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Complete IF Receiver Has 16-Bit, 130Msps ADC, Fixed-Gain Amplifier and Antialias Filter in 11.25mm × 11.25mm µModule Package

by Todd Nelson

Introduction

In the design of high speed receivers for communications, test or instrumentation equipment, several specialized disciplines converge in one place—the analog-to-digital converter (ADC). Unfortunately, the ADC is not a simple black box where an RF designer applies the signal and a digital designer retrieves the accurate output. Careful design of the signal conditioning circuitry to drive the ADC is critical. Something as seemingly straightforward as board layout can degrade the downstream signal by a few precious decibels. The problem is that the disciplines required for the engineering on either side of the ADC, namely RF/IF design and digital design, do not include mastery of the art of ADC interface design. Someone has to put in the effort to properly drive the ADC. But who? Instead of adding more work to either designer's plate, what if the ADC were really a black box, already loaded with integrated signal conditioning components in an optimized layout? Now, *that* would be a better solution.

The LTM9001 is built using Linear Technology's µModule technology to create an IC form factor System-in-a-Package (SiP) that includes a high speed 16-bit ADC, antialiasing filter and a low noise, differential amplifier with fixed gain. It can digitize wide dynamic range signals with an intermediate frequency (IF) range up to 300MHz.

The LTM9001 is exactly that black box. It is built using Linear Technology's µModule™ technology to create an IC form factor System-in-a-Package (SiP) that includes a high speed 16-bit ADC, antialiasing filter and a low noise, differential amplifier with fixed gain. It can digitize wide dynamic range

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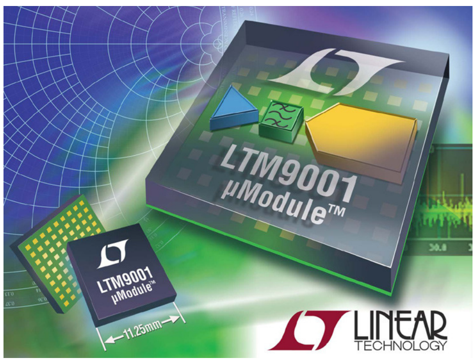
Linear in the News…

New µModule Receiver Family Launched

Recently, Linear introduced a new family of signal chain µModule receiver products. The LTM9001, the first in a series of System in Package (SiP) signal chain receiver modules, uses Linear's breakthrough µModule packaging technology, now incorporated in a growing family of power µModule DC/DC controllers. The LTM9001 is a semi-customizable IF/baseband receiver subsystem that includes a high performance 16-bit Analog-to-Digital converter (ADC) sampling up to 160Msps, an antialiasing filter, and fixed gain differential ADC driver. The LTM9001 µModule receiver is applicable in high sensitivity wireless basestations and high resolution instrumentation. Systems designers benefit from simplified design and test, consistent high performance, a compact footprint and the elimination of layout-related performance problems.



Announced in early February, the LTM9001 µModule receiver has already received coverage in several major technical publications. The product will be featured in upcoming cover articles in *High Frequency Electronics* in the US, *Electronic Product Design* in the UK, *Elektronik Informationen* in Germany, as well as in articles in key publications throughout Asia.

The LTM9001 is gaining significant interest from receiver manufacturers as a way reduce time-to-market while improving functionality. It does so by delivering a high level of integration without compromising performance. The device combines RF, digital and mixed-signal technology in a tiny package, precluding the need to call on applications specialists when a project is underway. All internal components are optimized for the highest system performance, with integration and layout issues resolved in the package. The LTM9001 is a tested, individual package that can be picked and placed easily on the board, thus reducing the required design time and complexity normally associated with such functions.

In addition, the LTM9001 has the potential for customization. For orders meeting a minimum size, the LTM9001 can be configured for various sampling rates and the differential ADC driver can be substituted for fixed gain versions ranging from 8dB up to 26dB. As a result, the LTM9001 significantly eases the challenge in designing high performance communications and instrumentation systems.

EDN Innovation Award Finalists

EDN magazine in January announced finalists for the annual *EDN* Innovation Awards, which includes several Linear Technology nominees.

- ❑ For Innovator of the Year, *EDN* nominated Linear co-founder and Chief Technology Officer Robert Dobkin.
- ❑ In the Power ICs category, *EDN* selected as a finalist the LT3080 3-terminal adjustable LDO regulator, which was designed by Bob Dobkin and his team at Linear Technology.
- ❑ For the Analog IC category, the LTC6102 current sense amplifier.
- ❑ For Best Contributed Article, Jim Williams' article, "Designing Instrumentation Circuitry with RMS/DC Converters."

Visit www.linear.com for complete descriptions and data sheets for these products. See www.edn.com for Jim Williams' article.

On the Road in China

Linear Technology is on the road in China, exhibiting in the 4-city IIC Conference & Exhibition. Linear is participating with a booth at all four conference locations:

- ❑ Chengdu—February 28–29, Booth 5D32
- ❑ Shenzhen—March 3–4, Booth 2H06
- ❑ Beijing—March 6–7, Booth B17
- ❑ Shanghai—March 10–11, Booth 4Q09

At the IIC Conference, where overall attendance is expected to exceed 30,000, Linear will highlight a broad range of products and solutions. These include Power Management ICs (PMICs), power µModule controllers, LT3080 3-terminal linear regulator, high speed ADCs, the new LTM9001 µModule receiver, high frequency RF products including the LT5570 RMS power detector, the LTC6102 current sense amplifier, ADC drivers, DACs, and LED drivers.

Linear Technology will highlight a broad range of products at the IIC Conference with a booth at all four conference locations in China.

LTM9001, continued from page 1

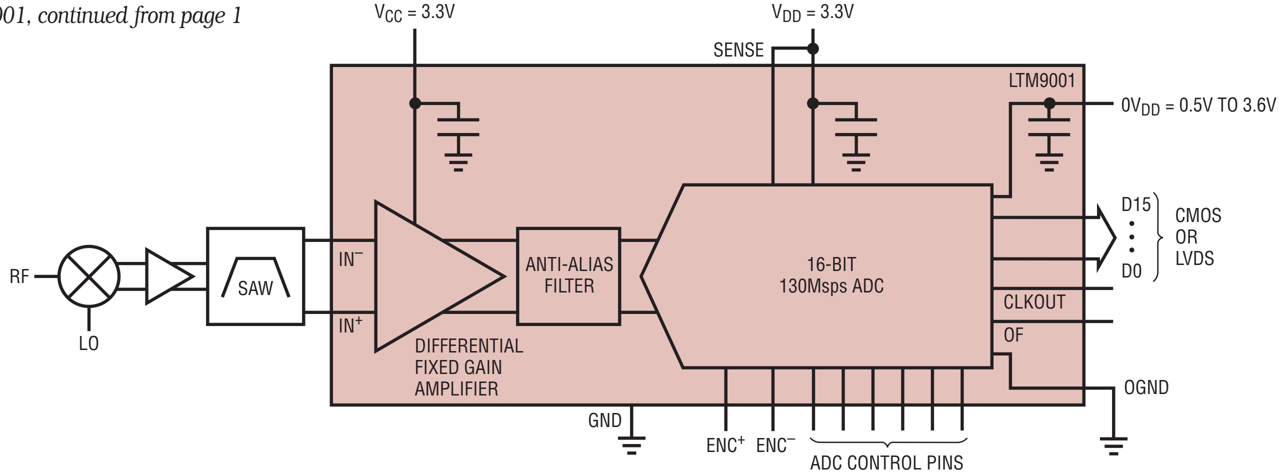


Figure 1. A typical application and simplified block diagram of the LTM9001

signals with an intermediate frequency (IF) range up to 300MHz. Figure 1 shows a typical application.

How is a µModule component different than a traditional IC? The µModule construction allows the LTM9001 to mix standard ADC and amplifier components regardless of their process technology and match them with passive components for a particular application. The result is a high performance product with no process technology compromises and the potential for semi-custom adaptations.

What's Inside?

The µModule receiver consists of wire-bonded die, packaged components and passives mounted on a high performance, 4-layer, Bismaleimide-Triazine (BT) substrate. BT is similar to other laminate substrates such as FR4 but has superior stiffness and a lower coefficient of thermal expansion.

In time, several different versions of the LTM9001 will be available. The LTM9001-AA, as the first release, is configured with a 16-bit, 130Msps ADC. The amplifier gain is 20dB with an input impedance of 200Ω and an input range of ±250mV. The matching network is designed to optimize the interface between the amplifier outputs and the ADC inputs under these conditions. Additionally, there is a second order bandpass filter designed for 162.5MHz, ±25MHz to prevent aliasing and to limit the noise from the amplifier.

Extracting the full performance from 16-bit, high speed ADCs requires careful layout as well as good circuit design. The substrate design carefully shields sensitive analog traces, maximizes thermal conduction through multiple ground pads and minimizes coupled noise by including bypass capacitors inside the module and close to the ADC. A common problem with traditional ADC board layouts is long traces from the bypass capacitors to the ADC. The bare die construction with internal bypass capacitors provides the closest possible decoupling and eliminates the need for external bypass capacitors.

The passive filter network implements an antialias filter and matches the amplifier outputs to the ADC inputs. Most communications receiver applications utilize a highly selective filter between the mixer and the ADC driver. The antialias filter between the ADC driver and the ADC inputs limits the wideband amplifier noise and helps preserve the high SNR of the ADC. Printed circuit board (PCB) layout has a significant impact on the performance even if the circuit topology and component values are correct. The signal paths must be symmetric and isolated from the clock inputs and digital outputs.

The low noise, low distortion amplifier stage provides gain without adding significant noise or distortion to the signal. Despite the low noise of the amplifier, the noise is multiplied by the same gain as the amplifier, so higher gain unavoidably adds noise to the system. However, the input range of the amplifier is proportionately smaller thanks to the gain and this smaller input range allows for lower distortion from the preceding components. The amplifier inputs present a resistive 200Ω differential input impedance which is simple to match to most common, high speed, single-ended or differential signal paths. This presents a more straightforward interface than a switched-capacitor ADC and simplifies the connection to the final stage of the RF signal chain.

Why 162.5MHz?

The ADC inside the LTM9001 has a full power bandwidth of 700MHz and the amplifier is suitable for input frequencies up to 300MHz, so why was 162.5MHz chosen for this first version? Nyquist theory tells us that the minimum sample rate for a given input frequency is twice that frequency. Working backwards, an ADC sampling at 130Msps can capture a frequency range up to 65MHz wide. Undersampling allows us to move that frequency range. Hence the first Nyquist zone is DC – 65MHz, the second is 65MHz to 130MHz, the third is 130MHz to 195MHz, and so on, see Figure 2.

The LTM9001-AA is intended for instrumentation applications. In such applications, the linearity and dynamic range requirements are extremely high. Traditional instruments utilize preselectors and multiple down-con-

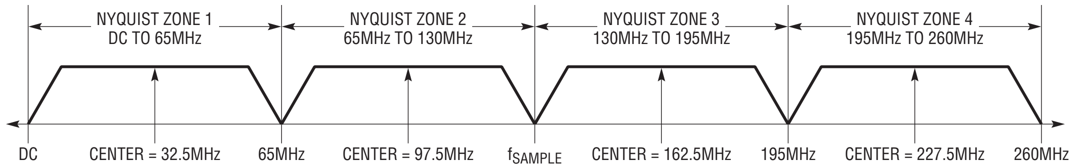


Figure 2. Nyquist zones for 130MHz sample rate

version stages to place the band of interest at DC. With the advent of high performance ADCs capable of undersampling, modern instruments are able to eliminate the final down-conversion stage without sacrificing performance. The LTM9001-AA configuration selects the third Nyquist zone with the bandpass filter set squarely in the middle of the zone.

More than Just a Buffered ADC

The sample-and-hold front end of discrete ADCs presents a complex charge/discharge profile to the drive circuitry. Ideally, the input circuitry should be fast enough to fully charge the sampling capacitor during the sampling period (half of the clock period), but this is not always possible and the incomplete settling may degrade the SNR and SFDR. Some manufacturers promote a “buffered” ADC as a solution but this falls short of addressing the system-level solution since a low distortion amplifier is still required to provide the full-scale input to the ADC.

From the system view, the ADC follows the RF and IF portions of the receiver chain and converts the signal to a digital format. The signal comes from the antenna with very little power.

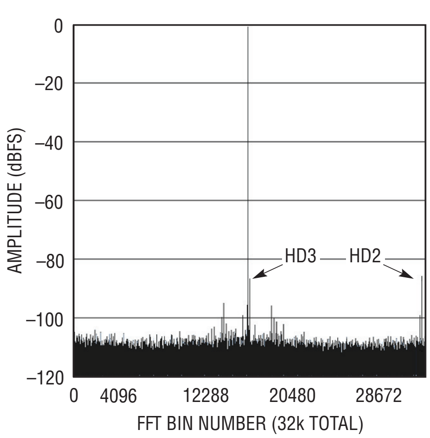


Figure 3. An FFT of the LTM9001 at 160MHz input frequency with the randomizer on

The signal must be filtered and amplified through each stage. Amplification (gain) increases the total noise and reduces the headroom, which generally causes more distortion. The added distortion may be addressed with a higher supply voltage or a higher power amplifier, neither of which is preferable. Therefore, from the system-level point of view, an ADC with a small input range is better.

The LTM9001 meets these system-level criteria. The resistive amplifier inputs are easily matched and it has an input range of ±250mV, enabling the use of low OIP3 components or higher loss SAW filters. The noise of the amplifier is low enough that the SNR of the LTM9001 is good despite the high gain (see Figure 3).

Working with a µModule Receiver

The LTM9001 uses a land grid array (LGA), which provides higher pin density than dual in-line or quad packages and better thermal conduction than BGA packages. The high integration of the LTM9001 makes the PCB board layout simple. The multilayer substrate allows greater flexibility in pin placement on the package relative to pin placement on the die. The LTM9001 has been optimized for a flow-through layout so that the interaction between inputs, clock and digital outputs is minimized. The analog and clock inputs are surrounded by ground pads and a continuous row of ground pads further separate the analog and digital signal lines. However, to optimize its electrical and thermal performance, some layout considerations are still necessary. See the actual evaluation board in Figure 4.

Use large PCB copper areas for ground. This helps to dissipate heat through the board and also helps to shield sensitive on-board analog signals. Common ground (GND) and output ground (OGND) are electrically isolated on the LTM9001, but for most digital output configurations should be connected on the PCB underneath the part to provide a common return path.

Use multiple ground vias. Using as many vias as possible helps to improve the thermal performance of the board and creates necessary barriers separating analog and digital traces on the board at high frequencies. Take care to separate analog and digital traces as much as possible, using vias to create high frequency barriers. This reduces digital feedback that can reduce the signal-to-noise ratio (SNR) and dynamic range of the LTM9001.

Conclusion

µModule technology, introduced first by Linear Technology for DC/DC converters, now brings the advantages of small size, higher integration and ease of use for high speed ADC applications. By integrating fine-line CMOS and SiGe components with appropriate passive networks, the challenging task of matching a fixed gain amplifier to a high speed ADC is done. All is reduced to an easy-to-use black box: the LTM9001.

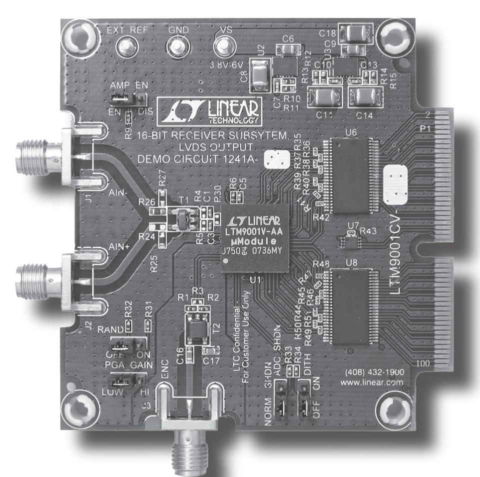


Figure 4. An evaluation board shows the small overall circuit. Note that no external components are required.

Voltage and Current Monitoring from 7V to 80V in 3mm × 3mm DFN-10

by Zhizhong Hou

Introduction

Accurate power supply voltage and current monitoring is increasingly important in everything from industrial and telecom applications to automotive and consumer electronics. A complete power monitoring system typically includes a sense resistor, a precision amplifier, an analog to digital converter (ADC) and a proper interface to report data to a host controller. The LTC4151 and LTC4151-1 combine all of these components (except the sense resistor) into one IC, resulting in a full featured, rugged and simple-to-use solution for accurate high side current sensing and voltage monitoring (see Figure 1).

The LTC4151 and LTC4151-1 offer the benefits of high side current sensing without any of the usual complexity. Each integrates a precision high voltage amplifier and associated level shift circuit for high side current sensing, a precision voltage divider for supply voltage monitoring, a 12-bit ADC and an I²C interface—all in small MS10 or tiny 3mm × 3mm DFN-10 packages.

High Side vs Low Side Sensing

In a power monitoring system, the sense resistor can be placed either between the system ground and the load (low side sensing) or between the system supply and the load (high side sensing). For many applications, high side sensing is desirable, but it is traditionally more difficult to implement.

Low side sensing is relatively simple in concept and design, but a low side sense resistor floats the load above system ground. Thus, the ground potential seen by the load varies with changing load current. This can result in the load seeing significant ground noise during transient spiking load currents. Worse yet, a failed or disconnected low side sense resistor causes the load ground to be charged to the full supply voltage, presenting a potential safety hazard.

High side sensing avoids these problems, but requires a number of high performance devices and interfaces. For instance, a robust high side sense amplifier is required to withstand high supply voltage or high voltage transients. Also, a precision level shift circuit is needed to accurately translate the large supply-referred signals to appropriate ground level signals for the ADC.

Full Featured High Side, High Voltage Digital Monitors

The LTC4151 and LTC4151-1 offer the benefits of high side current sensing without any of the usual complexity, plus they provide supply voltage monitoring in the same package. Each

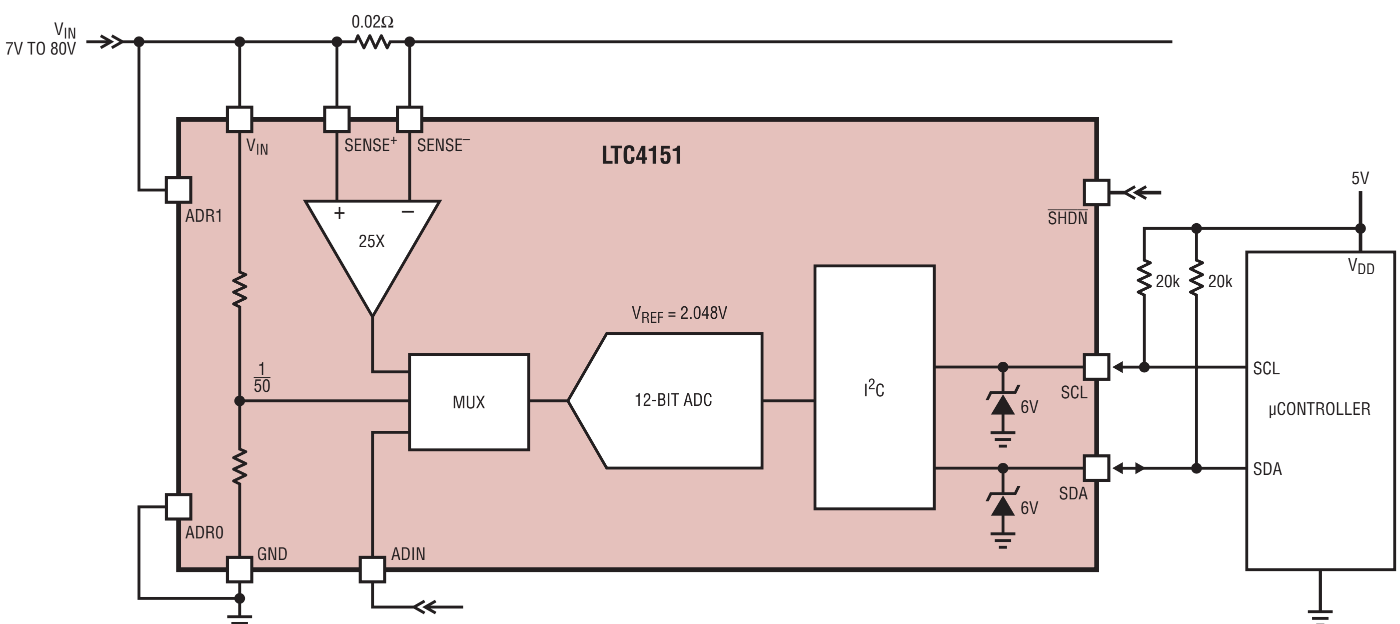


Figure 1. Full featured current and voltage monitor simplifies high voltage, high side sensing.

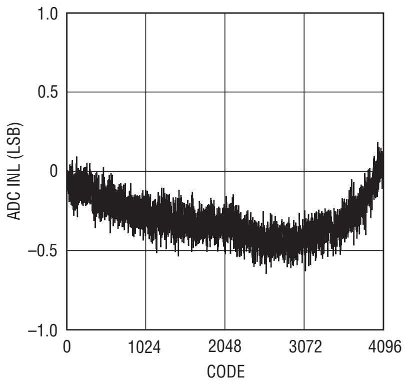


Figure 2. Typical INL error of ADIN voltage is within ±0.5LSB.

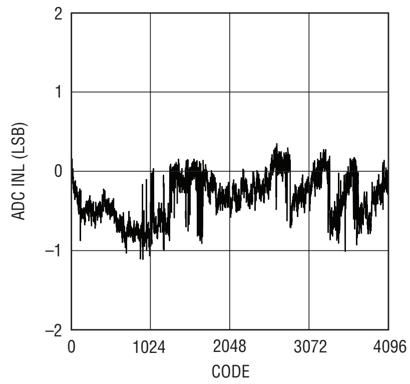


Figure 3. Typical INL error of current sense voltage is within ±1LSB.

integrates a precision high voltage amplifier and associated level shift circuit for high side current sensing, a precision voltage divider for supply voltage monitoring, a 12-bit ADC and an I²C interface—all in small MS10 or tiny 3mm × 3mm DFN-10 packages. A dedicated ADIN pin is directly connected to the ADC input for monitoring any external voltage. See Figure 1 for a simplified block diagram.

Using the I²C interface, the parts can be configured into either a continuous scan mode (default upon power up) or a snapshot mode. In continuous scan mode, the parts repeatedly measure three voltages in sequence: the differential high side sense voltage between the $SENSE^+$ and $SENSE^-$ pins, the supply voltage at the V_{IN} pin and an external voltage at the ADIN pin at a refreshing frequency of 7.5Hz. In snapshot mode, the host controller can instruct the parts to perform a one-time measurement of a specific signal. The conversion time of SENSE voltage is 67ms and that of V_{IN} and ADIN voltages is 33ms. Thanks to the oversampling Sigma-Delta ADC, any ripples within each conversion cycle are simply averaged out.

Easy to Use

Figure 1 shows just how easy it is to put together a complete voltage and high side current monitor. The only required external components are a sense resistor and two pull-up resistors (with the $\overline{SHDN}$ pin float and ADIN pin tied to GND).

The LTC4151 and the LTC4151-1 maintain high precision for supplies from 7V to 80V, an ideal range for applications with 12V, 24V or 48V supply voltages. The absolute maximum voltages of the supply pin and the two sense input pins are all rated at 90V, which helps the part survive high voltage transients. This wide input voltage range allows the part to be directly connected to high voltage supplies without the need of a secondary supply, unlike many other supply monitors.

