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## New LTC1148/LTC1149 Switching Regulators Maximize Efficiency from Milliamps to Amps

by Milton Wilcox and  
Randy Flatness

### Introduction

The LTC1148 and LTC1149 are the first stepdown switching regulators that provide extremely high operating efficiencies (typically greater than 90%) over the entire load-current range demanded by the next generation of sophisticated notebook computers, cellular phones, and handheld instruments. The LTC1148/LTC1149 extends battery life by providing efficiencies, when these devices are in sleep or standby modes, that are nearly as high as those for full-power operation. Furthermore, losses are reduced to the point where no heat sinking is required.

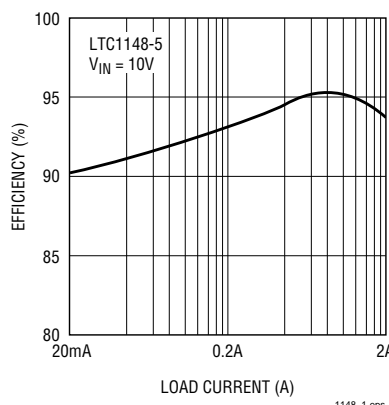


Figure 1. Thanks to Burst Mode™ operation, the LTC1148-5 is capable of greater than 90% efficiency from 20mA to 2A of output current

The extremely wide operating range is illustrated by the typical efficiency curve of Figure 1. The LTC1148 and LTC1149 accomplish this feat by automatically and smoothly changing from synchronously switched current-mode operation at high output currents to Burst Mode™ operation at low output currents. Members of the LTC1148/LTC1149 family can operate from input voltages as low as 4V (LTC1148) to as high as 48V (LTC1149). They are all capable of 100% duty cycles for very-low-dropout operation, and all have built-in current limiting. Line and load transient response is excellent under a variety of conditions, including when making the transition from Burst Mode™ operation to full-current operation.

The small size and high efficiency of the LTC1148/LTC1149 family make DC-to-DC conversion feasible in the most restricted spaces of today's portable electronics. Take, for example, the problem of locally dropping 5V to 3.3V on a logic board. In many cases the dissipation of a linear regulator, even for this modest voltage drop, is unacceptable, because there is simply no way to remove the heat from the enclosed space. A linear regulator delivering 1A in this application would dissipate over 1.7W.

Continued on page 10

# LTC Switching Regulators Break the 90% Efficiency Barrier—The LTC Technology Machine Marches On

by Richard Markell

This issue of *Linear Technology* proudly spotlights our LTC1148/1149 switching regulators, which break the elusive 90% efficiency barrier. Not only do we pass the barrier but we burst through, without stopping, across the entire load range from milliamps to amps. Our lead article introduces the LTC1148/LTC1149 synchronous switching regulators, which provide very high efficiencies at all current levels. In addition to the 94%-efficient 5 volt to 3.3 volt converter mentioned in the article, we have achieved the following efficiencies in the lab since the article was written:

- An LTC1148 converter using 6-to-12 volt input with a 5 volt output at 4 amps output current. This converter achieves greater than 90% efficiency.
- An LTC1148 circuit that converts 6 volts to 5 volts at 1/2 amp, achieving 96% efficiency.
- An LTC1149 24 volt to 5 volt converter with output current of >1 amp, achieving 90% efficiency.

- A high-current circuit using the LT1158 (featured in the February 1992 *LT Magazine*), which converts 5 volts to 3.3 volts. This circuit's efficiency is 90% at 10 amps and 88% at 15 amps.

Efficiency, by itself, is no panacea, but higher and higher efficiencies imply less and less heat in your enclosure. This may not be a problem for a remote data-collection system in the Canadian North, but it certainly is a problem in notebook and laptop computers. (If you require additional information on these leading-edge developments in power-supply efficiencies, do not hesitate to call the Applications Group at the LTC factory.)

Another design feature highlights signal isolation applications and circuitry using a new isolation device from LTC. This device, the LTC1145/LTC1146 uses a special integrated-circuit lead frame to form the isolation capacitors. The device uses two dice (one driver and one receiver) coupled

through the isolation capacitors on the opposite ends of the lead frame. The article also describes how the design provides sufficient high-voltage isolation for even the most critical requirements with high transient immunity.

High speed, precision operational amplifiers are also featured in this issue, as are new 12-bit ADCs. Six new high-speed op amps—their circuit topologies, performance specifications, and some application areas—are discussed at length in another Design Feature. Analog-to-Digital converters are featured in an article describing the new 3.3 and 5 volt, 12-bit converters from LTC.

Also in this issue, I am pleased to note, is a large collection of Design Ideas. These range from a helium-neon laser power supply, to a multi-output power supply from two AA batteries, to an H-bridge driver circuit for a 15-amp DC motor. Circuitry for PCMCIA card power conditioning and 12-bit battery current monitoring are also featured in the Design Idea area. Good reading!

## F&E Cameo: Tom Mosteller


LTC has eighteen Field Application Engineers (or FAEs) spread throughout the world to assist customers in the design and selection of circuits available from LTC. Each FAE has a system-design background and has a working knowledge of the world from a system designer's point of view. All of our FAEs are available by phone and, in certain situations, in person, to help with the design of your circuitry. This space will profile one FAE per issue.

Tom Mosteller works out of LTC's Northeast Office. He covers the states of Pennsylvania, Maryland, West Virginia, Virginia, and Delaware, and parts of New York and New Jersey. Tom's

expertise is in the areas of signal processing and switching power supply design. He also has extensive experience in process control. "My greatest challenge in the signal processing field," writes Tom, "was an ECG-monitor front end that amplified millivolts while ignoring kilovolts. This monitor had an isolated power supply, low-level amplifiers, slew-rate limiters, switched-capacitor filters, a pressure-bridge exciter and amplifiers, and A-to-D converters."

