Linear Technology Magazine Circuit Collection, Volume 1

Richard Markell, Editor

INTRODUCTION

Over the past several years *Linear Technology*, the magazine, has come of age. From nothing, the publication has come into its own, as has its subscriber list. Many innovative circuits have seen the light of day in the pages of our now hallowed publication.

This Application Note is meant to consolidate the circuits from the first few years of the magazine in one place. Circuits herein range from laser diode driver circuits to data acquisition systems to a 50W high efficiency switcher circuit. Enough said. I'll stand aside and let the authors explain their circuits.

CIRCUIT INDEX

A to D Converters 2
LTC1292: 12-BIT DATA ACQUISITION CIRCUITS 2
Temperature-Measurement System 2
Floating, 12-Bit Data Acquisition System 2
Differential Temperature Measurement System 2
MICROPOWER SO8 PACKAGED ADC CIRCUITS 4
Floating 8-Bit Data Acquisition System 4
0°C – 70°C Thermometer 5
Interface 6
LOW DROPOUT REGULATOR SIMPLIFIES ACTIVE SCSI TERMINATORS 6
Power 7
LT1110 SUPPLIES 6 VOLTS AT 550mA FROM 2 AA NiCAD CELLS 7
50 WATT HIGH EFFICIENCY SWITCHER 9
Filters 10
CASCADED 8TH-ORDER BUTTERWORTH FILTERS PROVIDE STEEP ROLL-OFF LOWPASS FILTER 10
DC-ACCURATE, PROGRAMMABLE-CUTOFF, FIFTH-ORDER BUTTERWORTH LOWPASS FILTER REQUIRES NO ON-BOARD CLOCK 11
Miscellaneous Circuits 12
A SINGLE CELL LASER DIODE DRIVER USING THE LT1110 12
LT1109 GENERATES VPP FOR FLASH MEMORY 13
RF LEVELING LOOP 13
HIGH ACCURACY INSTRUMENTATION AMPLIFIER 14
A FAST, LINEAR, HIGH CURRENT LINE DRIVER 15

A to D Converters

LTC1292: 12-BIT DATA ACQUISITION CIRCUITS

by Sammy Lum

Temperature-Measurement System

The circuit in Figure 1 shows how a transducer output, such as a platinum RTD bridge, can be digitized with one op amp. This circuit is a modification of that found in Application Note 43.[1] The differential input of the LTC1292 removes the common mode voltage. The LT1006 is used for amplification. The resistor tied between the + input of the LT1006 and the +IN input of the LTC1292 is to compensate for the loading of the bridge by resistor R_S. Full scale can be adjusted by the 500kΩ trim pot and offset can be adjusted by the 100Ω trim pot in series with R_S. A lower R_{PLAT} value than that in AN43 is used here to improve dynamic range. The signal voltage on the +IN pin must not exceed V_{REF}. The differential voltage range is V_{REF} minus approximately 100mV. This is enough range to measure 0°C to 400°C with 0.1°C resolution.

Floating, 12-Bit Data Acquisition System

The circuit in Figure 2 demonstrates how to float the LTC1292 to make a differential measurement. This circuit will digitize a 5V range from 10V to 15V with 12 bits of resolution. The digital I/O has been level translated. The LT1019-5 is used in shunt mode to create the floating analog ground for the LTC1292. The digital I/O lines make use of 4.3V Zeners to clamp the single-transistor inverters. Opto-isolators can also be used. The floating analog ground should be laid out as a ground plane for the LTC1292. The 47µF bypass capacitor should be tied from the V_{CC} pin to the floating ground plane with minimum lead length and placed as close to the device as possible. Likewise, keep the lead length from the GND pin to the floating ground plane at a minimum (a low-profile socket is acceptable).

[1] Williams, Jim, "Bridge Circuits, Marrying Gain and Balance," Application Note 43, Linear Technology Corp.

Differential Temperature Measurement System

The circuit in Figure 3 digitizes the difference in temperature between two locations. The two LM134s are used as temperature sensors. These are ideally suited for remote applications because they are current output devices. This allows long wires to run from the sensor back to the LTC1292 without any degradation to the signal from the sensor. Resistor R_{SET} sets the current to 1µA/°K. The current is converted to a voltage by the resistor R1 connected from V^- to ground. The reference voltage and resistor were selected to give a change of 0.05°C/LSB. The resolution is given by $°C/LSB = V_{REF} / ((4096)(1mA)(R1))$. The maximum temperature at each input is 125°C. Note

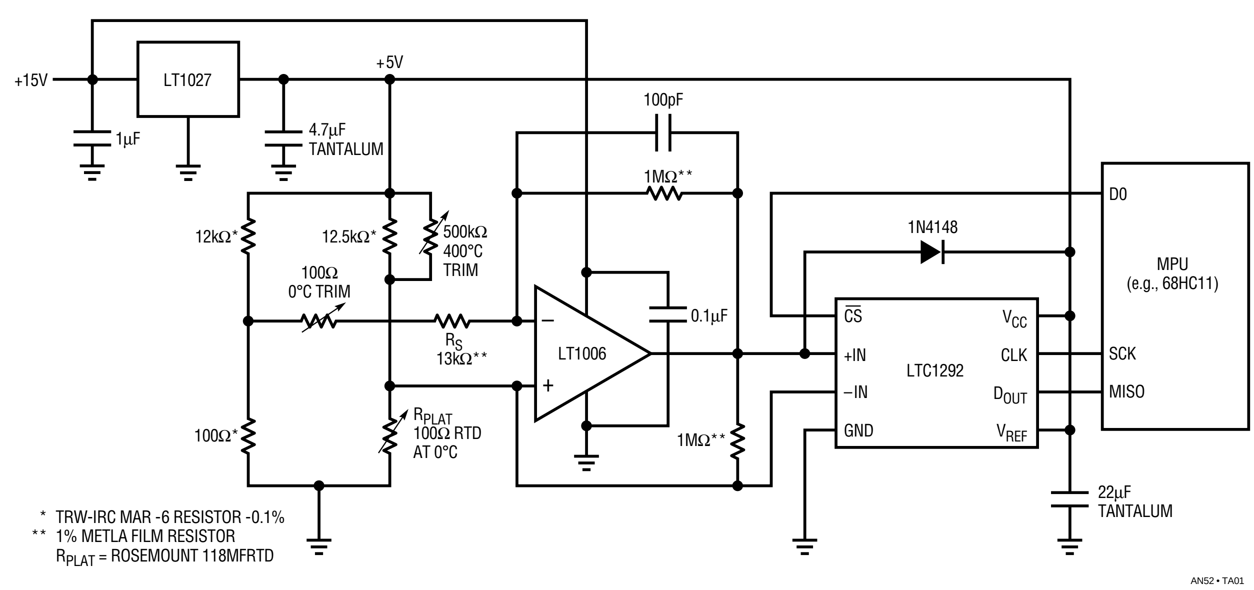


Figure 1. 0° to 400°C Temperature-Measurement System

that if the temperature on the +IN pin is less than the temperature on the –IN pin, the output will be zero. Because the LTC1292 is being driven from a high source impedance, you should limit the CLK frequency to 100kHz or less.

The software code for interfacing the LTC1292 to the Motorola MC68HC11 or the Intel 8051 is found in the LTC1292 data sheet. The code needs to be modified for the circuit in Figure 2 to account for the inversion introduced by the digital level translators.

