/°C temperature stability
- <0.055%/V supply stability
- Small SOT-23-5 surface mount package

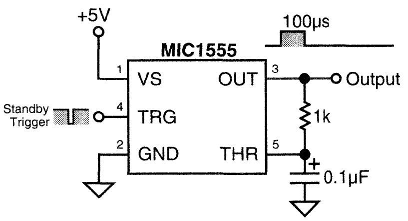
Applications

- Precision timer
- Pulse generation
- Sequential timing
- Time-delay generation
- Missing pulse detector
- Micropower oscillator to 5MHz
- Charge-pump driver
- LED blinker
- Voltage converter
- Linear sweep generator
- Variable frequency and duty cycle oscillator
- Isolated feedback for power supplies

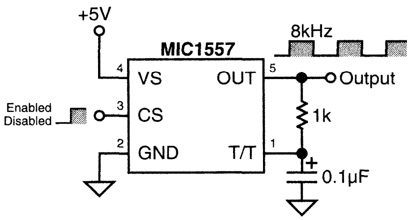
Ordering Information

Part Number	Temperature Range	Package
MIC1555BM5	–40°C to +85°C	SOT-23-5
MIC1557BM5	–40°C to +85°C	SOT-23-5

Typical Applications



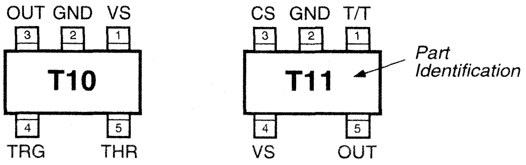
Monostable (One-Shot)



Astable (Oscillator)

Pin Configuration

Part Number	Identification
MIC1555BM5	T10
MIC1557BM5	T11



SOT-23-5 (M5)

Pin Description

Pin Number MIC1555	Pin Number MIC1557	Pin Name	Pin Function
1	4	VS	Supply (Input): +2.7 to +18V supply.
2	2	GND	Ground: Supply return.
	3	CS	Chip Select/Reset (Input): Active high at 0.4V. Output off when low.
3	5	OUT	Output: CMOS totem-pole output.
4		TRG	Trigger (Input): Sets output high. Active low (at ≤ ⅓V_S nominal).
5		THR	Threshold (Dominant Input): Sets output low. Active high (at ≥ ⅔V_S nominal).
	1	T/T	Trigger/Threshold (Input): Internally connected to both threshold and trigger functions. See TRG and THR.

Absolute Maximum Ratings

Supply Voltage (V_S)	+22V
Threshold Voltage (V_{THR}, $V_{T/T}$)	+22V
Trigger Voltage (V_{TRG}, $V_{T/T}$)	+22V
Ambient Temperature Range	–40°C to +85°C
Lead Temperature, Soldering	300°C for 10s

Operating Ratings

Supply Voltage (V_S)	+2.7V to +18V
Package Thermal Resistance	
SOT-23-5 θ_{JA}	220°C/W
SOT-23-5 θ_{JC}	130°C/W

Electrical Characteristics

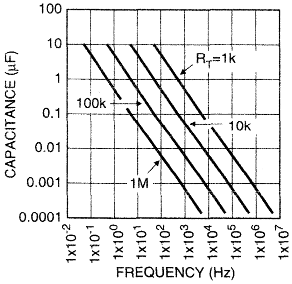
Parameter	Condition (Note 1)	Min	Typ	Max	Units
Supply current	V_S = 5V		250	300	µA
	V_S = 15V		300	400	µA
Monostable Timing Accuracy	R_A = 10K, C =0.1µF, V_S = 5V		2		%
	R_A = 10K, C =0.1µF, V_S = 5V	858		1161	µs
Monostable Drift over Temp	V_S = 5V, $-55 \le T_A \le +125$°C, Note 2		100		ppm/°C
	V_S =10V, $-55 \le T_A \le +125$°C, Note 2		150		ppm/°C
	V_S = 15V, $-55 \le T_A \le +125$°C, Note 2		200		ppm/°C
Monostable Drift over Supply	V_S = 5V to 15V, Note 2		0.5		%/V
Astable Timing Accuracy	$R_A = R_B$ = 10K, C = 0.1µF, V_S = 5V		2		%
	$R_A = R_B$ = 10K, C = 0.1µF, V_S = 5V	1717		2323	µs
Maximum Astable Frequency	R_T = 1k, C_T = 47pF, V_s = 8V		5		MHz
Astable Drift over Temp	V_S = 5V, $-55 \le T_A \le +125$°C, Note 2		100		ppm/°C
	V_S =10V, $-55 \le T_A \le +125$°C, Note 2		150		ppm/°C
	V_S = 15V, $-55 \le T_A \le +125$°C, Note 2		200		ppm/°C
Astable Drift over Supply	V_S = 5V to 15V, Note 2		0.5		%/V
Threshold Voltage	V_S = 15V	61	67	72	%V_S
Trigger Voltage	V_S = 15V	27	32	37	%V_S
Trigger Current	V_S = 15V			50	nA
Threshold Current	V_S = 15V			50	nA
Chip Select	V_S = 15V	61	67	72	%V_S
Output Voltage Drop	V_S = 15V, I_{SINK} = 20mA		0.4	1.25	V
	V_S = 5V, I_{SINK} = 3.2mA		0.2	0.5	V
Output Voltage Drop	V_S = 15V, I_{SOURCE} = 20mA	14.1	14.7		V
	V_S = 5V, I_{SOURCE} = 3.2mA	3.8	4.7		V
Supply Voltage	Functional Oper., Note 2	2.7		18	V
Output Rise Time	R_L = 10M, C_L = 10pF, V_S = 5V, Note 2		15		ns
Output Fall Time	R_L = 10M, C_L = 10pF, V_S = 5V, Note 2	—	15	—	ns

General Note: Devices are ESD protected, however handling precautions are recommended.

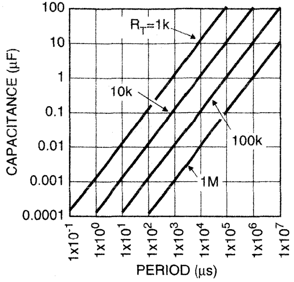
Note 1: Typical values at T_A = 25°C. Minimum and maximum values at $-40°C \le T_A \le +85°C$.

Note 2: Not tested.

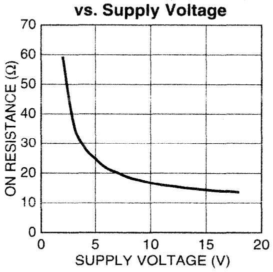
Typical Characteristics Note 1



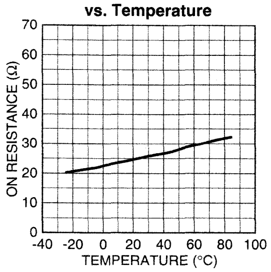
Astable Frequency



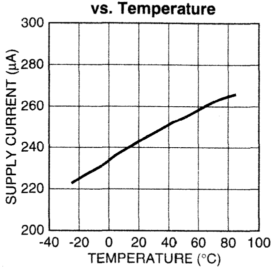
Pulse Width



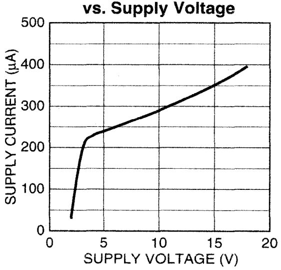
On Resistance vs. Supply Voltage



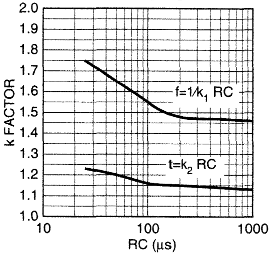
On Resistance vs. Temperature



Supply Current vs. Temperature

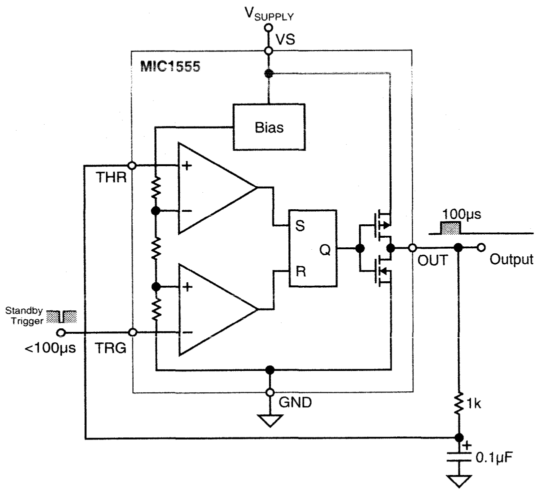


Supply Current vs. Supply Voltage

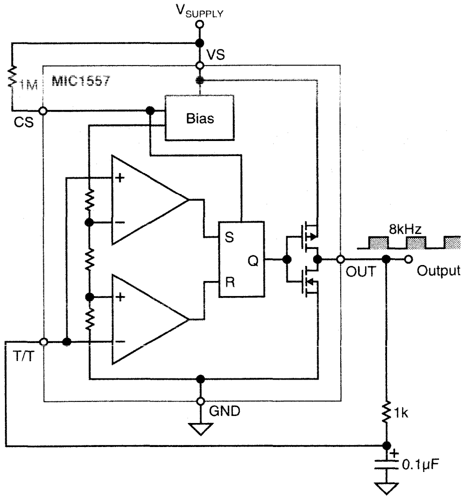


k Factors Times RC

Functional Diagrams



MIC1555 Block Diagram with External Components (Monostable Configuration)



MIC1557 Block Diagram with External Components (Astable Configuration)

Functional Description

Refer to the block diagrams.

The MIC1555/7 provides the logic for creating simple RC timer or oscillator circuits.

The MIC1555 has separate THR (threshold) and TRG (trigger) connections for monostable (one-shot) or astable (oscillator) operation.

The MIC1557 has a single T/T (threshold and trigger) connection for astable (oscillator) operation only. The MIC1557 includes a CS (chip select/reset) control.

Supply

VS (supply) is rated for +2.7V to +18V. An external capacitor is recommended to decouple noise.

Resistive Divider

The resistive voltage divider is constructed of three equal value resistors to produce $\frac{1}{3}V_S$ and $\frac{2}{3}V_S$ voltage for trigger and threshold reference voltages.

Chip Select/Reset (MIC1557 only)

CS (chip select/reset) controls the bias supply to the oscillator's internal circuitry. CS must be connected to logic high or logic low. Floating CS will result in unpredictable operation. When the chip is deselected, the supply current is less than 1µA. Forcing CS low resets the MIC1557 by setting the flip flop, forcing the output low.

Threshold Comparator

The threshold comparator is connected to S (set) on the RS flip-flop. When the threshold voltage ($\frac{2}{3}V_S$) is reached, the flip-flop is set, making the output low. THR is dominant over TRG.

Trigger Comparator

The trigger comparator is connected to R (reset) on the RS flip-flop. When TRG (trigger) goes below the trigger voltage ($\frac{1}{3}V_S$), the flip-flop resets, making the output high.

Flip-Flop and Output

A reset signal causes Q to go low, turning on the P-channel MOSFET and turning off the N-channel MOSFET. This makes the output rise to nearly V_S.

A set signal causes Q to go high, turning off the P-channel MOSFET, and turning on the N-channel MOSFET, grounding OUT.

Basic Monostable Operation

Refer to the MIC1555 functional diagram.

A momentary low signal applied to TRG causes the output to go high. The external capacitor charges slowly through the external resistor. When V_{THR} (threshold voltage) reaches $\frac{2}{3}$ V_S, the output is switched off, discharging the capacitor.

Basic Astable Operation

Refer to the MIC1557 functional diagram.

The MIC1557 starts with T/T low, causing the output to go high. The external capacitor charges slowly through the external resistor. When $V_{T/T}$ reaches $\frac{2}{3}V_S$ (threshold voltage), the output is switched off, slowly discharging the capacitor. When $V_{T/T}$ decreases to $\frac{1}{3}V_S$ (trigger voltage), the output is switched on, causing $V_{T/T}$ to rise again, repeating the cycle.

Application Information

Basic Monostable (One-Shot) Circuit

A monostable oscillator produces a single pulse each time that it is triggered, and is often referred to as a "one-shot". The pulse width is constant, while the time between pulses depends on the trigger input. One-shots are generally used to "stretch" incoming pulses, of varying widths, to a fixed width. The IttyBitty MIC1555 is designed for monostable operation, but may also be connected to provide astable oscillations. The pulse width is determined by the time it takes to charge a capacitor from ground to a comparator trip point. If the capacitor (C_T) is charged through a resistor (R_T) connected to the output of an MIC1555, the trip point is approximately $1.1RC_T$ (the same time as the initial power-on cycle of an astable circuit.) If the trigger pulse of an MIC1555 remains low longer than the output pulse width, short oscillations may be seen in the output of a one-shot circuit, since the threshold pin has precedence over the trigger pin. These occur since the output goes low when the threshold is exceeded, and then goes high again as the trigger function is asserted. AC coupling the input with a series capacitor and a pull-up resistor, with an RC time constant less than the pulse width, will prevent these short oscillations. A diode (D_T) in parallel with (R_T) resets the astable quickly.

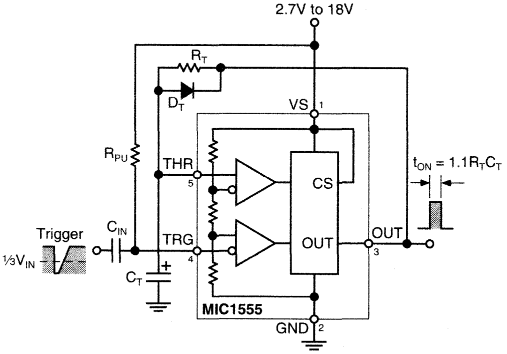


Figure 1. One-Shot Diagram

The period of a monostable circuit is:

$$t = k_1 R C$$

where:

t = period (s)
k_1 = constant [from Typical Characteristics graph]
R = resistance (Ω)
C = capacitance (F)

Basic Astable (Oscillator) Circuits

An astable oscillator switches between two states, "on" and "off", producing a continuous square wave. The IttyBitty MIC1557 is optimized for this function, with the two comparator inputs, threshold and trigger (T/T), tied together internally. Chip select (CS) is brought out to allow on-off control of the oscillator.

The MIC1555 may also be used as an astable oscillator by tying the threshold and trigger pins together, forming a T/T pin. If a resistor (R_T) is connected from the output to a grounded timing capacitor, (C_T) the voltage at their junction will ramp up from ground when the output goes high. If the T/T pin is connected to this junction, the output will switch low when the ramp exceeds ⅔ of the input voltage. The junction's voltage ramps down toward ground while the output is low. When the ramp is below ⅓ of the input voltage, the output switches to high, and the junction ramps up again. The continuing frequency of an MIC1555/7 astable oscillator depends on the RC time constant, and is approximately 0.7/RC below 1MHz. At frequencies above 1MHz the RC multiplier increases as capacitance is decreased, and propagation delay becomes dominant. Non-symmetrical oscillator operation is possible at frequencies up to 5MHz.

If a duty cycle other than 50% is desired, a low-power signal diode may be connected in series with the timing resistor (R_A), and a second resistor (R_B) in series with an opposite facing diode connected in parallel. The frequency is then made up of two components, the charging time (t_A) and the discharging time (t_B) $t_A = 0.7R_AC$ and $t_B = 0.7R_BC$. The frequency is the reciprocal of the sum of the two times $t_A + t_B$, so the total time is $1.4R_TC_T$. The first half-cycle of an astable, after power-on or CS enable, is lengthened since the capacitor is charging from ground instead of the 1⁄3 input trigger trip voltage, to 1.1RC.

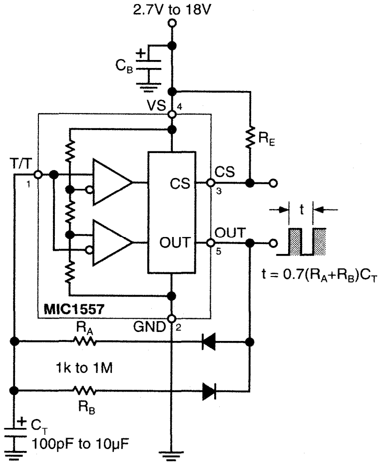


Figure 2. Oscillator Diagram

The MIC1555 or MIC1557 can be used to construct an oscillator.

The frequency of an astable oscillator is:

$$f = \frac{1}{k_2 R C}$$

where:

f = frequency (Hz)
k_2 = constant [from Typical Characteristics graph]
R = resistance (Ω)
C = capacitance (F)

To use the MIC1555 as an oscillator, connect TRG to THR.

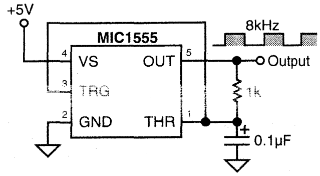


Figure 3. MIC1555 Oscillator Configuration

The MIC1557 features a CS input. When logic-low, CS places the MIC1557 into a <1µA shutdown state. If unused, the MIC1557 CS input on must be pulled up.

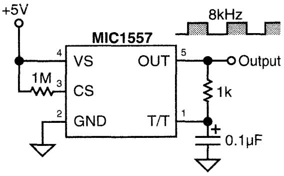


Figure 4. MIC1557 Oscillator Configuration

Falling-Edge Triggered Monostable Circuit

The MIC1555 may be triggered by an ac-coupled falling-edge, as shown in figure 5. The RC time constant of the input capacitor and pull-up resistor should be less than the output pulse time, to prevent multiple output pulses. A diode across the timing resistor provides a fast reset at the end of the positive timing pulse.

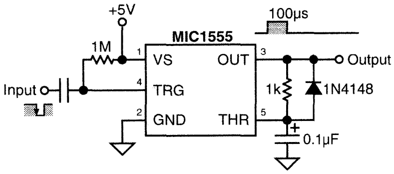


Figure 5. Falling-Edge Trigger Configuration

Rising-Edge Triggered Monostable Circuit

The MIC1555 may be triggered by an ac-coupled rising-edge, as shown in figure 6. The pulse begins when the ac-coupled input rises, and a diode from the output holds the THR input low until TRG discharges to $1/3V_S$. This circuit provides a low-going output pulse.

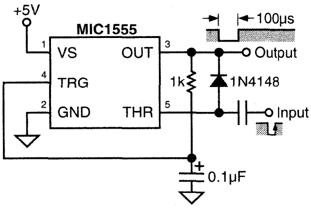


Figure 6. Rising-Edge Trigger Configuration

Accuracy

The two comparators in the MIC1555/7 use a resistor voltage divider to set the threshold and trigger trip points to approximately $2/3$ and $1/3$ of the input voltage, respectively. Since the charge and discharge rates of an RC circuit are dependent on the applied voltage, the timing remains constant if the input voltage varies. If a duty cycle of exactly 50% (or any other value from 1 to 99%), two resistors (or a variable resistor) and two diodes are needed to vary the charge and discharge times. The forward voltage of diodes varies with temperature, so some change in frequency will be seen with temperature extremes, but the duty cycle should track. For absolute timing accuracy, the MIC1555/7 output could be used to control constant current sources to linearly charge and discharge the capacitor, at the expense of added components and board space.

Long Time Delays

Timing resistors larger than 1MΩ or capacitors larger than 10µF are not recommended due to leakage current inaccuracies. Time delays greater than 10 seconds are more accurately produced by dividing the output of an oscillator by a chain of flip-flop counter stages. To produce an accurate one-hour delay, for example, divide an 4.55Hz MIC1557 oscillator by 16,384 (4000_{hex}, 2^{14}) using a CD4020 CMOS divider. 4.5Hz may be generated with a 1µF C_T and approximately 156kΩ.

Inverting Schmitt Trigger

The trip points of the MIC1555/7 are defined as $1/3$ and $2/3V_S$, which allows either device to be used as a signal conditioning inverter, with hysteresis. A slowly changing input on T/T will be converted to a fast rise or fall-time opposite direction rail-to-rail output voltage. This output may be used to directly drive the gate of a logic-level P-channel MOSFET with a gate pull-up resistor. This is an inverted logic low-side logic level MOSFET driver. A standard N-channel MOSFET may be driven by a second MIC1555/7, powered by 12V to 15V, to level-shift the input.