The LTC4151 and the LTC4151-1 can be configured with one of nine I²C addresses via the ADR1 and ADR0 pins (high, low or open). These two pins are also rated at an absolute maximum voltage of 90V, again precluding the need for a separate low voltage supply.

Wide Dynamic Range and High Accuracy

LTC4151 and LTC4151-1 each combine a precision high side sense amplifier and a true 12-bit ADC. The result is a current and voltage monitor that offers a unique combination of high resolution and wide dynamic range. The full scale of the current sense voltage is 81.92mV with a resolution of 20µV/LSB. The full scale of the supply voltage is 102.4V with a resolution of 25mV/LSB. The full scale at ADIN is 2.048V with a resolution of 500µV/LSB. As Figures 2 and 3 show, the typical integral nonlinearity errors

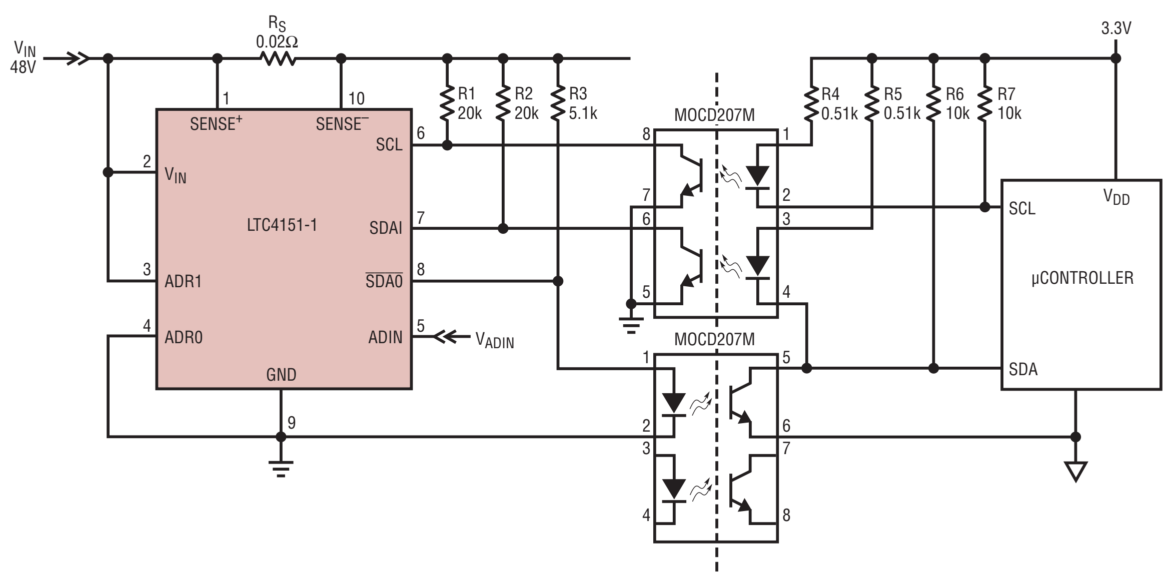


Figure 4. The LTC4151-1 makes it easy to implement optoisolation.

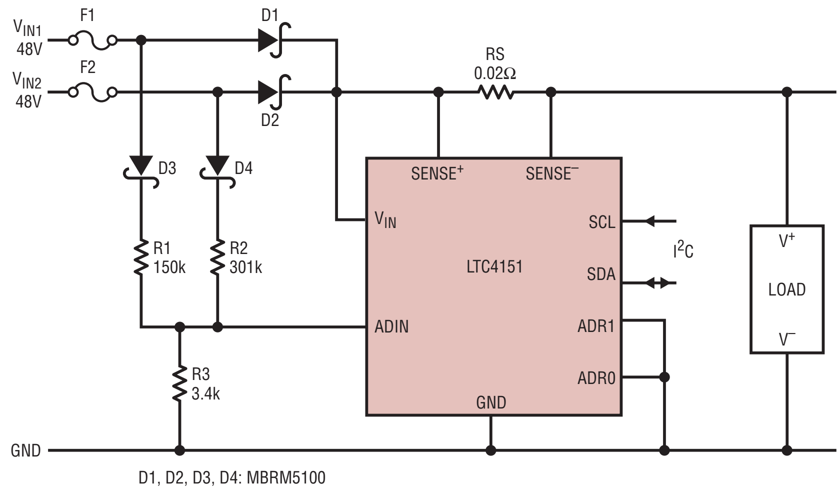
(INLs) of the ADIN voltage and the current sense voltage are both within ±1LSB. In addition, the current sense voltage, the supply voltage and the ADIN voltage are all measured with high accuracy at the full scale (1.25%, 1% and 1%, respectively) over the full industrial temperature range.

Power-Saving Shutdown or Easy Optoisolation? You Choose.

The LTC4151 features a $\overline{SHDN}$ pin with an internal 5µA pullup. When $\overline{SHDN}$ is tied to GND, the part enters shut down mode and the typical quiescent current is reduced to 120µA at 12V, about 10% of the normal operating current (1.2mA). In applications with battery supplies, one can use this pin to save power consumption.

The LTC4151-1 trades in the $\overline{SHDN}$ pin for an inverted $\overline{SDAO}$ pin to enable a simple optoisolation scheme. Optoisolation is inevitably required in applications where the host controller sits at a different ground level from the power monitor. The LTC4151-1 makes this job easy with split SDA pins: the SDAI (data input) pin and a unique $\overline{SDAO}$ (inverted data output) pin. In addition, the SCL and the SDAI pins each have an internal 6V clamp (sinking up to 5mA current).

When using optoisolators with the LTC4151-1, connect the SCL and SDAI pins to the outputs of the incoming optoisolators and connect the $\overline{SDAO}$ pin to the anode of the outgoing optoisolator, as shown Figure 4. With the outgoing optoisolator clamping the $\overline{SDAO}$ and the internal 6V clamps on SDAI and SCL, all pull-up resistors on these three pins can be directly connected to the high voltage supply, eliminating the need for a separate low voltage pull-up supply.



CONDITION*	RESULT
$N_{ADIN} \geq 1.375 \bullet N_{VIN}$	NORMAL OPERATION
$0.835 \bullet N_{VIN} \leq N_{ADIN} < 1.375 \bullet N_{VIN}$	F2 IS OPEN
$0.285 \bullet N_{VIN} \leq N_{ADIN} < 0.835 \bullet N_{VIN}$	F1 IS OPEN
(I^2C NOT RESPONDING)	BOTH F1 AND F2 ARE OPEN

* V_{IN1} and V_{IN2} differ by less than 20%. N_{ADIN} and N_{VIN} are digital codes measured by the ADC at the ADIN and V_{IN} pins, respectively.

Figure 5. A single LTC4151 monitors current, supply voltage and fuses.

ADIN Pin is Useful for Fuse Monitoring and Temperature Sensing

The LTC4151 and the LTC4151-1 feature a dedicated ADIN pin that can be used to monitor any external voltage. Figure 5 shows a simple circuit that not only measures current and supply voltage but also monitors a pair of fuses on the high side.

The fuses are monitored by comparing the voltages at the V_{IN} and ADIN pins. ADIN is connected to the two inputs after the fuses through a Y divider. Diodes D3 and D4 compensate the diode-OR D1 and D2. The voltage at ADIN varies as the status of the fuses changes, as shown in the table in Figure 5. Since the ADIN voltage is approximately ratiometric to V_{IN}, the results are independent of the supply seen at V_{IN}. The limitation of this circuit is that the two inputs must remain within 20% of each other.

The ADIN pin can also be used to monitor board temperature with an NTC thermistor as shown in Figure 6. In that circuit, V_{IN} is connected on the downstream side of the sense resistor so that the quiescent current of the LTC4151 is measured.

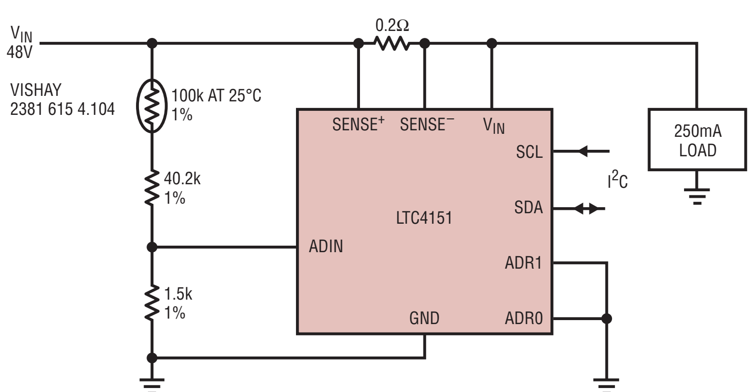


Figure 6. Temperature monitoring is simple with LTC4151 and an NTC thermistor.

Conclusion

High side current sensing and voltage monitoring could not be easier than with the LTC4151 and the LTC4151-1 supply monitors. Their wide supply range and high level of integration simplifies design, while desirable features, such as 12-bit resolution, high accuracy, I^2C interface, optoisolation support and small footprints make them an easy fit in a wide variety of applications.

Increase I²C or SMBus Data Rate and Reduce Power Consumption with Low Power Bus Accelerator

by Sam Tran

Introduction

I²C and SMBus 2-wire buses use simple open-drain pull-down drivers with resistive or current source pull-ups. Communications protocols in these systems allow multiple devices to drive and monitor the bus without bus contention, creating a robust communications link. Unfortunately, as systems trend towards higher complexity and lower supply voltages, the advantages gained by the simplicity of the open-drain pull-down protocol are offset by the disadvantages of increased rise times and greater DC bus power consumption.

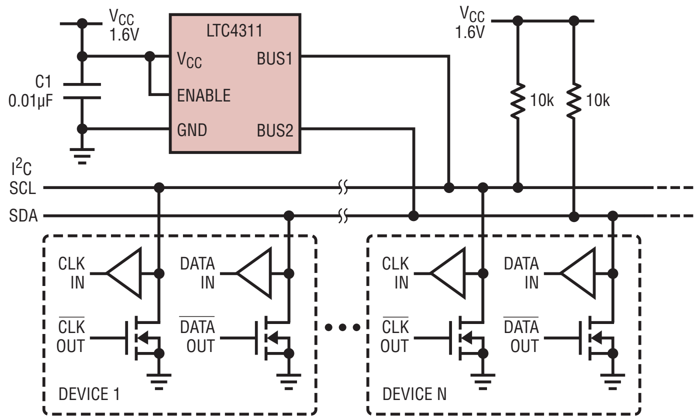


Figure 1. Typical LTC4311 low voltage application circuit

As designs require higher reliability and a greater number of features, the number of peripherals attached to the I²C or SMBus system increases. Some systems extend the bus to edge connectors where I/O cards with additional peripherals are removed and inserted onto the bus. The added peripherals directly increase the equivalent capacitance on the bus, slowing rise times. Slow rise times can seriously impact data reliability and limit the maximum practical bus speed to well below the established I²C or SMBus maximum transmission rate. Rise times can be improved by using lower bus pull-up resistor values or higher fixed current source values, but the additional bus pull-up current raises the low state bus voltage, V_{OL}, as well as the DC bus power consumption. Another issue in systems with swappable I/O cards is ESD susceptibility.

The LTC4311 bus accelerator addresses all of these issues. It comes in a tiny 2mm × 2mm DFN or SC70 package and operates over a wide power supply range of 1.6V to 5.5V, making it easy to fit in any number of applications.

Figure 1 shows a typical low voltage application circuit. The LTC4311 provides strong slew rate controlled pull-up currents on the bus for smooth, controlled transitions during rising edges to decrease rise times in highly capacitive systems, as shown in Figure 2. The LTC4311's slew rate controlled pull-up currents are strong enough to allow I²C or SMBus systems to achieve switching frequencies up to 400kHz for bus capacitances in excess of 1nF. In addition, because the accelerator pull-up impedance is significantly lower than the bus pull-up resistance, the system has greater immunity to noise on rising edges.

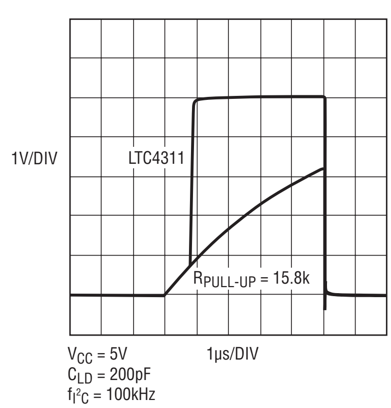


Figure 2. Comparison of I²C waveform for the LTC4311 vs resistive pull-up

The LTC4311's strong pull-up currents allow users to choose larger bus pull-up resistor values to reduce V_{OL}, DC bus power consumption and fall times, while still meeting rise time and switching frequency requirements. This is especially helpful for 2-wire systems where devices require resistances in series with their pull-down devices for ESD protection, since V_{OL} on these devices is reduced with larger bus pull-up resistor values. The larger bus pull-up resistor values are also beneficial in systems operating at bus supplies below 2.7V, where V_{OL} can be reduced well below the I²C specification, thereby increasing noise margins.

For I²C or SMBus systems where large numbers of I/O cards can be inserted and removed, the LTC4311's slew rate controlled pull-up currents properly address rise time issues despite large variations in bus capacitance. The controlled slew rate regulates the rise rate of the bus to 50V/µs–100V/µs, independent of bus capacitance.

With very light loads, as occurs when some or all cards are removed, no reflections occur on the bus due to the slew rate controlled nature of the pull-up currents. When the bus is heavily loaded, the LTC4311 provides strong, controlled pull-up currents to significantly decrease rise times on the bus for capacitive loads well beyond 1nF.

All of these features, coupled with high ±8kV HBM ESD ruggedness, make the LTC4311 ideally suited, and in many cases necessary, for I^2C or SMBus systems having large numbers of removable I/O cards.

Circuit Operation

Figure 3 shows a functional block diagram of the LTC4311. The LTC4311 consists of two independent but identical circuits for each bus, consisting of a slew rate detector, two voltage comparators, and a slew rate controlled bus pull-up current.

The slew-rate detector monitors the bus and activates the accelerators only when the bus rise rate is greater than 0.2V/µs. This ensures that the accelerators never turn on when the bus voltage is in a DC state or falling. The first voltage comparator is used to hold off the accelerator until the bus voltage exceeds a threshold voltage, V_{THR}. For supply voltages below 2.7V, V_{THR} is supply dependent, defined as $0.3 \bullet V_{CC}$. At higher supply voltages, V_{THR} is a constant 0.8V. This optimizes the LTC4311 for use in low voltage systems, while offering rise time acceleration over a larger voltage range for I^2C and SMBus systems operating at bus voltages above 2.7V.

Once both conditions are met, the slew limited bus accelerator is enabled to quickly slew the bus. An internal slew rate comparator monitors the bus rise rate and controls the accelerator pull-up current to limit the bus rise rate to 50V/µs–100V/µs, independent of the bus capacitance. A second voltage comparator disables the pull-up current when the bus is within 400mV of the bus pull-up supply.

For systems where a single bus accelerator is not sufficient to meet the rise time requirement, additional bus accelerators can be added in parallel to further decrease the rise time.

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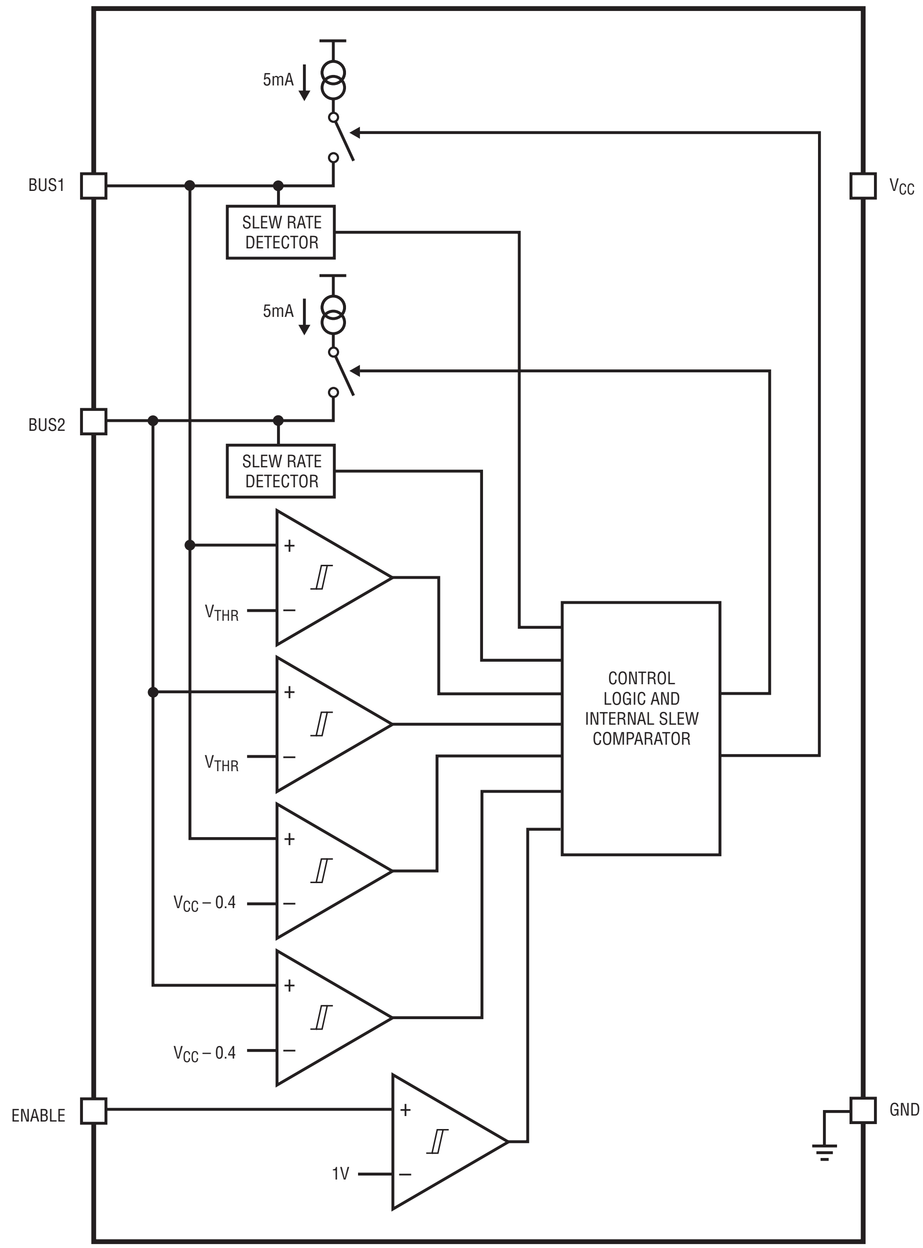


Figure 3. LTC4311 functional block diagram

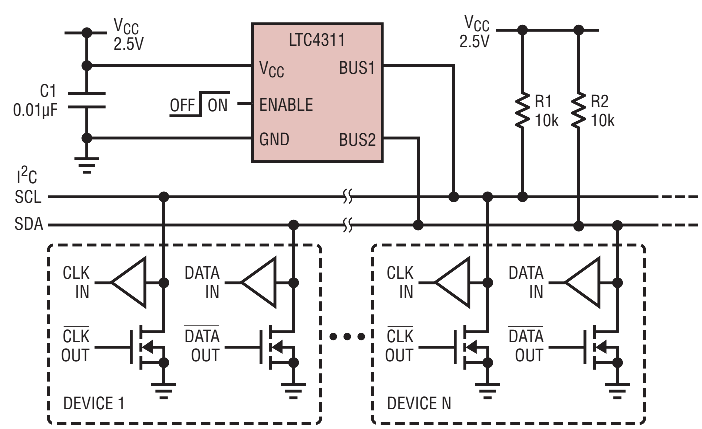


Figure 4. Typical LTC4311 application with low current shutdown

6-Input Supervisors Offer Accurate Monitoring and 125°C Operation

by Shuley Nakamura and Al Hinckley

Introduction

The latest trio of power supply supervisors from Linear Technology is ideal for today's multi-voltage systems that require accurate supply monitoring. The LTC2930, LTC2931, and LTC2932 are 6-input voltage monitors capable of maintaining 1.5% threshold accuracy from –40°C to 125°C. The combination of monitored supply voltages is set by a single pin. Each part offers 16 threshold voltage combinations, thus meeting the needs of almost any multi-voltage system. This programmability eliminates the need to qualify, source and stock unique part numbers for different threshold voltage combinations.

The overall architecture and operating specifications of these three devices are similar, but each has unique features (see Table 1). The LTC2930 generates a reset after any undervoltage event or when the manual reset input ($\overline{MR}$) pulls low. It is ideal for space-constrained applications as it comes in a compact 3mm × 3mm 12-lead DFN package. The LTC2931 includes a watchdog input (WDI), a watchdog output ($\overline{WDO}$) and user-adjustable watchdog periods to enable microprocessor monitoring and control. The LTC2932 can vary its monitor thresholds from 5% to 12.5%, and a reset disable pin provides margining capability. Both the LTC2931 and LTC2932 are packaged in 20-pin TSSOP packages and have separate comparator outputs, enabling individual supply monitoring and/or sequencing.

Table 1. LTC2930, LTC2931, LTC2932 feature summary

Feature	LTC2930	LTC2931	LTC2932
Configurable Input Threshold Combinations	16	16	16
Threshold Accuracy	1.5%	1.5%	1.5%
Adjustable Reset Time	✓	✓	✓
Buffered Reference	✓	✓	✓
Individual Comparator Outputs		✓	✓
Manual Reset	✓		
Independent Watchdog Circuitry		✓	
Reset Disable			✓
Supply Tolerance	Fixed, 5%	Fixed, 5%	User Selectable 5%, 7.5%, 10%, 12.5%
Package	12-lead 3mm × 3mm DFN	20-lead F Package	20-lead F Package

Single Pin Configuration Makes Life Easy

These supervisors offer an elegant method of configuring the input voltage thresholds. Figure 1 shows how a single resistive divider at the VPG pin sets the supervisor into one of the 16 threshold options shown in Table 2. See the data sheet for suggested mode-setting resistor values.

The actual thresholds are set by integrated precision dividers for 5V, 3.3V, 3V, 2.5V, 1.8V, and 1.5V supply monitoring. For other supply values, uncommitted comparators with 0.5V thresholds allow virtually any positive supply to be monitored using a resistive divider, as shown in Figure 2a. The V4 input also monitors negative voltages—with the same 1.5% accuracy—using the integrated buffered reference for offset (see Figure 2b).

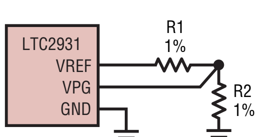
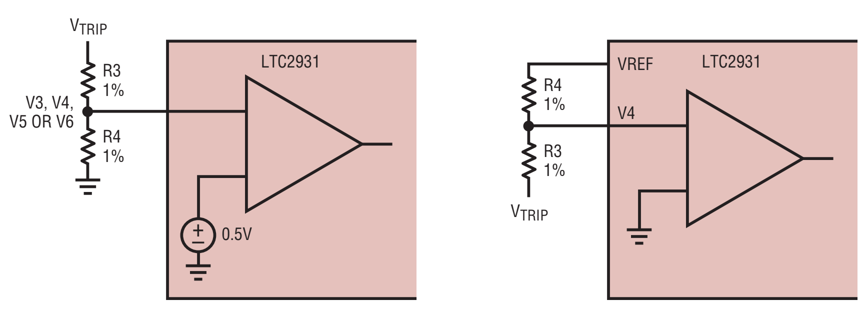


Figure 1. Mode selection



2a. 2b.

Figure 2. Using a resistive divider to set the voltage trip point

What Does Threshold Accuracy Mean?