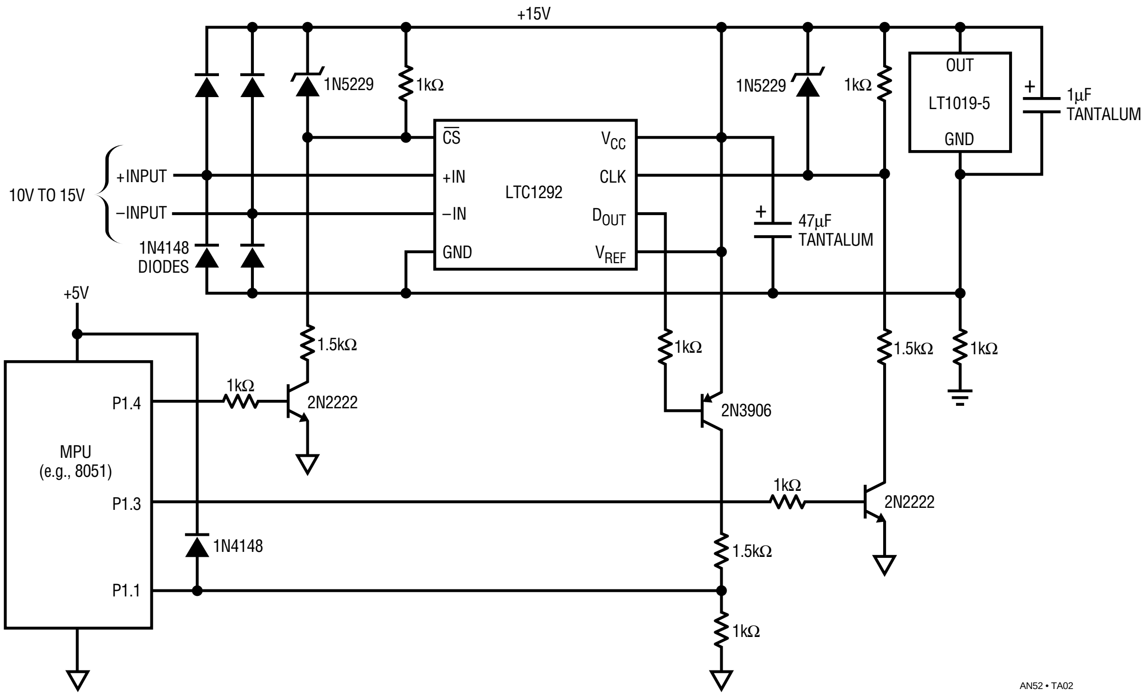


Figure 2. Floating, 12-Bit Data Acquisition System

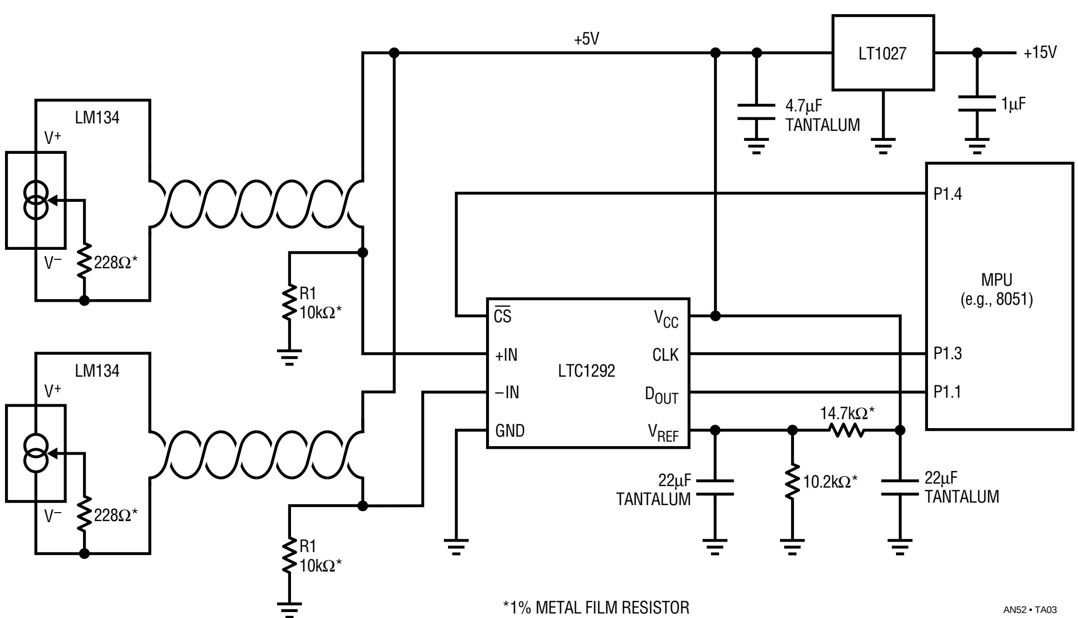


Figure 3. Differential Temperature-Measurement System

MICROPOWER SO8 PACKAGED ADC CIRCUITS

by William Rempfer

Floating 8-Bit Data Acquisition System

Figure 4 shows a floating system that sends data to a grounded host system. The floating circuitry is isolated by two opto-isolators and powered by a simple capacitor-diode charge pump. The system has very low power requirements because the LTC1096 shuts down between conversions and the opto-isolators draw power only when data is being transferred. The system consumes only 50µA at a sample rate of 10Hz (1ms on-time and 99ms off-time). This is easily within the current supplied by the charge pump running at 5MHz. If a truly isolated system is required, the system's low power simplifies generating an isolated supply or powering the system from a battery.

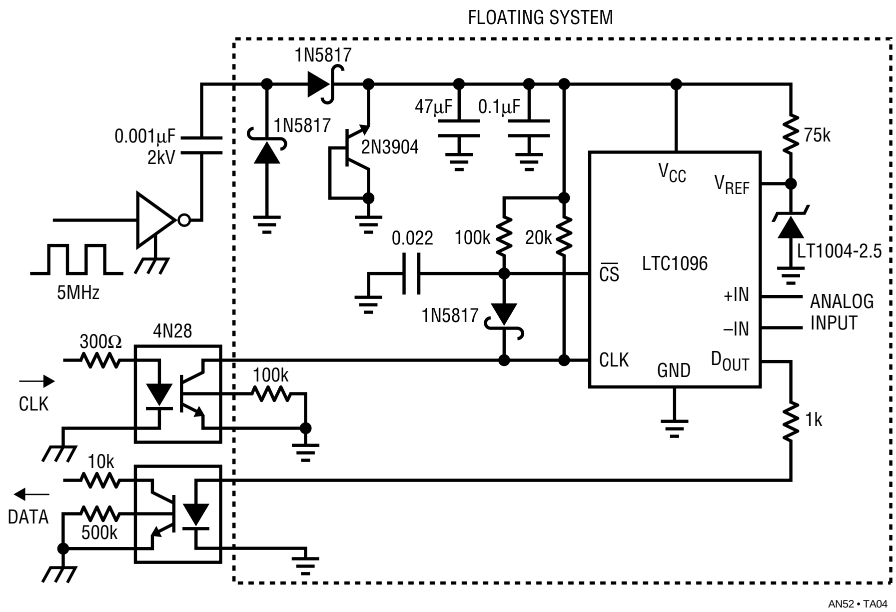


Figure 4. Power for this Floating ADC System is Provided by a Simple Capacitor-Diode Charge Pump. The Two Opto-Isolators Draw No Current Between Samples, Turning on Only to Send the Clock and Receive Data

0°C – 70°C Thermometer

Figure 5 shows a temperature-measurement system. The LTC1096 is connected directly to the low cost silicon temperature sensor. The voltage applied to the V_{REF} pin adjusts the full scale of the ADC to the output range of the sensor. The zero point of the converter is matched to the zero output voltage of the sensor by the voltage on the LTC1096's negative input.