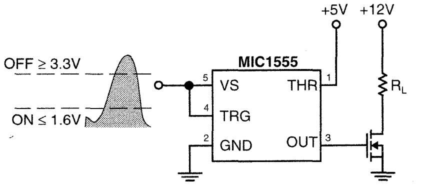


Figure 5. Schmitt trigger

Charge-Pump Low-Side MOSFET Drivers

A standard MOSFET requires approximately 15V to fully enhance the gate for minimum $R_{DS(on)}$. Substituting a logic-level MOSFET reduces the required gate voltage, allowing an MIC1557 to be used as an inverting Schmitt Trigger, described above. An MIC1557 may be configured as a voltage quadrupler to boost a 5V input to over 15V to fully enhance an N-channel MOSFET which may have its drain connected to a higher voltage, through a high-side load. A TTL high signal applied to CS enables a 10kHz oscillator, which quickly develops 15V at the gate of the MOSFET, clamped by a zener diode. A resistor from the gate to ground ensures that the FET will turn off quickly when the MIC1557 is turned off.

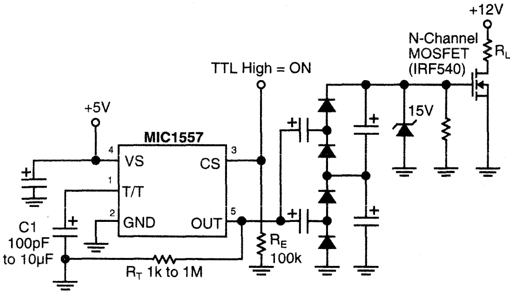


Figure 6. Charge-Pump

Audible Voltmeter

If an additional charge or discharge source is connected to the timing capacitor, the frequency may be shifted by turning the source on or off. An MIC1555 oscillator, powered by the circuit under test, may be used to drive a small loudspeaker or piezo-electric transducer to provide a medium frequency for an open or high impedance state at the probe. A high tone is generated for a high level, and a lower frequency for a logic low on the probe.

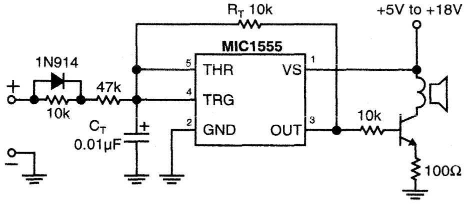


Figure 7. Audible Voltmeter

MIC2660

IttyBitty™ Charge Pump

Preliminary Information

General Description

The MIC2660 IttyBitty™ charge pump functions as a low-current, step-up converter where conventional inductor based, dc-to-dc converters are too complex and expensive. This device features a complete, self-contained charge pump in a tiny 5-lead SOT-23-5 package.

The MIC2660 is powered from a 3V to 5V nominal supply and produces nominally 5V to 9V as a function of the input voltage. The output is unregulated and follows a load-line type function.

The MIC2660 can be used with or without external components. When used with two noncritical external capacitors, a 3V input will produce 5V at 3.8mA. With no external components, a 3V input will produce 5V at 2.5mA.

The MIC2660 charge pump consists of an approximately 18MHz oscillator and a voltage tripler.

The MIC2660 is available in the SOT-23-5 package and is rated for –40°C to +85°C ambient temperature range.

Features

- 3V input produces approx. 5V unregulated output*
  - 3.8mA with 1μF external output capacitor
  - 2.5mA without external capacitor
- 5V input produces approx. 9V unregulated output*
  - 4.5mA output without external capacitor
- CMOS-logic compatible enable
- ESD protected

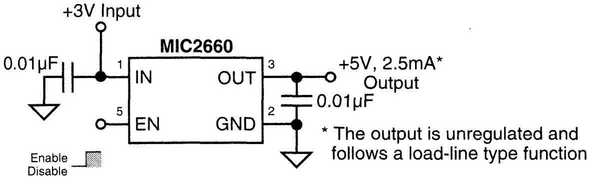
Applications

- Squib firing
- Refresh
- Burst/dump
- Low duty cycle load
- LCD bias generator
- Local 5V logic supply
- MOSFET driver
- Battery or solarcell boost

Ordering Information

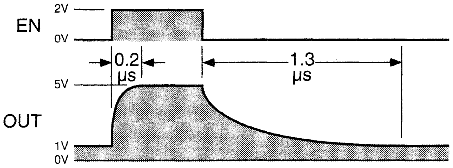
Part Number	Temperature Range	Package
MIC2660BM5	–40°C to +85°C	SOT-23-5

Typical Application



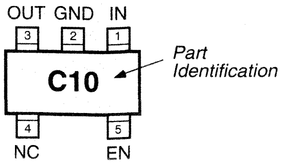
Low-Current Unregulated Step-Up Supply

Timing Diagram



Output vs. Enable Input

Pin Configuration



SOT-23-5 (M5)

Pin Description

Pin Number	Pin Name	Pin Function
1	IN	Supply (Input): +3V to +5V supply.
2	GND	Ground: Power return.
3	OUT	Output: Charge pump output. Connect to load.
4	NC	Not internally connected.
5	EN	Enable (Input): CMOS compatible input. EN high ($V_{EN} = V_{IN}$) enables the charge pump . EN low (V_{IN} = 0V) disables the charge pump.

Absolute Maximum Ratings

Input Voltage (V_{IN}) .... +5.5V

Enable Voltage (V_{EN}) .... V_{IN} + 1.3V

Ambient Temperature Range (T_A) .... –40°C to +85°C

Lead Temperature, Soldering 10sec. ....300°C

Package Thermal Resistance

SOT-23-5 θ_{JA} .... 220°C/W

SOT-23-5 θ_{JC} .... 130°C/W

Electrical Characteristics

Parameter	Condition (Note 1)	Min	Typ	Max	Units
Output Voltage, Enabled	$V_{IN} = 3V, V_{EN} = V_{IN}, C_{OUT} = 1000pF, R_L = 2k\Omega$	4.5	5		V
	$V_{IN} = 5V, V_{EN} = V_{IN}, C_{OUT} = 1000pF, R_L = 2k\Omega$	8.1	9		V
Output Voltage, Disabled	$V_{IN} = 3V, V_{EN} = GND, C_{OUT} = 1000pF, R_L = 2k\Omega$	.9	1.0	1.3	V
	$V_{IN} = 5V, V_{EN} = GND, C_{OUT} = 1000pF, R_L = 2k\Omega$	2.9	3.0	3.3	V
Input Current	$V_{IN} = 3V, V_{EN} = V_{IN}, R_L = 2k\Omega$		14.5	19.5	mA
	$V_{IN} = 5V, V_{EN} = V_{IN}, R_L = 2k\Omega$		28.5	38.5	mA
Quiescent Current	$V_{IN} = 3V, V_{EN} < 0.4V$	1.5		3	µA
	$V_{IN} = 5V, V_{EN} < 0.4V$	3.5		5	µA
Output Current	$V_{IN} = 3V, V_{EN} = V_{IN}, V_{OUT} = V_{OUT\ min}$	1.9	2.5		mA
	$V_{IN} = 5V, V_{EN} = V_{IN}, V_{OUT} = V_{OUT\ min}$	3.4	4.5		mA
Enable Threshold	$V_{IN} = 3V$		1.5		V
	$V_{IN} = 5V$		2.5		V
Enable Current	$V_{IN} = 5V, V_{EN} = V_{IN}$			10	µA
Turn-On Time	$V_{IN} = 3V$ Load = 2kΩ, C_{OUT} = 1000pF, **Note 2**		200		ns
Turn-Off Time	$V_{IN} = 3V$ Load = 2kΩ, C_{OUT} = 1000pF, **Note 3**		1.3		µs

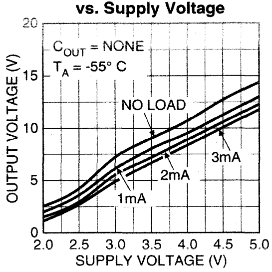
General Note: Devices are ESD protected, however handling precautions are recommended.

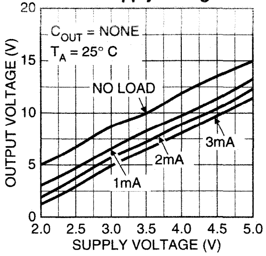
Note 1: Typicals values at T_A = 25°C. Minimum and maximum values at $-40°C \le T_A \le +85°C$.

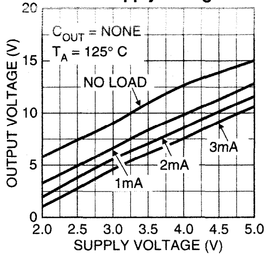
Note 2: Turn-on time is the time between $V_{EN} = 0.5 \times V_{IN}$ and $V_{OUT} = 0.9\ (V_{OUTmax} - V_{OUTmin})$ for a rising EN input.

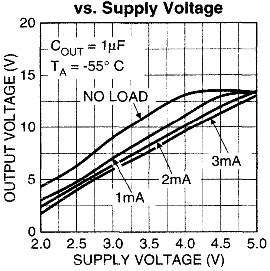
Note 3: Turn-off time is the time between $V_{EN} = 0.5 \times V_{IN}$ and $V_{OUT} = V_{IN} - 1.9V$ for a falling EN input.

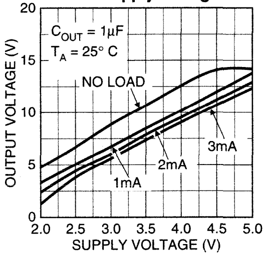
Typical Characteristics

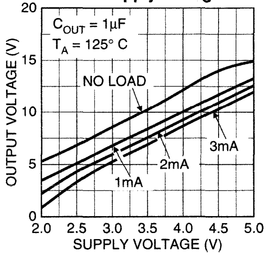

Output Voltage vs. Supply Voltage

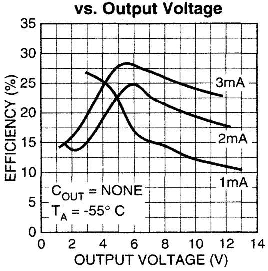

Output Voltage vs. Supply Voltage

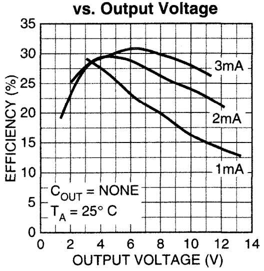

Output Voltage vs. Supply Voltage

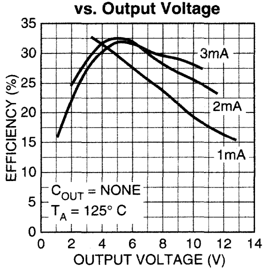

Output Voltage vs. Supply Voltage

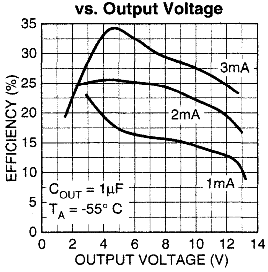

Output Voltage vs. Supply Voltage

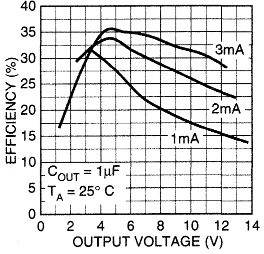

Output Voltage vs. Supply Voltage

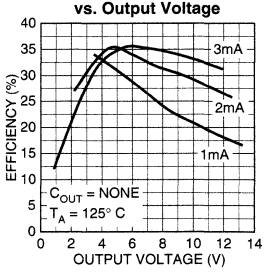

Efficiency vs. Output Voltage


Efficiency vs. Output Voltage

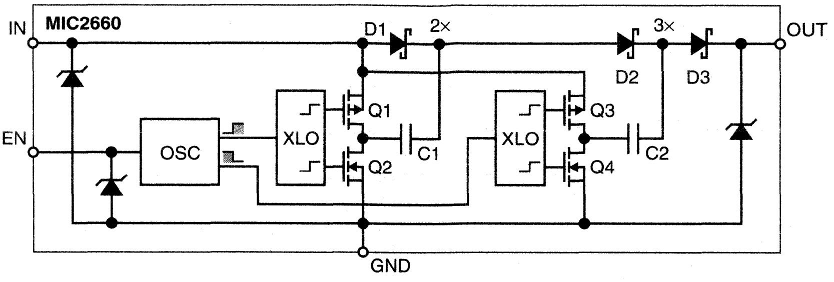

Efficiency vs. Output Voltage


Efficiency vs. Output Voltage


Efficiency vs. Output Voltage


Efficiency vs. Output Voltage

Block Diagram



Functional Description

Refer to the block diagram.

The MIC2660 charge pump consists of an oscillator and a voltage tripler. A logic-high applied to EN activates the charge pump. The charge pump produces an output voltage that is higher than the input voltage.

Supply Input

IN (supply input) is rated for +2.7V to +5.5V.

Ouput

OUT is connected to IN, less 3 diode drops, at all times.

Enable

EN (enable) is a CMOS input. A logic low turns the oscillator off. The threshold is approximately half the supply voltage. A floating EN input may cause unpredictable operation.

Oscillator

The oscillator produces a square wave at approximately 18MHz. It has a noninverting and an inverting output.

Crossover Lockout

The charge pump contains two crossover lockout (XLO) circuits. Each crossover lockout circuit drives a totem pole, consisting of a P-channel MOSFET and an N-channel MOSFET. The crossover lockout alternately switches the MOSFETs with no significant transition current (shoot-through current from supply to ground).

Tripler

Voltage stepup is performed by charging an internal capacitor then switching the charged capacitor in series with the supply voltage to produce a higher voltage. A description of the nominal voltage tripler output is:

$$V_{OUT} = 3V_{IN} - 3V_D.$$

where:

V_{OUT} = output voltage
V_{IN} = supply voltage
V_D = voltage drop across forward biased diode

All formulas are simplified. Refer to the last paragraph of this subsection about the actual output voltage.

The following sequence describes the basic operation of the tripler by showing how the voltage at the "2×" and "3×" nodes, $V_{2\times}$ and $V_{3\times}$, increases.

Q2 turns on, completing the ground path to charge C1 (and the 2× node) to the supply voltage, less a diode voltage drop.

$$V_{2\times\,(\text{charging})} = V_{IN} - V_{D1}$$

After Q2 turns off, Q1 turns on. The Q1-Q2 side of C1 is switched (offset upward) from ground to V_{IN}. The 2× node, that was nominally at the supply voltage, becomes nominally twice the supply voltage.

$$V_{2\times} = V_{IN} - V_{D1} + \mathbf{V_{IN}}$$

While Q1 is on, Q4 is also on. When Q4 is on, the nominally doubled voltage at the 2× node is applied across C2, through D2.

$$V_{3\times\,(\text{charging})} = V_{IN} - V_{D1} + V_{IN} - \mathbf{V_{D2}}$$

After Q4 turns off, Q3 turns on. The Q3-Q4 side of C2 is switched from ground to V_{IN}. The 3× node, that was nominally twice the supply voltage, becomes nominally three times the supply voltage.

$$V_{3\times} = V_{IN} - V_{D1} + V_{IN} - V_{D2} + \mathbf{V_{IN}}$$

The tripled voltage is available at the output through D3.

$$V_{OUT} = V_{IN} - V_{D1} + V_{IN} - V_{D2} + V_{IN} - \mathbf{V_{D3}}$$

The output is nominally 3 times the supply voltage less the voltage drop across three diodes.

The actual output is lower. These simplified formulas do not show that the voltage across the capacitors decreases when charge flows to the following stage or output. An actual device also has some internal loss.

ESD Protection

Zener diodes are provided at IN, EN, and OUT to limit ESD voltage.

Applications Information

Electromagnetic Interference

The 18MHz oscillator may cause interference to radio circuits. 0.01µF bypass capacitors should be mounted close to the IN and OUT terminals.

Low-Side MOSFET Charge-Pump Driver

A standard MOSFET requires approximately 15V to fully enhance the gate for minimum $R_{DS(on)}$. Substituting a logic-level MOSFET reduces the required gate voltage, allowing an MIC2660 to be used as an low-side FET driver.

A 3V powered MIC2660 will fully enhance a **logic-level** N-channel MOSFET low-side switch, with a 5k gate pull-down resistor, in less than 1ms after the enable pin rises above 1.5V. The 1nF MOSFET gate capacitance will be discharged to turn-off in less than 10ms after the enable pin goes below 1.5V.

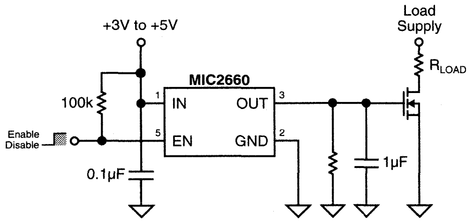


Figure 1. Charge-Pump Driver

An MIC2660 boosts a 5V input to 9V–12V to fully enhance an N-channel MOSFET, which may have its drain connected to a higher voltage, through a high-side load. A TTL high signal applied to CS enables the internal oscillator, which quickly develops 9V–12V at the gate of the MOSFET, clamped by a zener diode. A resistor from the gate to ground ensures that the FET will turn off quickly when the MIC2660 is turned off.

Charge-Pump/Dump

A large capacitor can be charged to the **unloaded** tripled voltage output after a time based on the maximum current provided by the MIC2660. A 1000µF Capacitor can be charged from 2V to approximately 12V in less than 3 seconds by a 5V powered MIC2660. (i = C *dv*/*dt*).

Once charged, a maximum current of 3mA may be drawn continuously at the 12V level. A high value bleeder resistor (100k) is not needed to prevent spikes from exceeding the capacitor voltage rating, since the MIC2660's internal 15V ESD zener limits maximum output. A 68Ω resistor in series with the output limits short-circuit current to 30mA.

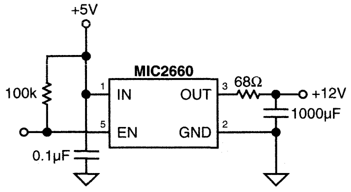


Figure 2. Charge-Pump/Dump

5-Volt Lamp Flasher

An IttyBitty MIC1557 oscillator provides a short pulse once per second, enabling the CS pin of an MIC2660, which charges the gate-to-drain capacitance of a logic-level N-channel MOSFET to approximately 9V, which turns on a lamp. When the CS pin is low, a 2k resistor discharges the gate capacitance, turning off the lamp. A resistor (R_S) in series with a diode determines the "on" time to approximately $R_S || R_T \times C_T$,while R_T and C_T set the "off" time to $1.1 R_T \times C_T$.

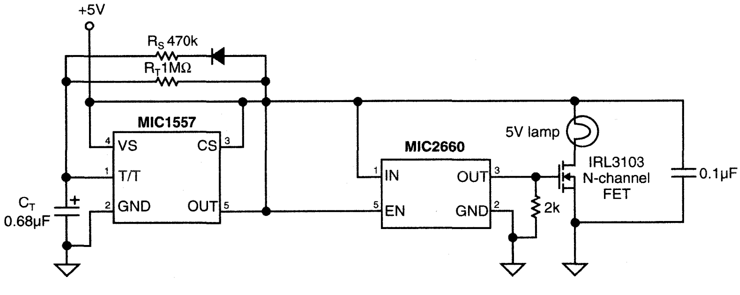


Figure 3. 5-Volt Lamp Flasher

LM4040/4041

Precision Micropower Shunt Voltage Reference

Preliminary Information

General Description

Ideal for space critical applications, the LM4040 and LM4041 precision voltage references are available in the sub-miniature (3mm × 1.3mm) SOT-23 surface-mount package, the SO-8 surface-mount package, or the TO-92 package.

The LM4040 is the available in several fixed reverse breakdown voltages: 2.500V, 4.096V, 5.000V, and 10.000V.

The LM4041 is available with a fixed 1.225V or an adjustable reverse breakdown voltage.

The LM4040 and LM4041's advanced design eliminates the need for an external stabilizing capacitor while ensuring stability with any capacitive load, making them easy to use.

The minimum operating current increases from 60μA for the LM4041-1.2 to 100μA for the LM4040-10.0. LM4040 versions have a maximum operating current of 15mA. LM4041 versions have a maximum operating current of 12mA.

The LM4040 and LM4041 utilizes zener-zap reverse breakdown voltage trim during wafer sort to ensure that the prime parts have an accuracy of better than ±0.5% (C grade) at 25°C. Bandgap reference temperature drift curvature correction and low dynamic impedance ensure stable reverse breakdown voltage accuracy over a wide range of operating temperatures and currents.