Consider a 5V system with ±5% supply tolerance. The 5V supply may vary between 4.75V to 5.25V. System ICs powered by this supply must operate reliably within this band (and a little more, as explained below). A perfectly accurate supervisor for this supply generates a reset at exactly 4.75V. However, no supervisor is this perfect. The actual reset threshold of a supervisor fluctuates over a specified band; the LTC2930, LTC2931 and LTC2932 vary ±1.5% around their nominal threshold voltage over temperature (Figure 3). The reset threshold band and the power supply tolerance bands should not overlap. This prevents false or nuisance resets when the power supply is actually within its specified tolerance band.

The LTC2930, LTC2931 and LTC2932 boast a ±1.5% reset threshold accuracy, so a "5%" threshold is usually set to 6.5% below the nominal input voltage. Therefore, a typical 5V, "5%" threshold is 4.675V. The threshold is guaranteed to lie in the band between 4.750V and 4.600V over temperature. The powered system must work reliably down to the low end of the threshold band, or risk malfunction before a reset signal is properly issued.

A less accurate supervisor increases the required system voltage margin and increases the probability of system malfunction. The tight ±1.5% accuracy specification of the LTC2930, LTC2931 and LTC2932 improves the reliability of the system over supervisors with wider threshold specifications.

Table 2. Voltage threshold modes

V1 (V)	V2 (V)	V3 (V)	V4 (V)	V5 (V)	V6 (V)
5.0	3.3	2.5	1.8	ADJ	ADJ
5.0	3.3	2.5	1.5	ADJ	ADJ
5.0	3.3	2.5	ADJ	ADJ	ADJ
5.0	3.3	1.8	ADJ	ADJ	ADJ
5.0	3.3	1.8	–ADJ	ADJ	ADJ
5.0	3.3	ADJ	ADJ	ADJ	ADJ
5.0	3.3	ADJ	–ADJ	ADJ	ADJ
5.0	3.0	2.5	ADJ	ADJ	ADJ
5.0	3.0	1.8	ADJ	ADJ	ADJ
5.0	3.0	ADJ	ADJ	ADJ	ADJ
3.3	2.5	1.8	1.5	ADJ	ADJ
3.3	2.5	1.8	ADJ	ADJ	ADJ
3.3	2.5	1.8	–ADJ	ADJ	ADJ
3.3	2.5	1.5	ADJ	ADJ	ADJ
3.3	2.5	ADJ	ADJ	ADJ	ADJ
3.3	2.5	ADJ	–ADJ	ADJ	ADJ

Glitch Immunity = No Spurious Resets!

Monitored supply voltages are far from being ideal, perfectly flat DC signals. Riding on top of these supplies are high frequency components caused by a number of sources such as the output ripple of the power supply or coupling from other signals. If the monitored voltage is near or at the reset threshold voltage, this noise could cause spurious resets. Fortunately, the LTC2930, LTC2931 and LTC2932 have been designed with this potential issue in mind, so spurious resets are of little to no concern.

Some supply monitors overcome spurious resets by adding hysteresis to the input comparator. The amount of applied hysteresis is stated as a percentage of the trip threshold. Unfortunately, this degrades monitor accuracy because the true accuracy of the trip threshold is now the percentage of added hysteresis plus the advertised accuracy of the part. The LTC2930, LTC2931 and LTC2932 do not use hysteresis, but instead use an integration scheme that requires transients to possess enough magnitude and duration to switch the comparators. This suppresses spurious resets without degrading the monitor accuracy.

The COMP5 comparator output response to a "noisy" input on the LTC2931 is demonstrated in Figure 4.

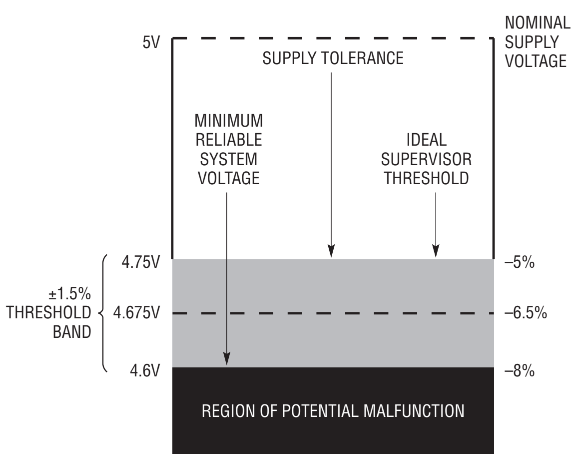


Figure 3. Tight 1.5% threshold accuracy yields high system reliability

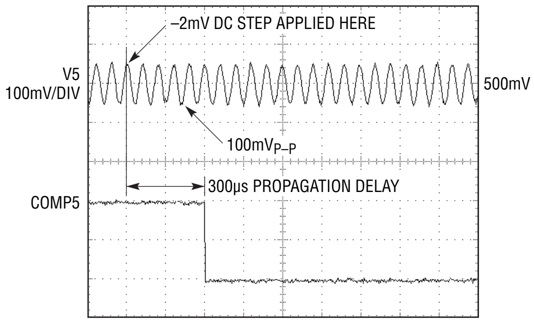


Figure 4. Comparator output is resistant to noisy input voltage

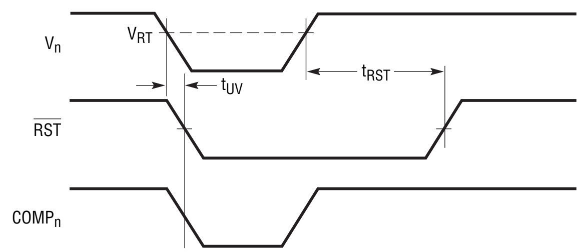


Figure 5. $\overline{\text{RST}}$ timing diagram

In the example shown, a 500kHz, $100mV_{P-P}$ sine wave centered at 500mV is applied to the V5 input. The threshold voltage of the adjustable input, V5, is 500mV. Even though the signal amplitude goes as low as 450mV, COMP5 remains high. Next, the DC level of the input is dropped 2mV. In response, COMP5 pulls low and remains low. As mentioned earlier, only transients of long enough duration and magnitude trigger the comparator output to pull high or low.

Adjustable Reset Timeout Period for Varied Application Needs

Each of the supervisors includes an adjustable reset timeout period, t_{RST}. Once all the inputs are above their threshold values, the reset timer is started (Figure 5). $\overline{\text{RST}}$ stays low for the duration of t_{RST} and remains low as long as the time between transients is less than the reset timeout. In other words, the reset timeout prevents supply transients with frequencies greater than $1/t_{RST}$ from causing undesired toggling at the $\overline{\text{RST}}$ output. Keeping $\overline{\text{RST}}$ low during these supply transients suppresses spurious resets.

The reset timeout period is adjustable to accommodate a variety of microprocessor applications. Configure the reset timeout period, t_{RST}, by connecting a capacitor, C_{RT}, between the CRT pin and GND. The value of this capacitor is determined by

$$C_{RT} = \frac{t_{RST}}{2M\Omega} = 500(pF/ms) \bullet t_{RST}$$

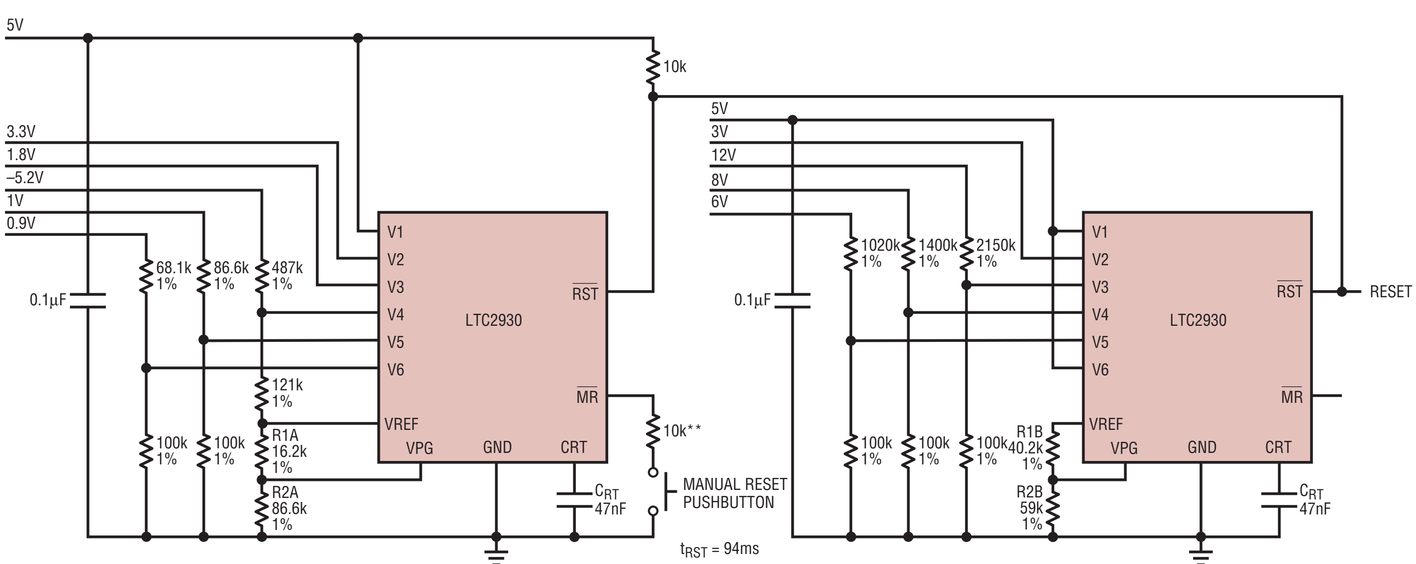
Leaving the CRT pin unconnected generates a minimum reset timeout of approximately 25μs. Maximum reset timeout is limited by the largest available low leakage capacitor.

Additional Glitch Filtering

Even though all six comparators have built-in glitch filtering, adding bypass capacitors on the V1 and V2 inputs is recommended, because of these two, the input with the higher voltage functions as V_{CC} for the entire chip. Additional filter capacitors may be added to the V3, V4, V5 and V6 inputs if needed to suppress troublesome noise.

Open-Drain Reset

The $\overline{\text{RST}}$ outputs on the LTC2930, LTC2931 and LTC2932 are open-drain and contain weak pull-up current sources to the V2 voltage.



**OPTIONAL FOR EXTENDED ESD TOLERANCE

Figure 6. Wired-OR system reset

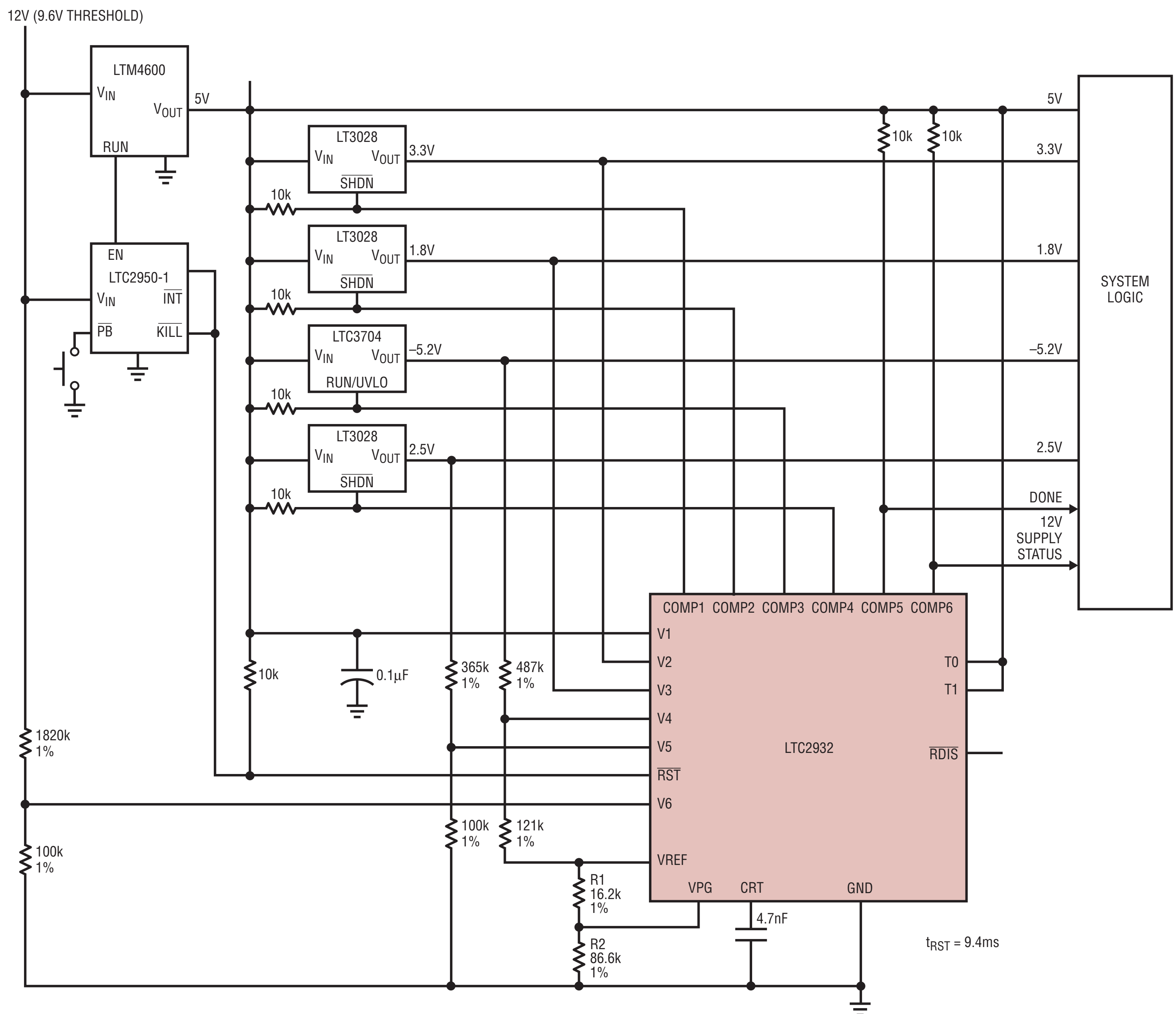


Figure 7. Five supply 12.5% tolerance power-up sequencer with pushbutton

The open-drain structure provides many advantages. For instance, each of these outputs can be externally pulled-up to voltages higher than V2 using a pull-up resistor. This facilitates the use of multiple devices operating under different I/O voltages. In addition, multiple open-drain outputs can be configured in a "wired-OR" format where the outputs are tied together. Figure 6 showcases two LTC2930 supervisors, whose open-drain $\overline{RST}$ outputs are tied together and pulled-up to 5V via a 10k pull-up resistor. If one $\overline{RST}$ output pulls low due to a reset event, it sinks current and pulls the other output low.

Comparator Outputs Enable Individual Supply Monitoring and Sequencing Support

Real-time comparator outputs on both the LTC2931 and LTC2932 indicate the status of the individual inputs. Similar to the $\overline{RST}$ output, the comparator outputs are also open-drain and have weak pull-up current sources to the V2 voltage.

While $\overline{RST}$ pulls low when an undervoltage event occurs on any of the monitored supplies, a comparator output pulls low only when its counterpart input is below its threshold voltage. The ability to monitor the status of each supply is useful in multi-voltage systems where it is important to know which particular supply has failed.

The individual comparator outputs also allow power supply sequencing. Figure 7 shows the LTC2932 in a 5-supply power-up sequencer. As an input reaches its threshold, the respective comparator output pulls high and enables the next DC/DC converter.

The LTC2950-1 is used to provide pushbutton control for the sequencer. After the pushbutton is pressed, the LTC2950-1 pulls the RUN pin of the LTM4600 high. Subsequently, the LTM4600 generates a 5V output which supplies power to each of the four DC/DC converters.

Three Supervisor Flavors

LTC2930: Manual Reset ($\overline{MR}$) Forces $\overline{RST}$ Low

Use the manual reset input ($\overline{MR}$) on the LTC2930 to issue a forced reset, independent of input voltage levels. A 10µA (typical) internal current source pulls the $\overline{MR}$ pin to V_{CC}. A logic low on this pin pulls $\overline{RST}$ low. When the $\overline{MR}$ pin returns high, $\overline{RST}$ returns high after the selected reset timeout period has elapsed, assuming all six voltage inputs are above their thresholds (Figure 8). The input-high threshold on the $\overline{MR}$ pin is 1.6V (max), allowing the pin to be driven by low voltage logic as well.

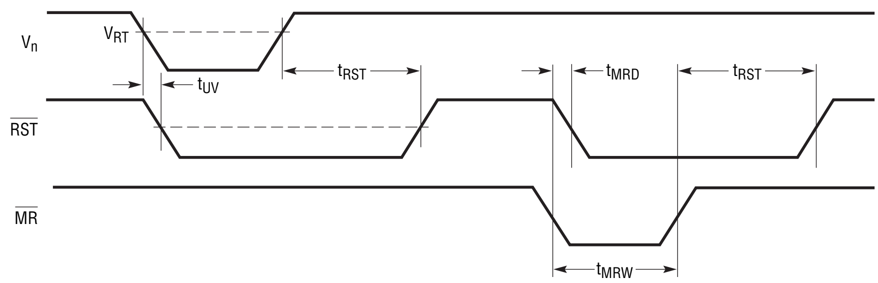


Figure 8. $\overline{MR}$ timing diagram

LTC2931: Monitor a Microprocessor with the Watchdog Function

The LTC2931's independent watchdog circuitry monitors a microprocessor's activity. The microprocessor is required to change the logic state of the WDI pin on a periodic basis in order to clear the watchdog timer. The LTC2931 consists of a watchdog input (WDI), a watchdog output ($\overline{WDO}$) and a timing pin (CWT), which allows for a user adjustable watchdog timeout period. Figure 9 illustrates the watchdog timer and its relationship to the reset timer and WDI.

The watchdog timeout period is adjustable and can be optimized for software execution. The watchdog timeout period, t_{WD}, is adjusted by connecting a capacitor, C_{WT}, between the CWT pin and ground. The value of this capacitor is determined by

$$C_{WT} = \frac{t_{WD}}{20M\Omega} = 50\left(pF/ms\right) \bullet t_{WD}$$

Leaving the CWT pin unconnected generates a minimum watchdog timeout of approximately 200µs. Maximum watchdog timeout is limited by the largest available low leakage capacitor.

LTC2932: Margining Capabilities and Wider Threshold Tolerances

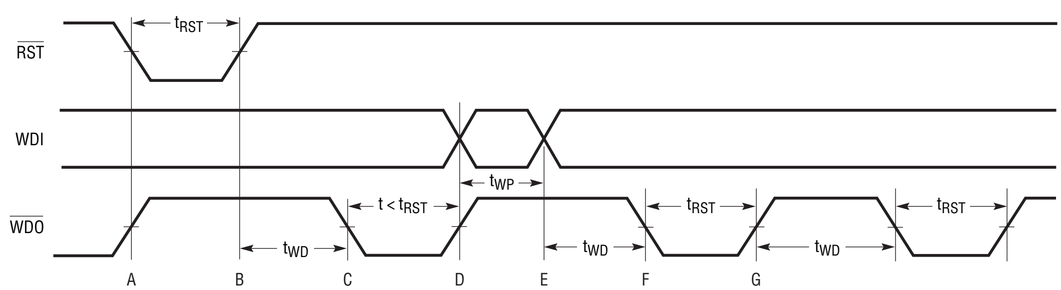
In high reliability system manufacturing and testing, it is important to verify that the components will continue to operate at or below the rated power supply tolerance. Verification usually involves margining the power supplies, running their outputs at or beyond rated tolerances. The LTC2932 is designed to complement such testing in two ways. First, the $\overline{RST}$ output can be disabled by pulling $\overline{RDIS}$ low. In this state, the $\overline{RST}$ output remains high despite any undervoltage events which may occur during margining tests. This does not affect the individual supply monitoring, which is independent of the logic state of $\overline{RDIS}$. Second, lowering the trip thresholds can increase supply headroom to match the margining ranges. This is simply a matter of changing the two tolerance selection inputs, T0 and T1, to adjust the global supply tolerance to 5%, 7.5%, 10%, or 12.5% (see Table 3).

Table 3. LTC2932 Tolerance Selection

T0	T1	TOLERANCE (%)	V_{REF} (V)
Low	Low	5	1.210
Low	High	7.5	1.175
High	Low	10	1.146
High	High	12.5	1.113

Automotive Application

The ease of implementation, wide operating temperature range, and low supply current requirements for the LTC2930, LTC2931 and LTC2932 supervisors make them ideal for automotive applications. Figure 10



A. UNDERVOLTAGE EVENT OCCURS, $\overline{RST}$ PULLS LOW, $\overline{WDO}$ PULLS HIGH, AND $\overline{RST}$ TIMER STARTS.
B. $\overline{RST}$ TIMES OUT (ALL INPUT VOLTAGES BECOME GOOD BEFORE $\overline{RST}$ TIMEOUT), t_{RST}, THEN WATCHDOG TIMER STARTS.
C. WATCHDOG TIMES OUT, t_{WD}, AND $\overline{WDO}$ PULLS LOW. $\overline{RST}$ TIMER STARTS.
D. WDI TRANSITION OCCURS BEFORE $\overline{RST}$ TIMEOUT. $\overline{WDO}$ PULLS HIGH AND $\overline{WDO}$ TIMER STARTS.
E. WDI TRANSITION OCCURS WHILE $\overline{WDO}$ IS HIGH. WATCHDOG TIMER CLEARS AND RESTARTS.
F. WATCHDOG TIMES OUT. $\overline{WDO}$ PULLS LOW AND $\overline{RST}$ TIMER STARTS.
G. $\overline{RST}$ TIMES OUT. $\overline{WDO}$ PULLS HIGH AND WATCHDOG TIMER STARTS.