Tom also enjoys writing. He wrote most of Application Note 50 on a portable computer while on a balcony overlooking the beach in Lewes,

Delaware (while he was on vacation, no less!). Tom's byline has also appeared in *PC Magazine*, *Circuit Cellar Ink*, and other publications.

Tom has been married to his wife Rose for eleven years. They have one son, Kyle, who is seven years old and in the second grade. Tom enjoys playing computer games and writing stories with Kyle on the computer. (Who enjoys computer games?) He also enjoys audio, YMCA Indian Guides, camping and fishing with Kyle, and helping with Rose's software business. Tom can be reached through LTC's Northeast Region Sales Office as listed on the back of this magazine. 

# New Isolators Replace "Optos" by James Herr

The LTC1145 and LTC1146 are a new generation of signal isolators. Previously, signal isolation was accomplished by means of opto-isolators. Light from an LED was detected across a physical isolation barrier by either a photo diode or transistor and converted to an electrical signal. Isolation levels up to thousands of volts were easily achieved.

Attempts have been made to provide signal isolation on a single silicon die. Problems arose due to reliability constraints of damage from ESD or over-voltage. A new technique, using a capacitive lead frame, overcomes the problems associated with single-package signal isolation. Further, this technique is suitable for use in thin surface-mount packages—a solution not available with opto-isolators. The data rates are 200kbps for the LTC1145 and 20kbps for the LTC1146. Both parts can sustain over 1000V across their isolation barriers.

## Circuit Design

The isolator IC includes two dice (see Figure 1). The first is a driver designed to drive two isolation capacitors. The second contains a receiver and filter which detect the drive signal and provide a digital output. The driver

is powered from the input signal. This allows interchangeability with opto-isolators, since no auxiliary power source is needed on the input side. The driver contains a high-frequency oscillator whose differential outputs are capacitively coupled to the receiver. The receiver detects the presence or absence of the driver's oscillations and outputs a logic 1 or 0, as appropriate.

The driver consists of a bias circuit, a Schmitt trigger, and a differential output oscillator to drive the isolation capacitors. The Schmitt trigger prevents the oscillator from driving the capacitors until the input rises to a sufficient level (3V for the LTC1145 or 2V for the LTC1146) to provide a clean square-wave output. Two versions of the drivers are available, one with a 5MHz oscillator frequency (LTC1145), and one with a 400kHz oscillator frequency (LTC1146). The 5MHz unit provides reliable data communication at 200kbps whereas the 400kHz unit can operate at 20kbps. Speed has its price: the LTC1145 consumes 600 $\mu$ A while the LTC1146 requires only 60 $\mu$ A of input current. These power levels are significantly below LED opto-isolators.

The receiver is designed to detect differential drive from the capacitors. A differential input comparator with

300mV of hysteresis detects the incoming signal while rejecting common-mode noise. The output of the comparator triggers a one-shot circuit with a period longer than that of the drive frequency. The retriggerable one-shot has a constant output as long as the input signal exists. When an input signal is absent for one time-out period, the one-shot goes low.

Also connected to the one-shot is a two-bit counter that works as a digital filter. The counter is clocked from a second oscillator running at around 10MHz. The output of the counter requires four oscillator clock periods to change state and is gated by the output of the one-shot. When an input signal triggers the one-shot, a logical 1 is presented to the data input of the filter. Four clock periods later the output of the filter goes high. If the signal is absent for four clock cycles, the filter output returns low. This digital filter eliminates possible erratic operation from spikes or temporary overloads of the input amplifier. The noise or interference signal must exist for four clock periods of the digital filter before an output-stage change can occur.

The LTC1145's digital filter can be clocked externally to lower its effective bandwidth. The LTC1146's

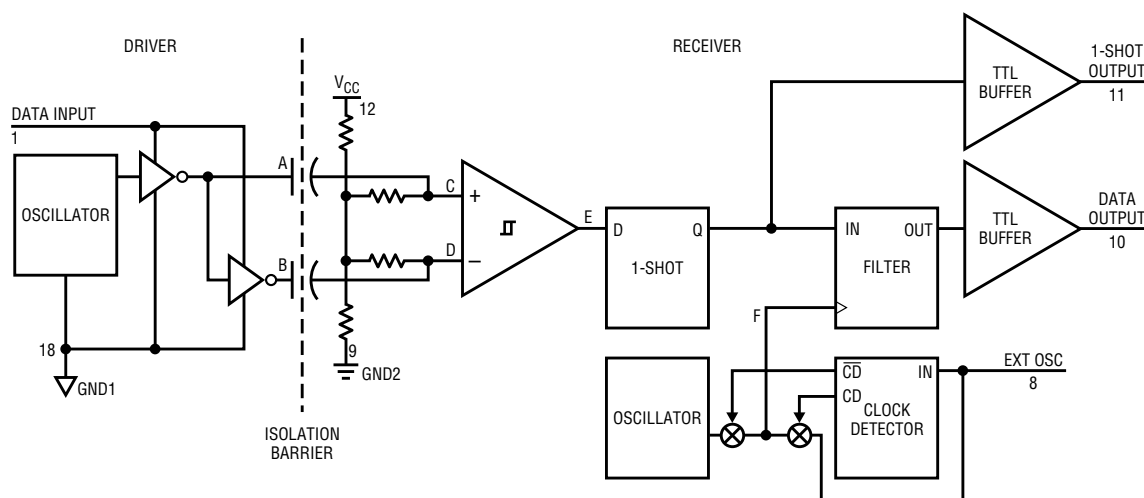


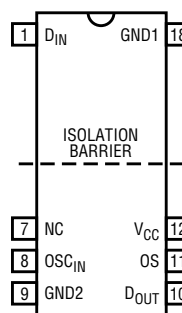
Figure 1. Two-chip design provides isolation barrier

digital-filter bandwidth can be reduced by connecting a capacitor at pin 8. Lower filter bandwidths are desirable to eliminate longer noise bursts. Experimental work using this isolator and filter has shown no corrupted data over a wide range of common-mode inputs.