Operating the ADC directly off batteries can eliminate the space taken by a voltage regulator. Connecting the ADC directly to sensors can eliminate op amps and gain stages. The LTC1096/LTC1098 can operate with small, 0.1µF or 0.01µF chip bypass capacitors.

Figure 6 shows the operating sequence of the LTC1096. The converter draws power when the $\overline{CS}$ pin is low and shuts itself down when that pin is high. In systems that convert continuously, the LTC1096/LTC1098 will draw its normal operating power continuously. A 10µs wake up time must be provided to the LTC1096 after each falling $\overline{CS}$.

In systems that have significant time between conversions, lowest power drain will occur with the minimum $\overline{CS}$ low time. Bringing $\overline{CS}$ low, waiting 10µs for the wake up time, transferring data as quickly as possible, and then bringing it back high will result in the lowest current drain.

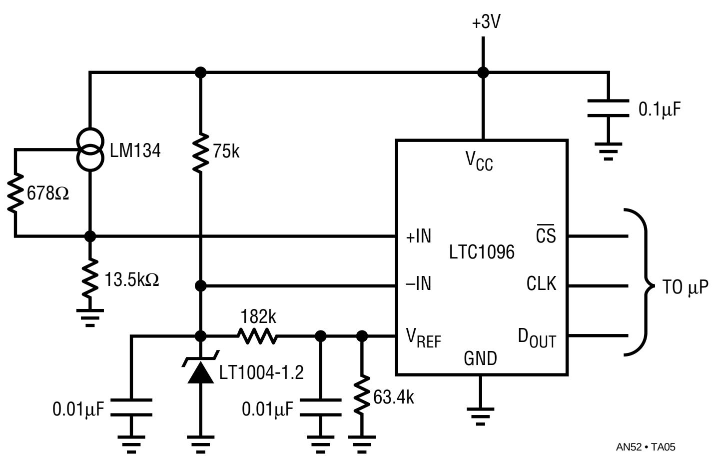


Figure 5. The LTC1096's High-Impedance Input Connects Directly to this Temperature Sensor, Eliminating Signal Conditioning Circuitry in this 0°C–70°C Thermometer

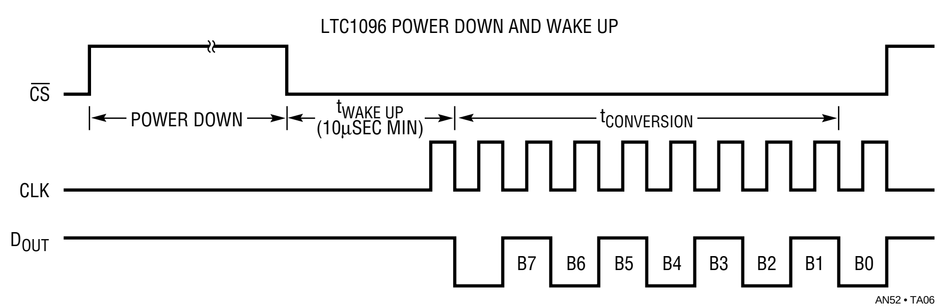


Figure 6. The ADC's Power Consumption Drops to Zero When $\overline{CS}$ Goes High. 10µs After CS Goes Low, the ADC is Ready to Convert. For Minimum Power Consumption Keep $\overline{CS}$ High for as Much Time as Possible Between Conversions

Interface

LOW DROPOUT REGULATOR SIMPLIFIES ACTIVE SCSI TERMINATORS

by Sean Gold

The circuit shown in Figure 7 uses an LT1117 low dropout three terminal regulator to control the terminator's local logic supply. The LT1117's line regulation makes the output immune to variations in TERMPWR. After accounting for resistor tolerances and variations in the LT1117's reference voltage, the absolute variation in the 2.85V output is only 4% over temperature. When the regulator drops out at TERMPWR-2.85, or 1.25V, the output linearly tracks the input with a 1V/V slope. The regulator provides effective signal termination because the 110Ω series resistor closely matches the transmission line's characteristic impedance, and the regulator provides a good AC ground.

In contrast to a passive terminator, two LT1117s require half as many termination resistors, and operate at 1/15 the quiescent current or 20mA. At these power levels, PC traces provide adequate heat sinking for the LT1117's SOT-223 package. Beyond solving basic signal conditioning problems, this LT1117 terminator handles fault conditions with short circuit current limiting, thermal shutdown, and on-chip ESD protection.

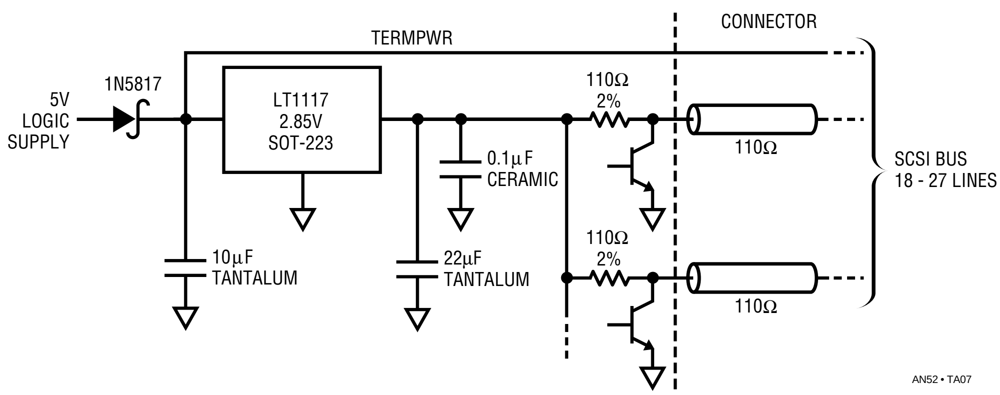


Figure 7. SCSI Active Termination

Power

LT1110 SUPPLIES 6 VOLTS AT 550mA FROM 2 AA NiCAD CELLS

by Steve Pietkiewicz

The LT1110 micropower DC-DC converter can provide 5V at 150mA when operating from two AA alkaline cells. The internal switch $V_{CE(SAT)}$ sets this power limit. Even with an external low drop switch, more power is not realistically possible. The internal impedance (typically 200mΩ fresh and 500mΩ at end-of-life) of alkaline AA cells limits peak obtainable battery power. Conversely, nickel-cadmium cells have a constant internal impedance (35mΩ–50mΩ) for AA size) that increases only when the cell is completely discharged. This allows power to be drawn from the cell at a far greater rate. The circuit in Figure 8 uses two AA NiCad cells to supply 6 volts at 550mA. The circuit, developed for pagers with transmit capability, runs at full output current for 15 minutes with two Gates Millennium AA NiCad cells. With a 250mA load, the circuit runs for 36 minutes (see Figure 9). Less heat is generated with a reduced load, resulting in the watt-hour difference observable above.