Figure 9. Watchdog timing diagram

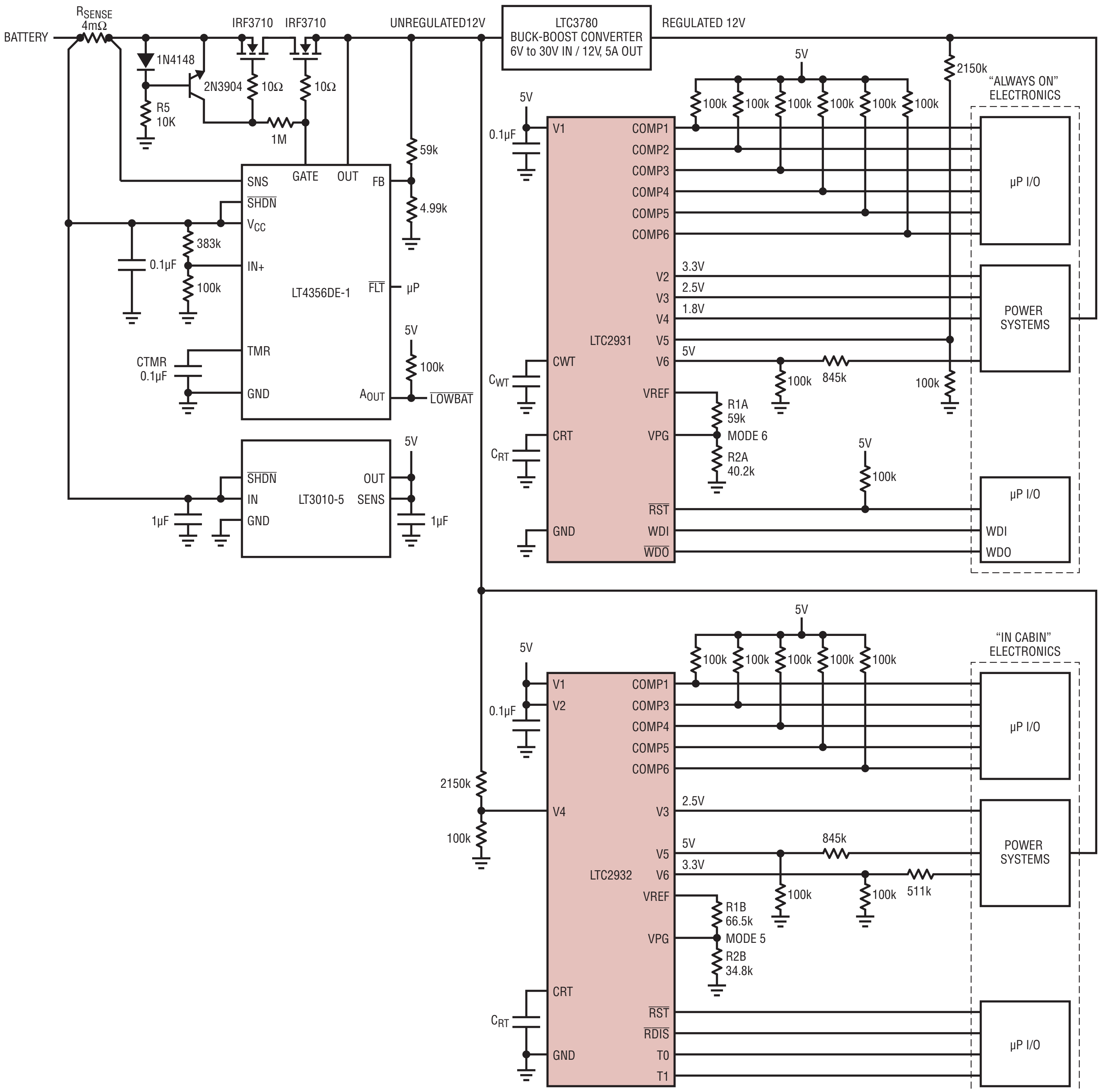


Figure 10. The LTC2931 and LTC2932 in an automotive application

is a block diagram schematic of an automotive application that uses the LTC2931 and LTC2932. It was designed to highlight and utilize the features of these parts beyond simple voltage monitoring. The voltage monitors are powered by the LT3010-5, a fixed 5V micropower linear regulator. Voltage transient protection is provided by the LT4356DE-1 overvoltage protection regulator and inrush limiter.

In a typical automotive power system, a distinction is made between "Always On" and "In Cabin" electronics. "Always On" systems include critical electronics that deal with the safety and security of an automobile and, as the name implies, are always on. "In Cabin" electronics pertain to comfort and entertainment accessories used in automobiles. In the event the battery is low, for instance, the in cabin electronics are turned off to preserve and siphon power to the critical path.

In this automotive application, power for the always on critical electronics is generated by the LTC3780 buck

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High Power, Single Inductor, Surface Mount Buck-Boost µModule Regulators Handle $36V_{IN}$, 10A Loads

by Manjing Xie

Introduction

One of the most daunting tasks for a power supply designer is producing a high power density supply where the output voltage sits within the input voltage range. High power density buck-boost converters usually require complex and bulky magnetics, run at low efficiency, and place high electrical and thermal stresses on devices. The LTM4605 and LTM4607 µModule regulators can cure these buck-boost headaches. The secret is in reducing the component selection to an inductor, a sense resistor and bulk input and output capacitors. The resulting solution is as close to a plug-and-play buck-boost converter you can get in an IC form factor.

The LTM4605 and LTM4607 incorporate most of the components needed for a complete buck-boost solution in their 15mm × 15mm × 2.8mm low profile packages, including the switching controller, power FETs and support components.

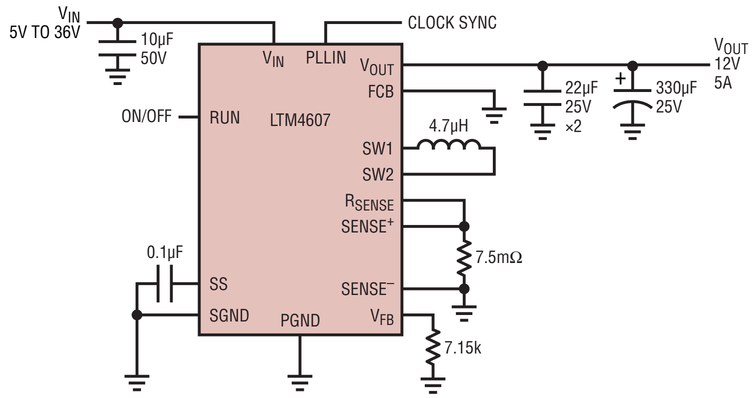


Figure 1. Remarkable simplicity in the face of an otherwise daunting task. Only a few components are required to provide an efficient 12V, 5A output from a 5V-to-36V input.

The LTM4605 and LTM4607 incorporate most of the components needed for a complete buck-boost solution in their 15mm × 15mm × 2.8mm low profile packages, including the switching controller, power FETs and support components. Their synchronous 4-switch architecture can achieve up to 92% efficiency in boost mode and 97.7% efficiency in buck mode.

The LTM4605 has a 4.5V to 20V input range and a 0.8V to 20V output range, while the LTM4607 takes a 4.5V to 36V input to a 0.8V to 24V output. Such wide voltage ranges save signifi-

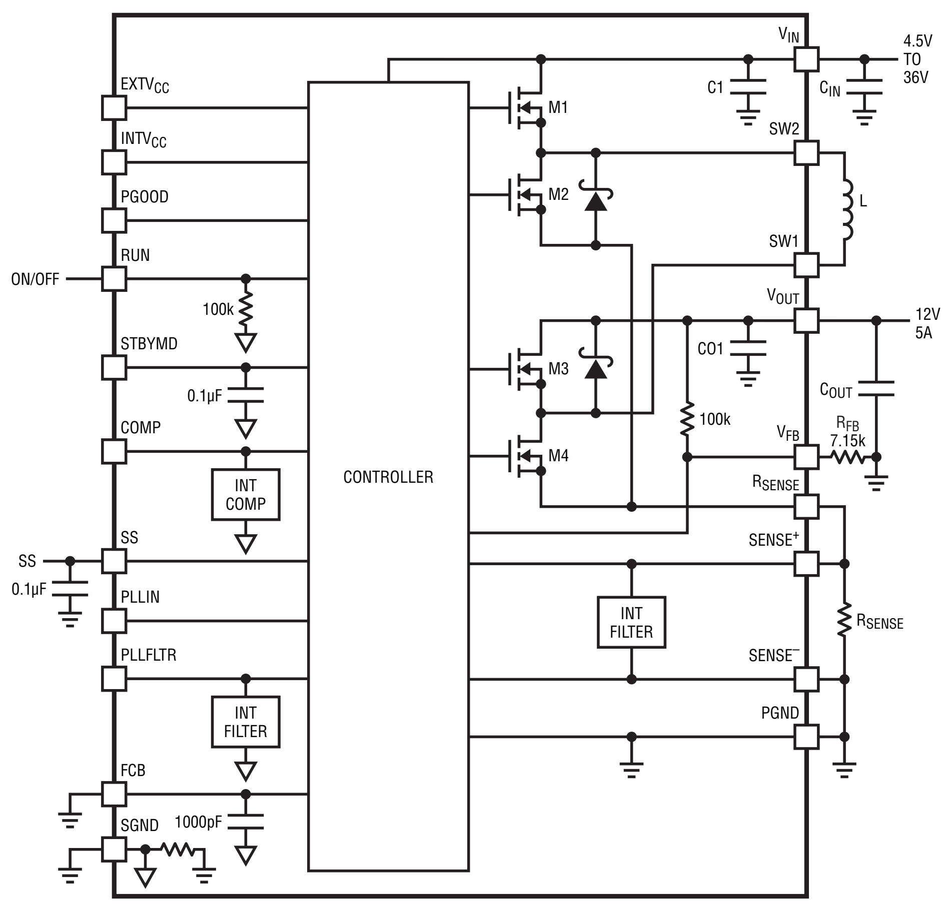


Figure 2. Simplified block diagram of the LTM4607

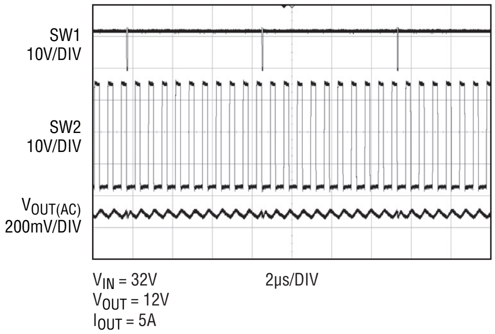


Figure 3. Buck mode waveforms

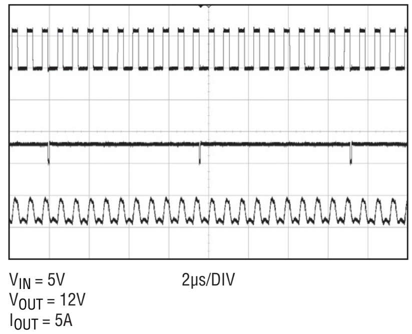


Figure 4. Boost mode waveforms

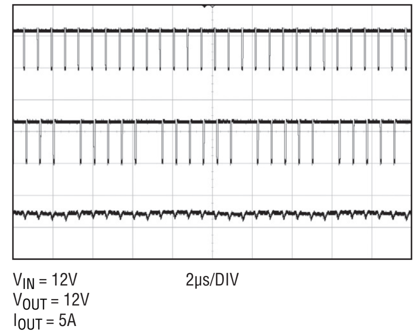


Figure 5. Transition mode waveforms

cant design time as one part can serve a wide variety of applications—reducing the need to certify and stock different parts for different applications. To round out these devices as complete power supplies, both include important safety features including true soft-start, output overvoltage protection (OVP) and foldback protection in buck, boost and buck-boost modes.

12V, 5A Supply from a 5V–36V Input

Figure 1 shows the LTM4607 providing a 12V, 5A output from a 5V–36V input. The LTM4607 operates as a buck converter at input voltages above the output, as a boost converter at input voltages well below the output, and a combination of the two in the transition region where the input voltage is close to the output.

Inside the LTM4605 and LTM4607

Figure 2 is a simplified internal diagram of the LTM4607, showing the two switching legs: the boost leg connected to the output, and the buck leg to the input. Each synchronous switching leg is formed by two MOSFETs. SW1 and SW2 tap the middle of the internal boost leg and buck leg respectively.

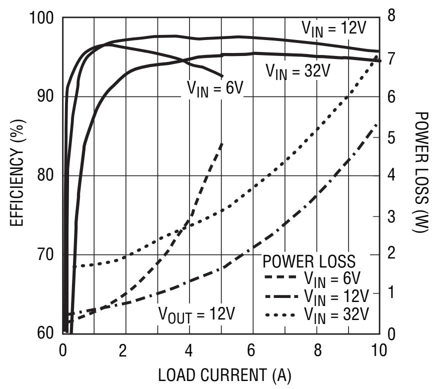
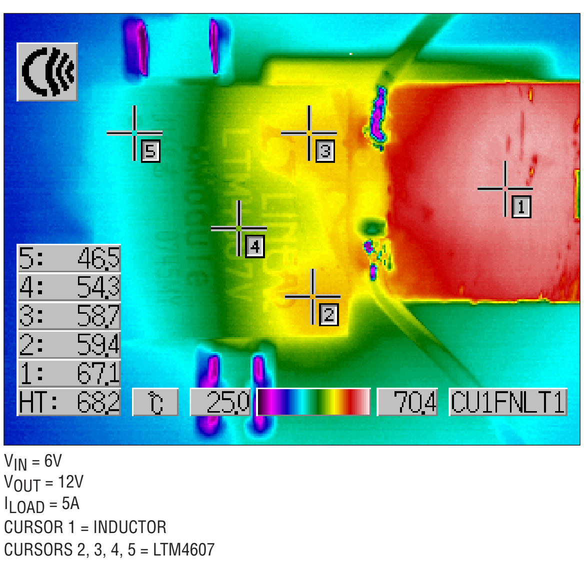


Figure 6. Efficiency and power loss for the LTM4607 at different input voltages

Operation of the LTM4607 buck, boost and transition regions can be seen in Figures 3 to 5. In buck mode, SW1 is connected to the output and the internal buck leg switches to regulate the output voltage. In boost mode, SW2 is connected to the input and the boost leg is in action. During the transition mode, when the input voltage is close to the output, both buck leg and boost legs are in action. To keep the internal bootstrap circuits constantly alive for both legs, the “inactive” leg refreshes every tenth cycle of the “active” leg. That is, the boost leg switches once for every ten switching cycles in buck mode while the buck leg switches similarly in boost mode.



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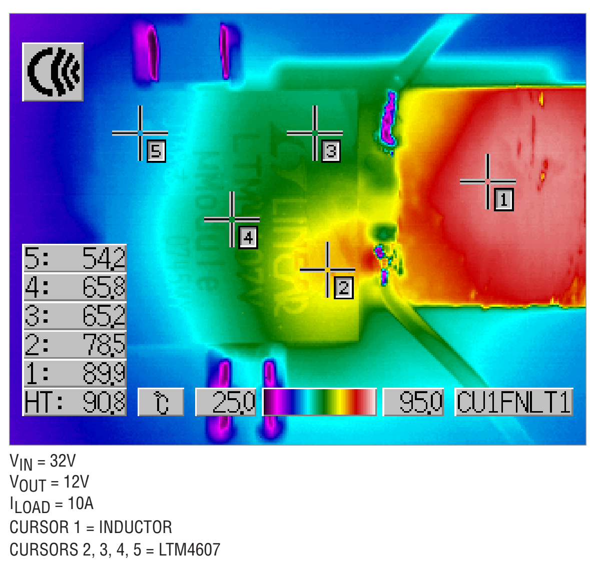

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Figure 7. Thermal images with V_{OUT} = 12V and 25°C ambient temperature.

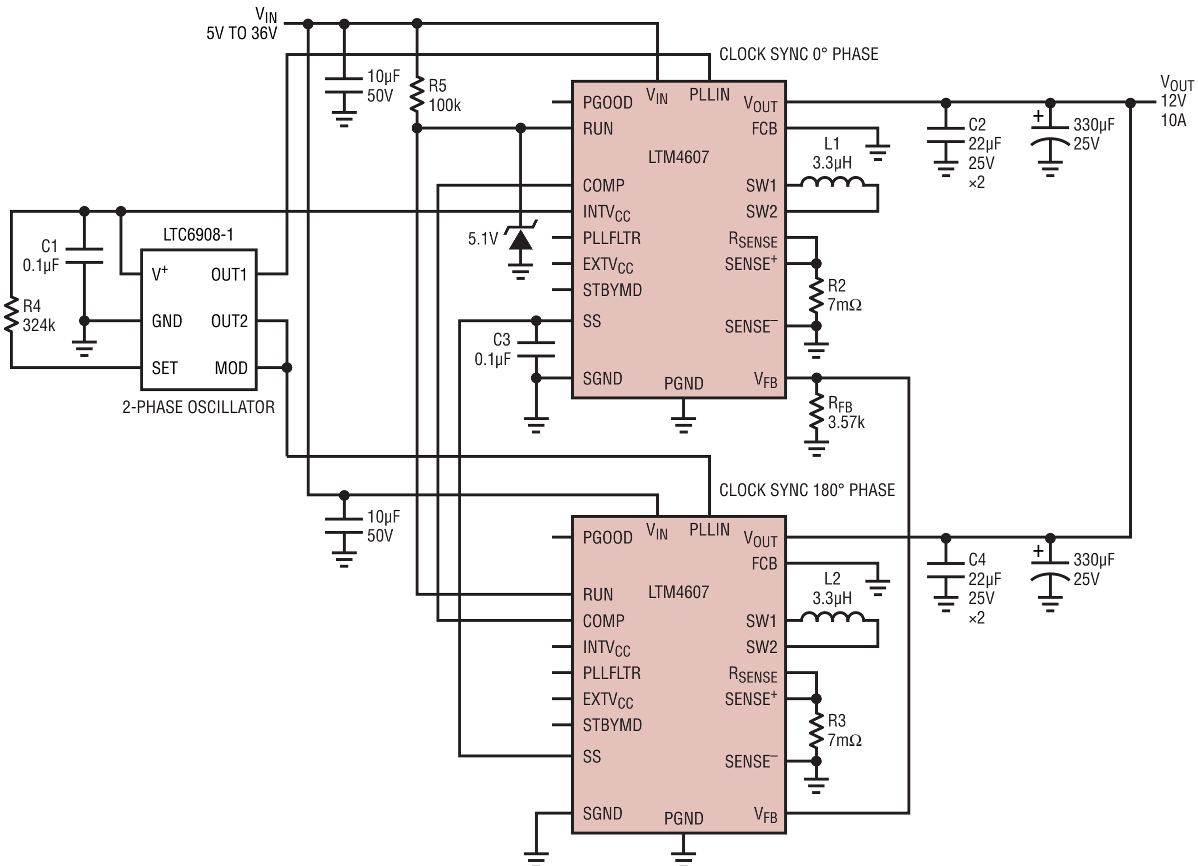

Figure 8. Schematic of two LTM4607 in parallel to provide 12V at 10A output from 6V to 36V source

Efficiency Considerations

The internal MOSFETs are optimized and able to deliver up to 12A output current for the LTM4605 and 10A for the LTM4607 in buck mode. The LTM4607's maximum output current in boost mode is rated at 5A DC (typical). Either part can be easily paralleled for higher current applications (see next section). The current limitations are imposed by power losses from the internal MOSFETs.

Figure 6 shows the typical efficiency of the LTM4607 at various input voltages. Worst-case efficiency usually occurs at minimum and maximum V_{IN}. At minimum V_{IN}, increased inductor current and related conduction losses take the biggest bite out of efficiency, while at maximum V_{IN}, switching losses dominate. Derating is necessary under certain input, output and thermal conditions. Thermal images of the circuit shown in Figure 1 are shown in Figure 7. Note that Figure 7b shows a single µModule regulator supplying 10A in buck mode.

PolyPhase® Paralleling for High Output Current

If an application requires higher current than a single LTM4605 or LTM4607 can supply, two or more µModule regulators can be connected in parallel (Figure 8) to increase the available output current. The current

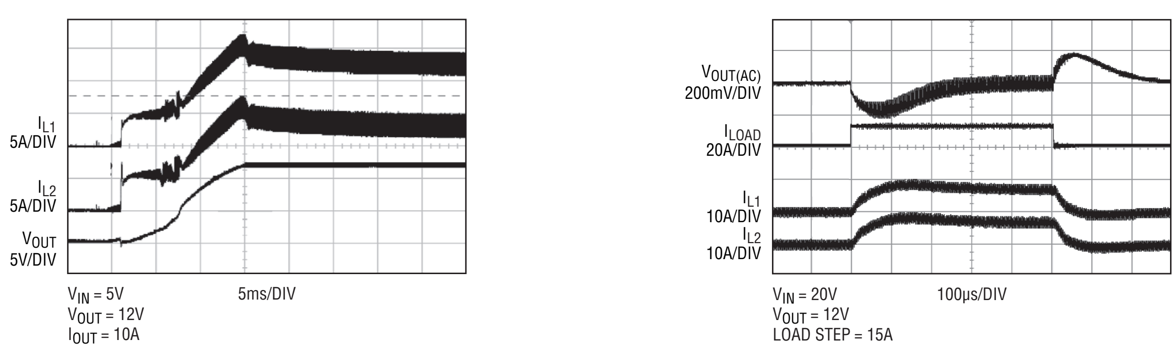

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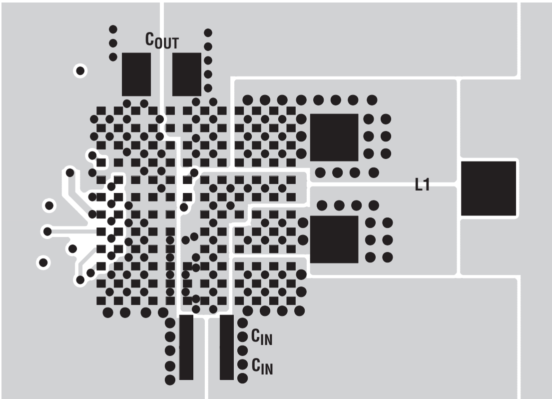
Figure 9. Inductor current waveforms at start-up and load transient with two LTM4607s in parallel



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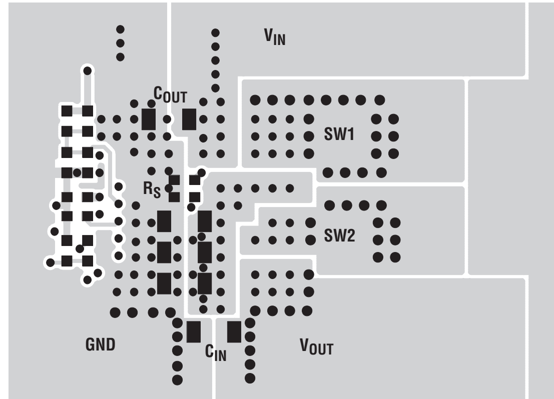

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Figure 10. Recommended parts placement and layout

mode architecture of the LTM4607 facilitates efficient PolyPhase operation (interleaved switch operation) of the parallel regulators. In a parallel setup, a single V_{OUT} set resistor is shared by the regulators. The current control signal and COMP pins are tied together, thus resulting in balanced current sharing, as shown in Figure 9

The 200kHz to 400kHz phase lock loop of LTM4607 enables interleaved switch operation, which reduces input and output ripple current. Figure 8 shows two LTM4607s connected in parallel to provide a 12V, 10A output. Interleaved clock signals are generated by the LTC6908-1.

PCB Layout Considerations

With over 12A of inductor current and four switching MOSFETs, care must be taken during the PCB layout to minimize EMI and thermal stress. Figure 10 shows the recommended component placement of components on both the top and bottom of the board.

There are two critical loops. One is formed by input capacitors, the SW2 pins, the sense resistor and GND; the other is formed by output capacitor, the SW1 pins, the sense resistor and GND. Because of the high dI/dt pulsing current in both loops, their area should be minimized. Thus, the sense resistor should be put directly beneath the module with as many vias as possible on R_{SENSE} and GND. When components are restricted to one layer, place the sense resistor as close as possible to the module. Low ESR and ESL ceramic capacitors should be used at the input and output and be placed as close to the module as possible. The second layer should be a solid ground plane.

Because both the LTM4605 and LTM4607 use a versatile and responsive current mode control architecture, an external sense resistor is required. Accurate sensing of the inductor current is required for both system stability and an accurate current limit. Because the sensed current is pulsating, parasitic inductance along the current path should be minimized. A Kelvin connection is recommended as shown in Figure 11, and the current sense traces should be close to each other.[1]

Layout with the LTM4605 and LTM4607 couldn't be easier—there are so few components—but it is important to carefully consider thermal design.

SW1 and SW2 nodes should be connected to a large sized copper conductor utilizing the inner and bottom layers to help dissipate heat. Thermal vias should be placed beneath the module and on the copper planes as shown in Figure 10.

Since both the SW1 and SW2 nodes produce high dV/dt values, it is better to keep control signal traces away from these nodes.