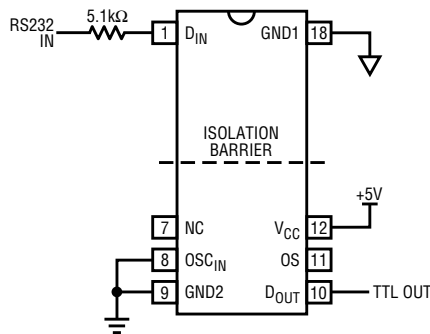
## Isolation Capacitors

A specialized lead frame is needed to form the isolation capacitors. This lead frame can be manufactured with the same high-volume techniques used for conventional integrated-circuit lead frames, and at approximately the same cost. The two dice (driver and receiver) are placed at the opposite ends of the lead frame and coupled through the isolation capacitors. The capacitance between the input and output is on the order of 1pF. This provides sufficient isolation in even the most critical of applications and is suitable for handling high voltages with high dV/dt.

Each 1pF capacitor is formed by three parallel metal fingers spaced about 20 mils apart. The capacitors'



**Figure 2. LTC1145/LTC1146 pin description**



**Figure 3. Isolated, low-power RS232**

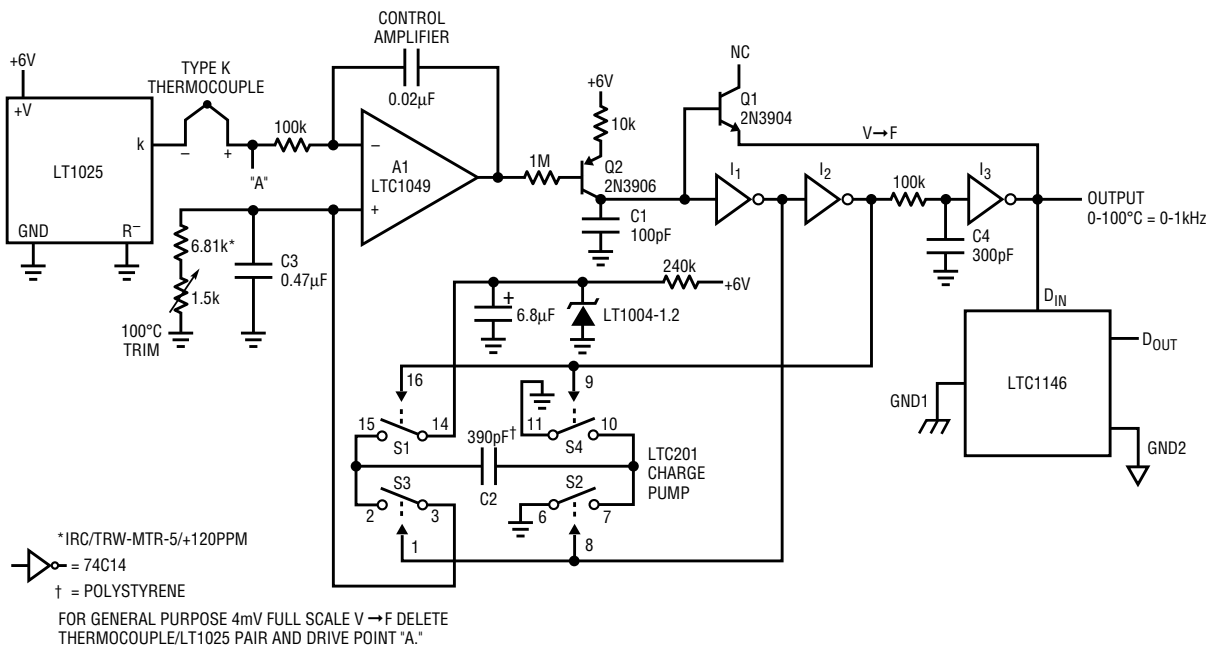
opto-isolator replacement. One possible application is an isolated RS232 receiver. The D<sub>IN</sub> pin of LTC1145 is driven by an RS232 signal through a 5.1kΩ resistor (Figure 3). The D<sub>OUT</sub> pin of the LTC1145 presents isolated, TTL-compatible output signals. The GND2 pin of the LTC1145 is connected to the same ground potential as the receiving end of the link. The isolator

can accommodate differences of up to 1kV between GND1 and GND2.

Another application is an isolated, thermocouple-sensed temperature-to-frequency converter (see Figure 4). The output of I<sub>3</sub> produces a 0kHz–1kHz pulse train in response to a 0°C to 100°C temperature excursion (see LTC Application Note 45 for the details). The pulses from I<sub>3</sub> drive the D<sub>IN</sub> pin of LTC1146. The GND1 pin is connected to the same ground potential as I<sub>3</sub>. The D<sub>OUT</sub> pin of LTC1146 presents isolated, TTL-compatible output signals. The circuit consumes only 460μA maximum, allowing it to operate from a 9V battery. **LT**

## Applications

The LTC1145/LTC1146 can be used in a wide range of applications where voltage transients, differential ground potentials, or high noise may be encountered, such as isolated serial data interfaces, isolated analog-to-digital converters for process control, isolated FET drivers, and low-power



**Figure 4. Isolated temperature-to-frequency converter**

# High Speed Comes to Precision, Single-Supply Op Amps

by William H. Gross

## The LT1211-LT1216 Family

LTC proudly introduces a new family of dual and quad single-supply precision op amps. These new amplifiers are fast, with slew rates of up to 50V/ $\mu$ s and gain-bandwidth products to 28MHz. All members of the family are unity-gain stable and operate on any single supply between 2.5V and 36V as well as on split supplies from  $\pm$ 2V to  $\pm$ 18V. The design of an op amp involves a trade off between slew rate and supply current consumption. Rather than force a major compromise, three new amplifiers were developed. Each of the three amplifier types is offered as both a dual and a quad; hence there are six part numbers.