Features

- Small Package: SOT-23, TO-92, and SO-8
- No output capacitor required
- Tolerates capacitive loads
- Fixed reverse breakdown voltages of 1.225, 2.500V, 4.096V, 5.000V, and 10.000V
- Adjustable reverse breakdown version
- Contact Micrel for parts with extended temperature range.

Key Specifications

- Output voltage tolerance (C grade, 25°C) .. ±0.5% (max)
- Low output noise (10Hz to 100Hz)
  - LM4040 .... $35\mu V_{RMS}$ (typ)
  - LM4041 .... $20\mu V_{RMS}$ (typ)
- Wide operating current range
  - LM4040 .... 60μA to 15mA
  - LM4041 .... 60μA to 12mA
- Industrial temperature range .... –40°C to +85°C
- Low temperature coefficient .... 100ppm/°C (max)

Applications

- Battery-Powered Equipment
- Data Acquisition Systems
- Instrumentation
- Process Control
- Energy Management
- Product Testing
- Automotive Electronics
- Precision Audio Components

Typical Applications

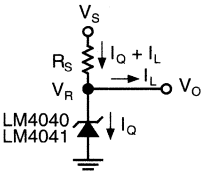


Figure 1. LM4040, LM4041 Fixed Shunt Regulator Application

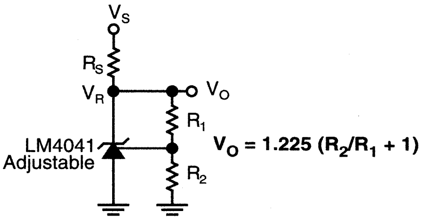
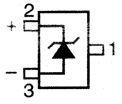


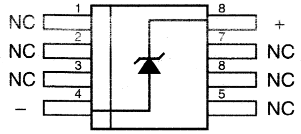
Figure 2. LM4041 Adjustable Shunt Regulator Application

Pin Configuration

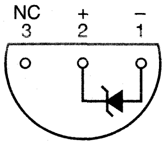


Pin 1 must float or be connected to pin 3.

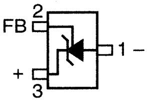
Fixed Version
SOT-23 (M3) Package
Top View



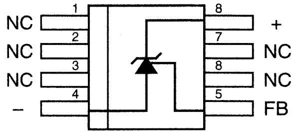
Fixed Version
SO-8 (M) Package
Top View



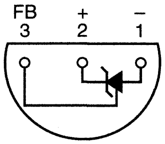
Fixed Version
TO-92 (Z) Package
Bottom View



Adjustable Version
SOT-23 (M3) Package
Top View



Adjustable Version
SO-8 (M) Package
Top View



Adjustable Version
TO-92 (Z) Package
Bottom View

Ordering Information

Part Number	Voltage	Accuracy, Temp. Coefficient
LM4040CIM3-2.5	2.500V	±0.5%, 100ppm/°C
LM4040DIM-2.5	2.500V	±1.0%, 150ppm/°C
LM4040DIM3-2.5	2.500V	±1.0%, 150ppm/°C
LM4040DIZ-2.5	2.500V	±1.0%, 150ppm/°C
LM4040EIM3-2.5	2.500V	±2.0%, 150ppm/°C
LM4040CIM3-4.1	4.096V	±0.5%, 100ppm/°C
LM4040DIM-4.1	4.096V	±1.0%, 150ppm/°C
LM4040DIM3-4.1	4.096V	±1.0%, 150ppm/°C
LM4040DIZ-4.1	4.096V	±1.0%, 150ppm/°C
LM4040CIM3-5.0	5.000V	±0.5%, 100ppm/°C
LM4040DIM-5.0	5.000V	±1.0%, 150ppm/°C
LM4040DIM3-5.0	5.000V	±1.0%, 150ppm/°C
LM4040DIZ-5.0	5.000V	±1.0%, 150ppm/°C

Part Number	Voltage	Accuracy, Temp. Coefficient
LM4040CIM3-10.0	10.00V	±0.5%, 100ppm/°C
LM4040DIM-10.0	10.00V	±1.0%, 150ppm/°C
LM4040DIM3-10.0	10.00V	±1.0%, 150ppm/°C
LM4040DIZ-10.0	10.00V	±1.0%, 150ppm/°C
LM4041CIM3-1.2	1.225V	±0.5%, 100ppm/°C
LM4041DIM-1.2	1.225V	±1.0%, 150ppm/°C
LM4041DIM3-1.2	1.225V	±1.0%, 150ppm/°C
LM4041DIZ-1.2	1.225V	±1.0%, 150ppm/°C
LM4041EIM3-1.2	1.225V	±2.0%, 150ppm/°C
LM4041CIM3-ADJ	1.24V to 10V	±0.5%, 100ppm/°C
LM4041DIM-ADJ	1.24V to 10V	±1.0%, 150ppm/°C
LM4041DIM3-ADJ	1.24V to 10V	±1.0%, 150ppm/°C
LM4041DIZ-ADJ	1.24V to 10V	±1.0%, 150ppm/°C

SOT-23 Package Markings

Example	Field	Code
R _ _	1st Character	R = Reference

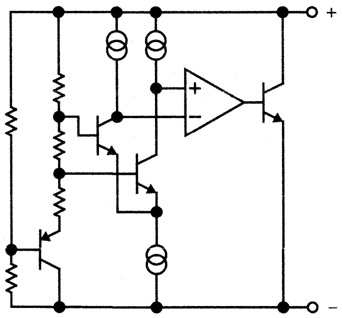
Example: R4C represents *Reference, 4.096V, ±0.5%* (LM4040CIM3-4.1)

Example	Field	Code
_ 4 _	2nd Character	1 = 1.225V 2 = 2.500V 4 = 4.096V 5 = 5.000V 10 = 10.00V A = Adjustable

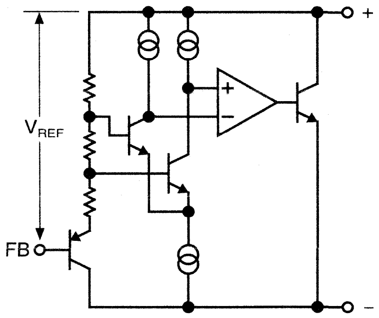
Example	Field	Code
_ _ A	3rd Character	C = ±0.5% D = ±1.0% E = ±2.0%

Note: If 3rd character is omitted, container will indicate tolerance.

Functional Diagram LM4040, LM4041 Fixed



Functional Diagram LM4041 Adjustable



Absolute Maximum Ratings

Reverse Current	20mA
Forward Current	10mA
Maximum Output Voltage	
LM4041-Adjustable	15V
Power Dissipation (T_A = 25°C) (Note 2)	
M Package	540mW
M3 Package	306mW
Z Package	550mW
Storage Temperature	–65°C to +150°C
Lead Temperature	
M and M3 Packages	
Vapor phase (60 seconds)	+215°C
Infrared (15 seconds)	+220°C
Z Package	
Soldering (10 seconds)	+260°C
ESD Susceptibility	
Human Body Model (Note 3)	2kV
Machine Model (Note 3)	200V

Operating Ratings (Notes 1 & 2)

Temperature Range	
($T_{MIN} \le T_A \le T_{MAX}$)	$-40°C \le T_A \le +85°C$
Reverse Current	
LM4040-2.5	60µA to 15mA
LM4040-4.1	68µA to 15mA
LM4040-5.0	74µA to 15mA
LM4040-10.0	100µA to 15mA
LM4041-1.2	60µA to 12mA
LM4041-ADJ	60µA to 12mA
Output Voltage Range	
LM4041-ADJ	1.24V to 10V

LM4040 and LM4041 Applications Information

The LM4040 and LM4041 have been designed for stable operation without the need of an external capacitor connected between the (+) and (–) pins. If a bypass capacitor is used, the references remain stable.

SOT-23 Versions

LM4040-x.x and LM4041-1.2s in the SOT-23 packages have a parasitic Schottky diode between pin 3 (–) and pin 1 (die attach interface connect). Pin 1 of the SOT-23 package must float or be connected to pin 3. LM4041-ADJs use pin 1 as the (–) output.

Conventional Shunt Regulator

In a conventional shunt regulator application (see Figure 1), an external series resistor (R_S) is connected between the supply voltage and the LM4040-x.x or LM4041-1.2 reference. R_S determines the current that flows through the load (I_L) and the reference (I_Q). Since load current and supply voltage may vary, R_S should be small enough to supply at least the minimum acceptable I_Q to the reference even when the supply voltage is at its minimum and the load current is at its

(continued following LM4041 typical characteristics)

LM4040-2.5 Electrical Characteristics

Symbol	Parameter	Conditions	Typical (Note 4)	LM4040CIM3 Limits (Note 5)	LM4040DIM LM4040DIM3 LM4040DIZ Limits (Note 5)	LM4040EIM3 Limits (Note 5)	Units (Limit)
V_R	Reverse Breakdown Voltage	I_R = 100µA	2.500				V
	Reverse Breakdown Voltage Tolerance	I_R = 100µA		±12 **±29**	±25 **±49**	±50 **±74**	mV (max) mV (max)
I_{RMIN}	Minimum Operating Current		45	60 **65**	65 **70**	µA 65 **70**	µA (max) µA (max)
$\Delta V_R/\Delta T$	Average Reverse Breakdown Voltage Temperature Coefficient	I_R = 10mA I_R = 1mA I_R = 100µA	20 15 15	**100**	**150**	**150**	ppm/°C ppm/°C (max) ppm/°C (max)
$\Delta V_R/\Delta I_R$	Reverse Breakdown Voltage Change with Operating Current Change	$I_{RMIN} \leq I_R$ 1mA	0.3	0.8 **1.0**	1.0 **1.2**	1.0 **1.2**	mV mV (max) mV (max)
		1mA ≤ I_R 15mA	2.5	6.0 **8.0**	8.0 **10.0**	8.0 **10.0**	mV mV (max) mV (max)
Z_R	Reverse Dynamic Impedance	I_R = 1mA, f = 120Hz $I_{AC} = 0.1\ I_R$	0.3	0.9	1.1	1.1	Ω Ω (max)
e_N	Wideband Noise	I_R = 100µA 10Hz ≤ f ≤ 10kHz	35				μV_{RMS}
ΔV_R	Reverse Breakdown Voltage Long Term Stability	t = 1000hrs T = 25°C ±0.1°C I_R = 100µA	120				ppm

LM4040-4.1 Electrical Characteristics

Symbol	Parameter	Conditions	Typical (Note 4)	LM4040CIM3 Limits (Note 5)	LM4040DIM LM4040DIM3 LM4040DIZ Limits (Note 5)	Units (Limits)
V_R	Reverse Breakdown Voltage	I_R = 100µA	4.096			V
	Reverse Breakdown Voltage Tolerance	I_R = 100µA		±20 **±47**	±41 **±81**	mV (max) mV (max)
I_{RMIN}	Minimum Operating Current		50	68 **73**	73 **78**	µA µA (max) µA (max)
$\Delta V_R/\Delta T$	Average Reverse Breakdown Voltage Temperature Coefficient	I_R = 10mA I_R = 1mA I_R = 100µA	30 20 20	**100**	**150**	ppm/°C ppm/°C (max) ppm/°C (max)
$\Delta V_R/\Delta I_R$	Reverse Breakdown Voltage Change with Operating Current Change	$I_{RMIN} \leq I_R$ 1mA	0.5	0.9 **1.2**	1.2 **1.5**	mV mV (max) mV (max)
		1mA ≤ I_R 15mA	3.0	7.0 **10.0**	9.0 **13.0**	mV mV (max) mV (max)
Z_R	Reverse Dynamic Impedance	I_R = 1mA, f = 120Hz $I_{AC} = 0.1\ I_R$	0.5	1.0	1.3	Ω Ω (max)
e_N	Wideband Noise	I_R = 100µA 10Hz ≤ f ≤ 10kHz	80			μV_{RMS}
ΔV_R	Reverse Breakdown Voltage Long Term Stability	t = 1000hrs T = 25°C ±0.1°C I_R = 100µA	120			ppm

Boldface limits apply for $T_A = T_J = T_{MIN}$ to T_{MAX}; all other limits $T_A = T_J$ = 25°C. The grades C, D, and E designate initial Reverse Breakdown Voltage tolerance of ±0.5%, ±1.0%, and ±2.0 respectively.

LM4040-5.0 Electrical Characteristics

Symbol	Parameter	Conditions	Typical (Note 4)	LM4040CIM3 Limits (Note 5)	LM4040DIM LM4040DIM3 LM4040DIZ Limits (Note 5)	Units (Limits)
V_R	Reverse Breakdown Voltage	$I_R = 100\mu A$	5.000			V
	Reverse Breakdown Voltage Tolerance	$I_R = 100\mu A$		±25 **±58**	±50 **±99**	mV (max) mV (max)
I_{RMIN}	Minimum Operating Current		54	74 **80**	79 **85**	µA µA (max) µA (max)
$\Delta V_R/\Delta T$	Average Reverse Breakdown Voltage Temperature Coefficient	$I_R = 10mA$ $I_R = 1mA$ $I_R = 100\mu A$	30 20 20	**100**	**150**	ppm/°C ppm/°C (max) ppm/°C (max)
$\Delta V_R/\Delta I_R$	Reverse Breakdown Voltage Change with Operating Current Change	$I_{RMIN} \leq I_R$ 1mA	0.5	1.0 **1.3**	1.3 **1.8**	mV mV (max) mV (max)
		$1mA \leq I_R$ 15mA	3.5	8.0 **12.0**	10.0 **15.0**	mV mV (max) mV (max)
Z_R	Reverse Dynamic Impedance	$I_R = 1mA$, $f = 120Hz$ $I_{AC} = 0.1\ I_R$	0.5	1.1	1.5	Ω Ω (max)
e_N	Wideband Noise	$I_R = 100\mu A$ $10Hz \leq f \leq 10kHz$	80			μV_{RMS}
ΔV_R	Reverse Breakdown Voltage Long Term Stability	t = 1000hrs T = 25°C ±0.1°C $I_R = 100\mu A$	120			ppm

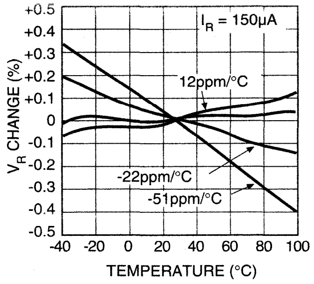
LM4040-10.0 Electrical Characteristics

Symbol	Parameter	Conditions	Typical (Note 4)	LM4040CIM3 Limits (Note 5)	LM4040DIM LM4040DIM3 LM4040DIZ Limits (Note 5)	Units (Limits)
V_R	Reverse Breakdown Voltage	$I_R = 150\mu A$	10.00			V
	Reverse Breakdown Voltage Tolerance	$I_R = 150\mu A$		±50 **±115**	±100 **±198**	mV (max) mV (max)
I_{RMIN}	Minimum Operating Current		75	100 **103**	110 **113**	µA µA (max) µA (max)
$\Delta V_R/\Delta T$	Average Reverse Breakdown Voltage Temperature Coefficient	$I_R = 10mA$ $I_R = 1mA$ $I_R = 150\mu A$	40 20 20	**100**	**150**	ppm/°C ppm/°C (max) ppm/°C (max)
$\Delta V_R/\Delta I_R$	Reverse Breakdown Voltage Change with Operating Current Change	$I_{RMIN} \leq I_R$ 1mA	0.8	1.5 **3.5**	2.0 **4.0**	mV mV (max) mV (max)
		$1mA \leq I_R$ 15mA	8.0	12.0 **23.0**	18.0 **29.0**	mV mV (max) mV (max)
Z_R	Reverse Dynamic Impedance	$I_R = 1mA$, $f = 120Hz$ $I_{AC} = 0.1\ I_R$	0.7	1.7	2.3	Ω Ω (max)
e_N	Wideband Noise	$I_R = 150\mu A$ $10Hz \leq f \leq 10kHz$	180			μV_{RMS}
ΔV_R	Reverse Breakdown Voltage Long Term Stability	t = 1000hrs T = 25°C ±0.1°C $I_R = 150\mu A$	120			ppm

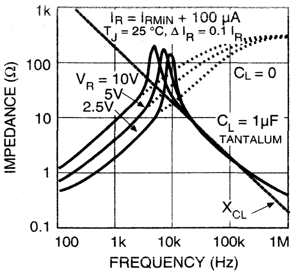
Boldface limits apply for $T_A = T_J = T_{MIN}$ to T_{MAX}; all other limits $T_A = T_J = 25°C$. The grades C and D designate initial Reverse Breakdown Voltage tolerance of ±0.5% and ± 1.0% respectively.

LM4040 Typical Characteristics

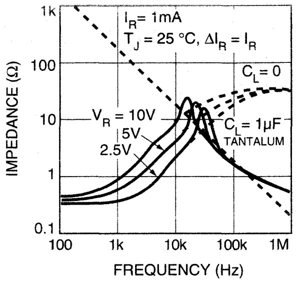
Temperature Drift for Different Average Temperature Coefficient



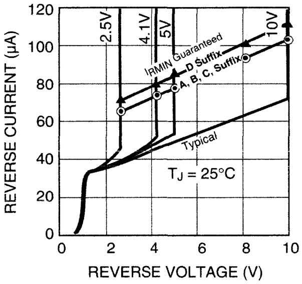
Output Impedance vs. Frequency



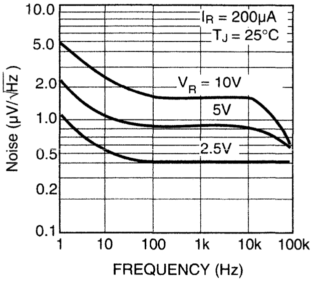
Output Impedance vs. Frequency

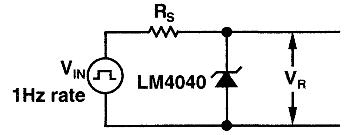


Reverse Characteristics and Minimum Operating Current



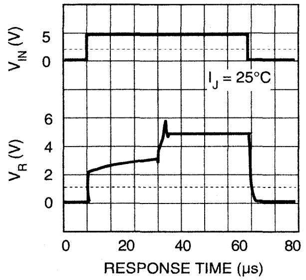
Noise Voltage vs. Frequency



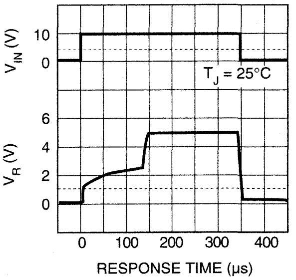


Test Circuit

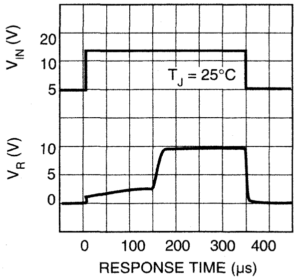
LM4040-2.5 R_S = 30k



LM4040-5.0 R_S = 30k



LM4040-10.0 R_S = 30k



LM4041-1.2 Electrical Characteristics

Symbol	Parameter	Conditions	Typical (Note 4)	LM4041CIM3 Limits (Note 5)	Units (Limit)
V_R	Reverse Breakdown Voltage	$I_R = 100\mu A$	1.225		V
	Reverse Breakdown Voltage Tolerance	$I_R = 100\mu A$		±6 **±14**	mV (max) mV (max)
I_{RMIN}	Minimum Operating Current		45	 60 **65**	µA µA (max) µA (max)
$\Delta V_R/\Delta T$	Average Reverse Breakdown Voltage Temperature Coefficient	$I_R = 10mA$ $I_R = 1mA$ $I_R = 100\mu A$	20 15 15	**±100**	ppm/°C ppm/°C (max) ppm/°C (max)
$\Delta V_R/\Delta I_R$	Reverse Breakdown Voltage Change with Operating Current Change	$I_{RMIN} \leq I_R$ 1mA	0.7	 1.5 **2.0**	mV mV (max) mV (max)
		$1mA \leq I_R$ 12mA	4.0	 6.0 **8.0**	mV mV (max) mV (max)
Z_R	Reverse Dynamic Impedance	$I_R = 1mA$, f = 120Hz $I_{AC} = 0.1\ I_R$	0.5	 1.5	Ω Ω (max)
e_N	Wideband Noise	$I_R = 100\mu A$ $10Hz \leq f \leq 10kHz$	20		μV_{RMS}
ΔV_R	Reverse Breakdown Voltage Long Term Stability	t = 1000hrs T = 25°C ±0.1°C $I_R = 100\mu A$	120		ppm

Symbol	Parameter	Conditions	Typical (Note 4)	LM4041DIM LM4041DIM3 LM4041DIZ Limits (Note 5)	LM4041EIM3 Limits (Note 5)	Units (Limit)
V_R	Reverse Breakdown Voltage	$I_R = 100\mu A$	1.225			V
	Reverse Breakdown Voltage Tolerance	$I_R = 100\mu A$		±12 **±24**	±25 **±36**	mV (max) mV (max)
I_{RMIN}	Minimum Operating Current		45	 65 **70**	 65 **70**	µA µA (max) µA (max)
$\Delta V_R/\Delta T$	Average Reverse Breakdown Voltage Temperature Coefficient	$I_R = 10mA$ $I_R = 1mA$ $I_R = 100\mu A$	20 15 15	**±150**	**±150**	ppm/°C ppm/°C (max) ppm/°C (max)
$\Delta V_R/\Delta I_R$	Reverse Breakdown Voltage Change with Operating Current Change	$I_{RMIN} \leq I_R$ 1mA	0.3	 2.0 **2.5**	 2.0 **2.5**	mV mV (max) mV (max)
		$1mA \leq I_R$ 15mA	2.5	 8.0 **10.0**	 8.0 **10.0**	mV mV (max) mV (max)
Z_R	Reverse Dynamic Impedance	$I_R = 1mA$, f = 120Hz $I_{AC} = 0.1\ I_R$	0.3	 2.0	 2.0	Ω Ω (max)
e_N	Wideband Noise	$I_R = 100\mu A$ $10Hz \leq f \leq 10kHz$	35			μV_{RMS}
ΔV_R	Reverse Breakdown Voltage Long Term Stability	t = 1000hrs T = 25°C ±0.1°C $I_R = 100\mu A$	120			ppm

Boldface limits apply for $T_A = T_J = T_{MIN}$ to T_{MAX}; all other limits $T_A = T_J = 25°C$. The grades C, D, and E designate initial Reverse Breakdown Voltage tolerance of ±0.5%, ± 1.0%, and ±2.0 respectively.