To improve reliability and thermal performance, the thermal profile should be tuned to minimize voids. Also try to place control signals in inner layers to free the thicker top and bottom layers for current conduction and thermal dissipation.

continued on page 36

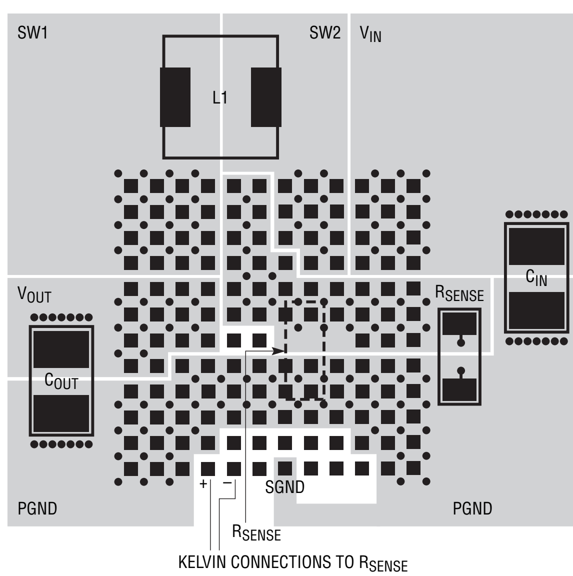


Figure 11. Kelvin connection used to sense current.

1.5% Accurate Single-Supply Supervisors Simplify Part Selection and Operate to 125°C

by Bob Jurgilewicz and Roger Zemke

Introduction

A new line of full-featured single-input supervisors are easy to place, easy to bias and easy to configure. They are also highly accurate, an important feature for keeping systems running reliably.

The LTC2915, LTC2916, LTC2917 and LTC2918 provide as many as twenty-seven integrated, user-selectable thresholds that are compatible with many standard power supply voltages. A user-adjustable input also allows for customizable thresholds. The reset timeout period is fixed at 200ms, or add a capacitor to generate a custom timeout. The even-numbered parts include an option to generate a reset-on-demand using the manual reset input, which is compatible with mechanical or electrical switching. The LTC2917 and LTC2918 have watchdog circuits that monitor processor signal activity within a user-adjustable window or non-windowed time period.

Electrical specifications are guaranteed to 125°C, so these supervisors are perfect for high temperature environments, such as automotive applications. Operating voltage range begins at a low 1.5V, and extends to any

Table 1. LTC2915, LTC2916, LTC2917 and LTC2918 feature summary

Feature	LTC2915	LTC2916	LTC2917	LTC2918
9 Selectable Thresholds	✓	✓	✓	✓
Wide Temperature Range −40°C to +125°C	✓	✓	✓	✓
Threshold Accuracy	±1.5%	±1.5%	±1.5%	±1.5%
Shunt Regulator for High Voltage Operation	✓	✓	✓	✓
Quiescent Current	30µA	30µA	30µA	30µA
Low Voltage Reset	0.8V	0.8V	0.8V	0.8V
Reset Timeout: 200ms Fixed or Externally Adjustable	✓	✓	✓	✓
Power Supply Glitch Immunity	✓	✓	✓	✓
Selectable Supply Tolerance −5%, −10%, −15%	✓		✓	
Manual Reset		✓		✓
Watchdog Timeout: 1.6s Fixed or Externally Adjustable			✓	✓
Non–Windowed Watchdog			-A	-A
Windowed Watchdog			-B	-B

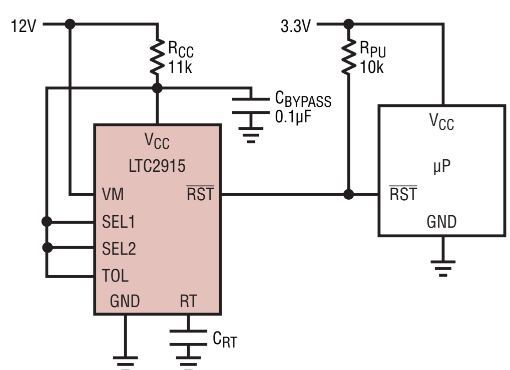


Figure 1. A 12V supply monitored from 12V, utilizing internal shunt regulator with 3.3V logic out

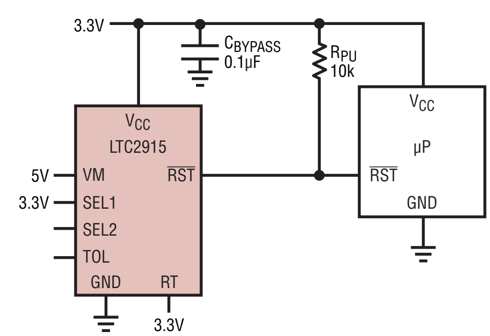


Figure 2. A 5V, –10% tolerance supply monitor with 200ms internal reset timeout

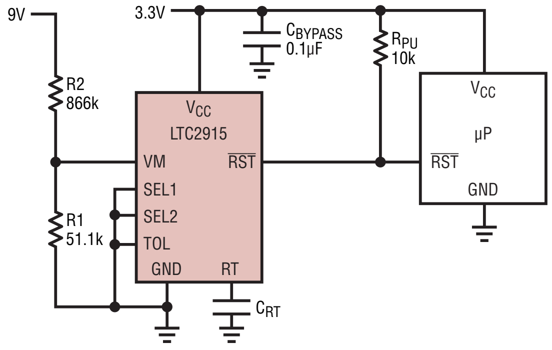


Figure 3. A 9V, –15% tolerance supply monitor with 3.3V logic out

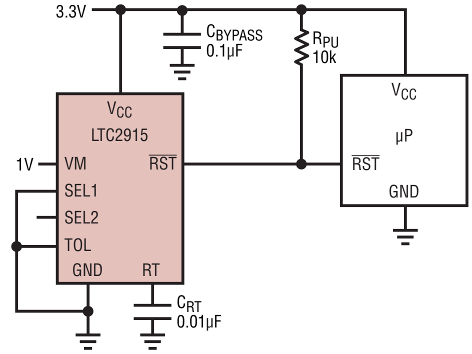


Figure 4. A 1V, –15% tolerance supply monitor with 90ms timeout

positive high voltage when biasing the integrated 6.2V shunt regulator. With all these features (and more discussed below), users can qualify one product to meet almost any supervisory need. Table 1 summarizes the features for all four products.

Easy Placement

Despite a general trend to integrate devices as much as possible, single-input supervisors have certain advantages over multi-voltage devices. The single-input supervisor is not taxed with the requirement to be engaged with multiple supply voltages so that it is much easier to place. Lead pitches on modern device packages dictate that multi-supply supervisors have their monitor inputs physically close to each other. Such covenants naturally lead to signal routing and congestion problems. Furthermore, due to the close proximity of multiple supply lines, undesirable noise coupling can be a problem.

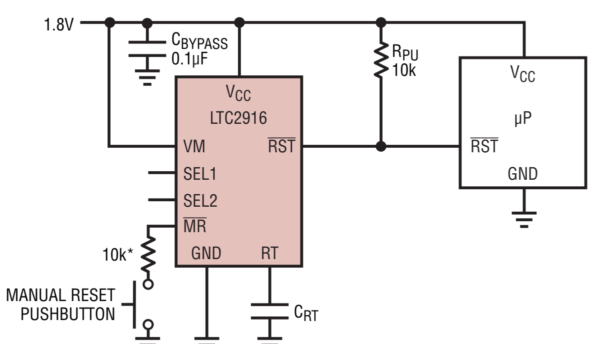
Specifying a physical system location for a multi-supply supervisor involves tradeoffs since an optimal distance between supplies, supervisor and microprocessor may be difficult to achieve. Systems using a single supervisor do not suffer from these problems; the supervisor may be located as near to the monitored supply or processor as desired. The LTC2915 and LTC2916 are available in low profile (1mm) TSOT-23 and DFN (3mm × 2mm) packaging. The LTC2917 and LTC2918 are available in 10-lead MSOP and DFN (3mm × 2mm) packaging.

Correct and Stable Operation

In concept, the job of a good supply monitoring supervisor is simple: when a power supply voltage drops below a specified value, generate a reset. In reality, the job of a supervisor is much more complicated. Start-up and shut-down conditions, noise, and transients all contribute to the complexity of a real supervisor's job. If the supervisor generates a reset while the monitored supply is actually within specification, the result is annoying and consumes operating margin. Spurious resets generated by typical supply noise are equally vexing. Worse yet, not eliciting a microprocessor reset at voltages too low for proper system behavior can be catastrophic.

Supervisor threshold accuracy is a critical specification and must be reckoned with during the system design phase. Most power supplies are specified to operate within a tolerance band. Consider the example of monitoring a 5V supply with a ±10% tolerance. The lowest specified output voltage is therefore 4.5V. An ideal voltage monitor (perfect accuracy) would generate a reset at precisely 4.5V and below, regardless of operating conditions, indicating an out-of-tolerance supply voltage. The problem is that ideal, perfectly accurate voltage monitors do not exist. A randomly selected real-world voltage monitor has a threshold that resides within a distributed band of values. All 27 of the LTC2915, LTC2916, LTC2917 and LTC2918 selectable thresholds have the same relative threshold band of ±1.5% of the selected nominal input voltage, over the full temperature range (–40°C to 125°C). The 5V monitor threshold band is therefore 150mV wide.

The upper limit of the threshold band should be coincident with the



*OPTIONAL RESISTOR RECOMMENDED TO EXTEND ESD TOLERANCE

Figure 5. 1.8V, –5% supply monitor with manual reset

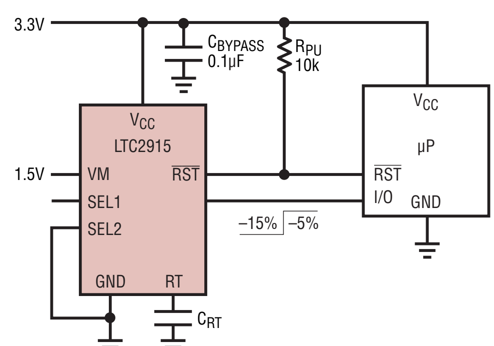


Figure 6. 1.5V supply monitor with tolerance control for margining, –5% operation with –15% margining

lowest specified power supply output voltage (4.5V in our example). Otherwise, operating range is potentially consumed if the monitor threshold reaches above 4.5V. Using the monitor voltage select (SEL1, SEL2) and tolerance (TOL) inputs on the LTC2915 and LTC2917 (for 5V supply, 10% reset threshold), we can configure the upper threshold limit to 4.5V. The lower threshold limit is 150mV below, or 4.35V. Statistically, most devices will have an actual threshold closer to 4.425V, which is the center of threshold band. Because of the threshold spread, the powered system must work reliably down to the *lower* threshold limit, over temperature. It is easy to see why less accurate monitors (larger threshold spreads) can contribute to system problems.

The monitor threshold discussion, so far, deals only with the DC value of the monitored supply. Real supplies also have AC components or noise from sources such as load transients and switching artifacts. These AC components should be ignored by the monitor, since they can cause undesirable spurious reset events. One way to avoid noise-induced sporadic resets is to add hysteresis to the monitor comparators—many monitors on the market use this method. There is a problem with this approach, in that the added hysteresis degrades the accuracy of the monitor and ushers in the design problems discussed earlier. The LTC2915, LTC2916, LTC2917 and LTC2918 single supervisors do not apply hysteresis. Instead, the

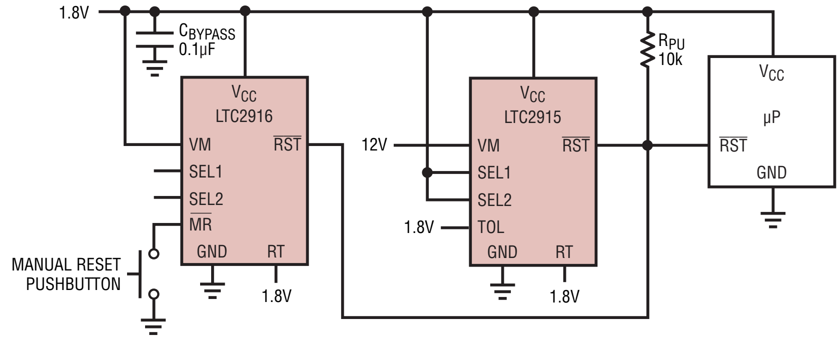


Figure 7. Dual supply monitor (1.8V and 12V) with manual reset and 200ms Reset timeout

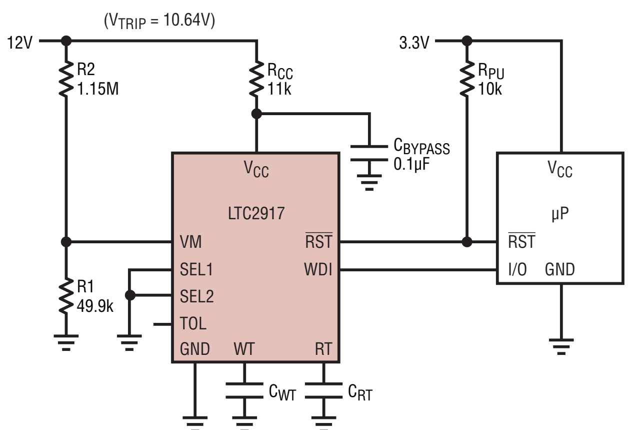


Figure 8. A 12V supply monitor powered from 12V, utilizing the internal shunt regulator with 3.3V logic out

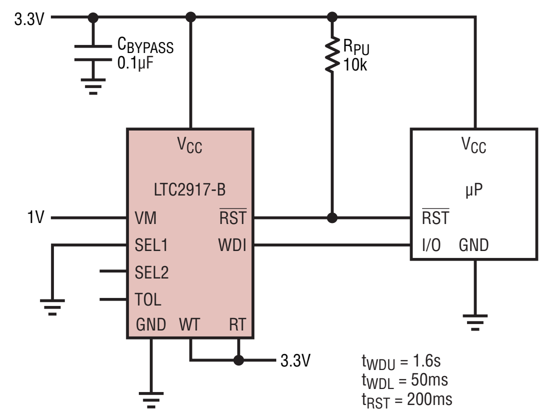


Figure 9. A 1V supply monitor with windowed watchdog timeout and internal timers selected

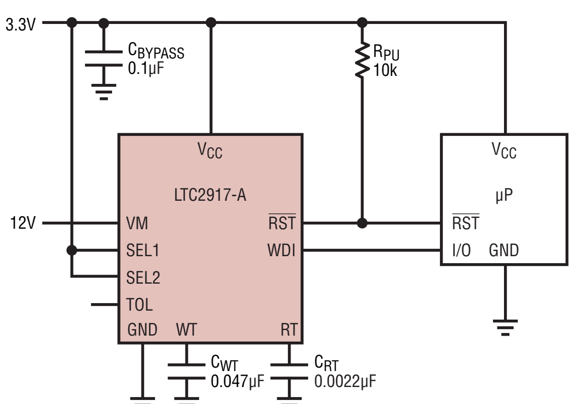


Figure 10. A 12V supply monitor with 20ms reset timeout and 3.4s watchdog timeout, with 3.3V logic out

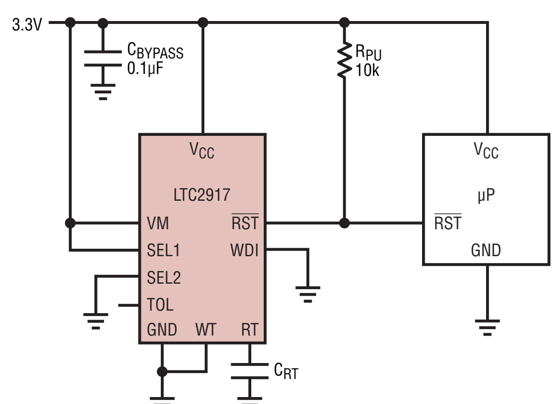


Figure 11. A 3.3V, –10% tolerance supply monitor with disabled watchdog

comparators incorporate anti-glitch circuitry. Any transient at the input of the monitor comparator must be of sufficient magnitude and duration (energy) to switch the comparator. Designs utilizing these single supervisors promote correct and glitch-free resets, which leads to stable and ultimately more reliable systems.

Processor Communication

Two of the monitors (LTC2917 and LTC2918) communicate with host processors through their watchdog circuits. The basic requirement for the processor is to "pet" the watchdog periodically to avoid being "bitten" by the dog. Processor resets are invoked by the built-in watchdog hardware when the watchdog petting frequency has become too slow or too fast. Precise knowledge of the system's timing characteristics is required to set the watchdog timeout period. Adjust the watchdog timeout period by connecting a capacitor between the watchdog timing input (WT) and ground. Connect WT to V_{CC} to achieve a default 1.6s timeout, without the need for external capacitance.

Simple and Compliant Bias

A unique feature common to all four of these devices is the ability to provide operating bias from almost any positive voltage. It does not matter whether it is a 1.8V LDO, 5V switcher, 12V car battery, 24V wall-wart or 48V telecom supply; the integrated 6.2V shunt regulator can work with any system. For input voltages above 5.7V the only requirement is to size the bias resistor (R_{CC}) to the range of the input voltage. Connect R_{CC} between the high voltage supply and the V_{CC} input. Below 5.7V, simply connect the supply directly to the V_{CC} input. Deriving resistor sizing for worst-case operation requires knowledge of the minimum ($V_{S(MIN)}$) and maximum ($V_{S(MAX)}$) input supply:

$$\frac{V_{S(MAX)} - 5.7V}{5mA} \le R_{CC} \le \frac{V_{S(MIN)} - 7V}{250\mu A}$$

Be sure to decouple the V_{CC} input using a 0.1µF (or greater) capacitor to ground.

Qualify Once, Specify Forever

During product development cycles, power supply requirements often change. While supply requirements are changing, your choice of supervisor doesn't have to. The LTC2915, LTC2916, LTC2917 and LTC2918 can relieve the burden of having to find the right supervisor for the job. Qualify any one of these parts and you can monitor any one of eight different supply voltages, each with three different internally fixed thresholds. You can also monitor any custom voltage down to 0.5V using an external resistor divider. Multi-supply monitoring is easily achieved by using two or more devices and connecting their $\overline{RST}$ outputs together.

Meet Your Match

The LTC2915, LTC2916, LTC2917 and LTC2918 single supervisors are the perfect match for a variety of applications. Browse the applications shown in the figures and quickly find the right application for your system.

Conclusion

The LTC2915, LTC2916, LTC2917 and LTC2918 are feature-laden single supervisors that can be comfortably placed near your monitored supply and/or microprocessor, leading to easy printed circuit board layout and reliable system operation.

Unprecedented configurability makes it possible to qualify and stock just one product that can meet all of your supervisory needs. Integration provides twenty-seven user-selectable monitor thresholds with ±1.5% accuracy. Any non-standard threshold can be user-configured with the adjustable setting.

Other features include high voltage operation, configurable reset and watchdog timers, manual reset, and low quiescent current. External components are seldom required to realize fully functional designs. Electrical specifications are guaranteed from –40°C to 125°C.

LTC4311, continued from page 9

Auto Detect Standby Mode and Disable Mode

To conserve power, when both bus voltages are within 400mV of the bus pull-up supply, the LTC4311 enters standby mode, consuming only 26µA of supply current. When ENABLE is forced low, as shown in Figure 4, the LTC4311 enters a disable mode and consumes less than 5µA of supply current. Both bus pins are high impedance when in disable mode or when the LTC4311 is powered down, regardless of the bus voltage.

Conclusion

The LTC4311 efficiently and effectively addresses slow rise times, decreased noise margins at low bus supplies, and increased DC bus power consumption found in 2-wire bus systems. Strong slew rate controlled pull-up currents quickly and smoothly slew the I^2C or SMBus bus lines, decreasing rise times to allow up to 400kHz operation for bus capacitances in excess of 1nF. The advantages of the strong slew rate controlled currents extend to reducing the low state bus voltage, DC bus power consumption, and fall times, since larger value bus pull-up resistors can be used.

With a small 2mm × 2mm × 0.75mm DFN or SC70 footprint, high ±8kV HBM ESD performance and low power consumption in standby or disable mode, the LTC4311 Low Voltage I^2C or SMBus accelerator is also ideally suited for all I^2C or SMBus systems. Examples of such systems include notebooks, palmtop computers, portable instruments, RAIDs, and servers where I/O cards are hot-swapped.

Versatile Current Sense Amplifiers Offer Rail-to-Rail Input, 150°C Operating Temperature

by William Jett and Glen Brisebois

Introduction

Fast and accurate current measurement is required in an increasing number of electronics subsystems. The list of applications that call for current sensing includes diagnostic system assessment, fault detection, load protection and scaling, battery "gas gauge" monitoring, and impending component failure detection, to name just a few. The challenge is that there is no one-size-fits-all solution for current measurement. For example, protection circuits often emphasize measurement speed, while battery applications usually emphasize accuracy and low power. Nevertheless, design time can be reduced by using an accurate current measurement amplifier with features suited to the task at hand, such as the latest members of Linear Technology's current sense amplifier family, the LT6105, LT6106 and LT6107.

The LT6105 is distinguished by its rail-to-rail inputs. It is a perfect fit for automatic test equipment (ATE) systems and other systems that use a combination of fixed voltage supplies and programmable or switched supplies. The LT6105 features an input voltage range of –0.1V to 44V that is independent of the power supply voltage. The supply voltage for the LT6105 can be obtained from any convenient source within the supply range of 2.85V to 36V. For instance, a programmable supply with an output of 0V to 24V can be monitored while the LT6105 is powered by a fixed 5V supply.

The LT6106 is distinguished by ease-of-use and accuracy in single supply environments. Just add two resistors and tie the supply to the sense resistor, and the device is configured to measure currents in supplies from 2.7V to 36V. Input offset voltage is a low 250µV and the power supply rejection of 106dB makes the accuracy almost independent of supply.

The LT6107 is functionally identical to the LT6106, but provides guaranteed performance and specifications at junction temperatures up to 150°C. This suits it to under hood automotive and some industrial applications that can exceed 125°C for relatively short periods of time. Input offset voltage is less than 400µV over the entire temperature range of –40°C to 150°C. As with the LT6106, two external resistors set the amplifier gain.

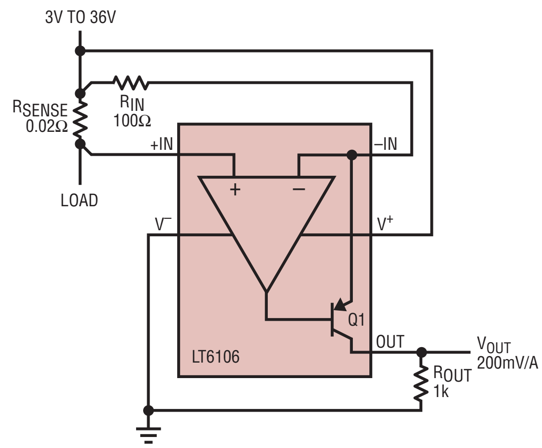


Figure 1. Typical current sense application using the LT6106. Sense resistor is 20mΩ and gain is 10, so transfer function is V_{OUT}/I_{LOAD} = 0.2V/A.

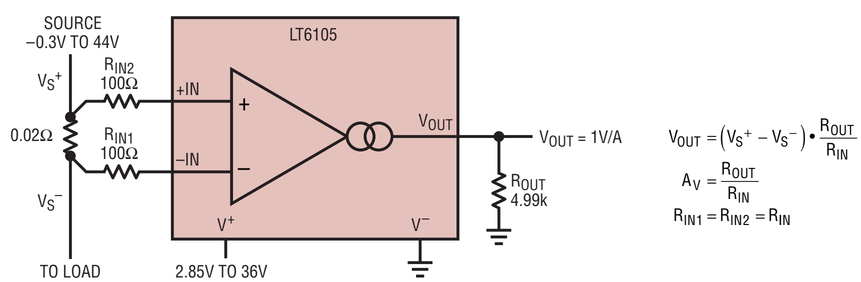


Figure 2. Typical LT6105 connection. Sense resistor is 20mΩ and gain is 50, so the transfer function is V_{OUT}/I_{LOAD} = 1V/A. Note the wide input source.