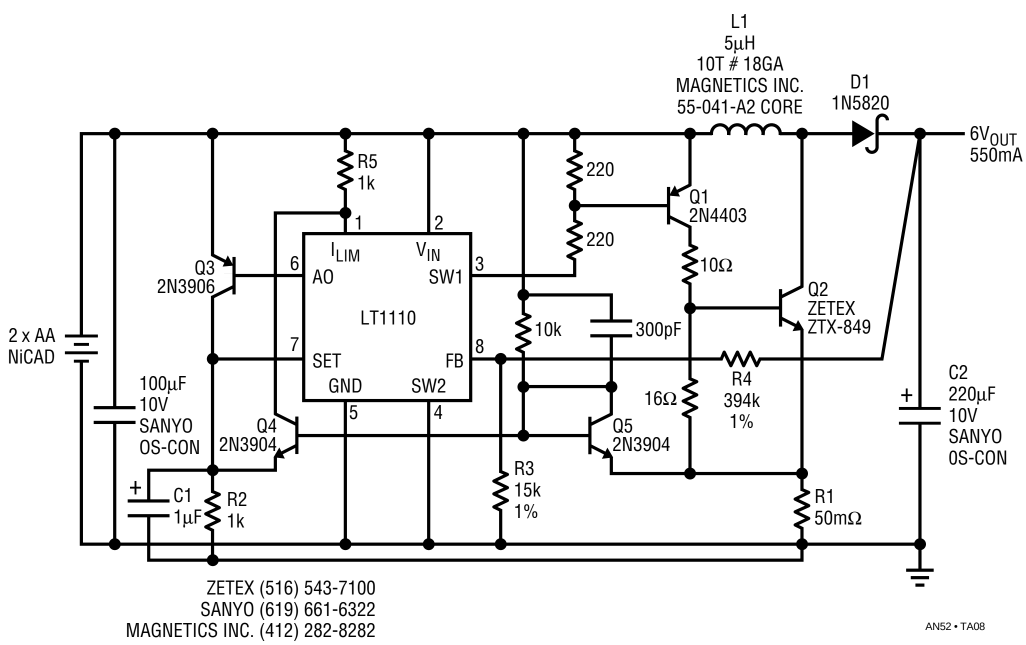


Figure 8. Schematic Diagram, 2 AA NiCad to +6 Volt Converter

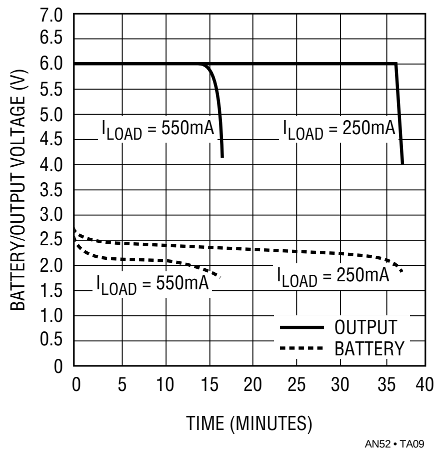


Figure 9. Operating Time at I_{LOAD} = 550mA and 250mA

The circuit uses a micropower LT1110 switching-regulator IC as a controller. The internal switch of the LT1110 furnishes base drive to Q1 through the 220Ω resistors. Q1, in turn, supplies base drive to the power switch Q2. The Zetex ZTX849 NPN device is rated at 5A current and comes in a TO-92 package. For surface-mount fans, the FZT-849, also from Zetex, provides the same performance in an SOT-223 package. The 16Ω resistor provides a turn off path for Q2's stored charge. When Q2 is on, current builds in L1. As Q2 turns off, its collector flies positive until D1 turns on. L1's built-up current discharges through D1 into C2 and the load. The voltage at V_{OUT} is divided by R4 and R3 and fed back into the FB pin of the LT1110, which controls Q2's cycling action. Switch current limit, which is necessary to ensure saturation over supply variations, is implemented by Q3–Q5. Q3, C1, R2, and the auxiliary gain block inside the LT1110, form a 220mV reference point at the LT1110's SET pin. Transistors Q4 and Q5 form a common-base differential amplifier. Q5's emitter monitors the voltage across 50mΩ resistor R1. When the voltage across R1 exceeds 220mV, Q4 turns on hard, pulling current through R5. When the voltage at the I_{LIM} pin of the LT1110 reaches a diode drop below the V_{IN} pin, the internal switch turns off. Thus, maximum switch current is maintained at 220mV/50mΩ, or 4.4A, over input variations and manufacturing spread in the LT1110's on time and frequency.

The circuit's output ripple measures $200mV_{P-P}$, and efficiency is 78% at full load with a 2.4V input. Output power can be scaled down for less demanding requirements. To reduce peak current, increase the value of R1. A 100mΩ resistor will limit current to 2.2A. L1 should be increased in value linearly as current is reduced. For a current limit of 2.2A, L1 should be 10μH. Base drive for Q2 can also be reduced by increasing the value of the 10Ω resistor. These lower peak currents are much easier on alkaline cells and will dramatically increase alkaline battery life.

50 WATT HIGH EFFICIENCY SWITCHER

by Milton Wilcox

The high efficiency 10A step-down (buck) switching regulator shown in Figure 10 illustrates how different sized MOSFETs can be driven by the LT1158 without having to worry about shoot-through currents. Since 24V is being dropped down to 5V, the duty cycle for the switch (top MOSFET) is only 5/24 or 21%. This means that the bottom MOSFET will dominate the $R_{DS(ON)}$ efficiency losses, because it is turned on nearly four times as long as the top. Therefore a smaller MOSFET is used on the top, and the bottom MOSFET is doubled up, all without having to worry about dead time.

The LT1158 uses an adaptive system that maintains dead time independent of the type, the size, and even the number of MOSFETs being driven. It does this by monitoring the gate turn-off to see that it has fully discharged before allowing the opposite MOSFET to turn on. During turn-on, the hold-off capability of the opposing driver is boosted to prevent transient shoot-through. In this way, cross-conduction is completely eliminated as a design constraint.

The non-critical Schottky diode across the bottom MOSFETs reduces reverse-recovery losses. Figure 11 shows the operating efficiency for the Figure 10 circuit.

Switching regulator applications can take advantage of an important protection feature of the LT1158: remote fault sensing. By sensing the current on the output side of the inductor and returning the LT1158 $\overline{\text{fault}}$ pin to the PWM soft-start pin, a true current-mode loop is formed. The Figure 10 circuit regulates maximum current in the inductor to 15A with no output voltage overshoot upon recovery from a short circuit.