LM4041-Adjustable Electrical Characteristics

Symbol	Parameter	Conditions	Typical (Note 4)	LM4041CIM3 Limits (Note 5)	LM4041DIM LM4041DIM3 LM4041DIZ Limits (Note 5)	Units (Limit)
V_{REF}	Reference Breakdown Voltage	$I_R = 100\mu A$ $V_{OUT} = 5V$	1.233			V
	Reference Breakdown Voltage Tolerance (Note 8)	$I_R = 100\mu A$		±6.2 **±14**	±12 **±24**	mV (max) mV (max)
I_{RMIN}	Minimum Operating Current		45	60 **65**	65 **70**	µA µA (max) µA (max)
ΔV_{REF} $/\Delta I_R$	Reference Voltage Change with Operating Current Change	$I_{RMIN} \le I_R$ 1mA SOT-23: $V_{OUT} \ge 1.6V$ (Note 7)	0.7	1.5 **2.0**	2.0 **2.5**	mV mV (max) mV (max)
		1mA $\le I_R$ 12mA SOT-23: $V_{OUT} \ge 1.6V$ (Note 7)	2	4 **6**	6 **8**	mV mV (max) mV (max)
ΔV_{REF} $/\Delta V_O$	Reference Voltage Change with Output Voltage Change	$I_R = 1mA$	−1.3	−2.0 **−2.5**	−2.5 **−3.0**	mV/V mV/V (max) mV/V (max)
I_{FB}	Feedback Current		60	100 **120**	150 **200**	nA nA (max) nA (max)
ΔV_{REF} $/\Delta T$	Average Reference Voltage Temperature Coefficient (Note 8)	$V_{OUT} = 5V$ $I_R = 10mA$ $I_R = 1mA$ $I_R = 100\mu A$	20 15 15	**±100**	**±150**	ppm/°C ppm/°C (max) ppm/°C (max)
Z_{OUT}	Dynamic Output Impedance	$I_R = 1mA$, f = 120Hz $I_{AC} = 0.1\ I_R$ $V_{OUT} = V_{REF}$ $V_{OUT} = 10V$	0.3 2			Ω Ω (max)
e_N	Wideband Noise	$I_R = 100\mu A$ 10Hz $\le f \le$ 10kHz	20			μV_{RMS}
ΔV_{REF}	Reference Voltage Long Term Stability	t = 1000hrs T = 25°C ±0.1°C $I_R = 100\mu A$	120			ppm

Boldface limits apply for $T_A = T_J = T_{MIN}$ to T_{MAX}; all other limits $T_J = 25°C$ unless otherwise specified (SOT-23, see Note 7), $I_{RMIN} \le I_R < 12mA$, $V_{REF} \le V_{OUT} \le 10V$. The grades C and D designate initial Reverse Breakdown Voltage tolerance of ±0.5% and ±1%, respectively for $V_{OUT} = 5V$.

LM4040 and LM4041 Electrical Characteristic Notes

Note 1 Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits. For guaranteed specification and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions.

Note 2 The maximum power dissipation must be derated at elevated temperatures and is dictated by T_{JMAX} (maximum junction temperature), θ_{JA} (junction to ambient thermal resistance), and T_A (ambient temperature). The maximum allowable power dissipation at any temperature is $PD_{MAX} = (T_{JMAX} - T_A)/\theta_{JA}$ or the number given in the Absolute Maximum Ratings, whichever is lower. For the LM4040 and LM4041, T_{JMAX} = 125°C, and the typical thermal resistance (θ_{JA}), when board mounted, is 185°C/W for the M package, 326°C/W for the SOT-23 package, and 180°C/W with 0.4" lead length and 170°C/W with 0.125" lead length for the TO-92 package.

Note 3 The human body model is a 100pF capacitor discharged through a 1.5kΩ resistor into each pin. The machine model is a 200pF capacitor discharged directly into each pin.

Note 4 Typicals are at T_J = 25°C and represent most likely parametric norm.

Note 5 Limits are 100% production tested at 25°C. Limits over temperature are guaranteed through correlation using Statistical Quality Control (SQL) methods.

Note 6 The boldface (over temperature limit for Reverse Breakdown Voltage Tolerance is defined as the room temperature Reverse Breakdown Voltage Tolerance $\pm[(\Delta V_R/\Delta T)(65°C)(V_R)]$. $\Delta V_R/\Delta T$ is the V_R temperature coefficient, 65°C is the temperature range from –40°C to the reference point of 25°C, and V_R is the reverse breakdown voltage. The total over temperature tolerance for the different grades follows:

C-grade: ±1.15% = ±0.5% ±100ppm/°C × 65°C
D-grade: ±1.98% = ±1.0% ±150ppm/°C × 65°C
E-grade: ±2.98% = ±1.0% ±150ppm/°C × 65°C

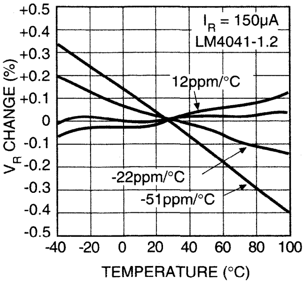
Example: The C-grade LM4040-2.5 has an over temperature Reverse Breakdown Voltage tolerance of ±2.5 × 1.15% = ±28.75mV.

Note 7 When $V_{OUT} \leq 1.6V$, the LM4041-ADJ in the SOT-23 package must operate at reduced I_R. This is caused by the series resistance of the die attach between the die (–) output and the package (–) output pin. See the Output Saturation (SOT-23 only) curve in the Typical Performance Characteristics section.

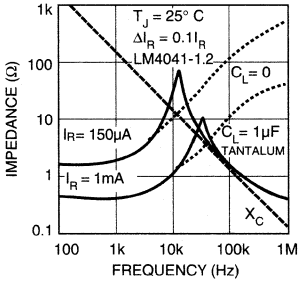
Note 8 Reference voltage and temperature coefficient will change with output voltage. See Typical Performance Characteristics curves.

LM4041 Typical Characteristics

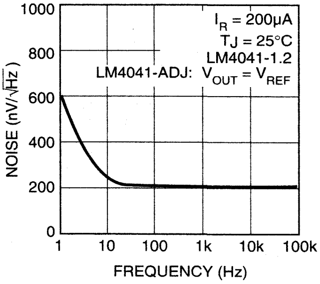
Temperature Drift for Different Average Temperature Coefficient



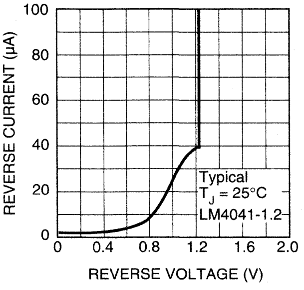
Output Impedence vs. Frequency



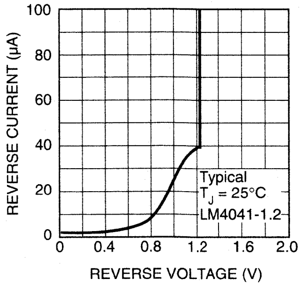
Voltage Impedance

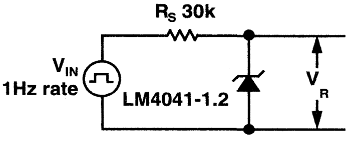


Reverse Characteristics and Minimum Operating Current



Reverse Characteristics and Minimum Operating Current

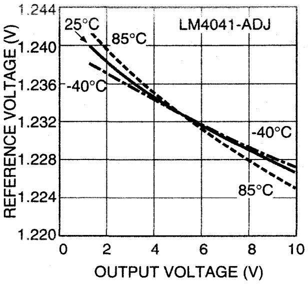




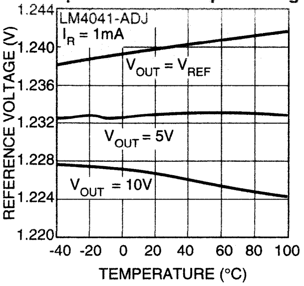
Test Circuit

LM4041 Typical Characteristics

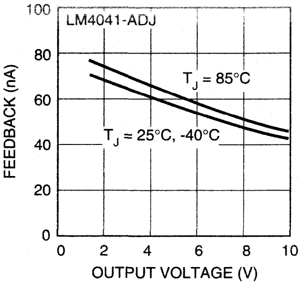
Reference Voltage vs. Output Voltage and Temperature



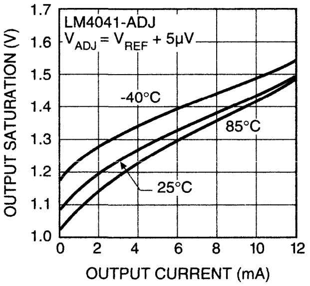
Reference Voltage vs. Temperature and Output Voltage



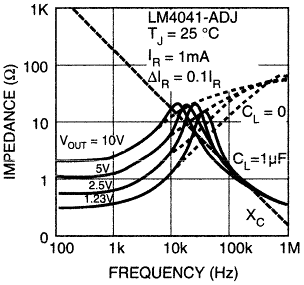
Feedback Current vs. Output Voltage and Temperature



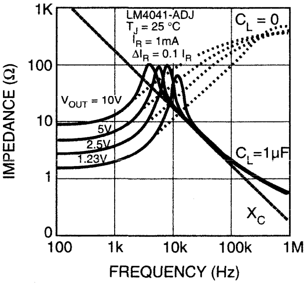
Output Saturation
(SOT-23 Only)



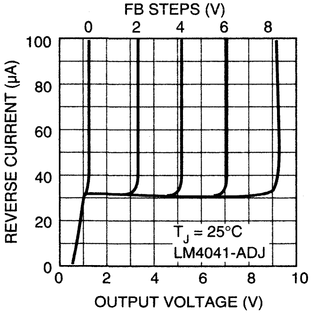
Output Impedence vs. Frequency *

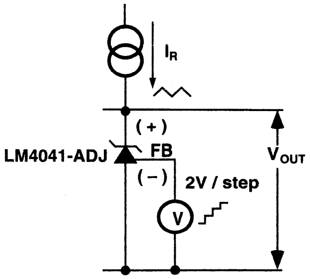


Output Impedence vs. Frequency *

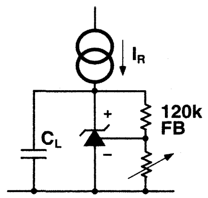


Reverse Characteristics †



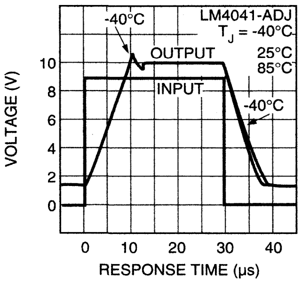


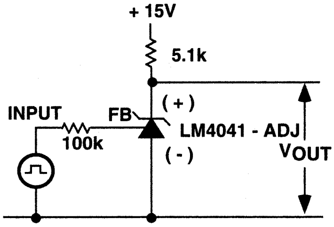
† Reverse Characteristics Test Circuit



*** Output Impedance vs. Freq. Test Circuit**

Large Signal Response †





‡ Large Signal Response Test Circuit

maximum value. When the supply voltage is at its maximum and I_L is at its minimum, R_S should be large enough so that the current flowing through the LM4040-x.x is less than 15mA, and the current flowing through the LM4041-1.2 or LM4041-ADJ is less than 12mA.

R_S is determined by the supply voltage (V_S), the load and operating current, (I_L and I_Q), and the reference's reverse breakdown voltage (V_R).

$$R_s = (V_s - V_R) / (I_L + I_Q)$$

Adjustable Regulator

The LM4041-ADJ's output voltage can be adjusted to any value in the range of 1.24V through 10V. It is a function of the internal reference voltage (V_{REF}) and the ratio of the external feedback resistors as shown in Figure 2. The output is found using the equation

(1) $V_O = V_{REF}' [(R2/R1) + 1]$

where V_O is the desired output voltage. The actual value of the internal V_{REF} is a function of V_O. The "corrected" V_{REF} is determined by

(2) $V_{REF}' = V_O (\Delta V_{REF} / \Delta V_O) + V_Y$

where V_O is the desired output voltage. $\Delta V_{REF} / \Delta V_O$ is found in the Electrical Characteristics and is typically −1.3mV/V and V_Y is equal to 1.233V. Replace the value of V_{REF}' in equation (1) with the value found using equation (2).

Note that actual output voltage can deviate from that predicted using the typical $\Delta V_{REF} / \Delta V_O$ in equation (2); for C-grade parts, the worst-case $\Delta V_{REF} / \Delta V_O$ is −2.5mV/V and $V_Y = 1.248V$.

The following example shows the difference in output voltage resulting from the typical and worst case values of $\Delta V_{REF} / \Delta V_O$:

Let $V_O = +9V$. Using the typical values of $\Delta V_{REF} / \Delta V_O$, V_{REF} is 1.228V. Choosing a value of R1 = 10kΩ, R2 = 63.272kΩ. Using the worst case $\Delta V_{REF} / \Delta V_O$ for the C-grade and D-grade parts, the output voltage is actually 8.965V and 8.946V respectively. This results in possible errors as large as 0.39% for the C-grade parts and 0.59% for the D-grade parts. Once again, resistor values found using the typical value of $\Delta V_{REF} / \Delta V_O$ will work in most cases, requiring no further adjustment.

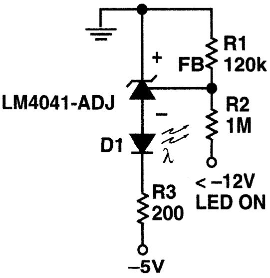


Figure 3. Voltage Level Detector

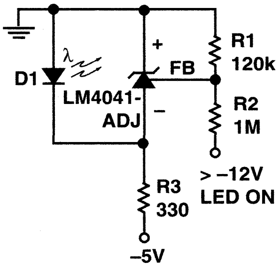


Figure 4. Voltage Level Detector

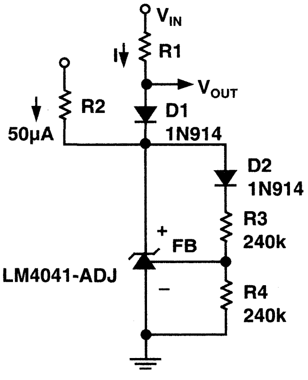


Figure 5. Fast Positive Clamp
$2.4V + \Delta V_{D1}$

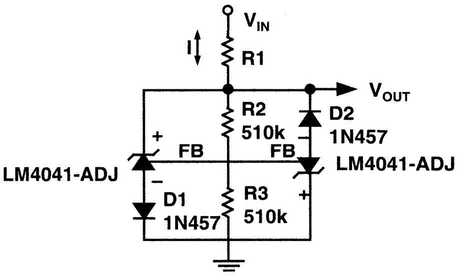


Figure 6. Bidirectional Clamp
±2.4V

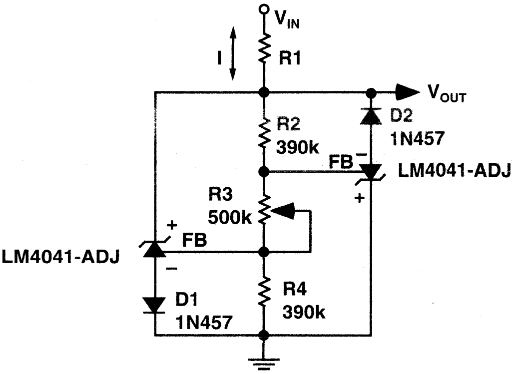


Figure 7. Bidirectional Adjustable Clamp ±18V to ±2.4V

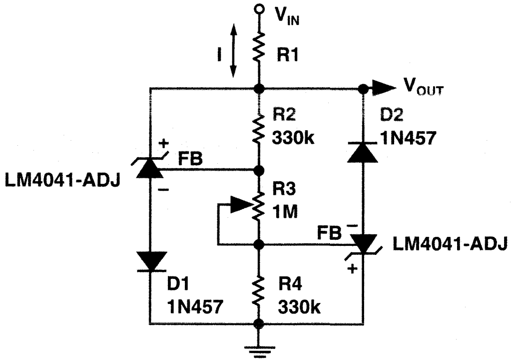
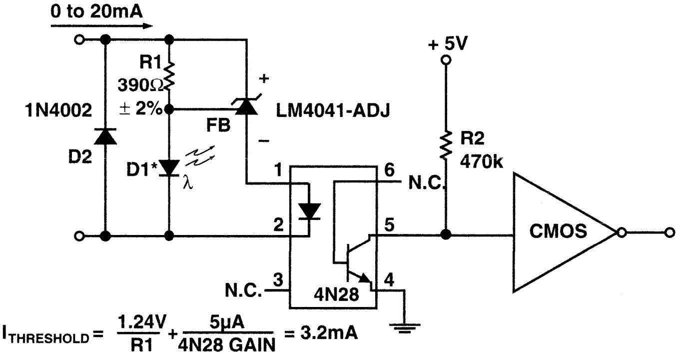
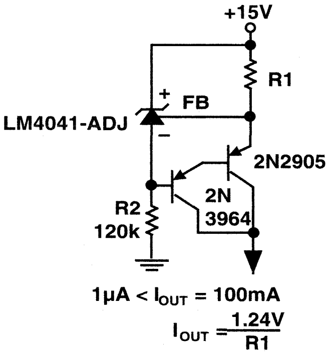


Figure 8. Bidirectional Adjustable Clamp ±2.4 to ±6V



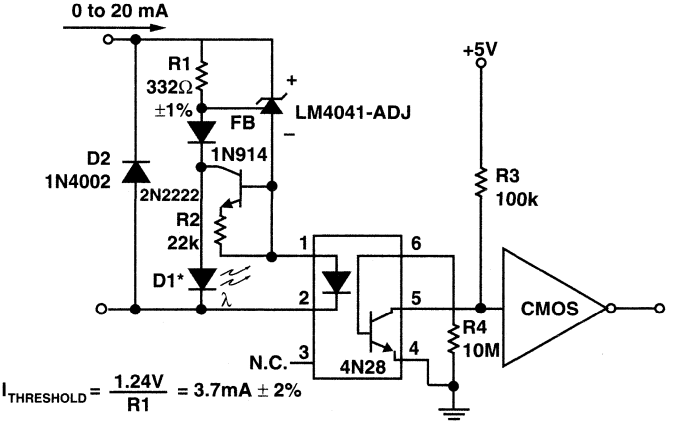
$$I_{THRESHOLD} = \frac{1.24V}{R1} + \frac{5\mu A}{4N28\ GAIN} = 3.2mA$$

Figure 9. Floating Current Detector



$1\mu A < I_{OUT} = 100mA$

$$I_{OUT} = \frac{1.24V}{R1}$$



$$I_{THRESHOLD} = \frac{1.24V}{R1} = 3.7mA \pm 2\%$$

Figure 10. Current Source **Figure 11. Precision Floating Current Detector**

* D1 can be any LED, V_F = 1.5V to 2.2V at 3mA. D1 may act as an indicator. D1 will be on if $I_{THRESHOLD}$ falls below the threshold current, except with I = O.