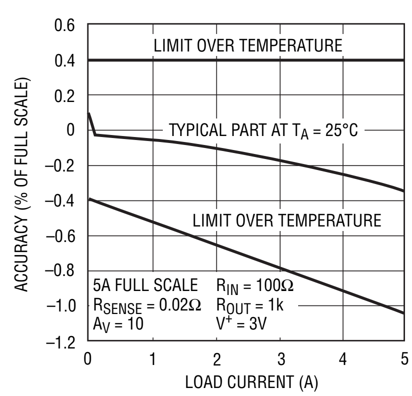


Figure 3. Measurement accuracy vs load current for the LT6106 and LT1607

Table 1 summarizes the guaranteed performance of the LT6105, LT6106 and the LT6107.

Flexible Gain Setting

The LT6105, LT6106 and LT6107 use traditional external gain-setting resistors. This is actually an important feature in a current sense amplifier. Most current sense applications require a very small maximum sense shunt voltage (to minimize power loss), which must be amplified to match either a very specific comparator threshold or ADC input voltage span. The ability to carefully control the gain is paramount to optimize performance. Figures 1 and 2 show typical applications of the LT6106 and LT6105.

LT6106, LT6107 Theory of Operation

Referring to Figure 1, the current to be measured, I_{LOAD}, passes through a sense resistor R_{SENSE}, resulting in a voltage drop of V_{SENSE}. Feedback from the amplifier causes a current to flow in R_{IN} and Q1 such that the amplifier inputs are equal, $V_{-IN} = V_{+IN}$. The current in Q1 also flows through R_{OUT}. The output voltage is therefore proportional to the load current and is given by

$$V_{OUT} = I_{LOAD} \bullet R_{SENSE} \bullet \frac{R_{OUT}}{R_{IN}}$$

The overall accuracy graph shown in Figure 3 combines the effects of gain error and input offset voltage to create a worst-case error band for the application circuit in Figure 1. A slight negative gain error, typically –0.25%, is due to the finite current gain of the PNP.

The LT6105: Robust and Easy to Use

The LT6105 tolerates negative voltages on its inputs of up to –9.5V. In addition, it can also be used to sense across fuses or MOSFETs as shown in Figure 4. The LT6105 has no problem when the fuse or MOSFET opens because it has high voltage PNP's and a unique input topology that features full high impedance differential input swing capability to ±44V. This allows

Table 1. Guaranteed performance specifications

Parameter	LT6105 25°C	LT6106 25°C	LT6107 –40°C to 150°C
Input Voltage Range	–0.3V to 44V	2.7V to 36V	2.7V to 36V
Supply Voltage Range	2.85V to 36V	2.7V to 36V	2.7V to 36V
V_{OS}	300µV/1000µV*	250µV	400µV
Maximum Differential Input Voltage	44V	0.5V	0.5V
CMRR	95dB	N/A	N/A
PSRR	100dB	106dB	106dB
Gain Error	±1%/±2.5%*	–0.65% to 0%	–0.65% to 0%
Output Current	1mA	1mA	1mA
Supply Current	340µA	95µA	125µA
Package	MS8, DFN	TSOT-5	TSOT-5

* Input common mode voltage = 12V, 0V

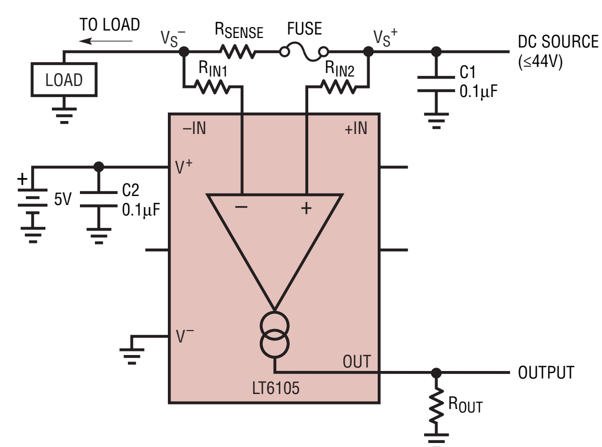


Figure 4. The LT6105 can monitor across a fuse or switch. It's inputs are undamaged even when split wide apart, and current is limited to about 3mA.

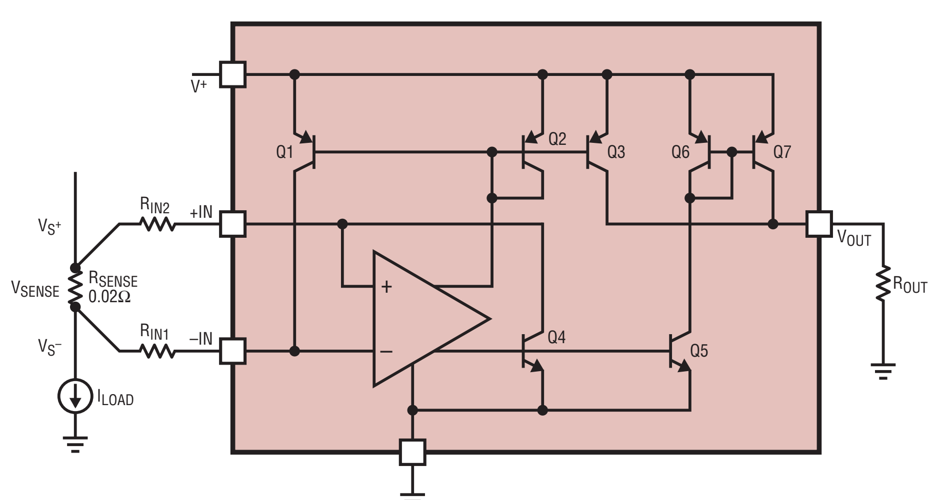


Figure 5. Block diagram of the LT6105

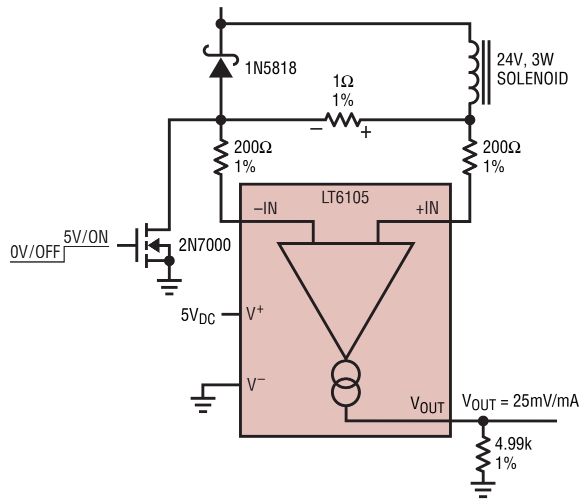


Figure 6. Simplest form of solenoid driver. The LT6105 monitors the current in both on and freewheel states. Lowest common mode voltage is 0V, while the highest is 24V plus the forward voltage of the Schottky diode. See waveforms, Figure 7.

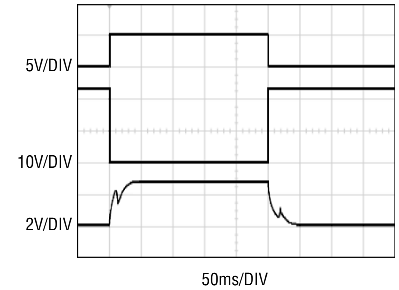


Figure 7. Waveforms for solenoid driver. Top trace is the MOSFET gate, with high on. Middle trace is the bottom of the solenoid/inductor. Bottom trace is the LT6105 output, representing solenoid current at 80mA/DIV. Glitches are useful indicators of solenoid plunger movement.

direct sensing of fuse or MOSFET voltage drops, without concern for an open circuit condition in the fuse or MOSFET.

Another benefit of the LT6105 is that you can leave it connected to a battery even when it is unpowered. When the LT6105 loses power, or is intentionally powered down, both sense inputs remain high impedance. In fact, when powered down, the LT6105 inputs actually draw less current than when powered up. Powered up or down, it represents a benign load.

The LT6105 extends the current sense measurement concept used in the LT6106 (and others) to accommodate an input voltage range that includes ground. For both the LT6105 and LT6106, the voltage developed across a sense resistor is translated into a current that appears in the output pin. The voltage gain is set by the ratio of the input and output resistors, (R_{OUT}/R_{IN}). The wide input range in the LT6105 is obtained by the use of two feedback paths to the input pins.

Referring to Figure 5, when the input voltage V_{S+} is between 0V and 1.6V, devices Q1, Q2, and Q3 are active and devices Q4–Q7 are off. Feedback from the amplifier causes the current to flow in Q1, which equalizes the amplifier input voltages. Devices Q1 and Q3 are matched, so the collector current of Q3 will equal the collector current of Q1. The output voltage is then

$$V_{OUT} = I_{LOAD} \bullet R_{SENSE} \bullet \frac{R_{OUT}}{R_{IN1}}$$

When the input voltage V_{S+} is greater than 1.6V, devices Q4, Q5, Q6, and Q7 are active and devices Q1–Q3 are off. Again, feedback from the amplifier causes the current to flow in Q4 which equalizes the amplifier input voltages. The current in Q4 is mirrored to the output through the matching of Q4 to Q5 and Q6 to Q7. The output voltage for this mode is given by

$$V_{OUT} = I_{LOAD} \bullet R_{SENSE} \bullet \frac{R_{OUT}}{R_{IN2}}$$

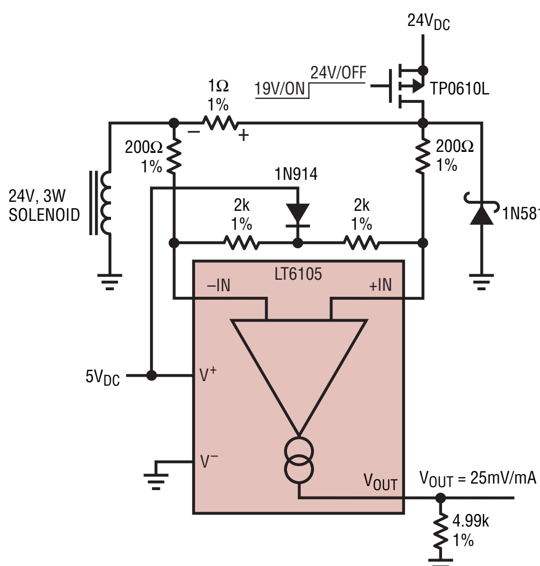


Figure 8. Similar circuit to Figure 6 but with solenoid grounded, so freewheeling forces inputs negative. Providing resistive pullups keeps amplifier inputs from falling outside of their accurate input range.

LT6105 Application: Solenoid Current Monitor

The large input common mode range of the LT6105 makes it suitable for monitoring currents in quarter, half, and full bridge inductive load driving applications. Figure 6 shows an example of a quarter bridge. The MOSFET pulls down on the bottom of the sole-

continued on page 38

Compact Hot Swap Solution Simplifies Advanced Mezzanine Card Design

by Chew Lye Huat

Introduction

Advanced Mezzanine Cards (AdvancedMC) are 80W add-on modules that are central to the extensibility of MicroTCA and AdvancedTCA high availability systems. AdvancedTCA targets high capacity, high performance applications whereas MicroTCA serves smaller, cost-sensitive applications with less demanding requirements. Unlike other mezzanine modules, which are bolted on, AdvancedMC modules can be inserted into a live backplane improving serviceability and flexibility.

The LTC4223 offers a compact and comprehensive Hot Swap solution for Advanced Mezzanine Cards, providing inrush control, overcurrent protection and supply monitoring. It also detects board insertion and extraction, thus protecting the connector.

The LTC4223 offers a compact and comprehensive Hot Swap solution for Advanced Mezzanine Cards, providing inrush control, overcurrent protection and supply monitoring. It detects board insertion and extraction, allowing the 12V and 3.3V auxiliary power supply to be delivered in a controlled manner without damaging the connector. The LTC4223 provides a current monitor output for the 12V supply, allowing real-time current monitoring. Short-circuit faults on the 12V and 3.3V output are rapidly isolated with

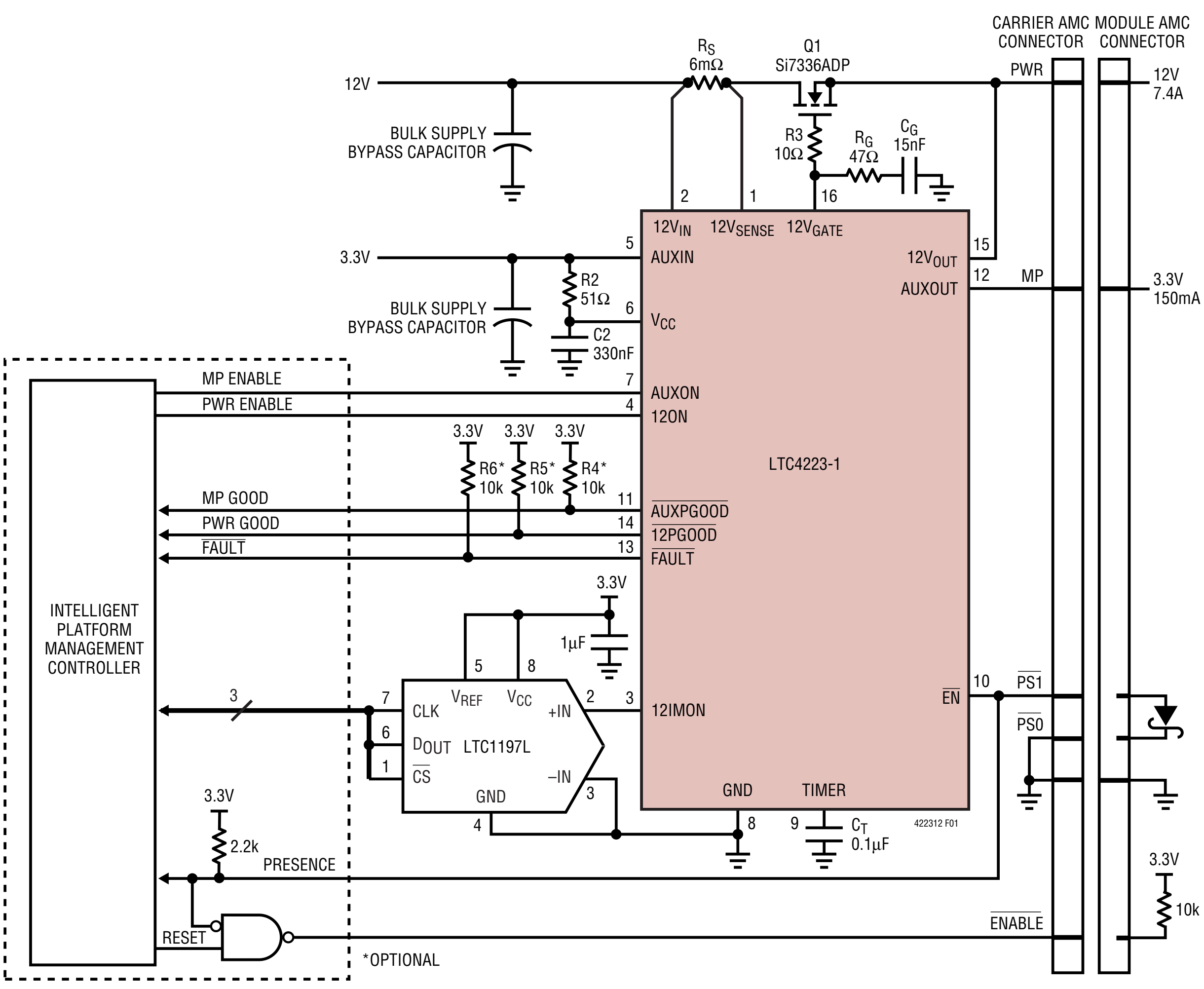


Figure 1. Typical Advanced Mezzanine Card application for MicroTCA systems

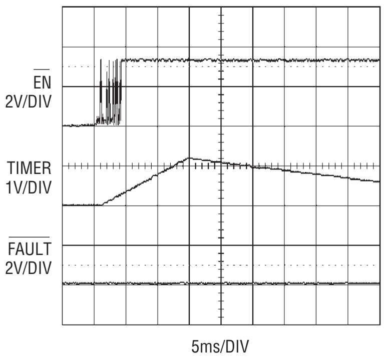


Figure 2. TIMER blanking time prevents false fault reset from $\overline{EN}$ pin contact bounces.

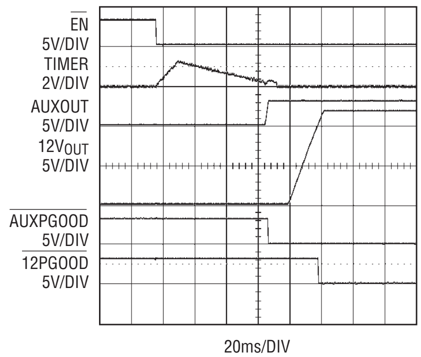


Figure 3. Normal power-up sequence with C_{L1} = 2200µF and C_{L2} = 150µF after a debounce timing cycle

a fast acting current limit to prevent the input supply from collapsing when the output is shorted or overloaded. The LTC4223-1 features a latch-off circuit breaker, while the LTC4223-2 provides automatic retry after a fault. Both options are available in 16-pin SSOP and space-saving 5mm × 4mm DFN packages.

Typical AdvancedMC Hot Swap Application

In a typical AdvancedMC application, the LTC4223 resides on the carrier board, delivering 12V and 3.3V auxiliary power to the modules, as shown in Figure 1. It controls the 12V main supply with an external N-channel MOSFET and the 3.3V auxiliary supply with an integrated 0.3Ω switch. The current for the 12V supply is monitored via sense resistor R_S. The monitored current is reproduced as a relative voltage signal at the 12IMON pin. This signal can be fed to a control system using an LTC1197L ADC.

Resistor R3 prevents high frequency MOSFET self-oscillation in Q1, and R_G/C_G compensates the active current limit loop. R2/C2 filters the input power supply, V_{CC}, from supply transients. Several timers are configured by the capacitor, C_T, including the debounce cycle delay (C_T • 741[ms/µF]), aux current limit time-out during start-up (C_T • 123[ms/µF]) and 12V supply overcurrent response (C_T • 6[ms/µF]). The two supplies can be independently controlled by their respective ON pins, and their power-good and fault status are indicated using open-drain outputs with internal pull-ups.

In a typical AdvancedMC application, the LTC4223 resides on the carrier board. It controls the 12V main supply with an external N-channel MOSFET and the 3.3V auxiliary supply with an integrated 0.3Ω switch. The current for the 12V supply is monitored via sense resistor and is reproduced at the 12IMON pin as a relative voltage signal, which can be fed to a control system using an LTC1197L ADC.

Card Presence Detect Ignores Contact Bounces

Contact bounces as connector pins are mated can trigger unwanted system resets or can cause supplies to turn on unintentionally. To prevent this behavior, the LTC4223 ignores these contact bounces for one TIMER cycle before turning on the supplies.

When the connector pin $\overline{PS1}$ is engaged low upon card insertion, $\overline{EN}$ goes low and initiates a start-up debounce cycle if the ON pin is high. Any contact bounces on the $\overline{EN}$ pin reset the TIMER and restart the ramp up until it reaches 1.235V, at which time the fault latches are cleared. If $\overline{EN}$ remains low at the end of the debounce cycle, the switches are allowed to turn on. If $\overline{EN}$ toggles high indicating card removal, all switches are turned off in 20µs, disconnecting the supplies to the modules. Latched faults are not cleared. However, because removing the card could cause the $\overline{EN}$ pin voltage to bounce, the clearing of latched faults is blanked internally by a TIMER ramp-up time given by C_T • 123[ms/µF], as shown in Figure 2.

Power-Up Sequence

Figure 3 shows the 3.3V auxiliary and 12V supplies powering up in sequence after $\overline{EN}$ transitions low. The pre-conditions for start-up are: V_{CC} and the input supplies exceed

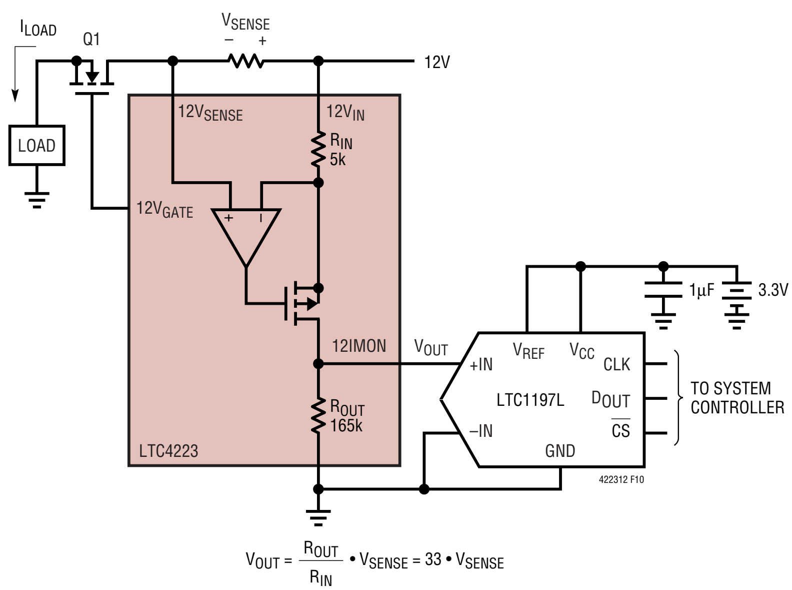


Figure 4. High side current sense monitor with the LTC1197L ADC

their undervoltage lockout thresholds, TIMER is less than 0.2V and $\overline{EN}$ is pulling low. If all of these conditions are met, a debounce timing cycle is initiated when the ON pin pulls high. By default, the internal Aux switch turns on first if both ON pins are high at the end of the debounce cycle. This satisfies the requirement to power up the controller first on the AdvancedMC module before turning on the 12V supply.

The charge current applied to the output capacitor C_{L2} is limited to 240mA by an internal ACL (Active Current Limit) amplifier, well below the maximum 500mA allowed for AdvancedMC modules. When the current limit is active, the TIMER pin ramps up with a 10µA pull-up. $\overline{AUXPGOOD}$ pulls low when AUXOUT exceeds its power-good threshold of 2.901V unless the TIMER pin reaches 1.235V and times out. When the TIMER pin falls below 0.2V with a 2µA pull-down, the 12V supply external MOSFET turns on by charging the GATE with a 10µA current source. The GATE voltage rises with a slope equal to 10µA/C_G and the inrush current flowing into the load capacitor C_{L1} is limited to (C_{L1}/C_G) • 10µA. If the sense resistor voltage drop becomes too large, the inrush current is limited at 60mV/R_S by the internal current limit circuitry. $\overline{12PGOOD}$ pulls low when $12V_{OUT}$ exceeds 10.36V.

Power Monitoring with High Side Current Sense

The LTC4223 features a high side current sense amplifier for the 12V supply that translates the sense resistor voltage drop from the positive rail to the negative rail. The voltage at the 12IMON pin is equal to 33 • V_{SENSE}. This can drive the input of an LTC1197L ADC, as shown in Figure 4 for data conversion, and allows the system controller to monitor the power consumed by the AdvancedMC module. Full scale input to the current sense amplifier is 82.5mV corresponding to an output of about 2.7V. If the input exceeds 100mV, the 12IMON output clamps at 3.2V.