The LT1211 dual and the LT1212 quad amplifiers draw the least quiescent current in the family, only 1.3mA per amplifier. The LT1211/LT1212 op amps have a 14MHz gain-bandwidth product and a peak slew rate of 7V/ $\mu$ s. They settle to 0.01% of a 10V step in 2.2 $\mu$ s.

The LT1213 dual and the LT1214 quad amplifiers have twice the gain-bandwidth product of the LT1211/LT1212 amps at 28MHz. The peak slew rate of the LT1213/LT1214 is 12V/ $\mu$ s and the supply current goes up to 3mA per amplifier. They settle to 0.01% of a 10V step in 1.2 $\mu$ s.

The LT1215 dual and the LT1216 quad amplifiers are the fastest in the family, with a slew rate of 50V/ $\mu$ s. The gain-bandwidth product is 23MHz, and the quiescent supply current is 5mA per amplifier. They settle to 0.01% of a 10V step in 480ns.

The dual op amps are available with the industry standard pin-out in either 8-pin SO or 8-pin mini-DIP packages. The quad op amps have the standard pin-out in the 14 pin DIP and the same pin-out, with two no-connect pins on one end, in the narrow (150mil) SO16 package. LTC is the first to offer a precision quad op amp in the narrow SO package. Precision amplifiers consist

of many transistors and require careful thermal layout; therefore precision op amps require much larger dice than simple commodity op amps. For this reason precision quad op amps have not been available in the narrow SO package; they are simply too wide to fit. To address this problem, LTC developed a special lead frame for the standard narrow SO16 mold. This new lead frame maximizes the area available for the die, but has an internal length-to-width ratio of 3 to 1. If one die were used to make a quad op amp for this package, it would also have to have a length-to-width ratio (aspect ratio) of 3 to 1.

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***There is a trend to lower supply voltages for analog signal processing. Engineers can no longer depend on having  $\pm$ 15V or  $\pm$ 12V supplies available. Often, only a single +5V supply is available, and the trend is to +3.3V***

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High aspect ratios cause manufacturing problems that increase costs. To solve this problem, we die-attach two dual op amp dice to the lead frame and bond them out with the standard pin-out. This gives us an effective aspect ratio of 3 to 1 without having to actually make a die with that aspect ratio.

## Performance Goals

There is a trend to lower supply voltages for analog signal processing. Engineers can no longer depend on having  $\pm$ 15V or  $\pm$ 12V supplies available. Often, only a single +5V supply is available, and the trend is to +3.3V. Our design goal was to make these single-supply op amps operate well with supply voltages as low as 2.5V.

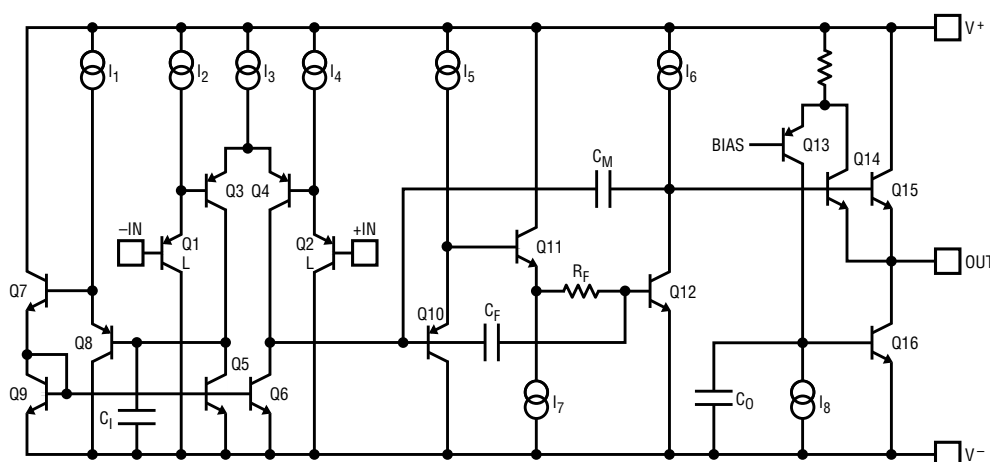
The introduction of LTC's 12-bit A-to-D converters that operate on 3.3V supplies, such as the LTC1282, LTC1287, and LTC1289, emphasizes the need for low voltage, 12-bit-accurate op amps. For converters operating with a 2.5V reference, we would like an op amp whose output swings from ground to 2.5V. The new LTC A-to-D converters include the sample-and-hold on the same chip; therefore an op amp is needed that settles cleanly after the input hold cap is connected. For the 160kHz-sampling LTC1282, the amplifier must deliver several milliamps of output current and settle in less than 1 $\mu$ s. Since the LSB in a 12-bit system using a 2.5V reference is only 610 $\mu$ V, the settling must have no thermal tails.

## Process Technology

The LT1211 family of amplifiers are manufactured on LTC's complementary bipolar process. The low drift and noise requirements of the amplifier, combined with the low open-loop output impedance required to drive sampling A-to-Ds precludes using a CMOS process. PNP transistors are used in the input stage so the common-mode range includes the negative supply. To make a fast amplifier we need fast PNPs, hence we could not use our standard bipolar process with lateral PNPs. The complementary process has 36V NPNs and PNPs that both have cutoff frequencies of 600MHz. Both transistors in this process are optimized for high gain, excellent matching, and low noise.