MPD8020

CMOS/DMOS Semicustom High-Voltage Array

Summary Information*

General Description

The Micrel MPD8020 is a *Smart Power* Application Specific Integrated Circuit (ASIC). The MPD8020 features an array of low-voltage CMOS analog and digital circuits and high-voltage DMOS power transistors on a monolithic integrated circuit. The MPD8020 provides the customer a proprietary design with size, reliability, performance advantages.

Quick Turnaround

Prepared wafers can be held prior to the final process (metallization) where the customer's unique interconnect pattern is applied. This speeds turnaround by allowing many of the fabrication steps to be completed before the final design is finished.

Voltage Ratings

The MPD8020's logic and analog circuitry operate from a single +5V to +15V supply. The high-voltage section operates from +20V to +100V. An optional internal charge pump, plus two external components, can drive the internal N-channel DMOS FET gates approximately 15V higher than the high-voltage supply as required by high-side switch applications.

Fabrication Process

The MPD8020 CMOS/DMOS Semicustom High-Voltage Array uses Micrel's proprietary process which combines TTL/CMOS compatible high-speed CMOS logic, CMOS analog, bipolar analog, and high-voltage DMOS power devices in single IC.

Package Options

- Dice
- 16-pin to 48-pin plastic DIPs
- 16-pin to 48-pin ceramic DIPs
- Ceramic LCCs
- PLCCs
- Surface mount packages
- Fused-lead PLCCs and DIPs
- Custom packages

Support

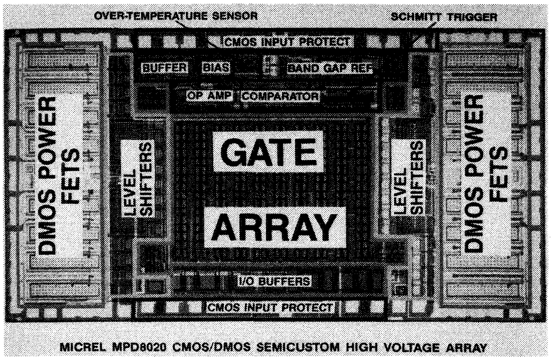
The MPD8020 is supported from concept to packaged ICs by Micrel's designers, CAD systems, CAE simulations (including SPICE, HILO, TIMVER), and an experienced fabrication and test group.

Features

- Sixteen 100V, 200mA, 10Ω, N-channel, DMOS power FETs with fully floating gates, drains, and sources
- DMOS can be paralleled for 100V, 3.2A, 0.625Ω, single, half-bridge, full-bridge, or bilateral switches
- 200 uncommitted CMOS gates array
- Twelve TTL/CMOS I/O buffers
- Three op amp/comparator/Schmitt trigger circuits
- One unity-gain analog buffer
- 1.25V/2.5V bandgap reference
- Overtemperature sensor
- Charge pump (drives high-side switch gates above V_{DD})
- Sixteen medium-current, current-sink drivers
- Sixteen high-voltage, level-shifting, high-side drivers
- Separate analog- and digital-ground pads
- Numerous logic, high-voltage, V_{CC}, and V_{DD} pads
- Resistors, capacitors, and a zener diode
- Military temperature specifications available
- Military, commercial, and power packages

Applications

- Switch-mode regulators
- Motor control
- Bilateral analog switch
- High-voltage switch
- Relay and solenoid driver
- Smart switch with bus decoder
- Half- or full-bridge driver
- 3-phase driver
- Lamp driver
- Differential line driver
- Automotive switch
- Printer solenoid driver
- High-voltage display driver



MPD8020 CMOS/DMOS/Bipolar Semicustom Array

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* Contact Micrel for more information.

Patents 4,951,101; 4,979,001

Available Macro Cells

- 16 fully floating 100V, 200mA, 10Ω vertical-DMOS FETs
- 16 high-voltage 100V P- and N-channel level shifters (configured from 32 cross coupled 20mA to 50mA P- and N-channel pairs)
- 200 CMOS gates in an uncommitted gate array
  - over 30 pre-designed logic "templates" of shift registers, decoders, flip-flops, NAND gates, NOR gates, etc.
  - general purpose op amps, comparators, and Schmitt triggers, implemented in the gate array
- 12 TTL/CMOS I/O buffers
- 16 logic drivers (with logic enable) for bottom-side DMOS drive
- 3 configurable op amp/comparator/Schmitt trigger cells configurable as:
  - ground or V_{CC} sensing amplifiers or comparators
  - folded cascode high-performance amplifiers
  - NPN input amplifiers
  - programmable bandwidth/power consumption amplifiers
- Unity-gain buffer with adaptive bias (to drive large loads with minimum quiescent current)
- 1.25V bandgap reference plus multiple programmable outputs up to V_{CC}
- Overtemperature protection circuit with programmable temperature trip points and hysteresis
- Master bias programming circuit for all the linears
- High-voltage V^{++} "doubler" for N-channel gate drive above the +100V V_{DD} supply
- Low-voltage (V_{CC}) pass regulator to drive a local low-voltage analog and digital power supply from the high-voltage supply.
- Multiple current mirrors both at high (100V) and low (15V) levels
- Floating zener clamps, avalanche zeners, references and Schottky diodes
- Diffusion, diffusion P-well, pinched and poly resistors
- 40pF of on-chip capacitance
- Isolated PNP and NPN transistors

Design Resources and Requirements

Supplied by Micrel

- MPD8020 CMOS/DMOS Semicustom High-Voltage Array data sheet
- MPD8020 Kit Part #1 (Analog SSI and MSI Circuits)
  - 40-pin DIP kit parts with 11 commonly used analog circuits
  - Kit Part Part #1 data sheet with specification and application hints
- MPD8020 Kit Part #2 (Digital SSI and MSI Circuits)
  - 40-pin DIP kit parts with 8 revealing digital circuits for checking speed and digital timing characteristics (also some ananlog circuits implemented in the gate array)
  - Kit Part #2 data sheet with specification and application hints
- Highly experienced design and applications engineers on call to discuss how to optimize a complex analog, digital, and power circuit on one I.C.

Requirements by Micrel

- System block diagram with basic I/O specifications, or...
- Schematic of circuit implemented with analog, digital,and discrete power transistors plus the I/O specification, or...
- Breadboard using Micrel kit parts plus "glue" logic and I/O specification, or...
- Spice and Hi-Low netlists or other compatible computer generated description and I/O specifications.

Typical Semicustom Design Cycle

The typical design cycle follows exploratory discussions and contract initiation.

Week	Activity
2	Specification and customer interface
8	Design and customer interface
12	Electrical and layout computerized checks
14	Mask generation
16	Apply ASIC masks to preprocessed wafers
17	Wafer test
19	Packaged test units
20	Final test, QA and ship 25 units

Section 11: PACKAGE INFORMATION

11

Section 11: PACKAGE INFORMATION (continued)

Packaging for Automatic Handling

Tape & Reel and Ammo Pack

General Description

Tape & Reel

Surface mount and TO-92 devices are available in tape and reel packaging. Surface mount components are retained in an embossed carrier tape by a cover tape. TO-92 device leads are secured to a backing tape by a cover tape. The tape is spooled on standard size reels.

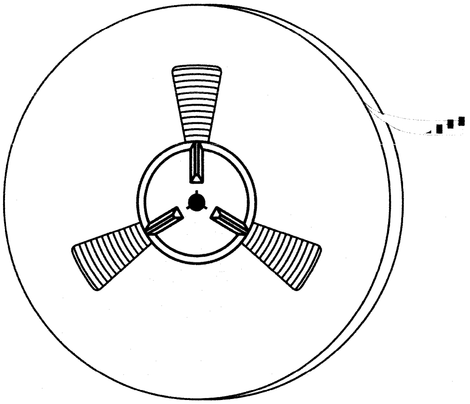
Ammo Pack

TO-92 devices are also available in an "ammo pack." TO-92 devices are secured to a backing tape by a cover tape and are fanfolded into a box. Ammo packs contain the same quantity, feed direction, and component orientation as a reel.

To order, specify the complete part number with the suffix "AP" (*example*[†]*: MICxxxxx***Z** AP).

Pricing

Contact the factory for price adder and availability.



Typical 13" Reel
for Surface Mount Components

Tape & Reel Standards

Embossed tape and reel packaging conforms to:

- *8mm & 12mm Taping of Surface Mount Components for Automatic Handling*, EIA-481-1*
- *16mm and 24mm Embossed Carrier Taping of Surface Mount Componets for Automatic Handling*, EIA-481-2*
- *32mm, 44mm and 56mm Embossed Carrier Taping of Surface Mount Components for Automatic Handling*, EIA-481-3*

Packages Available in Tape & Reel

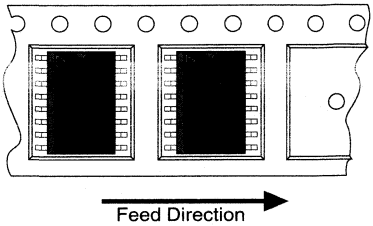
Part Number[†]	Package Description	Quantity / Reel	Reel Diameter	Carrier Tape Width	Carrier Tape Pitch
*MICxxxxx***M** T&R	8-lead SOIC	2,500	13"	12mm	8mm
	14-lead SOIC	2,500	13"	16mm	8mm
	16-lead SOIC	2,500	13"	16mm	8mm
*MICxxxx***WM** T&R	16-lead wide SOIC	1,000	13"	16mm	12mm
	18-lead wide SOIC	1,000	13"	16mm	12mm
	20-lead wide SOIC	1,000	13"	24mm	12mm
	24-lead wide SOIC	1,000	13"	24mm	12mm
*MICxxxx***SM** T&R	28-lead SSOP	1,000	13"	16mm	12mm
*MICxxxxx***V** T&R	20-lead PLCC	1,000	13"	16mm	12mm
	28-lead PLCC	500	13"	24mm	16mm
	44-lead PLCC	500	13"	32mm	24mm
*MICxxxxx***M4** T&R	SOT-143	3,000	7"	8mm	4mm
*MICxxxxx***M3** T&R	SOT-23	3,000	7"	8mm	4mm
*MICxxxxx***M5** T&R	SOT-23-5	3,000	7"	8mm	4mm
*MICxxxxx***S** T&R	SOT-223	2,500	13"	16mm	12mm
*MICxxxxx***U** T&R	3-lead TO-263	750	13"	24mm	16mm
	5-lead TO-263	750	13"	24mm	16mm
*MICxxxxx***Z** T&R	TO-92	2,000	14¼"[‡]	—	1/2"

* Standards are available from: Electronic Industries Associations, EIA Standards Sales Department, tel: (202) 457-4966

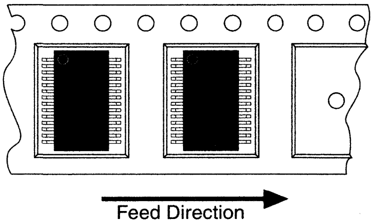
[†] xxxxx = base part number + temperature designation. Example: MIC2557BM T&R

[‡] Cardboard reel

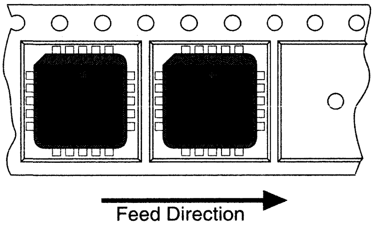
Package Orientation



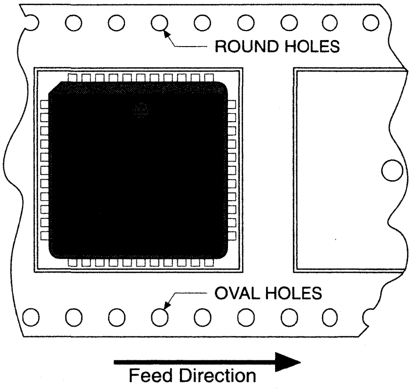
Typical SOIC Package Orientation 12mm, 16mm, 24mm Carrier Tape



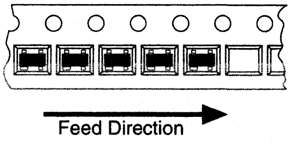
Typical SSOP Package Orientation 16mm Carrier Tape



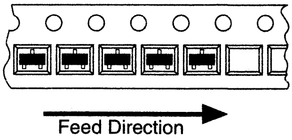
Typical PLCC Package Orientation 16mm, 24mm Carrier Tape



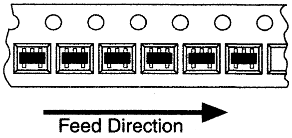
Typical PLCC Package Orientation 32mm Carrier Tape



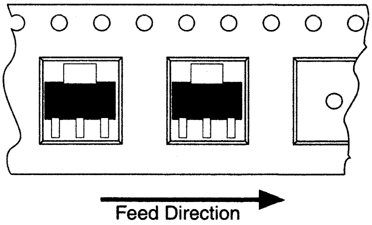
SOT-143 Package Orientation 8mm Carrier Tape



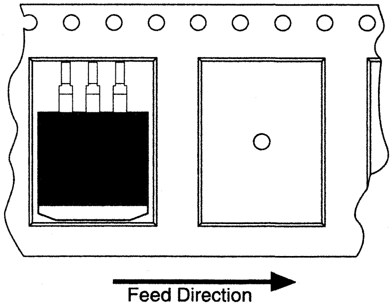
SOT-23 Package Orientation 8mm Carrier Tape



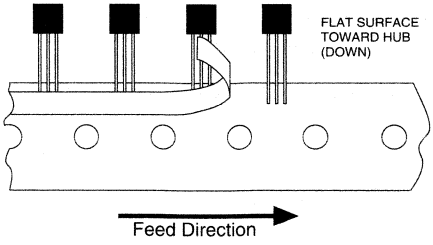
SOT-23-5 Package Orientation 8mm Carrier Tape



SOT-223 Package Orientation 16mm Carrier Tape



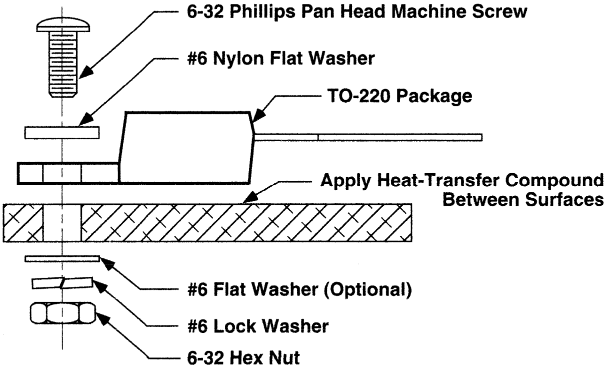
Typical TO-263 Package Orientation 24mm Carrier Tape



Typical TO-92 Package Orientation

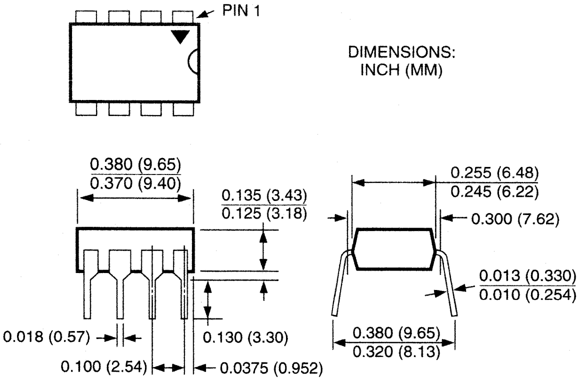
Mounting Information

TO-220



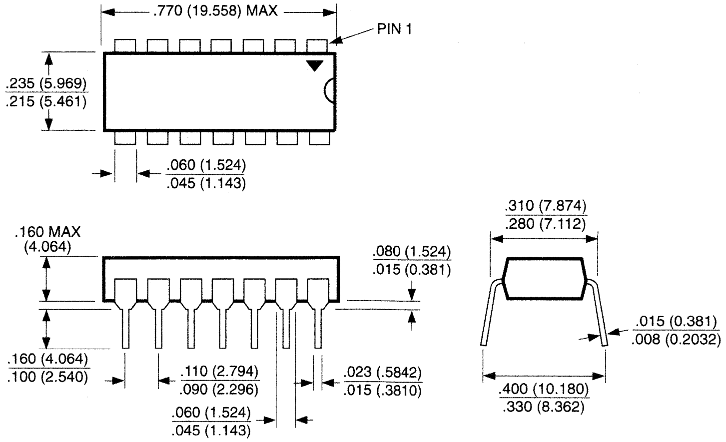
Maximum Torque: 0.68 N-m (6 in-lbs)
(Caution: Excessive torque may crack semiconductor)

Note: Micrel regulators have a grounded tab and do not require insulated spacers between the package and grounded or floating heat sinks.



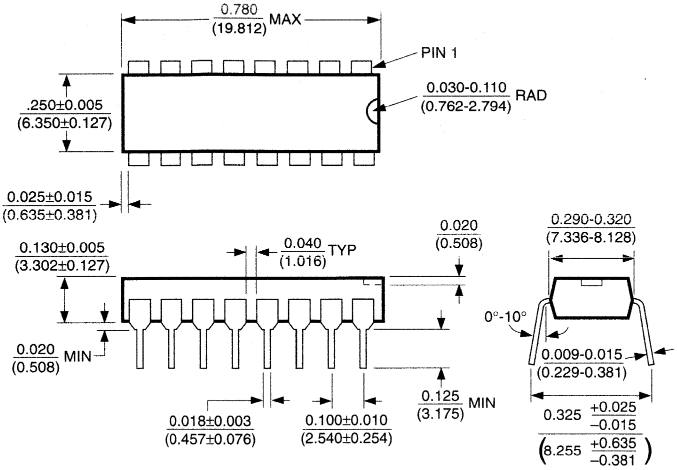
DIMENSIONS:
INCH (MM)

8-Pin Plastic DIP (N)

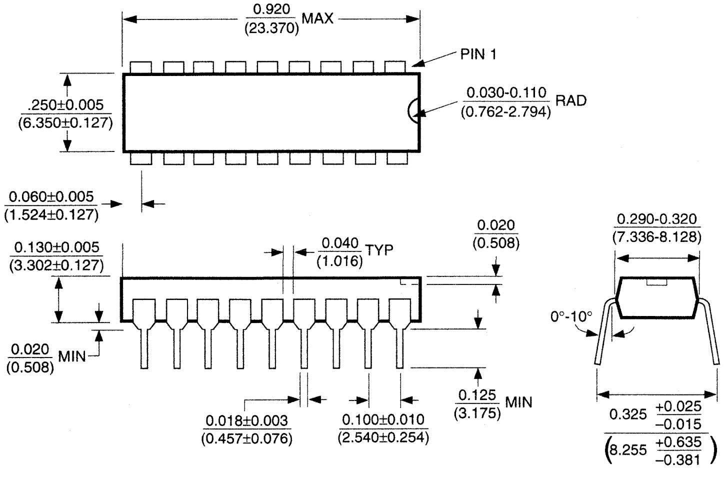


14-Pin Plastic DIP (N)

Note: Pin 1 is denoted by one or more of the following: a notch, a printed triangle, or a mold mark.