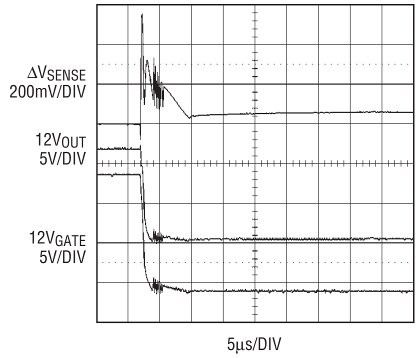


Figure 5. Fast acting current limit isolates severe short-circuit fault on 12V output

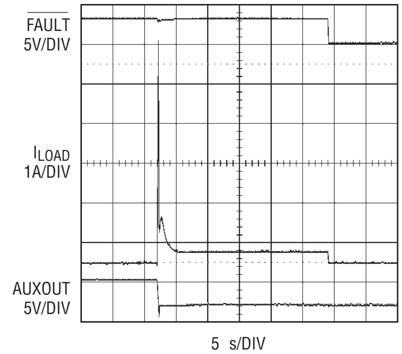


Figure 6. Fast acting current limit isolates short-circuit fault on 3.3V auxiliary output

Thermal Shutdown Protection

The internal 3.3V auxiliary supply switch is protected by a thermal shutdown circuit. If the switch's temperature reaches 150°C, the Aux switch shuts off immediately and $\overline{FAULT}$ pulls low. The external 12V supply switch also turns off. The switches are allowed to turn on again only after both the ON pins are cycled low and then high after the internal switch's temperature falls below 120°C.

Fast Acting Current Limit Isolates Fault

The LTC4223 features an adjustable current limit with circuit breaker function that protects the external MOSFET against excessive load current on the 12V supply. In the event of a severe short-circuit fault as shown in Figure 5, the LTC4223 brings the surge current under control within 1µs by pulling the MOSFET's GATE down to the SOURCE pin. Thereafter, the GATE recovers rapidly due to the R_G/C_G compensation network and enters into active current limiting that maintains 60mV across the sense resistor. When the sense voltage exceeds the circuit breaker threshold (50mV with 5% accuracy), the TIMER capacitor is pulled high with a 200µA current until the TIMER reaches 1.235V, after which it pulls down with 2µA. When this occurs, $\overline{FAULT}$ pulls low and the GATE is pulled down to ground with 1mA, turning off the MOSFET but not the internal Aux switch. Similarly, an internal ACL amplifier protects the 3.3V auxiliary supply from overcurrent by pulling down the gate of the internal pass transistor rapidly. Thereafter, the gate recovers and servos the output current to about 240mA for 25µs before pulling down to ground gently, turning the transistor off, as shown in Figure 6. At this time, $\overline{FAULT}$ pulls low and the 12V supply switch also shuts off.

Auto-Retry after a Fault

The LTC4223-1 latches off after an overcurrent fault while the LTC4223-2 automatically restarts. Following an

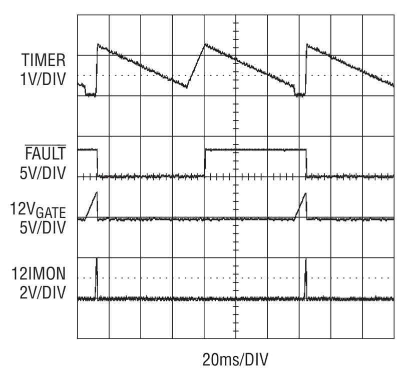


Figure 7. Auto-retry with 0.5% duty cycle during 12V output short

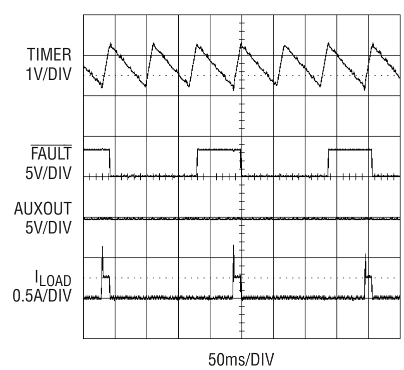


Figure 8. Auto-retry with 6.5% duty cycle during 3.3V auxiliary output short

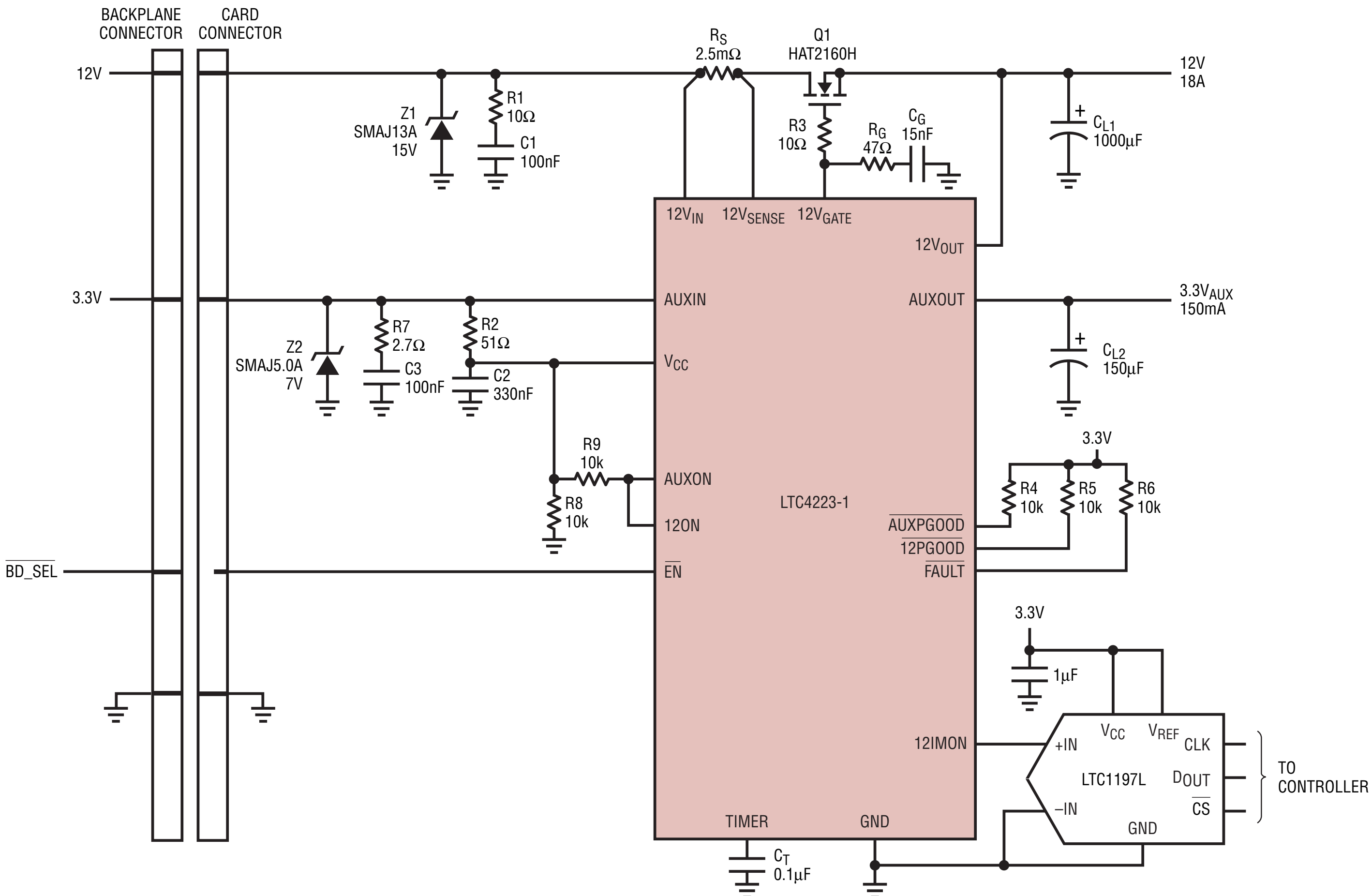


Figure 9. A 12V at 18A card-resident application

overcurrent fault, the LTC4223-1 does not power up again until the fault is cleared by either pulling the ON or $\overline{EN}$ pin from high to low or by V_{CC} falling below its UVLO threshold. The LTC4223-2 automatically clears faults after a cool-off cycle and powers up again, as shown in Figure 7 for a 12V fault and Figure 8 for a 3.3V fault.

The latched fault is cleared during the start-up cycle and $\overline{FAULT}$ pulls high. If the output-short persists, the device powers up into an output-short with active current limiting until the TIMER times out and $\overline{FAULT}$ pulls low again. The device restarts after a cool-off cycle and the process repeats until the output-short is removed. The cool-off cycle time is given by C_T • 1358[ms/µF] after a 12V supply fault and C_T • 1482 [ms/µF] after an auxiliary supply fault. If the TIMER capacitor C_T = 0.1µF, the auto-retry duty cycle is 0.5% for the 12V supply and 6.5% for the 3.3V auxiliary.

12V at 18A Card-Resident Application

In addition to the AdvancedMC application where the LTC4223 is on the carrier board, it can also reside on the plug-in card side of the connector. Figure 9 shows a typical 12V at 18A application. The 3.3V auxiliary supply may be used to power up on-board logic drawing not more than 150mA. The 12V supply inrush current is limited to 0.7A by R_G/C_G compensation network when powering up into a large load capacitor of 1000µF. When no bulk capacitor is present on the card supply, transient voltage suppressors (Z1, Z2) are required to clamp supply transients and the snubber (R1/C1, R7/C3) eliminates ringing during an output-short. For the LTC4223 to work with a different load at 12V output, choosing the correct sense resistor and external MOSFET is crucial. This ensures that the circuit breaker threshold is not exceeded under the maximum load condition, and that the power dissipated in the MOSFET is well within its safe operating area (SOA) while in active current limit during an output-short.

Conclusion

The LTC4223 provides Hot Swap control for a 3.3V auxiliary and a 12V supply. It features board insertion and extraction detection, active current limit into large load capacitors and sequenced supply turn-on with power-good status, all critical in Advanced Mezzanine Card applications. Its tight 5% circuit breaker threshold accuracy and fast acting current limit protect the supplies against overcurrent faults. The current monitor output allows measurement of the 12V supply's power consumption. With these features, the LTC4223 offers a compact Hot Swap solution that simplifies the Advanced Mezzanine Card design.

Tiny, Fast and Efficient Comparator Regenerates Clock Signals up to 3MHz

by Jim Sousae

What is it?

The LTC6702 is a tiny dual comparator that is designed to bridge the gap between relatively slow ultralow power comparators and very fast high power comparators. The LTC6702 combines speed, low voltage operation and micropower operation, making it ideal in battery powered circuits that require high performance. Additional features such as built-in hysteresis (to ensure stable operation) and CMOS inputs simplify designs and allow the use of large source impedances. Offered in the tiny 2mm × 2mm DFN package, the LTC6702 is the smallest dual comparator currently available, with a footprint nearly 40% smaller than that of a SOT-23.

What's So Special?

Guaranteed Speed

The two main benchmarks of a comparator are propagation delay and supply current. Most comparators only list a typical value for propagation delay. The LTC6702 goes one step further, fully testing and guaranteeing a propagation delay of 500ns maximum from –40°C to 125°C. It manages to do this while drawing only 30µA maximum supply current per comparator. Guaranteed operation with a supply voltage as low as 1.7V optimizes battery life.

The LTC6702 combines speed, low voltage operation and micropower operation, making it ideal in battery powered circuits that require high performance.

Excellent Output Swing

The LTC6702 uses patented break-before-make circuitry in its output stage to minimize shoot-through current when the output changes states (typically problematic in CMOS output stages). The result is an output stage with three times better swing than the typical bipolar output stage and much lower shoot-through current than the typical CMOS output stage, allowing the LTC6702 to maintain its efficient operation, even at high toggle rates. The push-pull output stage topology provides rail-to-rail operation without the need of a pull-up resistor.

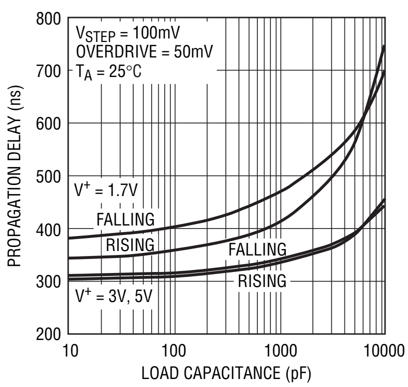


Figure 1. Speed is maintained with high capacitive loads

Capacitive Load Handling

The LTC6702 has the ability to drive large capacitive loads due to its high output drive current, unusual in such a small, low quiescent current device. The output current is specified at ±15mA from –40°C to 125°C and has a typical short circuit current of ±250mA. Competing products show capacitive load handling to 400pF due to the degradation of their rise/fall times and propagation delay with higher capacitive loads. Figure 1 shows the LTC6702's ability to drive up to 10,000pF with significantly less degradation to these parameters. The high output drive current also allows the LTC6702 to drive low current relays directly.

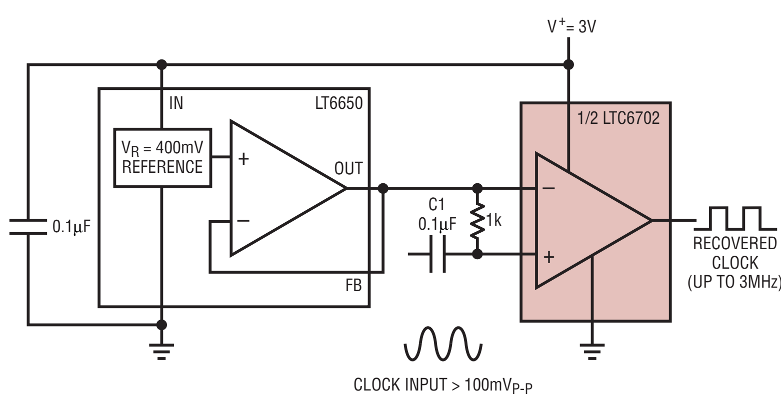


Figure 2. Clock recovery circuit efficiently recovers clock signals up to 3MHz

Inputs Operate Above V+

Most comparators protect their inputs from ESD strikes by diode clamping the inputs to supply. Instead, the LTC6702 uses a ground referenced ESD device on each input pin, thus allowing the inputs to operate above the positive supply without additional input current or damage to the device. As long as one input is within the allowed common-mode range, the other input can go as high as the absolute maximum rating of 6V, regardless of the supply voltage.

What's It Good For?

Clock Regeneration

The high toggle rate and efficiency of the LTC6702 is ideal for clock regeneration in battery powered circuits. It is no longer necessary to waste milliamps of supply current powering an ultrafast comparator when ultrafast speeds are not required. The simple circuit in Figure 2 can recover clock signals with frequencies up to 3MHz while burning only 225µA of supply current.

Level Translation

The LTC6702's push-pull output stage and its ability to operate with either input above the positive supply rail simplifies logic level translation. Many comparators use an open collector or open drain type output stage to enable level translation and require a pull-up resistor and separate supply to set the output logic level. The circuits in Figure 3 show how the LTC6702 can perform both high-to-low and low-to-high level translation without the need of an additional pull-up resistor, thus reducing component count and saving board space.

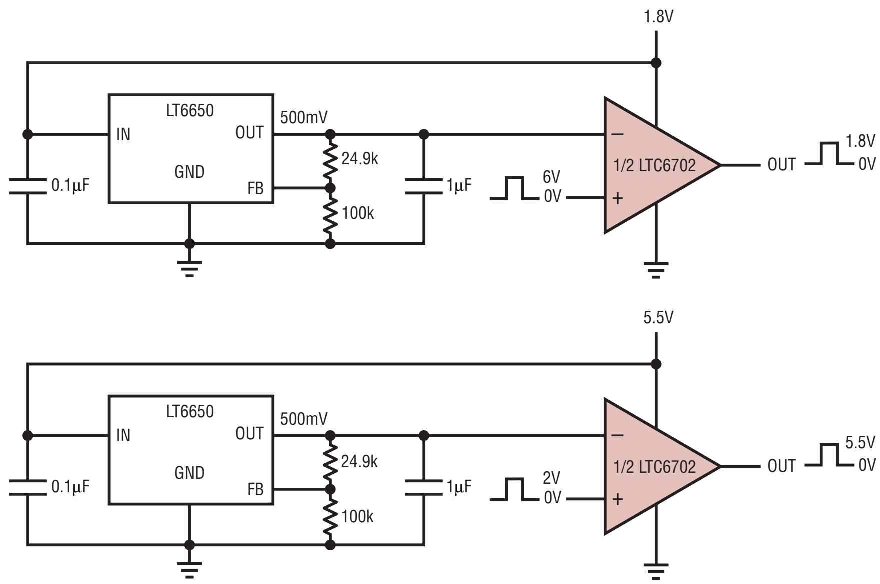


Figure 3. Level translation without the need of an additional supply or pull-up resistor

Current Sense Alarm

A typical swing of 300mV from either rail with ±60mA output drive allows the LTC6702 to directly drive an LED or relay for alarm annunciation or load protection switching. Figure 4 shows a dual load current sense alarm circuit that provides resistor programmable thresholds, turns on an LED when an overload condition is detected and has a quiescent current of only 31µA.

Conclusion

The unique feature set of the LTC6702 makes it a very versatile dual comparator. Its tiny footprint and rail-to-rail output capability allow the designer to conserve board space, while it's high speed to power ratio and low voltage operation enable efficient clock regeneration and maximize battery life.

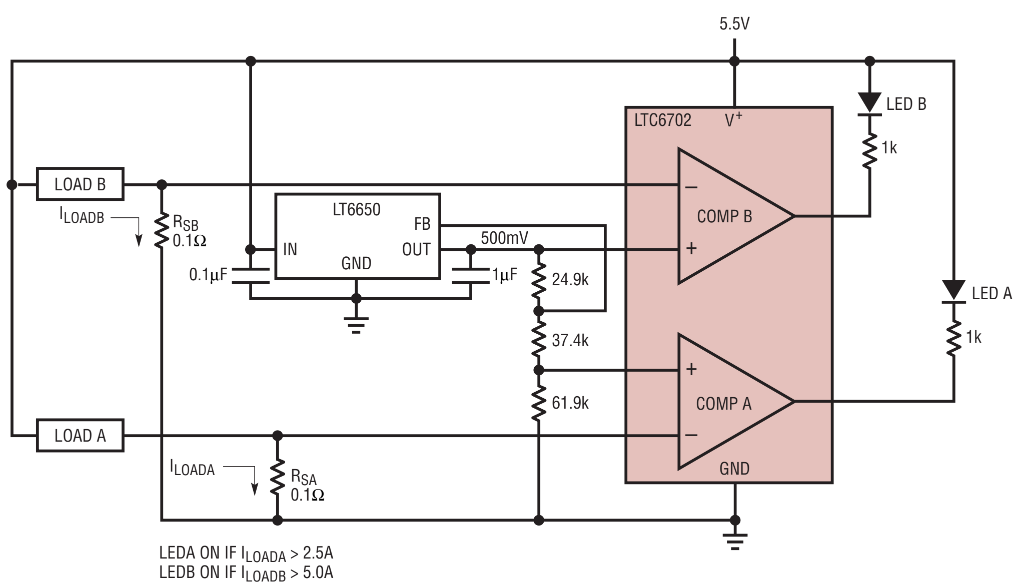


Figure 4. This micropower dual low side current sense alarm can drive an LED or relay

9V to 80V Ideal Diode Reduces Heat Dissipation by Order of Magnitude over Schottky

by Meilissa Lum

Introduction

High availability systems often employ parallel-connected power supplies or battery feeds to achieve redundancy and enhance system reliability. Schottky ORing diodes have long been used to connect these supplies at the point of load. Unfortunately, the forward voltage drop of these diodes reduces the available supply voltage and dissipates significant power at high currents. Costly heat sinks and elaborate layouts are needed to keep the Schottky diode cool.

A better solution is to replace the Schottky diode with a MOSFET-based ideal diode. This reduces the voltage drop and power dissipation, thereby reducing the complexity, size and cost of the thermal layout and increasing system efficiency. The LTC4357 is an ideal diode controller that drives an N-channel MOSFET and operates over a voltage range of 9V to 80V.

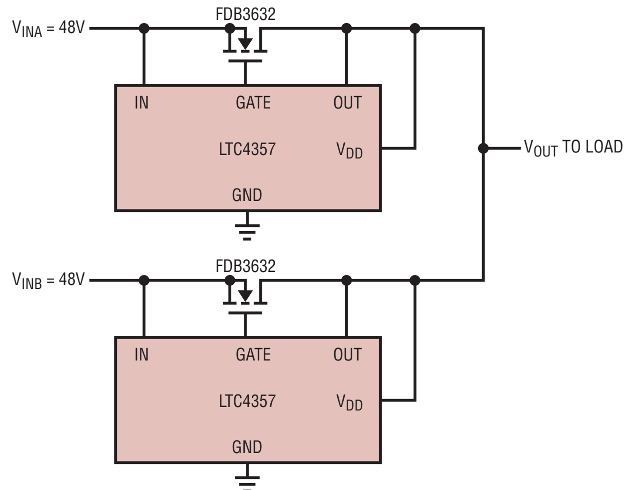


Figure 1. Two load-sharing, redundant, 48V/10A power supplies using an ideal diode

How It Works

The LTC4357's basic operation is straightforward. The external MOSFET source is connected to the input supply and acts like the anode of a diode, while the drain is the cathode. When power is first applied, the load current initially flows through the body diode of the MOSFET. The LTC4357 senses the voltage drop and drives the MOSFET on. The LTC4357's internal amplifier and charge pump try to maintain a 25mV drop across the MOSFET. If the load current causes more than 25mV of voltage drop, the MOSFET is driven fully on, and the forward drop becomes equal to $R_{DS(ON)} \bullet I_{LOAD}$. If the load current reverses, as may occur during an input short, the LTC4357 responds by quickly pulling the MOSFET gate low in less than 0.5µs.

Load Sharing Redundant Supplies

Figure 1 shows a 48V/10A ideal diode-OR application. An MBR10100 Schottky diode would dissipate 6W under these operating conditions. In contrast, the FDB3632 7.5mΩ MOSFET dissipates only $7.5m\Omega \bullet (10A)^2 = 0.75W$. The reduced power loss increases efficiency and saves space required for heat sinking. If the power supply voltages are nearly equal, the load current is shared between the two supplies. Otherwise, the supply with the highest output voltage provides the load current.

Load sharing is accomplished using a simple technique known as droop sharing. Load current is first taken from the highest supply output. As this output falls or droops with increased loading, the lower supply begins to contribute. Regulating the forward voltage drop to 25mV ensures smooth load sharing between outputs without oscillation. The degree of sharing is a function of MOSFET $R_{ds(on)}$, the output impedance of the supplies and their initial output voltages. Backfeeding of one supply into the other is precluded by the diode action of the LTC4357.

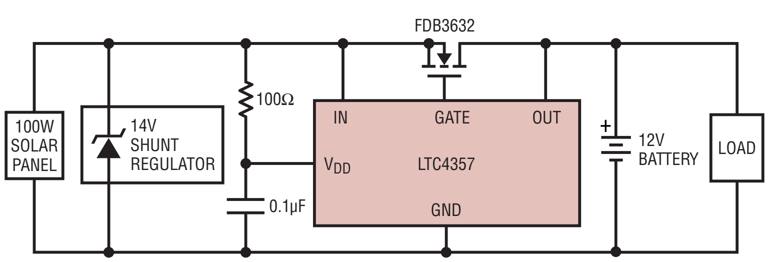


Figure 2. Solar panel charging 12V battery through ideal diode to prevent back feeding

Solar Power Application

In solar power systems, Schottky diodes are used to prevent discharge of the battery during hours of darkness. Unfortunately, the voltage drop and power dissipation of a Schottky diode can be quite large when used with high wattage solar panels, thus reducing the amount of power available to charge the battery. Figure 2 uses the

LTC4357 with a FDB3632 MOSFET to replace the Schottky diode.