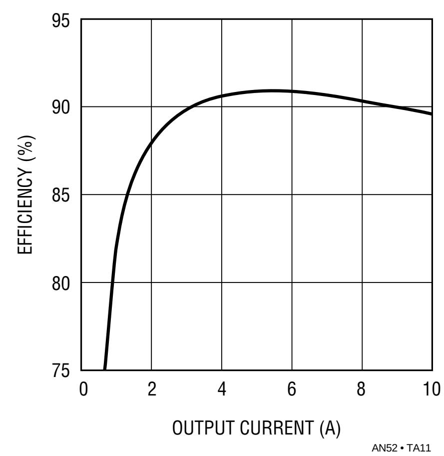


Figure 11. Operating Efficiency for Figure 10 Circuit. Current Limit is Set at 15A

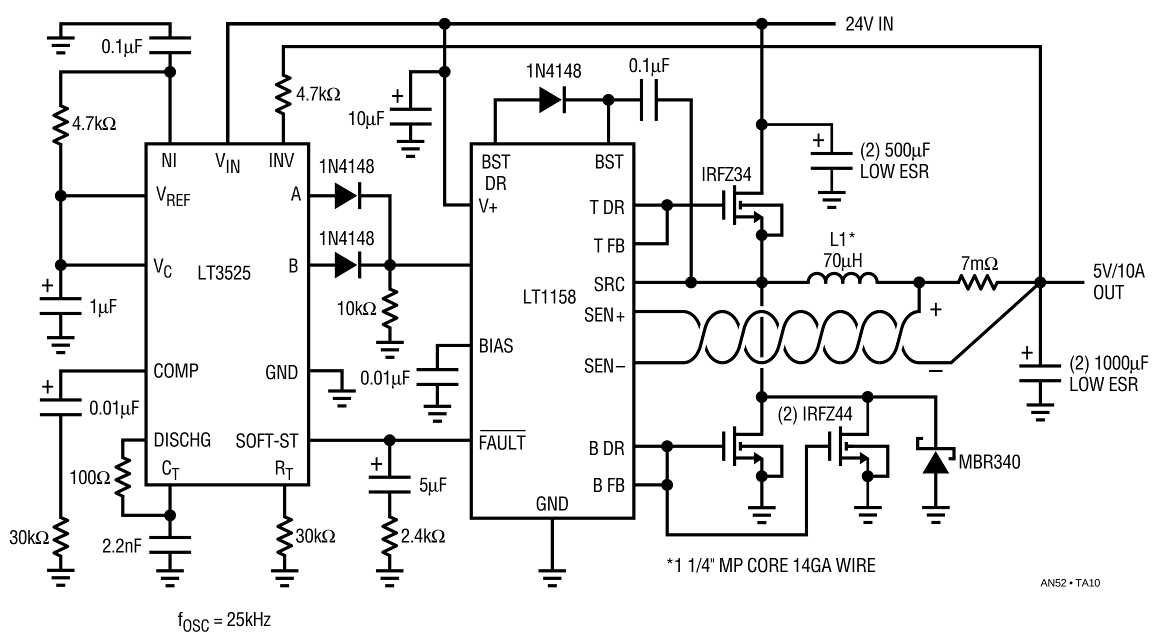


Figure 10. 50W High Efficiency Switching Regulator Illustrates the Design Ease Afforded by Adaptive Dead Time Generation

Filters

CASCADED 8TH-ORDER BUTTERWORTH FILTERS PROVIDE STEEP ROLL-OFF LOWPASS FILTER

by Philip Karantzalis and Richard Markell

Sometimes a design requires a filter that exceeds the specifications of the standard "dash-number" filter. In this case, the requirement was a low-distortion (–70dB) filter with roll-off faster than that of an 8th-order Butterworth. An elliptic filter was ruled out because its distortion specifications are too high. Two low power LTC1164-5s were wired in cascade to investigate the specifications that could be achieved with this architecture. The LTC1164-5 is a low power (4 milliamperes with ±5 volt supplies), clock-tunable, 8th-order filter, which can be configured for a Butterworth or Bessel response by strapping a pin. Figure 12 shows the schematic diagram of the two-filter system. The frequency response is shown in Figure 13, where it can be seen that the filter's attenuation is 80dB at 2.3 times the cutoff frequency. The distortion, as shown in Figure 14, is nothing less than spectacular. From 100Hz to 1kHz, the two filters have less than –74dB distortion specifications. At the standard measurement frequency of 1kHz, the specification is –78dB.

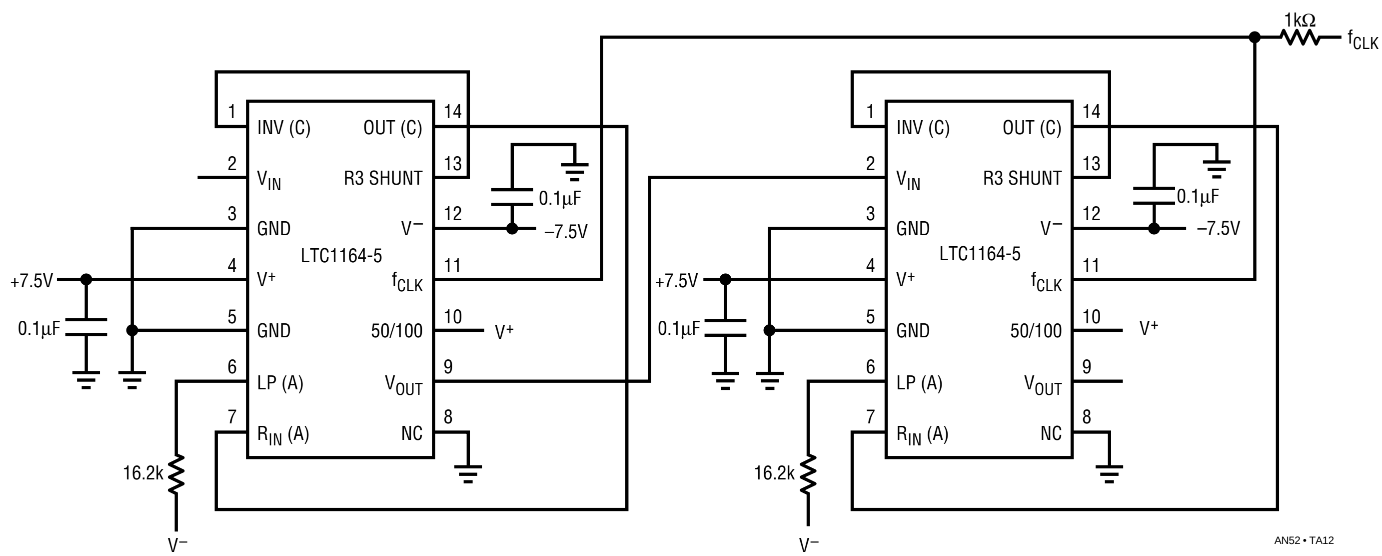


Figure 12. Schematic Diagram: Low Power, 16th-Order Lowpass Filter (Two 8th-Order Butterworths Cascaded)