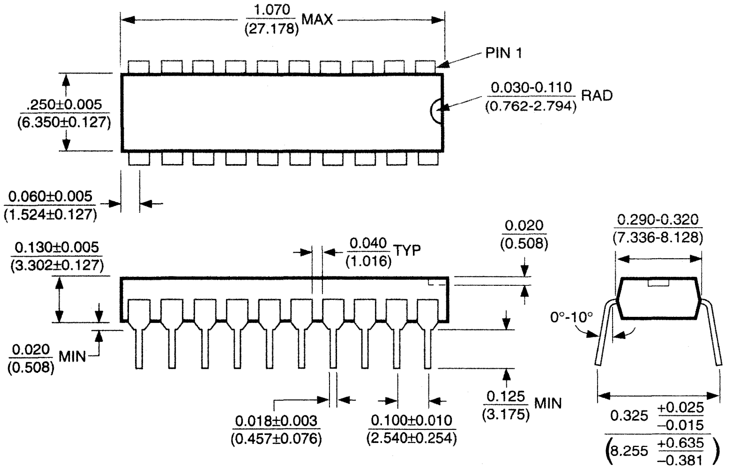


16-Pin Plastic DIP (N)

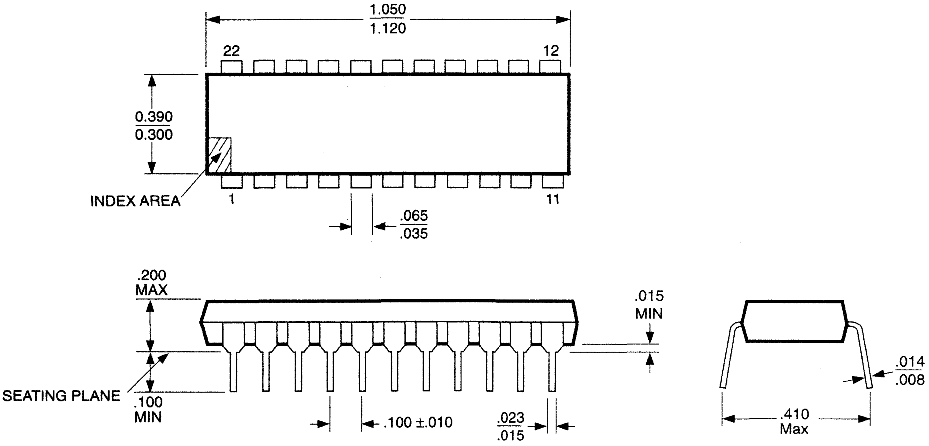


18-Pin Plastic DIP (N)

Note: Pin 1 is denoted by one or more of the following: a notch, a printed triangle, or a mold mark.

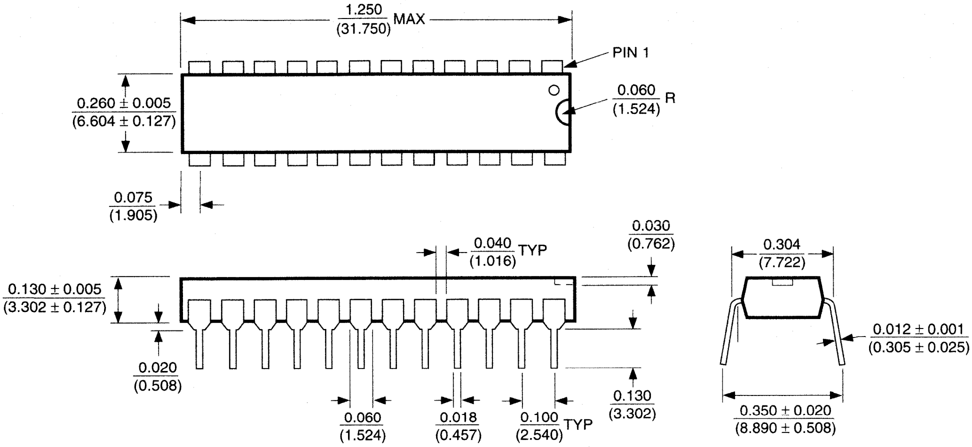


20-Pin Plastic DIP (N)

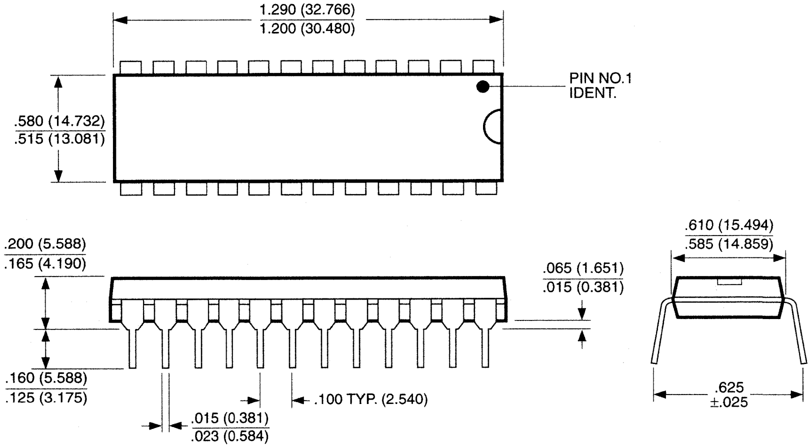


22-Pin Plastic DIP (N)

Note: Pin 1 is denoted by one or more of the following: a notch, a printed triangle, or a mold mark.

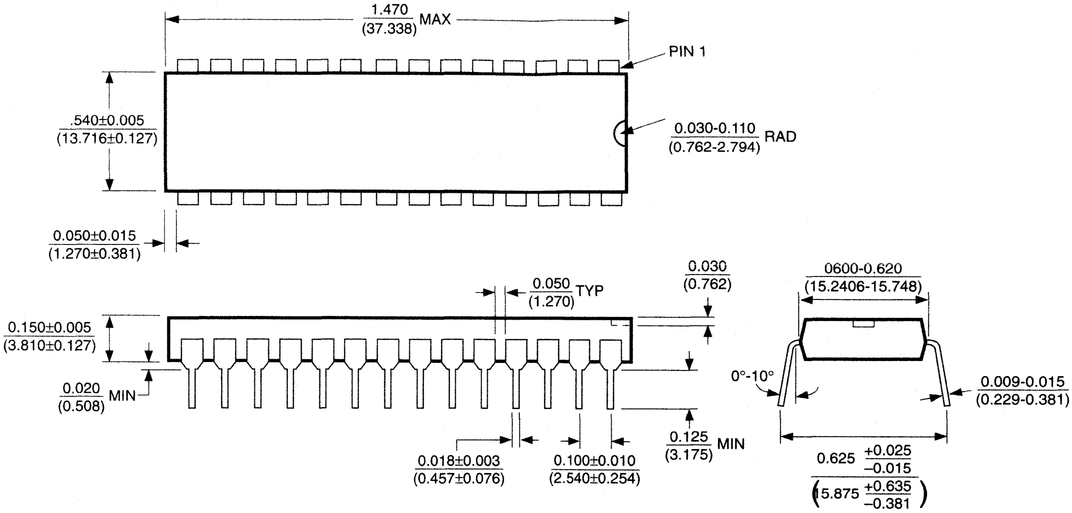


24-Pin Plastic Skinny DIP (N)

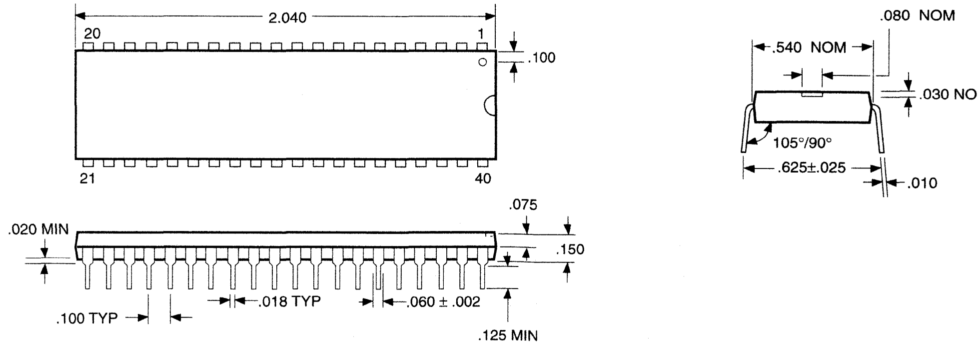


24-Pin Plastic DIP (N)

Note: Pin 1 is denoted by one or more of the following: a notch, a printed triangle, or a mold mark.

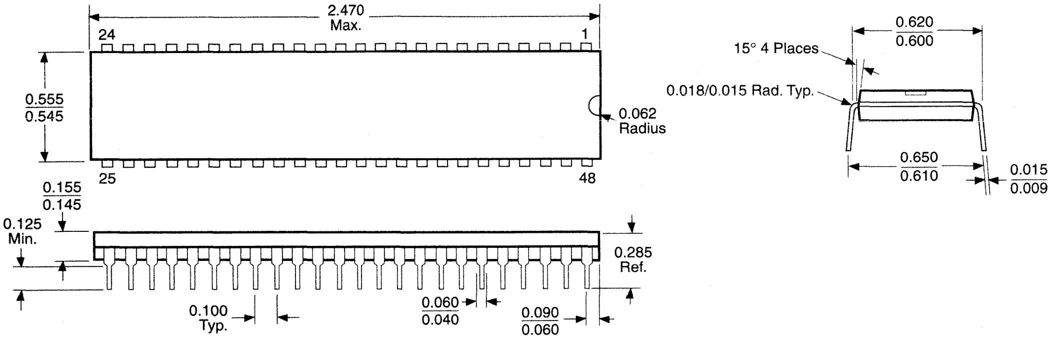


28-Pin Plastic DIP (N)



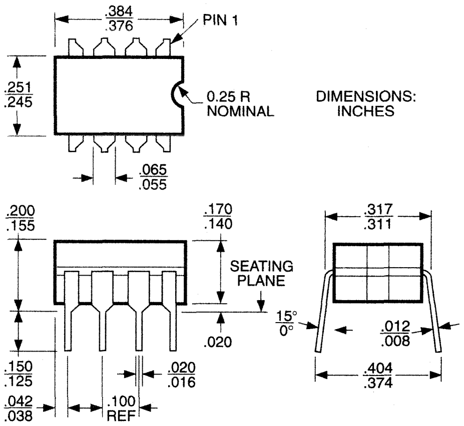
40-Pin Plastic DIP (N)

Note: Pin 1 is denoted by one or more of the following: a notch, a printed triangle, or a mold mark.

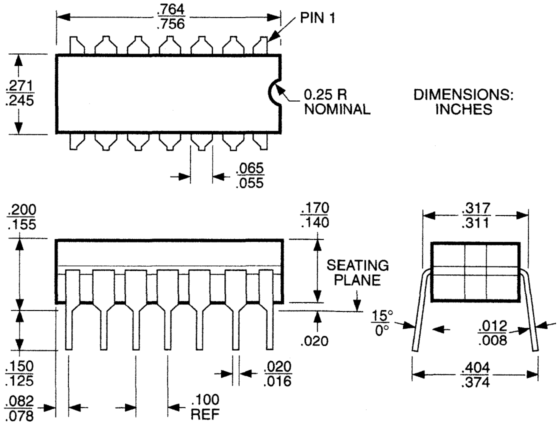


48-Pin Plastic DIP (N)

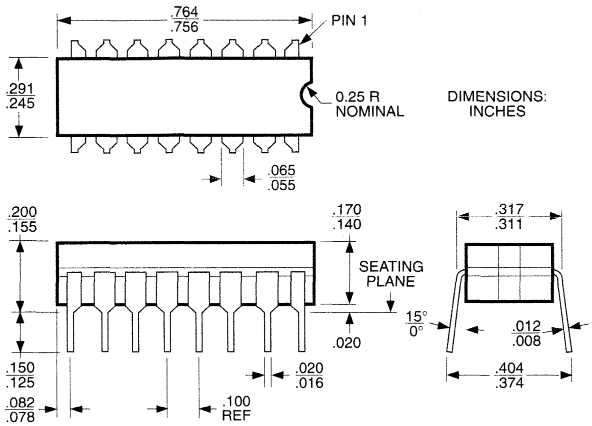
Note: Pin 1 is denoted by one or more of the following: a notch, a printed triangle, or a mold mark.



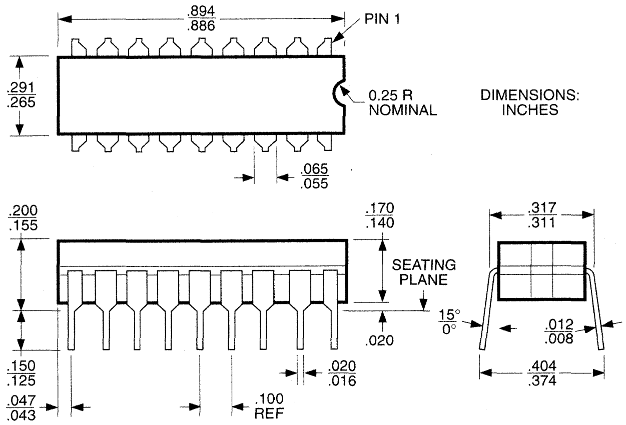
8-Pin Ceramic DIP (J)



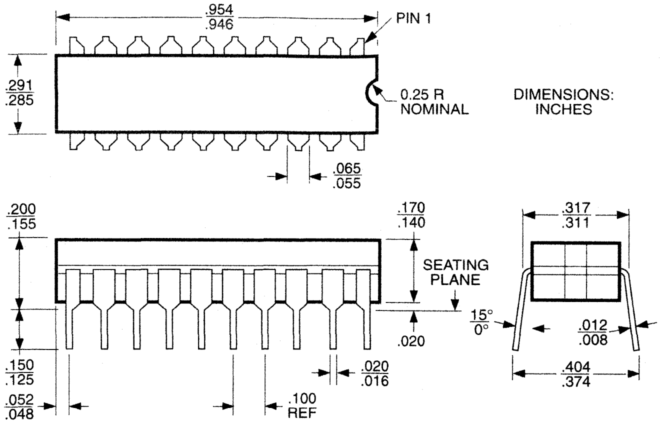
14-Pin Ceramic DIP (J)



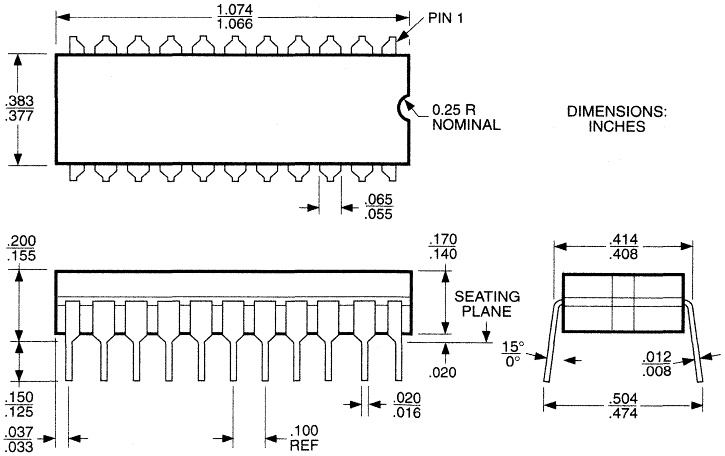
16-Pin Ceramic DIP (J)



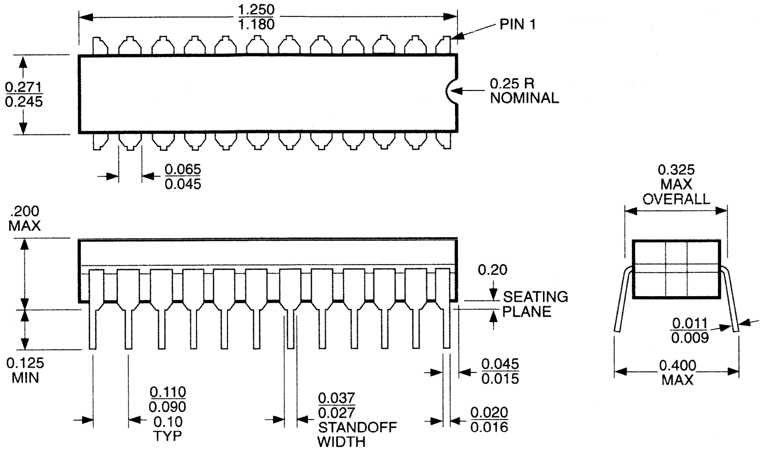
18-Pin Ceramic DIP (J)



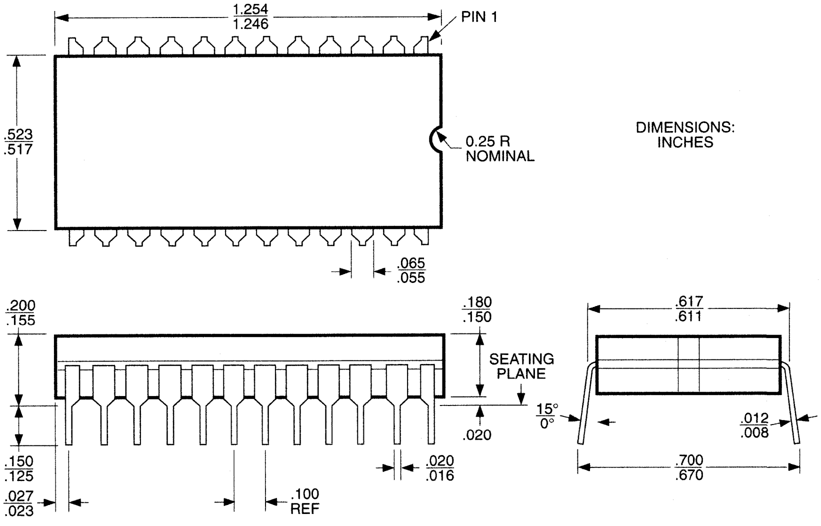
20-Pin Ceramic DIP (J)



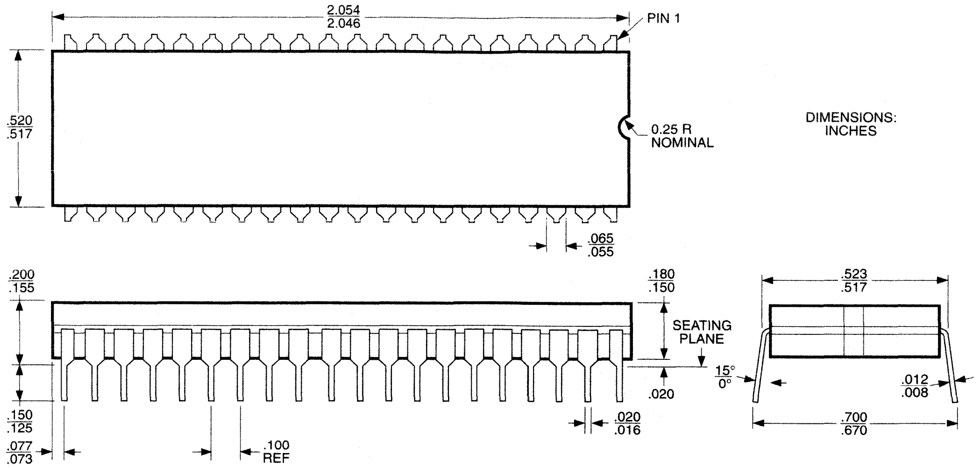
22-Pin Ceramic DIP (J)



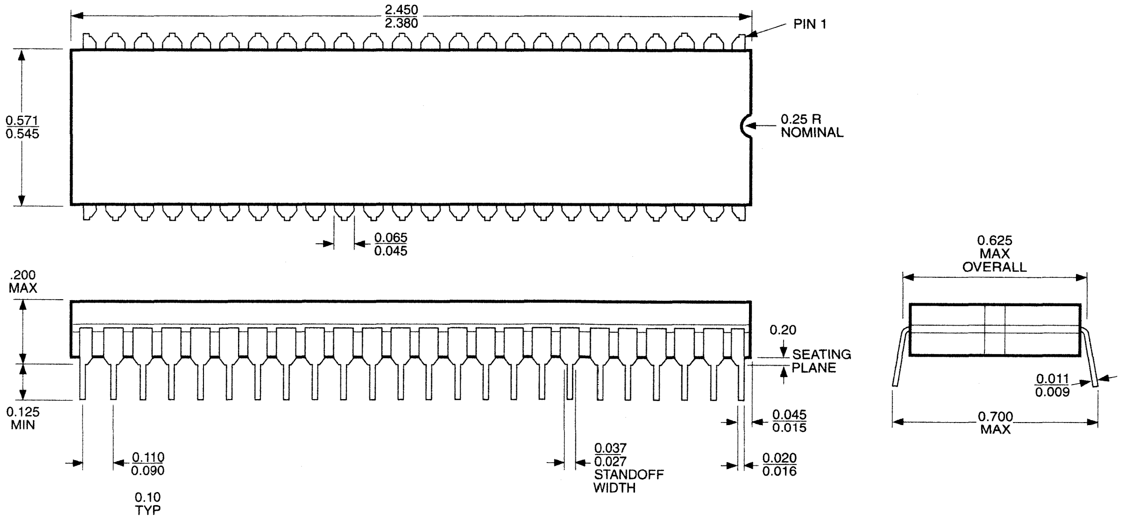
24-Pin Ceramic Skinny DIP (J)