When the solar panel is illuminated by full sunlight, it charges the battery. A shunt regulator absorbs any excess charging current to prevent overcharging. If the forward current is greater than $25mV/R_{DS(ON)}$, the MOSFET is fully enhanced and the voltage drop rises according to $R_{DS(ON)} \bullet (I_{BATTERY} + I_{LOAD})$. In darkness, or in the event of a short circuit across the solar panel or a component failure in the shunt regulator, the output voltage of the solar panel will be less than the battery voltage. In this case, the LTC4357 shuts off the MOSFET, so the battery will not discharge. The current drawn from the battery into the LTC4357's OUT pin is only 7µA at 12V.

Protecting Against Reverse Inputs

In automotive applications, the LTC4357 inputs can be reversed. An additional component, shown in Figure 3, prevents the MOSFET from turning on and protects the LTC4357.

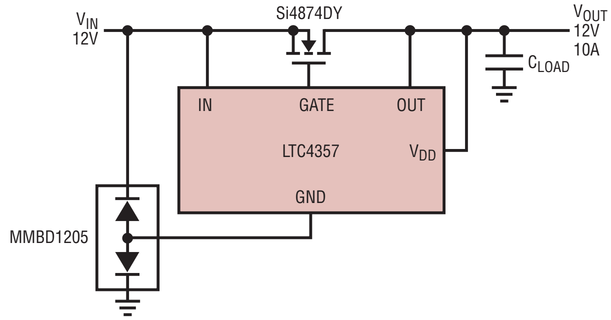


Figure 3. –12V Reverse input protection blocks reverse input voltage to the load

With a reverse input, the diode connected to system ground is reverse biased. The GND pin is pulled by the second diode to within 700mV of the reverse input voltage. Any loading or leakage current tends to hold the output near system ground, biasing the LTC4357 in the blocking condition. If the output is held up at +12V by a backup source or stored charge in the output capacitor, roughly double the input voltage appears across the MOSFET. The MOSFET is off and held in the blocking state.

Conclusion

The LTC4357 ideal diode controller can replace a Schottky diode in many applications. This simple solution reduces both voltage drop and power dissipation, thereby shrinking the thermal layout and reducing power loss. Its wide 9V to 80V supply operating range and 100V absolute maximum rating accommodate a broad range of input supply voltages and applications, including automotive, telecom and industrial. A dual version, the LTC4355, is available in 4mm × 3mm DFN-14 or SSOP-16 packages.

LTC293x, continued from page 15

boost regulator and monitored by the LTC2931. The LTC3780 is protected from transients by the LT4356DE-1 and is capable of delivering full power to the load with a supply voltage as low as 6V. The LTC2931 is configured to monitor four fixed and two adjustable voltages, including two independent 5V supplies. 1.5% voltage monitoring accuracy is guaranteed over the entire operating temperature range. Additionally, each voltage monitoring channel has its own comparator output that can be used by the microprocessor to identify a fault condition. The comparator outputs are pulled up to the 5V bus that powers both voltage monitoring devices. The LTC2931 has an adjustable watchdog timer, which allows the LTC2931 to report a malfunctioning microprocessor to the rest of the system.

The unregulated battery voltage and power supplies delivered to the in cabin electronics are monitored by the LTC2932. This application monitors the unregulated battery voltage, and the COMP4 output alerts the system to a low battery condition, allowing the system to enter a standby or power save mode.

The LTC2932 also provides a mechanism to override a reset or fault condition. This is accomplished by pulling the $\overline{RDIS}$ pin low. With $\overline{RDIS}$ pulled low, the $\overline{RST}$ output pulls up to the V2 input voltage. Since V2 is tied to V1, the reset high level is 5V. The $\overline{RDIS}$ function allows the system to have flexibility in controlling the power sources without generating system faults. Additionally, the LTC2932 allows real time setting of the voltage monitoring threshold. This could be useful when changes in loading or environment make for predictable supply variances.

Conclusion

The LTC2930, LTC2931 and LTC2932 can each monitor six supplies, saving valuable board area in space constrained applications. The LTC2930 is available in a 3mm × 3mm DFN, while the LTC2931 and LTC2932 are available in 20-pin TSSOP packages.

All include design-time saving features for multi-voltage applications. Voltage thresholds are accurate to ±1.5%, guaranteed over the entire –40°C to 125°C temperature range. This translates directly to simplified power supply design, as threshold accuracy must be accounted for in the entire power supply tolerance budget.

Comparator glitch immunity eliminates false resets, with no effect on the high accuracy of the monitor. These devices support a variety of voltage combinations, easily set with only a few external components. The reset timeout period is also adjustable with a single capacitor.

Lastly, the features which differentiate the LTC2930, LTC2931 and LTC2932 give users the flexibility to choose one for any application.

CMOS Op Amp Outperforms Bipolar Amps in Precision Applications

by Hengsheng Liu

Introduction

The LTC6081 and LTC6082 are dual and quad low offset, low drift, low noise CMOS operational amplifiers with rail-to-rail input and output stages. Their 0.8µV/°C maximum offset drift, 1pA input bias current, 1.3µV_{p-p} of 0.1Hz to 10Hz noise, 120dB open loop gain and 110dB CMRR and PSRR make them perfect for precision applications. The LTC6081 and LTC6082 have a gain bandwidth product of 3.6MHz, with each amplifier only consuming about 330µA current for a supply voltage of 2.7 to 5.5V. The 10-lead DFN package of the LTC6081 offers a shutdown function to reduce each amplifier's supply current to 2µA.

Superior Precision CMOS Op Amp

Bipolar amplifiers can have low offset and low offset drift, but their nA level input bias current make them inappropriate for high input impedance applications such as photodiode amplifiers. CMOS amplifiers usually offer inferior offset drift, CMRR, and PSRR specifications and therefore are not suitable for precision applications. Chopper stabilized amplifiers, also known as zero drift amplifiers, can achieve superior offset and offset drift by means of offset cancellation, but have clock noise and fold-back noise due to sampling. LTC6081 and LTC6082, however, are continuous time CMOS operational amplifiers, which use a patented methodology to improve their offset voltage, offset voltage drift and CMRR. They combine the features of low input bias current, low offset drift and low noise.

Instrumentation Amplifier

Figure 2 shows a typical three op amp instrumentation amplifier. If R1 = R2, R3 = R5 and R4 = R6, then

$$V_{OUT} = \left(1+\frac{2R1}{R0}\right)\left(\frac{R5}{R3}\right)\left(V_{IN2} - V_{IN1}\right)$$

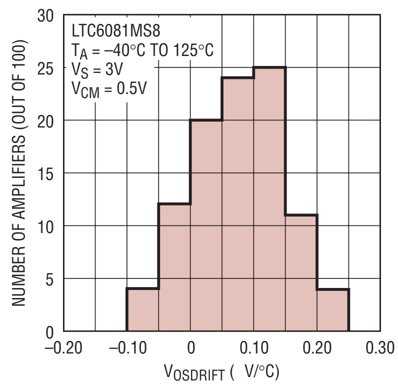


Figure 1. V_{OS} drift histogram of LTC6081

In this two stage structure, the differential voltage passes through the first gain stage with gain of 1 + 2R1/R0 while the common mode voltage has only unity gain at the first stage, thus improving CMRR. Ratio matching of R4/R3 and R6/R5 is critical for CMRR. Gain can be changed by simply changing R0 without affecting the resistor matching.

The input referred offset of the amplifier is

$$V_{OS} = V_{OSB} - V_{OSA} + \frac{V_{OSC}}{1+\frac{2R1}{R0}} \approx V_{OSB} - V_{OSA}$$

Statistically, the total V_{OS} is $\sqrt{2}$ times the V_{OS} of a single op amp. Since a single LTC6081 op amp drifts less than 0.8µV/°C, the amplifier in Figure 2 will drift less than 1.1µV/°C. One drawback of the circuit in Figure 2 is its common mode operating range is no longer rail-to-rail. Assuming

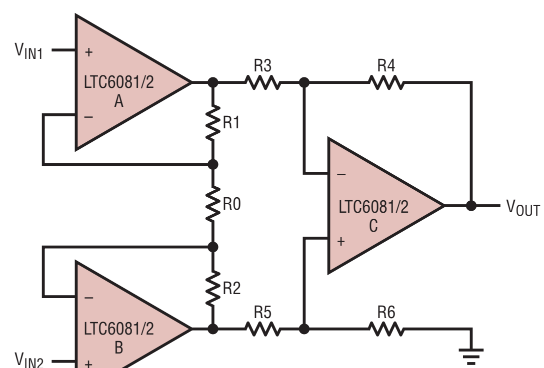


Figure 2. Typical three op amp structure of instrumentation amplifier

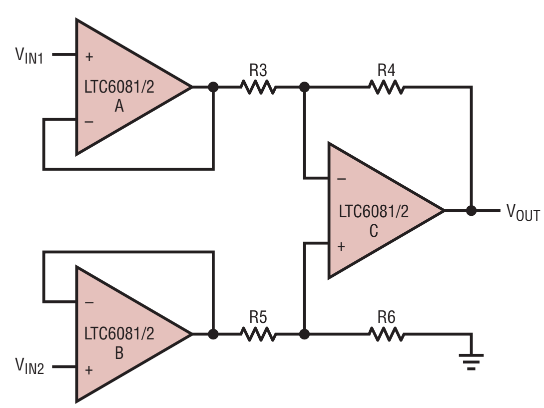


Figure 3. Instrumentation amplifier with unity gain buffers

the differential and common mode input voltage are $V_{IN(DM)}$ and $V_{IN(CM)}$ respectively, the output voltages of op amp A and B are then $V_{IN(CM)} - (2R1/R0)V_{IN(DM)}$ and $V_{IN(CM)} + (2R1/R0)V_{IN(DM)}$ respectively. So

$$V^- < V_{IN(CM)} \pm \frac{2R_1}{R_0} V_{IN(DM)} < V^+$$

$$V^- + \frac{2R_1}{R_0} V_{IN(DM)} < V_{IN(CM)} <$$

$$V^+ - \frac{2R_1}{R_0} V_{IN(DM)}$$

where V^+ and V^- are the positive and negative supply voltage respectively. The larger the first stage gain or input differential signal is, the narrower the input common mode range is. To widen the input common mode range, the first stage gain can be reduced, but this will compromise CMRR performance.

Figure 3 is a reduced circuit of Figure 2 with a unity gain buffer at the front stage. This circuit can achieve rail-to-rail input range. As mentioned previously, it won't have the high CMRR of the circuit in Figure 2 since we reduced the front stage gain to unity. If the input resistance requirement can be eased, Figure 3 can be reduced to Figure 4, a single stage difference amplifier. The impedance of the non-inverting and inverting inputs are R3 and R5 + R6, respectively. An obvious advantage of the LTC6081 is its super low input bias current. Even with a 1MΩ input resistor R3 or R5, the less than 1pA input bias current of LTC6081 will add less than 1µV to V_{OS}.

The above discussion assumes a perfect matching of R4/R3 and R6/R5. If

$$\frac{R6}{R5} = (1 + \varepsilon)\frac{R4}{R3}$$

then the CMRR degrades to

$$20\log\frac{A_V}{\varepsilon}$$

where A_V is the differential gain of the instrumentation amplifier. For example, at gain of 10, to achieve 80dB

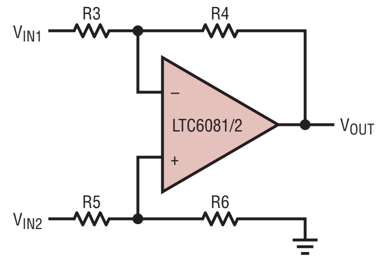


Figure 4. Difference amplifier with no input buffers

CMRR, mismatch of R4/R3 and R6/R5 should be less than 0.1%. This is true for all the above three circuits. The advantage of the circuit in Figure 2 is that gain can be put at the front stage to ease the matching requirements of the second stage. Matching of R1 and R2 in Figure 2 is not important.

Thermocouple Amplifier

Figure 5 shows the LTC6081 in a thermocouple amplifier. The 1MΩ resistors protect the circuit up to ±350V with no phase reversal to amplifier output. The 1pA maximum IBIAS of the LTC6081 translates to a miniscule 0.05°C temperature error with the 1MΩ input protection resistor. The ±90µV offset over the entire operating temperature range ensures a less than 2°C temperature offset.

Conclusion

The LTC6081 and LTC6082 are high performance dual and quad op amps combining excellent noise, offset drift, CMRR, PSRR and input bias current specifications. They perform in a variety of topologies without compromising performance. LTC6081 is available in 8-lead MSOP and 10-lead DFN packages. LTC6082 is available in 16-lead SSOP and DFN packages.

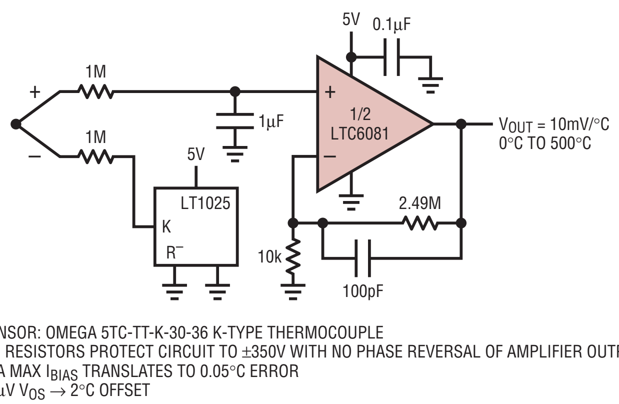


Figure 5. Thermocouple amplifier

LTM4605/07, continued from page 19

Conclusion

The LTM4605 and LTM4607 µModule regulators simplify the design of buck-boost power supplies. Their low profile 15mm × 15mm × 2.8mm packages and minimal component count help free up valuable PCB area. High input and high output ratings suit these regulators to networking, industrial, automotive systems and high power battery-operated devices. Their optimized internal 4-switch architecture provides high efficiency and high performance. Overall, the LTM4605 and LTM4607 reduce product design and test time with a mix of high performance features, flexible settings and ease-of-use.

Notes

1 For more about layout with Kelvin sense resistors, see "Using Current Sensing Resistors with Hot Swap Controllers and Current Mode Voltage Regulators" by Eric Trelewicz in *Linear Technology Magazine*, September 2003, page 34

New Device Cameos

Low Voltage Hot Swap Controller Provides Additional GPIO Capability

The LTC4215-1 is a low voltage Hot Swap controller with an onboard ADC and I^{2}C compatible interface. Functionally, the LTC4215-1 is similar to the LTC4215 with additional General Purpose Input/Output (GPIO) functionality for a total of three GPIO pins.

The additional GPIO pins of the LTC4215-1 may be used to light LEDs to flag a card for service, turn on or reset downstream circuits, or monitor digital signals from other blocks. GPIO1 and GPIO2 default to a high impedance state for an output high or digital input, and GPIO3 defaults to output low. This mix of states provides flexibility in the application—a simple circuit can be used to invert the state of the pin or provide a higher current if desired.

The GPIO1 pin may still be configured to signal power good, as in the LTC4215, and the GPIO2 pin may also still be used to generate fault alerts in addition to the new GPIO functionality. The GPIO3 pin replaces the ADR2 pin on the LTC4215, reducing the available addresses from 27 to 9.

The LTC4215-1 works in applications from 12V (with transients to 24V) down to 3.3V where the operating voltage can drop to 2.9V and is available in a 4mm × 5mm QFN package.

Low Voltage Current Limiting Hot Swap Controller

The LTC4210-3 and LTC4210-4 are new members of the LTC4210 family of tiny SOT-23 Hot Swap controllers. These two products are ideal for low voltage applications from 2.7V to 7V where superior current limit responses are absolutely essential to high performance systems. The LTC4210 rides through short duration of overload transients. Severe load faults are isolated after a programmable circuit breaker time-out to prevent system and MOSFET damages. The LTC4210-3 retries after circuit breaker timeout, whereas the LTC4210-4 continue latches off till system reset.

The gate driver maximum output voltage is clamped to ground with a 12V Zener.

The LTC4210-3 and LTC4210-4 allow safe board insertion and removal with inrush current control. The LTC4210-3 and LTC4210-4 also can be utilized as high side gate driver to control a small footprint logic level MOSFET.

Precision Voltage Reference with Wide Operating Temperature Range Simplifies High Temperature Industrial and Automotive Design

The LTC6652 is a high precision, low noise voltage reference with internal output buffering that is fully specified over the –40°C to 125°C temperature range. The wide operating temperature range, combined with low noise and low power consumption, allows system designers to achieve high performance in the most demanding applications.

First and foremost, the LTC6652 is a high precision voltage reference. Specifications include a maximum 0.05% initial accuracy and 5ppm/°C temperature drift. This precision satisfies the high performance application requirements of monitor and control systems, instrumentation and test equipment.

The part is designed using high precision circuitry carefully tailored to high temperature operation. In order to reliably meet the specifications in high volume manufacturing, the low temperature drift is consistent from part to part. These characteristics make it easy to design systems using the LTC6652. Perhaps most important, the performance is measured at the temperature extremes for every unit, not just sample tested. This gives system designers additional confidence in their product's quality. The electrical specifications are also guaranteed across the entire temperature range.

Second, the LTC6652 exhibits low noise, making it a good choice for systems that require large dynamic range. At only 2.1ppm$_{P-P}$ (0.1Hz to 10Hz), the noise is well below the drift, allowing full access to the high performance accuracy and drift characteristics. The LTC6652 makes it easy to achieve repeatability, stability and wide dynamic range in just about any high performance application.

Third, the LTC6652 simplifies system designs by eliminating the need for a buffer amplifier. The output can both sink and source 5mA, and is stable for a wide range of load capacitances. Both line and load regulation are exceptional, maintaining system performance under a wide range of conditions while reducing complexity.

Finally, the LTC6652 requires only a small amount of power and board space. It draws only 350µA supply current, and is available in an 8-lead MSOP package.

With its high precision, wide temperature range, low noise and small size, system designers should be able to meet the most demanding specifications. Using parts that are individually and fully tested at three temperatures will help them sleep at night.

Dual/Triple Supply Monitor Maintains 1.5% Accuracy Over Temperature

The LTC2919 is a triple/dual input monitor intended for a variety of system monitoring applications. The 0.5V threshold of the two adjustable inputs features a tight 1.5% accuracy over the entire operating temperature range. Additionally, an accurate threshold at the V_{CC} pin provides an undervoltage monitor for a 2.5V, 3.3V or 5V supply. Each input features glitch rejection, which ensures that the outputs operate reliably without false triggering.

The polarity selection pin (SEL) and buffered reference output (REF) allow the LTC2919 to monitor positive and negative supplies for undervoltage

(UV) and overvoltage (OV) conditions. It can monitor two supplies for UV or OV, or a single supply for UV and OV simultaneously. The adjustable trip thresholds are set with external resistive divider networks, giving users complete control over the trip voltage. An open-drain $\overline{RST}$ output is held low when any adjust supply is invalid or V_{CC} is in undervoltage. When all the inputs are valid, the $\overline{RST}$ pin is released after a timeout delay, which can be set to 200ms, adjusted with an external capacitor, or configured for no-delay.

When compared to the LTC2909, the LTC2919 provides two additional independent output pins to indicate the status of each adjustable input. When connected to the enable pins of power supplies these outputs can be used to implement start-up sequencing. In addition to providing a highly versatile, precise solution for supply monitoring, the low quiescent current of 50µA and the tiny DFN package makes the LTC2919 an ideal choice in space limited applications. With the addition of a single external current limiting resistor, the LTC2919's onboard 6.5V shunt regulator permits operation from a high voltage supply. The IC is offered in 10-pin plastic MSOP and 3mm × 2mm DFN packages and is specified over the C, I, and H temperature ranges.

LT6105/6/7, continued from page 26

noid to increase the solenoid current. It lets go to decrease current, and the solenoid voltage freewheels around the Schottky diode. Current measurement waveforms are shown in Figure 7. The small glitches occur due to the action of the solenoid plunger, and this provides an opportunity for mechanical system monitoring without an independent sensor or limit switch.

Figure 8 shows another solenoid driver circuit, a high side drive approach with one end of the solenoid grounded and a P-Channel MOSFET pulling up on the other end. In this case, the inductor freewheels around ground, imposing a negative input common mode voltage of one Schottky diode drop. This voltage may exceed the input range of the LT6105. This does not endanger the device, but it degrades the accuracy. In order to avoid exceeding the input range, pullup resistors may be used as shown.

LT6105 Application: Supply Monitor

The input common mode range of the LT6105 also makes it suitable for monitoring either positive or negative supplies. Figure 9 shows one LT6105 applied as a simple positive supply monitor, and another LT6105 as a simple negative supply monitor. Note that the schematics are practically identical, and both have outputs conveniently referred to ground. The only requirement for negative supply monitoring, in addition to the usual constraints of the absolute maximum ratings, is that the negative supply to the LT6105 be at least as negative as the supply it is monitoring.

Conclusion

The LT6105, LT6106, and LT6107 provide simple, flexible solutions to high side (and low side) current sensing. Common to all the parts is the flexibility of external gain setting. The –0.1V to 44V input range of the LT6105 enables the current in switched supplies to be monitored from initial turn-on/turn-off to the steady state value. The LT6106 provides a simple but accurate solution for systems with a single supply. The LT6107 extends the temperature range of current measurements to 150°C.

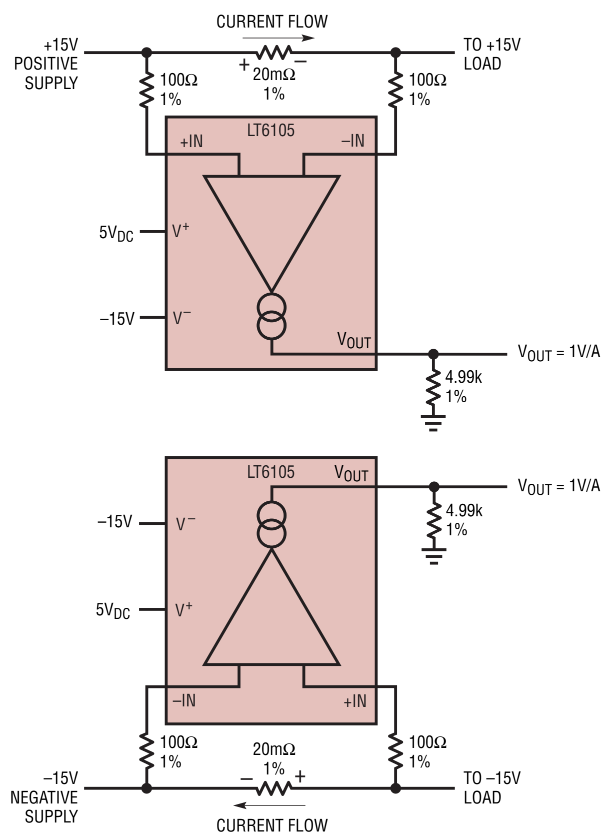


Figure 9. The LT6105 can monitor the current of either positive or negative supplies, without a schematic change. Just ensure that the current flow is in the correct direction.

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