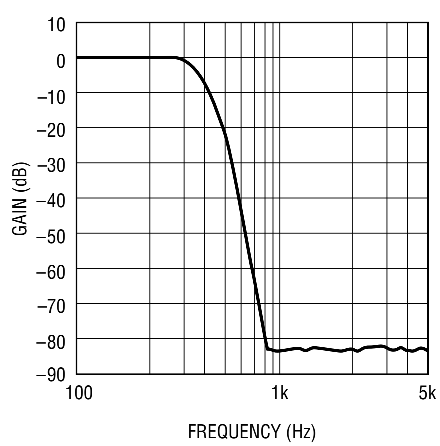


Figure 13. Frequency Response for f_{CLK} = 20kHz

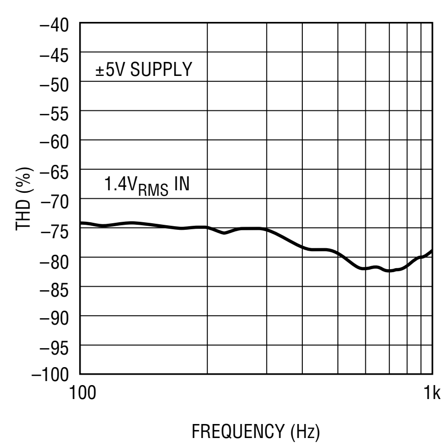


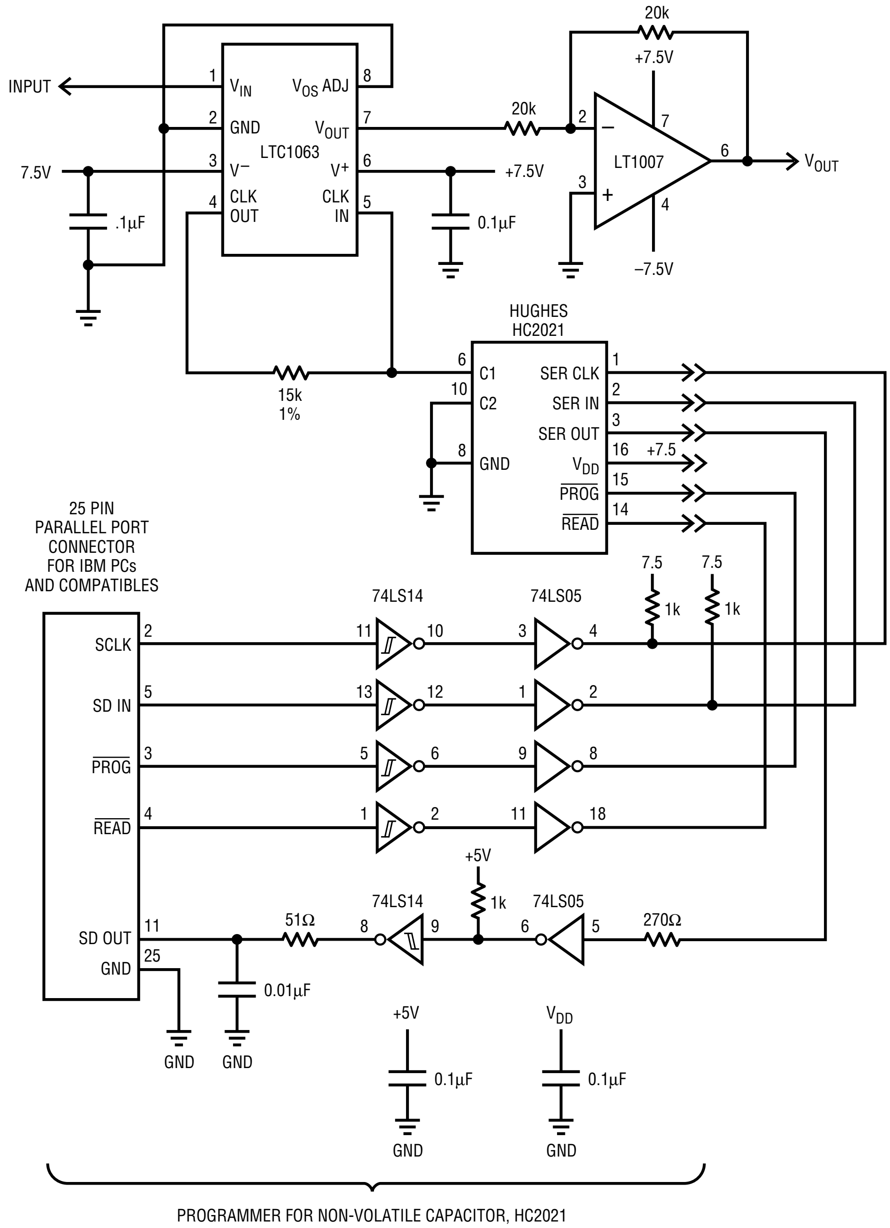
Figure 14. Distortion Performance: Two LTC1164-5s, f_{CLK} = 60kHz (57:1) Pin 10 Connected to V+

DC-ACCURATE, PROGRAMMABLE-CUTOFF, FIFTH-ORDER BUTTERWORTH LOWPASS FILTER REQUIRES NO ON-BOARD CLOCK

by Richard Markell

The new LTC1063 is a clock-tunable, monolithic filter with low-DC output offset (1mV typical with ±5V supplies). The frequency response of the filter closely approximates a fifth-order Butterworth polynomial.

Most users choose to tune the filter with an on-board microprocessor and/or timer. This is quite convenient if these components are available. If a clock is not available, the LTC1063 can be tuned with an external resistor and capacitor. The scheme shown here allows the filter's cutoff frequency to be programmed using an external microprocessor or the parallel port of a personal computer. This allows the cutoff frequency of the filter to be set before the product is shipped.



NOTES:
1. THE HC2021 SHOULD BE LOCATED CLOSE TO THE LTC1063 FOR BEST RESULTS.
2. $+3.5 \le V_{DD} \le +18.8$.
3. POSITIVE POWER SUPPLY FOR DEVICES 74LS05 AND 74LS14 IS +5V.
4. HUGHES TELEPHONE NUMBER (714) 759-2665.

AN52 • TA15

Figure 15. Schematic Diagram of LTC1063 with Programmable Cutoff Frequency

The tuning scheme makes use of non-volatile, tunable capacitors available from Hughes Semiconductor. These capacitors allow approximately a decade of tuning range. More range could be obtained by using dual devices. Figure 15 shows the schematic diagram of the application. Be sure to place the variable capacitor as close as possible to the LTC1063 to minimize parasitic elements. Figure 16 shows the frequency response of the filter when the capacitor is varied from minimum to half-value, and then to maximum capacitance. The programming part of the circuit may be disconnected once the variable capacitor is set. The capacitor will remember its value until it is reprogrammed.

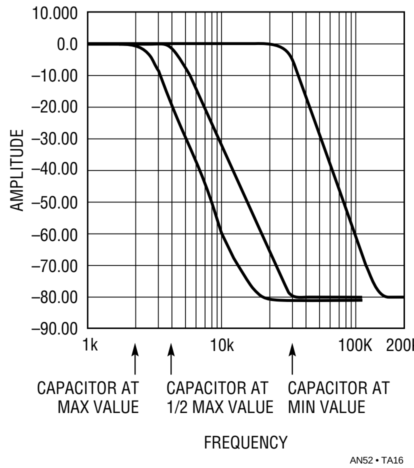


Figure 16. LTC1063 Frequency Response

Miscellaneous Circuits

A SINGLE CELL LASER DIODE DRIVER USING THE LT1110

by Steve Pietkiewicz

Recently available visible lasers can be operated from 1.5V supplies, given appropriate drive circuits. Because these lasers are exceptionally sensitive to overdrive, power to the laser must be carefully controlled lest it be damaged. Over-currents as brief as 2 microseconds can cause damage.

In the circuit of Figure 17, an LT1110 switching regulator serves as the controller within the single cell powered laser diode driver. The LT1110 regulator is a high speed LT1073.

The LT1110 is used here as an FM controller, driving a PNP power switch Q2, with a typical "ON" time of 1.5 microseconds. Current in L1 reaches a peak value of about 1.0A. The output capacitor C2 has been specified for low ESR, and should not be substituted (damage to the laser diode may result).

The Gain Block output of the LT1110 functions with Q1 as an error amplifier. The differential inputs compare the photodiode current developed as a voltage across R2 to the 212mV reference. The amplifier drives Q1, which modulates current into the I_{LIM} pin. This varies oscillator frequency to control average current.