## Circuit Topology

The circuit topology of the LT1211 is conventional, with some high speed innovations. The amplifier consists of two gain stages. The first is a differential-voltage to single-ended-current (transconductance) stage whose output drives a high-input-impedance, inverting voltage-gain stage configured



**Figure 1. LT1211 simplified schematic**

as a Miller integrator. An emitter follower buffers the output of the second stage and sources current into the load. The current in this follower is monitored with a second loop that provides the output sink current.

One advantage of general-purpose op amps is that they can take large differential inputs without excessive input current flowing. This is because they use lateral PNPs with emitter-base breakdown voltages greater than 36V in the input stage. Conventional NPNs and fast PNPs have low emitter-base breakdown voltages and require clamps across the inputs to protect them. To make the LT1211 as easy to use as possible, we use lateral PNP transistors in the input stage. Referring to the simplified schematic (Figure 1), the input PNP emitter followers (Q1 and Q2) are lateral transistors with high breakdown. The differential-amplifier PNPs (Q3 and Q4) that convert the differential voltage to a current are fast transistors. Because Q1 and Q2 drive the high impedance bases of Q3 and Q4, the base-emitter capacitance of Q1 and Q2 couples the input signal to the faster PNPs (Q3 and Q4) even above the cutoff frequency of the lateral transistors.

An active load, Q5 through Q9, maximizes the gain of the first stage for low noise and low offset-voltage drift. The base current of Q8 matches the base current of Q10 for low drift. The capacitor  $C_1$  introduces a pole and a zero in the open-loop gain by rolling off half the input-stage gain above 1MHz.

This reduces the unity-gain frequency to half the gain-bandwidth product and therefore increases the gain and phase margin.

The output current from the first stage drives the second stage, consisting of Q10, Q11, and Q12. Q10 and Q11 are emitter followers to increase the input impedance of this second stage. Q12 operates in a common-emitter configuration with a current-source load for maximum voltage gain. The capacitor  $C_M$  turns the gain stage into a Miller integrator. For good phase margin in the amplifier, the integrator must work well at the amplifier unity-gain frequency. Since Q10 and Q11 operate at fairly low currents, they generate significant phase shift that limits the accuracy of the integrator. To improve the frequency response of this stage, we add  $C_F$  and  $R_F$  to feed-forward the signal around Q10 and Q11.

The output stage buffers the second stage with emitter follower Q15 and a current-sink circuit. In order to sink output current and swing all the way to the negative supply, an NPN transistor, Q16, must drive the output. Q14's collector current is one tenth that of follower Q15's and is subtracted from Q13's emitter current. Then Q13's collector current is compared with current source I8; the excess drives Q16. When the current in Q15 drops, more current drives Q16 and the amplifier sinks current. Capacitor  $C_O$  stabilizes this feedback loop, which includes common-base transistor Q13. Because the gain of the

loop is quite large, Q15 never turns off and the open loop output impedance stays low for overall amplifier stability.

First order, the overall DC gain of the op amp is the input stage transconductance times the current gain of Q10, Q11, Q12, and Q15, times the load resistor. The transconductance of the LT1211 first stage is 500nA/mV; the gain of the transistors is about 100 each; with a 500Ω load the calculated gain is twenty-five million (25V per μV). The actual gain is about 2.5 million, due to second-order effects like Early voltage. The IC layout is optimized to eliminate thermal feedback that would reduce gain. The layout also optimizes channel-to-channel separation, which is typically 100nV/V (140dB).

## Performance

Table 1 describes the typical AC performance of each of these amplifiers.

Table 2 summarizes the DC electrical performance of the low cost grades of these new amplifiers. The dual op amps also have selections for improved offset voltage and drift in the DIP packages.

## Applications

Instead of describing several known op amp circuits, I will now discuss some general applications. The LT1211 family of amplifiers are the optimum solution whenever a combination of speed and accuracy is needed on low supply voltage.

With multimedia becoming more important, the need for CD-quality audio amplifiers that operate on single +5V supplies is growing. The LT1211 can handle  $1V_{rms}$  at a non-inverting gain of one while operating on single +5V supply. The LT1211 delivers distortion-free signals over the full 20Hz-to-20kHz range; THD is less than 0.001% for all signals up to  $1V_{rms}$ . Referenced to 1V, the signal-to-noise ratio is over 110dB and the supply current is only 2.6mA for both stereo channels.

The LT1216 is an ideal op amp for precision anti-aliasing filters. The 20MHz gain bandwidth supports high-Q filters up to 1MHz and the high slew rate results in a power bandwidth of 2.5MHz at  $2.5V_{p-p}$ . The quad is a natural for state-variable filters where three or four op amps are needed for each pole pair. The low offset-voltage drift of these amplifiers ensures that self-calibrating systems are accurate between calibrations.

The LTC1196 is an 8-bit A-to-D converter that operates on a 3.3V supply with an external 2.5V reference. This converter is fast; it samples the

input at a 450kHz rate. The input range is from  $10mV \pm 5mV$  to  $2.5V \pm 5mV$ . The LT1211/LT1213/LT1215 output swing is guaranteed to be such that only code "0000 0000" is missing when the devices are operated on the same 3.3V single supply.

***The LT1211 Family  
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The LTC1282 is a 12-bit A-to-D converter with an internal reference that operates on a single 3.3V supply. The nominal input range is from 0V to 2.5V. Since the LT1211 can only swing to within 5mV of ground, the lowest nine codes cannot be used. This is not

too bad considering that there are 4085 codes that are OK. When using the LTC1289, (another 3.3V, 12-bit A-to-D converter) these codes can be recovered because an external reference is used. The external reference can be positioned a little above ground to shift the full 4096 codes into the output range of the LT1211.