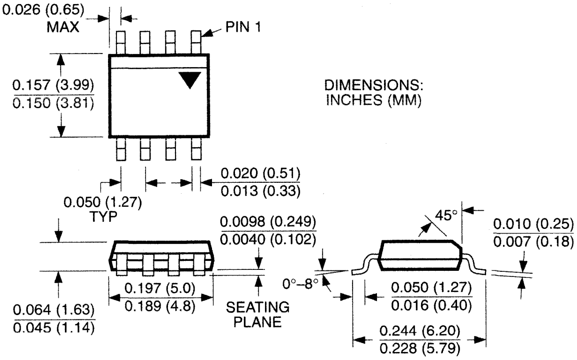
24-Pin Ceramic DIP (J)



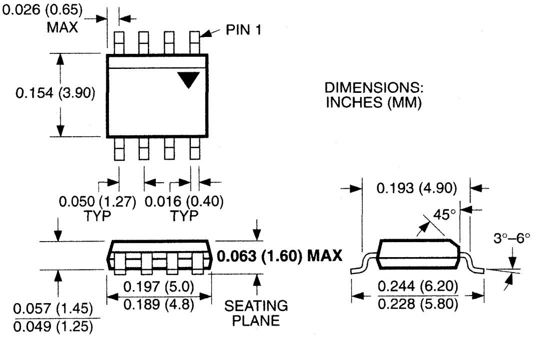
40-Pin Ceramic DIP (J)



48-Pin Ceramic DIP (J)

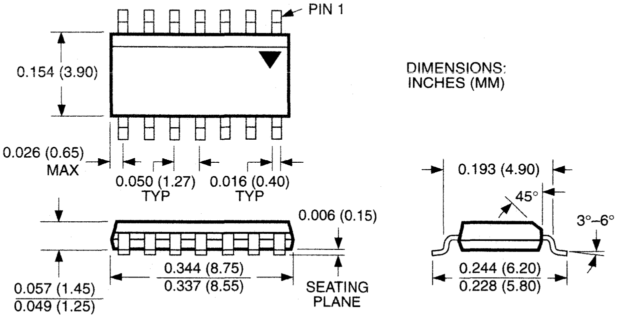


8-Pin SOIC (M)

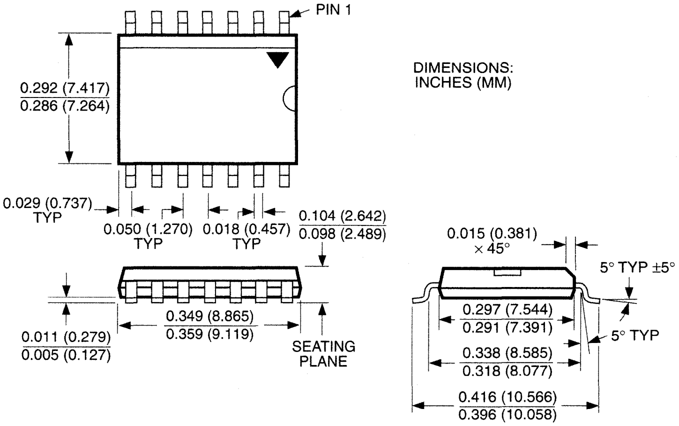


8-Pin Low-Profile SOIC (LM)

Note: Pin 1 is denoted by one or more of the following: a notch, a printed triangle, or a mold mark.

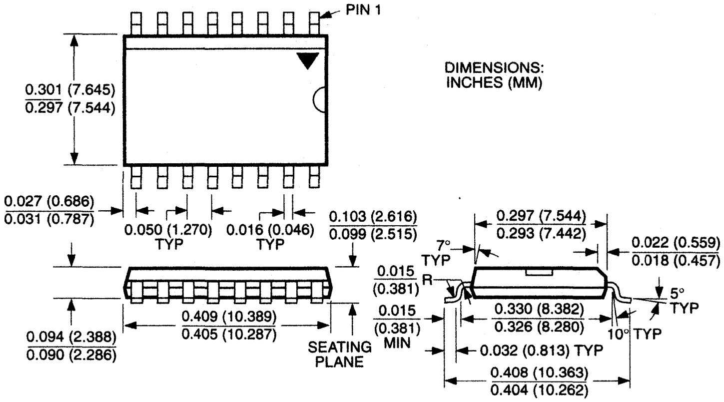


14-Pin SOIC (M)

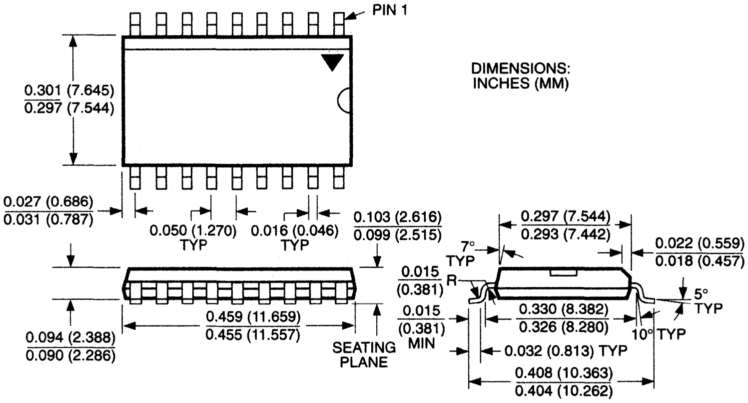


14-Pin SOIC Wide (WM)

Note: Pin 1 is denoted by one or more of the following: a notch, a printed triangle, or a mold mark.

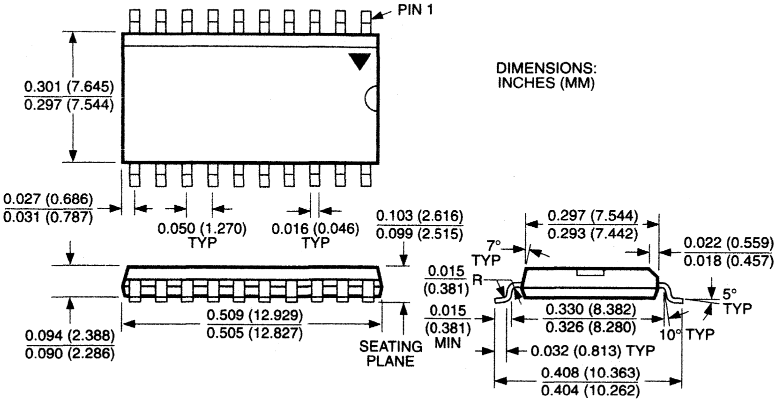


16-Pin Wide SOIC (WM)

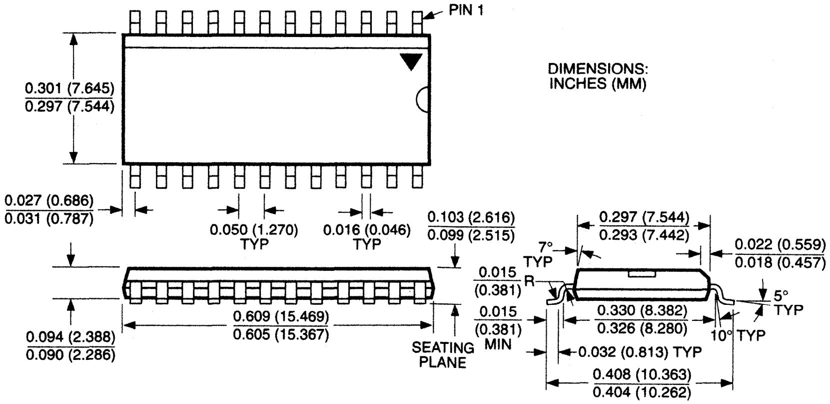


18-Pin Wide SOIC (WM)

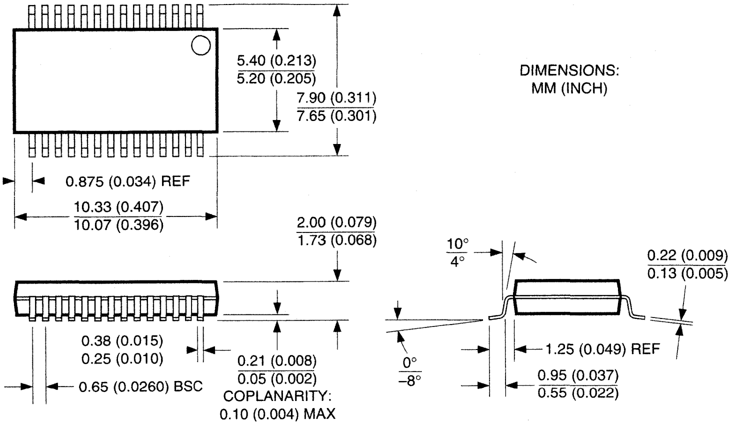
Note: Pin 1 is denoted by one or more of the following: a notch, a printed triangle, or a mold mark.



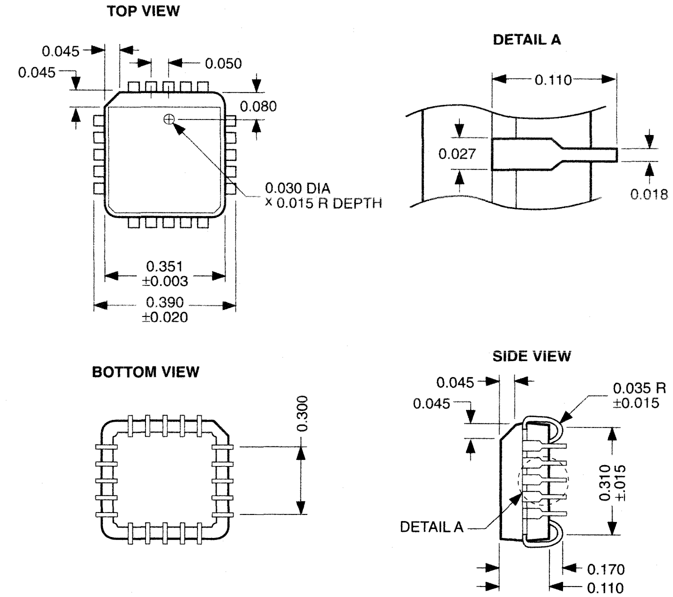
20-Pin Wide SOIC (WM)



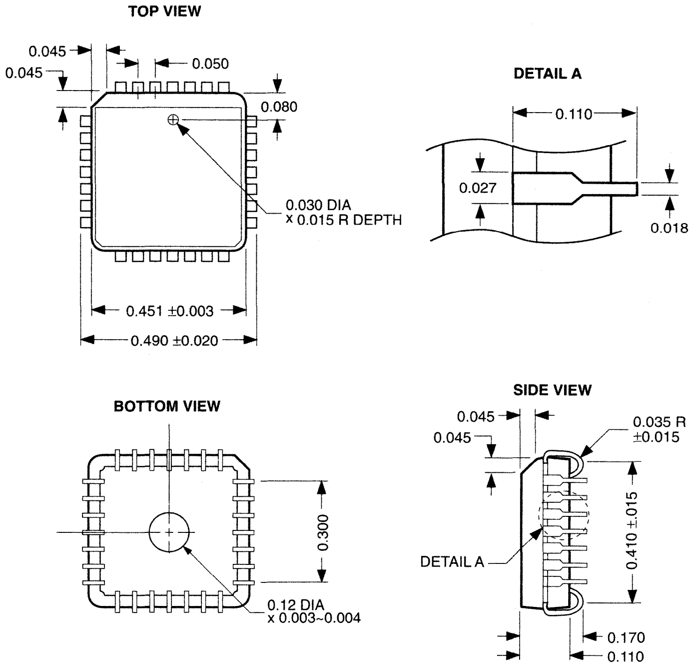
24-Pin Wide SOIC (WM)



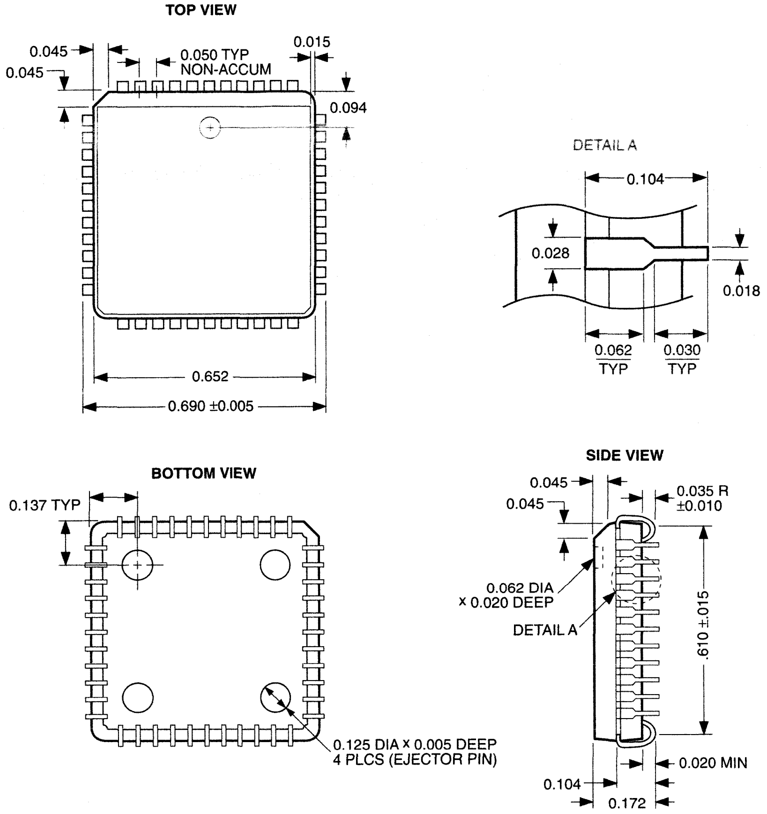
28-Lead SSOP (SM)



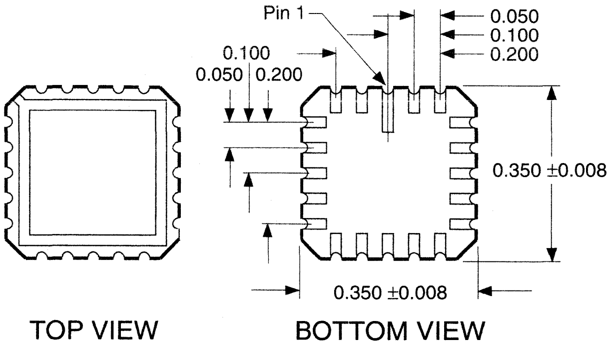
20-Pin PLCC (V)



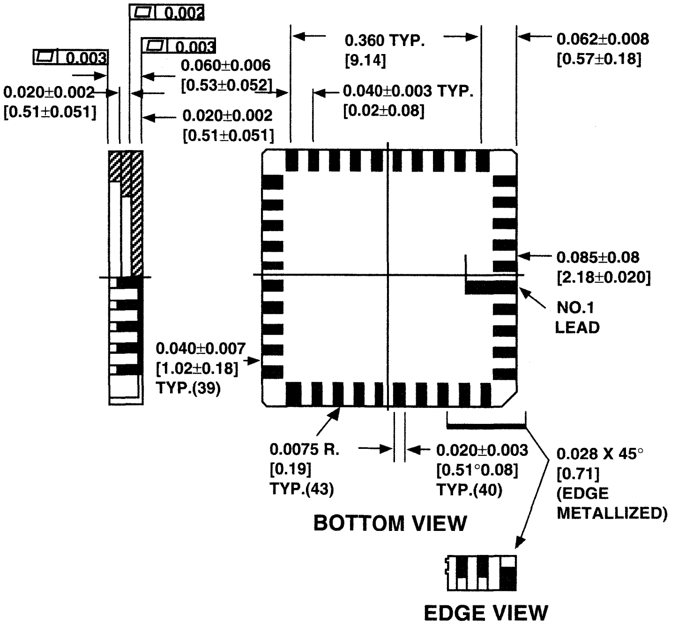
28-Pin PLCC (V)


TOP VIEW
0.045
0.045
0.050 TYP
NON-ACCUM
0.015
0.094
0.652
0.690 ±0.005
DETAIL A
0.104
0.028
0.018
0.062
TYP
0.030
TYP
BOTTOM VIEW
0.137 TYP
0.125 DIA x 0.005 DEEP
4 PLCS (EJECTOR PIN)
SIDE VIEW
0.045
0.045
0.035 R
±0.010
0.062 DIA
x 0.020 DEEP
DETAIL A
.610 ±.015
0.104
0.172
0.020 MIN

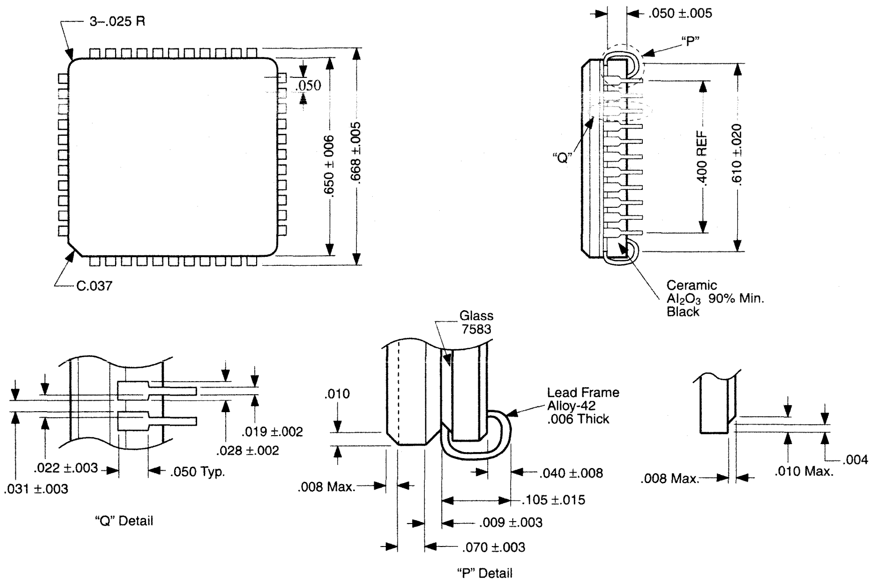
44-Pin PLCC (V)



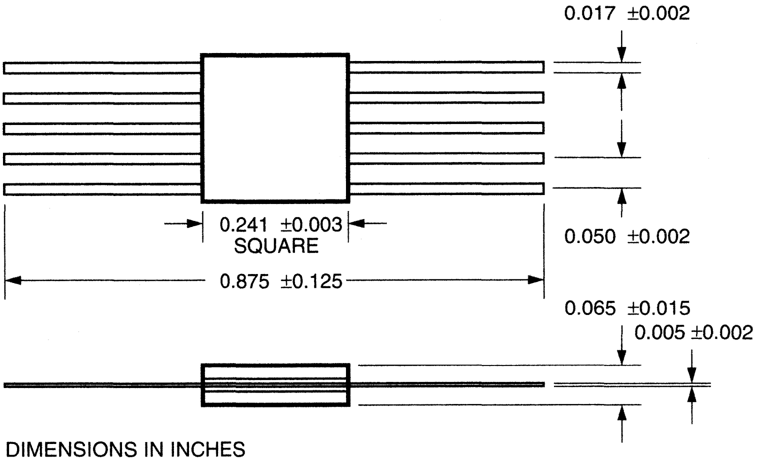
20-Lead LCC (L)



40-Lead LCC (L)