Overall frequency compensation is provided by R1 and C1, values carefully chosen to eliminate power-up overshoot. The value of current sense resistor R2 determines the laser diode power, as shown the 1000 ohms results in about a 0.8 milliwatt output.

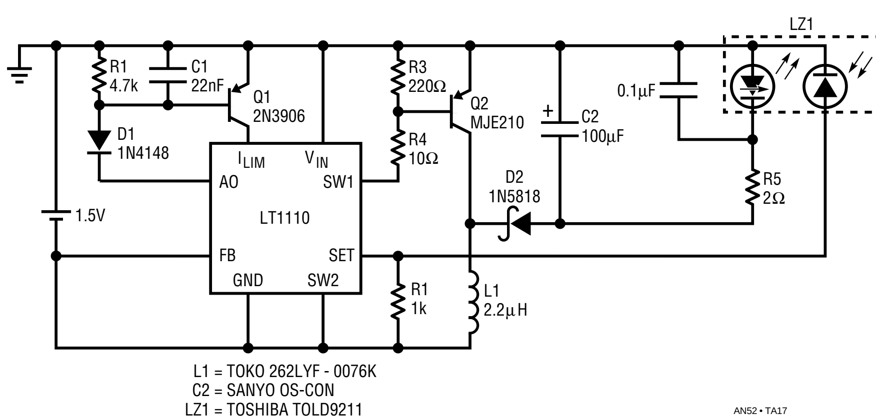


Figure 17. LT1110 Laser Diode Driver Operating from a Single Cell

LT1109 GENERATES VPP FOR FLASH MEMORY

by Steve Pietkiewicz

Flash memory chips such as the Intel 28F020 2Megabit device require a VPP program supply of 12 volts at 30mA. A DC-DC converter may be used to generate 12 volts from the 5 volt logic supply. The converter must be physically small, available in surface-mount packaging, and have logic-controlled shutdown. Additionally, the converter must have carefully controlled rise time and zero overshoot. VPP excursions beyond 14 volts for 20ns or longer will destroy the ETOX[2]-process based device.

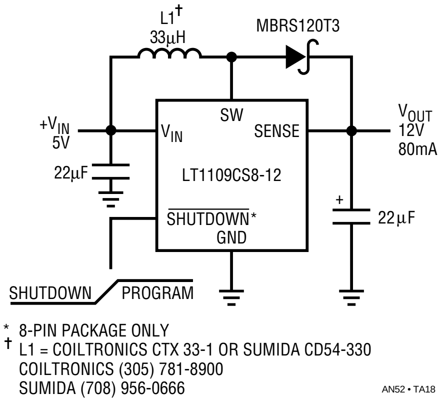


Figure 18. All Surface Mount Flash Memory VPP Generator

Figure 18's circuit is well suited for providing VPP power for single or multiple flash memory chips. All associated components, including the inductor, are surface mount devices. The $\overline{\text{SHUTDOWN}}$ input turns off the converter, reducing quiescent current to 300μA when pulled to a logic 0. VPP rises in a controlled fashion, reaching 12 volts ±5% in under 4ms. Output voltage goes to V_{CC} minus a diode drop when the converter is in shutdown mode. This is an acceptable condition for Intel flash memories and does not harm the memory.

[2]ETOX is a trademark of Intel Corporation.

RF LEVELING LOOP

by Jim Williams

Leveling loops are often a requirement for RF transmission systems. More often than not, low cost is more important than absolute accuracy. Figure 19 shows such a circuit.

The RF input is applied to A1, an LT1228 operational transconductance amplifier. A1's output feeds A2, the LT1228's current feedback amplifier. A2's output, the output of the circuit, is sampled by the A3-based gain control configuration. This arrangement closes a gain control loop back at A1. The 4pF capacitor compensates rectifier diode capacitance, enhancing output flatness vs frequency. A1's I_{SET} input current controls its gain, allowing overall output level control. This approach to RF leveling is simple and inexpensive, and provides low output drift and distortion.

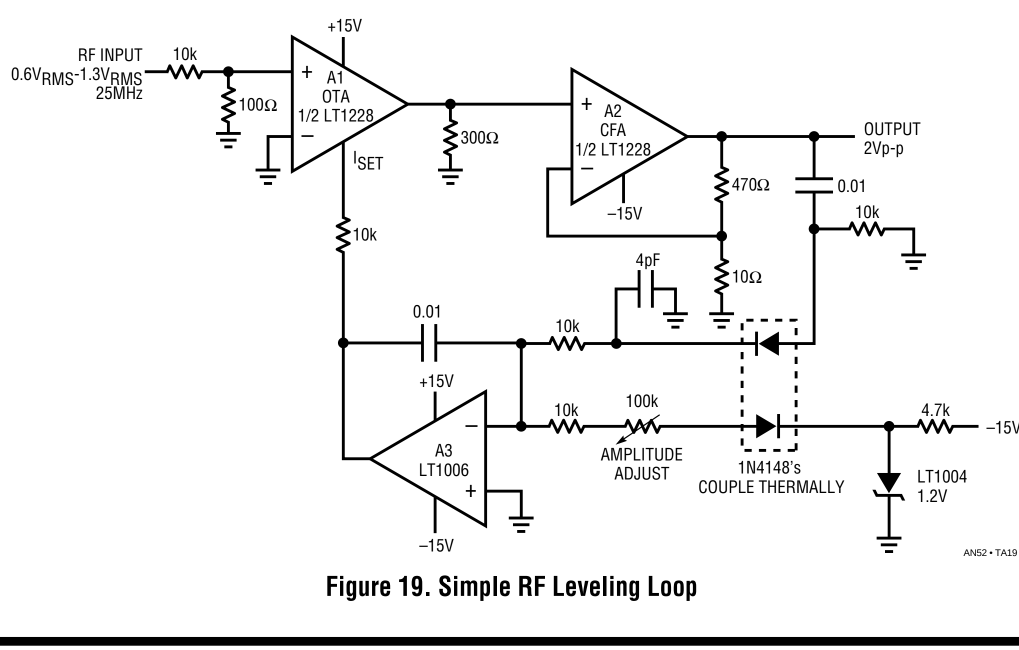


Figure 19. Simple RF Leveling Loop

HIGH ACCURACY INSTRUMENTATION AMPLIFIER

by Dave Dwelley

The LTC1043 and the LTC1047 combine to make a high performance low frequency instumentation amplifier as shown in Figure 20. The LTC1043 switched capacitor block is configured as a sampling front end, providing exceptional CMRR and rail-to-rail input operation. It works by attaching a 1μF capacitor across the two inputs, letting it charge to the input voltage. Once charged, the capacitor is disconnected from the input terminals and reconnected to the output terminals, where it transfers its charge to the 1μF capacitor at the LTC1047's input. Any common mode voltage present at the inputs is subjected to a capacitive divider between the 1μF flying cap and the IC's parasitic capacitance. With the LTC1043's parasitics typically below 1pF, this gives AC CMRR above 120dB. The analog switches in the LTC1043 are purely resistive, so they add no DC offset to the signal.