### Summary

The LT1211 family brings a level of precision and speed to low voltage systems that was previously unavailable. Operation is guaranteed over the full military temperature range with single supplies as low as 2.5V. Input offset voltage, input bias current, open-loop gain, and CMRR are comparable with the best op amps available today. The three amplifiers span a seven-to-one range of slew rate with a four-to-one range of supply current. The open-loop output impedance is low and these amps settle to microvolts in fractions of a microsecond, making them ideal for data-acquisition systems. These amplifiers are available in small surface-mount packages, including for the first time the narrow SO16 for the quads.



**Table 1. Typical AC performance**

AC Parameters	LT1211/12	LT1213/14	LT1215/16
Slew rate, $V_S = \pm 15V$	7V/ $\mu s$	12V/ $\mu s$	50V/ $\mu s$
Slew rate, $V_S = +5V$	4V/ $\mu s$	8V/ $\mu s$	30V/ $\mu s$
Settling time, 2V to 0.01%	800ns	500ns	250ns
Settling time, 10V to 0.01%	2.2 $\mu s$	1.2 $\mu s$	480ns
Gain bandwidth product	14MHz	28MHz	23MHz
Unity gain cross frequency	7MHz	13MHz	12MHz
Phase margin	55°	45°	45°
Noise voltage, 0.1 to 10Hz	125nV $_{p-p}$	125nV $_{p-p}$	400nV $_{p-p}$
Spot noise voltage, 10Hz	12.5nV/ $\sqrt{Hz}$	10nV/ $\sqrt{Hz}$	15nV/ $\sqrt{Hz}$
Spot noise voltage, 1kHz	12nV/ $\sqrt{Hz}$	10nV/ $\sqrt{Hz}$	12.5nV/ $\sqrt{Hz}$

**Table 2. Guaranteed DC performance of low-cost grades**

DC Parameters	LT1211/12	LT1213/14	LT1215/16
Max offset voltage	275 $\mu V$	275 $\mu V$	450 $\mu V$
Max offset voltage drift	6 $\mu V/^{\circ}C$	6 $\mu V/^{\circ}C$	10 $\mu V/^{\circ}C$
Max input offset current	30nA	40nA	120nA
Max input bias current	125nA	200nA	600nA
Min input voltage range			
$V_S = 3.3V$	0V – 1.8V	0V – 1.8V	0V – 1.3V
$V_S = 5.0V$	0V – 3.5V	0V – 3.5V	0V – 3.0V
Min CMRR	86dB	86dB	86dB
Min output voltage swing			
$V_S = 3.3V$	0.01V – 2.5V	0.01V – 2.5V	0.01V – 2.5V
$V_S = 5.0V$	0.01V – 4.2V	0.01V – 4.2V	0.01V – 4.2V
Min open loop gain			
$V_S = 3.3V$ or $5.0V$	250V/mV	250V/mV	150V/mV
$V_S = \pm 15V$	1200V/mV	1200V/mV	1000V/mV
Min channel separation	128dB	128dB	130dB
Min output current	20mA	30mA	30mA
Max supply current per amp	1.8mA	3.8mA	6.6mA
Operating supply voltage	2.5V – 36V	2.5V – 36V	2.5V – 36V

# Five and Three Volt, 12-Bit ADC Performance Comparison

by William Rempfer

Four new sampling A/D converters from Linear Technology, the LTC1273, LTC1275, LTC1276 and LTC1282, stand out above the crowd. These new 5V and 3V 12-bit ADCs offer the best speed/power performance available today (see Figure 1). They also provide precision references, internally trimmed clocks, and fast sample-and-holds. With additional features such as single-supply operation and high-impedance analog inputs, they reduce system complexity and cost. This article will describe the new ADCs and discuss the performance and power trade-offs that should be considered in selecting a 5V or 3V A/D converter.

## Complete ADCs Provide Lowest Power, Highest Speed on Single or Dual Supplies

The LTC1273, LTC1275, LTC1276, and LTC1282 provide complete A/D solutions at previously impossible speed/power levels. As shown in Table 1, the LTC1273, LTC1275, and LTC1276 all have the same 300kHz maximum sampling rate and 75mW typical power dissipation. The LTC1273 digitizes 0-to-5V inputs from a single 5V rail. The LTC1275 and LTC1276 operate on  $\pm 5V$  rails and digitize  $\pm 2.5V$  and  $\pm 5V$  inputs, respectively.

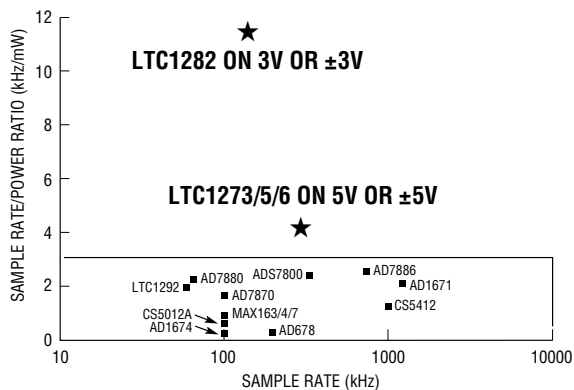


Figure 1. The LTC 1273/5/6 and the LTC1282 have up to 45 times higher speed/power ratios than competitive ADCs

Table 1. Four new complete ADCs offer high speed and low power on single or dual 5V or 3V supplies

Device	Power Supplies	Input Range	Sample Rate	S/(N + D) typ at $f_{\text{INPUT}}$	$P_{\text{DISS}}$ (typ)
LTC1273	+5V	0–5V	300kHz	70dB at 100kHz	75mW
LTC1275/6	$\pm 5V$	$\pm 2.5V/\pm 5V$	300kHz	70dB at 100kHz	75mW
LTC1282	+3V or $\pm 3V$	0–2.5V or $\pm 1.25V$	140kHz 140kHz	68dB at 70kHz	12mW

The LTC1282 samples at 140kHz and typically dissipates only 12mW from either 3V or  $\pm 3V$  supplies. It digitizes 0–2.5V inputs from a single 3V supply or  $\pm 1.25V$  inputs from  $\pm 3V$  supplies.