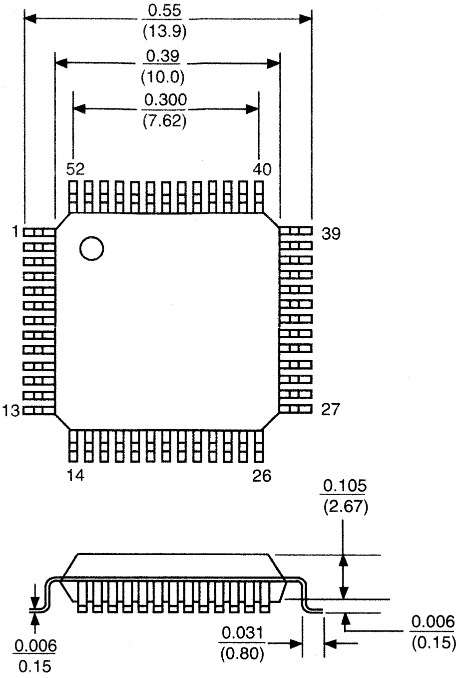


44-Pin CerQuad (E)

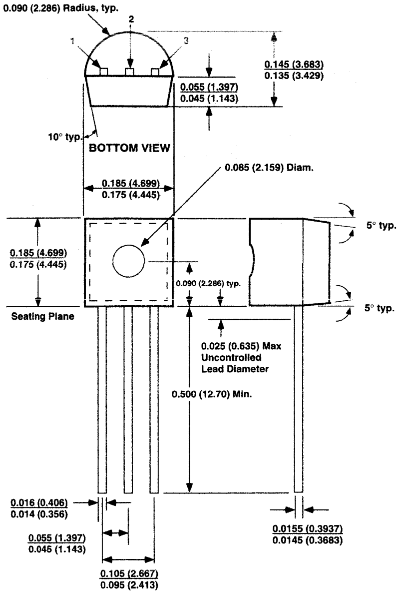


DIMENSIONS IN INCHES

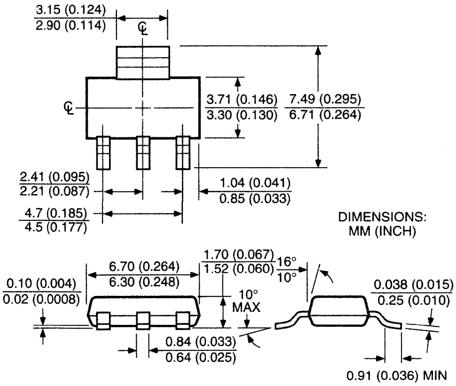
10-Pin CerPack (F)


0.55
(13.9)
0.39
(10.0)
0.300
(7.62)
52
40
1
39
13
27
14
26
0.105
(2.67)
0.006
0.15
0.031
(0.80)
0.006
(0.15)

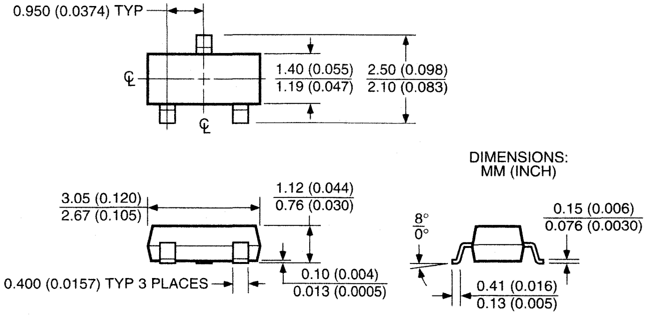
52-Pin QFP (Q)



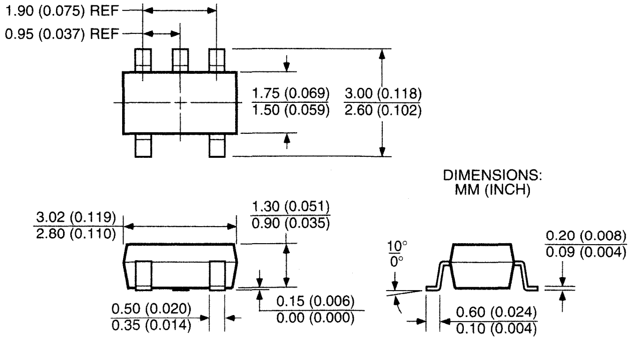
TO-92 (Z)



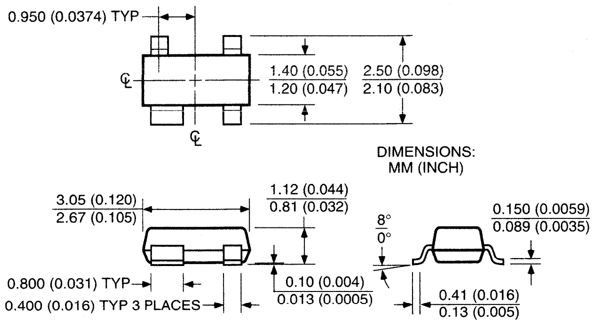
SOT-223 (S)



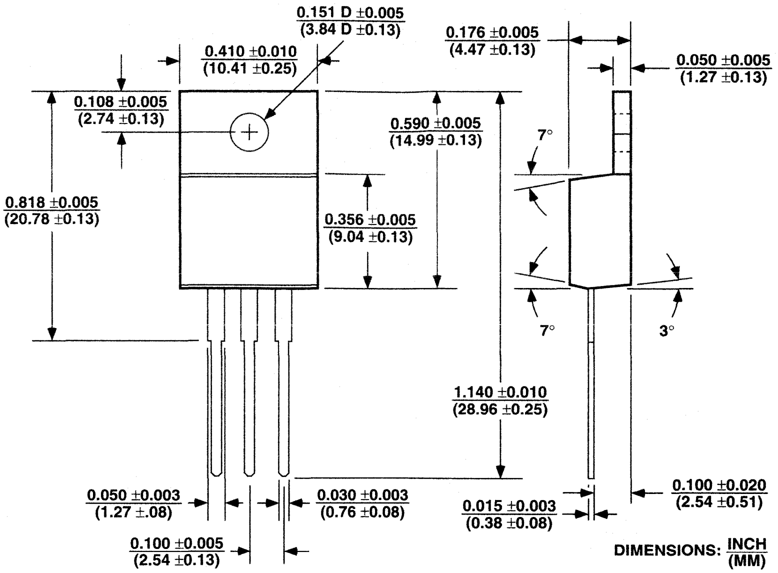
SOT-23 (M3)



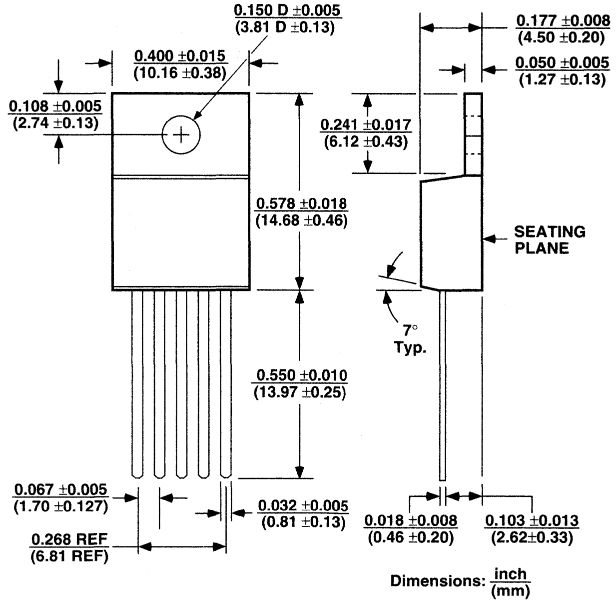
SOT-23-5 (M5)


0.950 (0.0374) TYP
1.40 (0.055)
1.20 (0.047)
2.50 (0.098)
2.10 (0.083)
DIMENSIONS:
MM (INCH)
3.05 (0.120)
2.67 (0.105)
1.12 (0.044)
0.81 (0.032)
8°
0°
0.150 (0.0059)
0.089 (0.0035)
0.800 (0.031) TYP
0.400 (0.016) TYP 3 PLACES
0.10 (0.004)
0.013 (0.0005)
0.41 (0.016)
0.13 (0.005)

SOT-143 (M4)



3-Lead TO-220 (T)

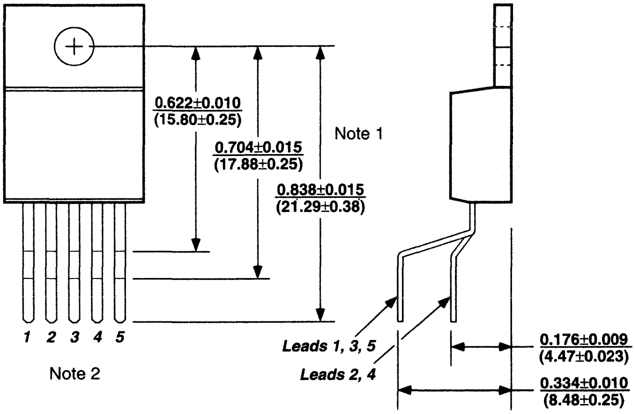


5-Lead TO-220 (T)

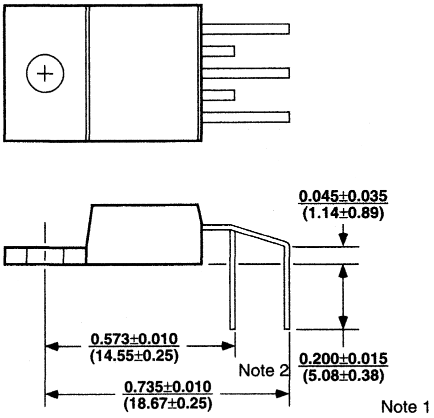
TO-220 Lead Bend Options *Contact Factory for Availability*

Part Number	Package	Lead Form
MICxxxxyT	5-lead TO-220	none (straight)
MICxxxxyT-LB03	5-lead TO-220	vertical, staggered leads, 0.704" seating
MICxxxxyT-LB02	5-lead TO-220	horizontal, staggered leads

MICxxxx = base part number, y = temperature range, T = TO-220
* Leads not trimmed after bending.



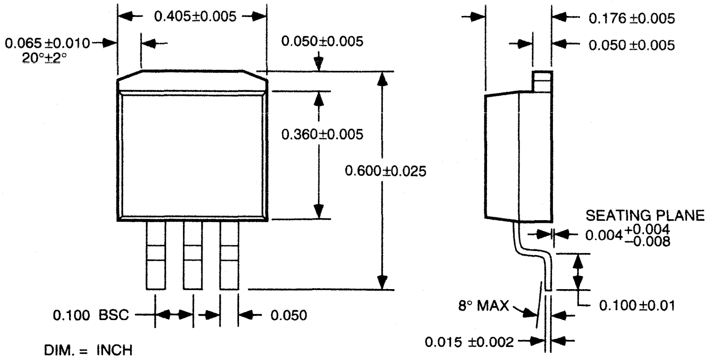
TO-220 Vertical Lead Bend Option -LB03



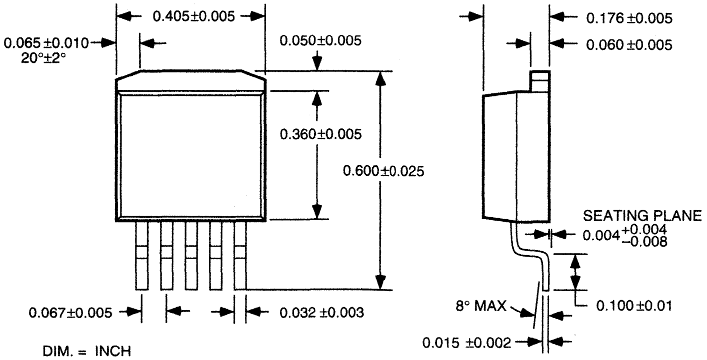
TO-220 Horizontal Lead Bend Option -LB02

Note 1. Lead protrusion through printed circuit board subject to change.

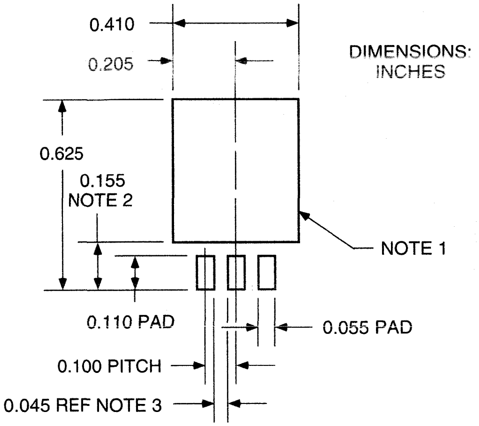
Note 2. Lead ends may be curved or square.



3-Lead TO-263 (U)

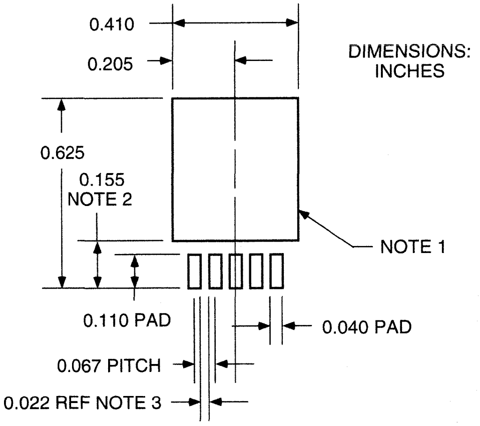


5-Lead TO-263 (U)



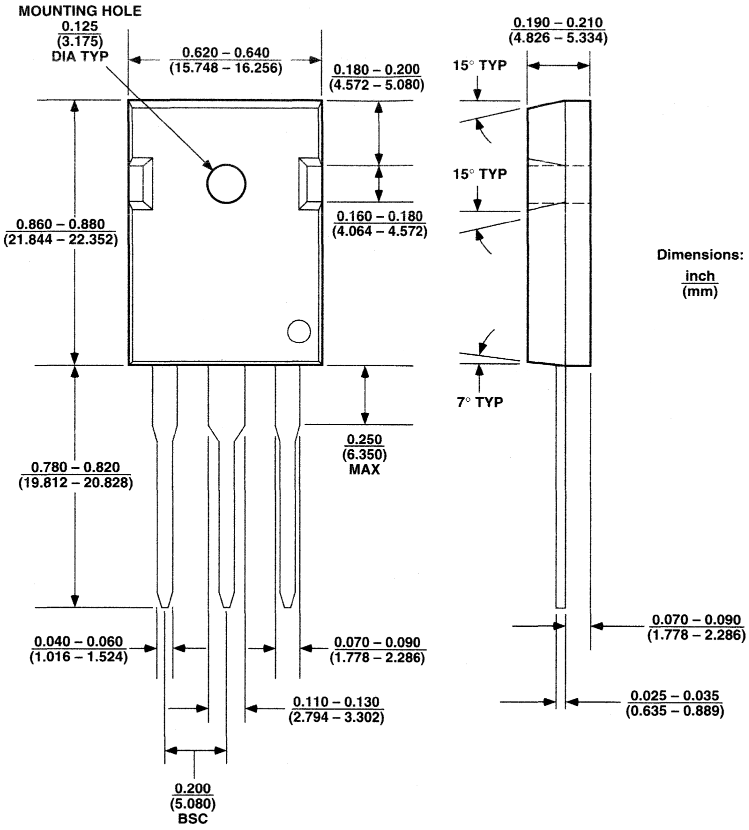
NOTE 1: PAD AREA MAY VARY WITH
HEAT SINK REQUIREMENTS
NOTE 2: MAINTAIN THIS DIMENSION
NOTE 3: AIR GAP (REFERENCE ONLY)

Typical 3-Lead TO-263 PCB Layout

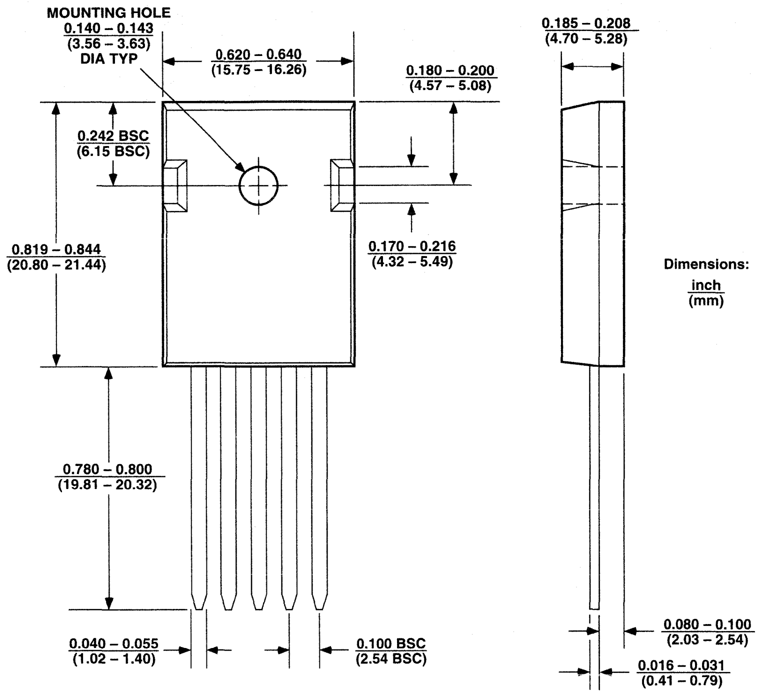


NOTE 1: PAD AREA MAY VARY WITH
HEAT SINK REQUIREMENTS
NOTE 2: MAINTAIN THIS DIMENSION
NOTE 3: AIR GAP (REFERENCE ONLY)

Typical 5-Lead TO-263 PCB Layout



3-Lead TO-247 (WT)



5-Lead TO-247 (WT)

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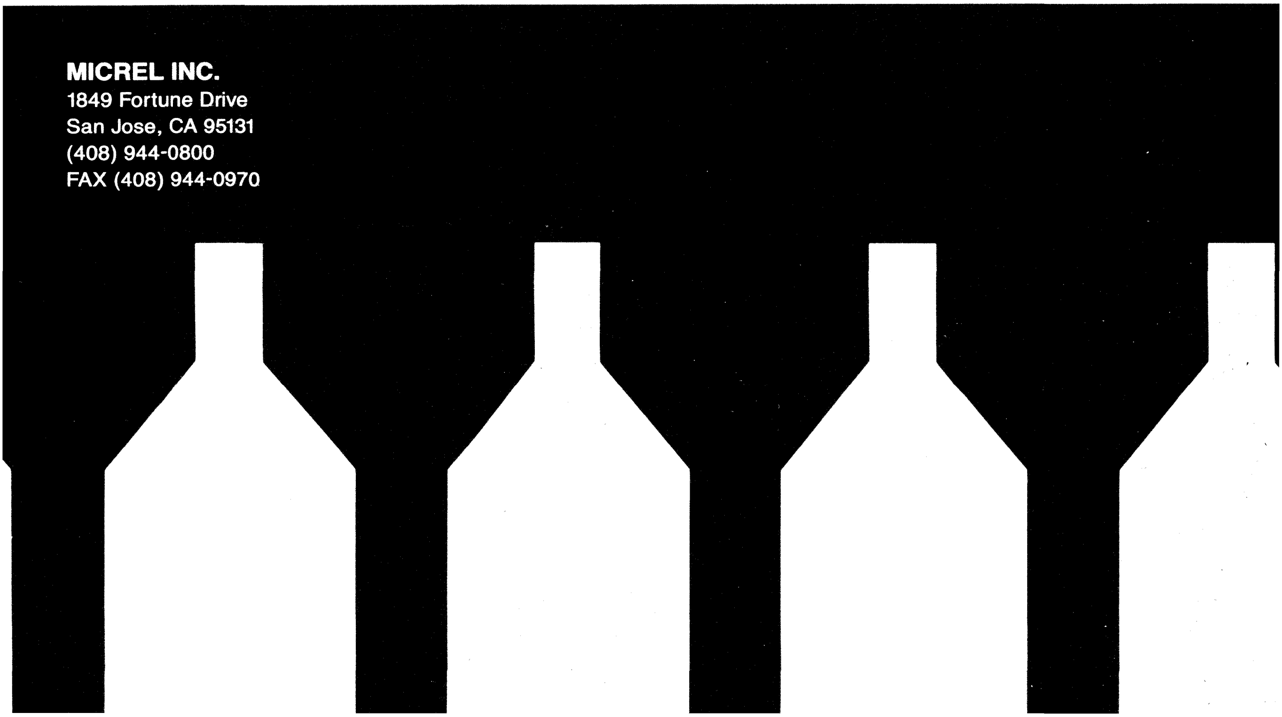

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