The output signal (with the common mode stripped off) is then amplified by the LTC1047, a precision, micropower zero-drift op amp. The LTC1047 amplifies the signal by the desired amount, adding less than 10μV offset and 0.05μV/°C drift. The sampling frequency of the LTC1043 with single 5V supply is about 400Hz, allowing differential signals below 200Hz to be amplified with no aliasing. Note that common mode signals are not sampled; thus they will not alias regardless of frequency until the common mode/differential mode signal ratio approaches 120dB! The entire system draws 60μA with a single 5V supply and provides two independent channels.

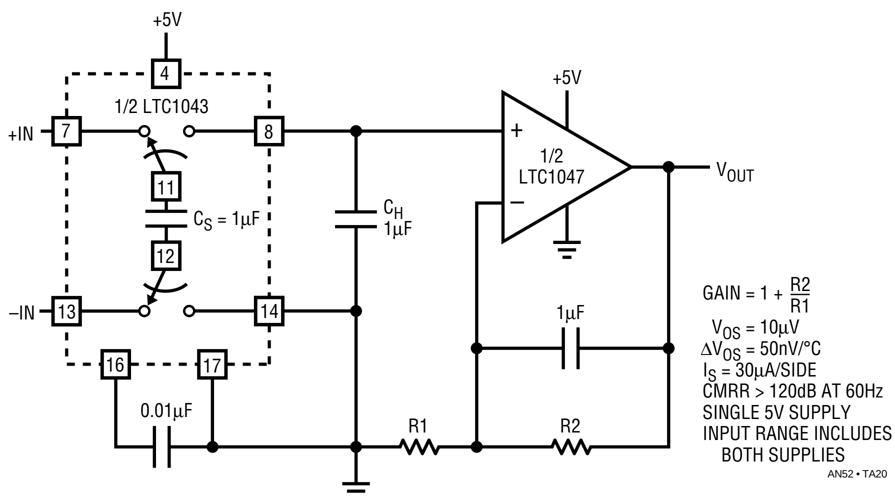


Figure 20. High Accuracy Instrumentation Amplifier

A FAST, LINEAR, HIGH CURRENT LINE DRIVER

by Walt Jung and Rich Markell

Among linear applications not usually seen are those which require high speed combined with either very low DC error, or high load current. Such applications can be solved by combining the best attributes of two ICs, either one of which may not be capable by itself of the entire requirement.

A case in point is the line driver of Figure 21, which uses an LT1122 JFET input op amp as the gain element combined with an LT1010 buffer. This provides the output current of the LT1010 (typically 150mA) but with the basic DC and low level AC characteristics of the LT1122. The circuit is capable of driving loads as low as 100Ω with very low distortion. The input referred DC error is the low DC offset of the LT1122, typically 0.5mV or less. Large signal characteristics are also very good, due to the 80V/µs symmetrical SR of the LT1122.

The circuit as shown is configured as a precise gain of 5 non-inverting amplifier by gain set resistors R2 and R1, with the LT1010 unity gain voltage follower inside the overall feedback loop. This provides current buffering to the op amp, allowing it to operate most linearly. Small signal bandwidth is set by the time constant of R2 and C1, and is 1MHz as shown, with a corresponding risetime of about 400ns.

Performance with ±18V supplies is shown in Figures 22a and 22b, with output generally $5V_{RMS}$ or equivalent, driving 100Ω directly. THD is shown in Figure 22a, with input level swept up to output clipping level, at a fixed 10kHz frequency. The distortion is generally well below 0.01%, and improves substantially for lower frequencies.

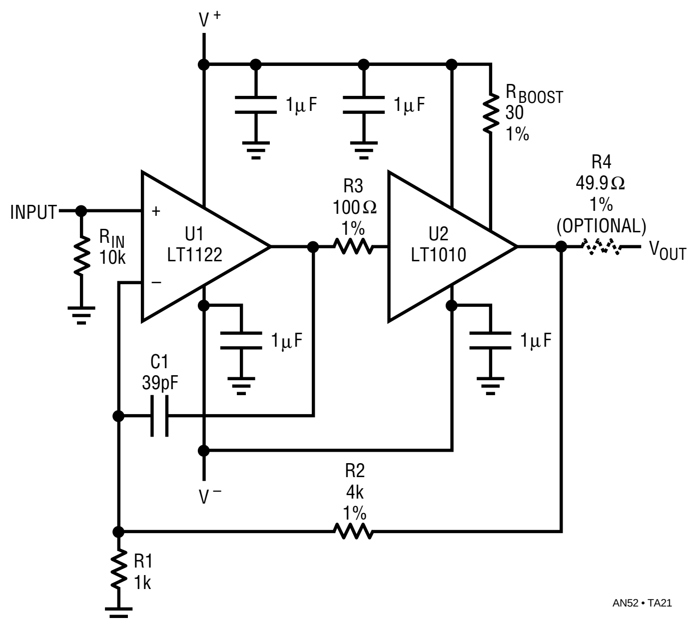


Figure 21. Line Driver

CCIF IM distortion performance of the circuit for similar loading is shown in Figure 22b, driving a load of 100Ω at a swept level, again up to output clipping. The LT1122 amplifier is represented by the lower of the two curves, with distortion around the 0.0001% level. Also shown for comparison in this plot is the distortion of a type 156 JFET op amp (also driving the LT1010 buffer with other conditions the same). The 156 op amp uses a design topology with an intrinsically *asymmetric* SR. This manifests itself as rising even order distortion for methods such as this CCIF test. For this example, the distortion is more than an order of magnitude higher than that of the faster, symmetric slewing LT1122 for the same conditions.

Applications of this circuit include low offset linear buffers such as for A/D inputs, line drivers for instrumentation use, and audio frequency range buffers such as very high quality headphone use.

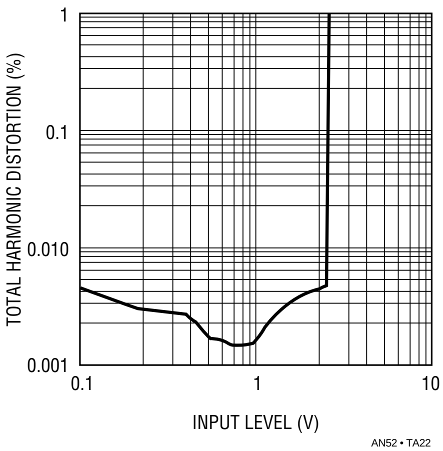


Figure 22a. THD vs Input Level

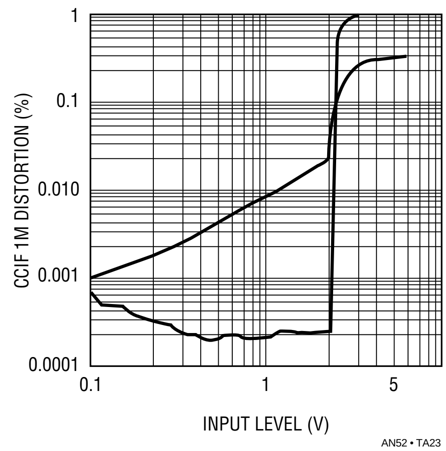


Figure 22b. CCIF IM Distortion vs Input Level

***Linear Technology*, the magazine, is published 3 times a year.**
The magazine features articles, circuits and new product
information from the designers at LTC. To subscribe please call
800-637-5545.

Linear Technology Corporation
1630 McCarthy Blvd., Milpitas, CA 95035-7487
(408) 432-1900 • FAX: (408) 434-0507 • TELEX: 499-3977
BA/GP 0193 10K REV 0