A complete ADC system is provided by the on-chip sample-and-holds, precision references, and internally trimmed clocks. The high-impedance analog inputs are easy to drive and can be multiplexed without buffer amplifiers. A single 5V or 3V power supply is all that is needed to digitize unipolar inputs. (Bipolar inputs require  $\pm 5V$  or  $\pm 3V$  supplies but the negative supply draws only microamperes of current). But most significant are the speed/power ratios, which are higher than those of any other ADC in this speed range.

## 5V ADCs Sample at 300kHz on 75mW of Power

The LTC1273, LTC1275, and LTC1276 have excellent DC specs, including  $\pm 1/2\text{LSB}$  linearity and 25ppm/ $^{\circ}\text{C}$  full-scale drift. In addition, they have excellent dynamic performance. As Figure 2 shows, the ADCs typically provide 72dB of Signal to Noise plus Distortion (11.7 effective bits) at the maximum sample rate of 300kHz. The S/(N + D) ratio is over 70dB (11.3 effective bits) for input frequencies up to 100kHz.

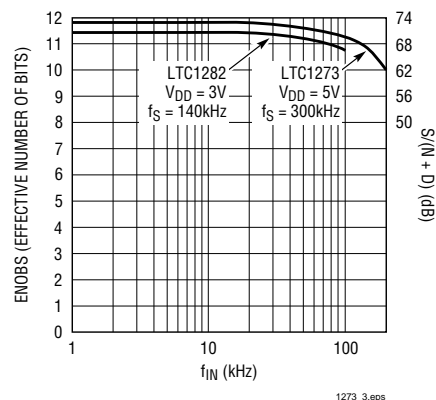


Figure 2. The 300kHz LTC1273 gives 70dB S/(N + D) with 100kHz inputs, the 140kHz LTC1282 gives 68dB at Nyquist

This 300kHz sample rate and dynamic performance comes at a power level that is more stingy than that of any other ADC in this speed range. Figure 1 shows a graph of speed/power ratios for the competitive ADCs. The speed/power ratio is defined as the maximum sample rate in kHz divided by the typical power dissipation



in mW. The 4.0kHz/mW of the LTC1273, LTC1275, and LTC1276 is better than the best competitive ADC.

Table 2 shows a competitive analysis of currently available ADCs. The LTC1273, LTC1275, and LTC1276 offer advantages over the rest in every area, including performance, function, and power.

### Even More Power Savings: 3V ADC Samples at 140kHz on 12mW

The low-power, 3V LTC1282 provides even more impressive speed/power performance. As fast and dynamically accurate as many power hungry, dual- and triple-supply ADCs, this complete 3V or  $\pm 3V$  sampling ADC provides extremely good performance on only 12mW of power. DC specs include  $\pm 1/2$ LSB maximum linearity and the internal reference provides 25ppm maximum full-scale drift. Figure 2 shows 11.4 effective bits at a 140kHz

sample rate with 11.0 effective bits at the Nyquist frequency of 70kHz. The speed/power ratio, as shown in Figure 1, is an outstanding 11.7kHz/mW.


The LTC1282 is ideal for 3V systems but will also find uses in 5V designs where the lowest possible power consumption is required. It interfaces easily to 3V logic but can also talk well to 5V systems. The LTC1282 can receive 5V CMOS levels directly and its 0-to-3V outputs can meet 5V TTL levels and connect directly to 5V systems.

### Performance Comparison

Table 3 compares the performance of the new ADCs to another recent, low-cost product, the AD1674. The 5V LTC1273 offers three times the speed at one fifth the power, and the 3V device goes even further. The table shows that using the 3V LTC1282 gives even greater savings in power than the LTC1273, with only modest reductions in speed, accuracy, and

noise. The power dissipation has been reduced six times with only a 50% reduction in speed. Linearity and drift don't degrade at all in going to the 3V device. The noise of the LTC1282 is slightly higher, due to the reduced input span and the lower operating current, but the converter still gives more than 70dB typical  $S/(N + D)$ . Compared to the AD1674, the LTC1282 offers 40% higher sampling rate and 30 times lower power.

### Conclusion

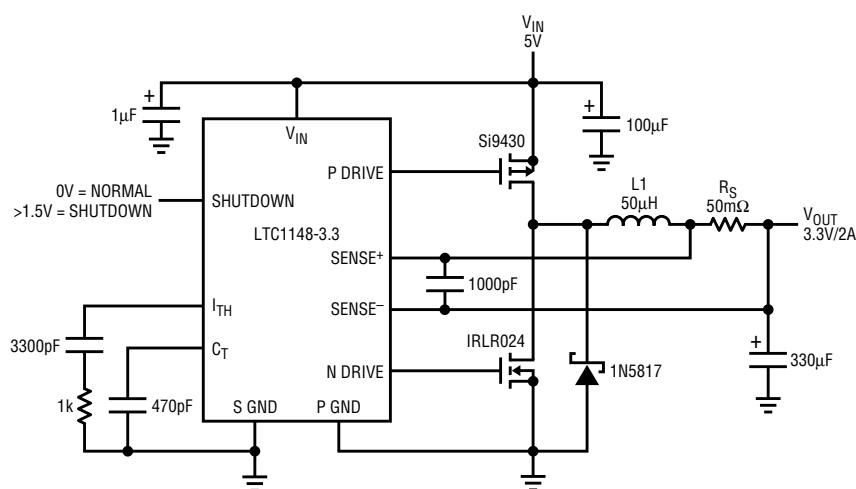
These new 5V and 3V ADCs offer the best speed/power performance available today. They also provide precision references, internally trimmed clocks, and fast sample-and-holds. With additional features such as single-supply operation and high-impedance analog inputs, they reduce system complexity and cost. For performance, power, and cost, these new ADCs must be considered for new designs. 

**Table 2. Competitive analysis of current ADCs**

	LTC1273/5	AD1674	AD7870/5/6	AD7800	AD678	ADS7880	MAX163/4/7
Internal reference	✓	✓	✓		✓	✓	✓
Internal clock (no crystal req'd)	✓	✓	✓	✓	✓	✓	
$S/(N + D)$ at $f_{IN}=100kHz$ (typ)	70dB	68dB	—	—	64dB	69dB	69dB
High-impedance analog input	✓			✓			✓
Unipolar and bipolar inputs	✓	✓					✓
$\geq 300kHz$ sample rate	✓					✓	
Single-supply operation	LTC1273			✓			
Low power (<150mW)	✓						
3V upgrade path	✓						

**Table 3. Performance comparison**

	LTC1273	LTC1282	AD1674
Parameter	on +5V	on +3V or $\pm 3V$	on +5V or $\pm 15V$
Power dissipation (typ)	75mW	12mW	385mW
Sample rate	300kHz	140kHz	100kHz
Conversion time (max)	2.7 $\mu s$	6 $\mu s$	10 $\mu s$
INL (max)	$\pm 1/2$ LSB	$\pm 1/2$ LSB	$\pm 1/2$ LSB
Typical ENOBs	11.7	11.4	11.5
Linear input bandwidth (ENOBs >11 bits)	125kHz	70kHz	100kHz



$R_S$  = SL-1R050J, KRL BANTRY (603) 668-3210  
 $L_1$  = CTX50-2-MP, COILTRONICS (305) 781-8900

**Figure 2. This LTC1148 5V-to-3V converter circuit achieves 94% efficiency at 1A output current**  
*Continued from page 1*

The LTC1148 5V to 3.3V converter shown in Figure 2 has 94% efficiency at 1A output. In other words, the LTC1148 dissipates only 200mW while delivering 3.3W to the load.

Table 1 gives an overview of the different members of the LTC1148/LTC1149 family and several of their applications. Each device has adjust-

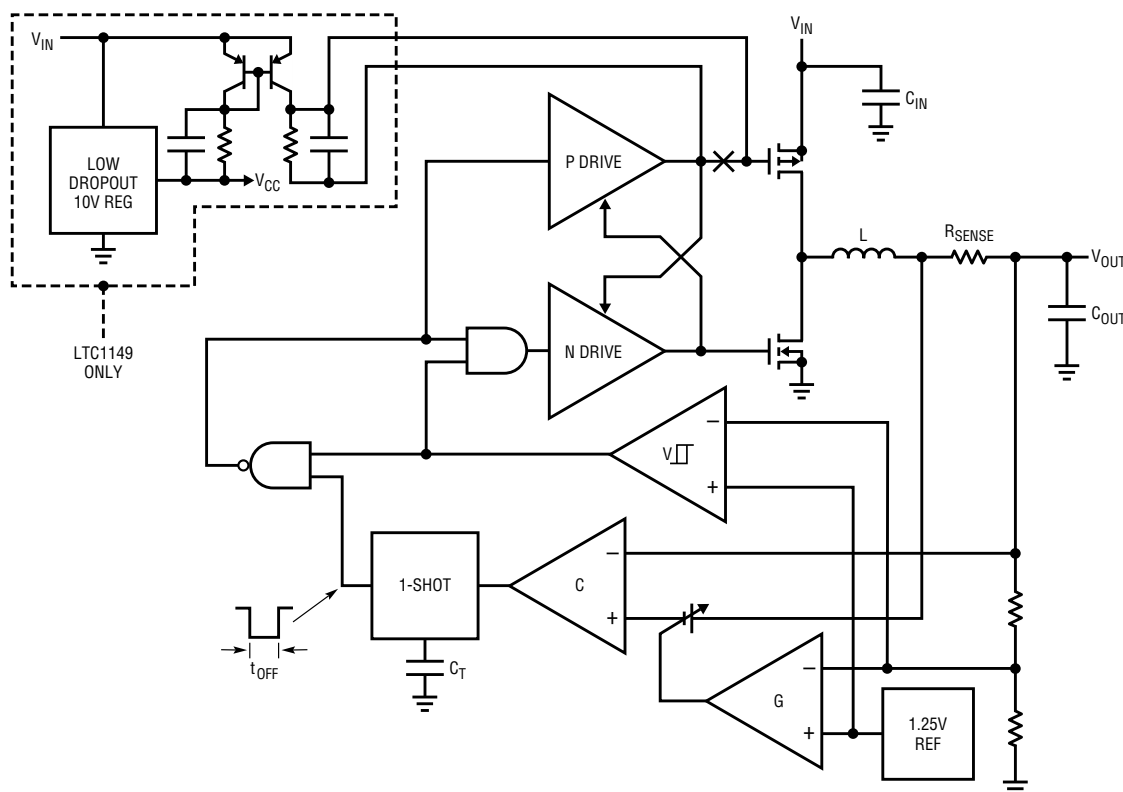
able, fixed 3.3V, and fixed 5V versions and is available in both DIP and SOIC (narrow) surface-mount packages.

### High Performance with High Efficiency

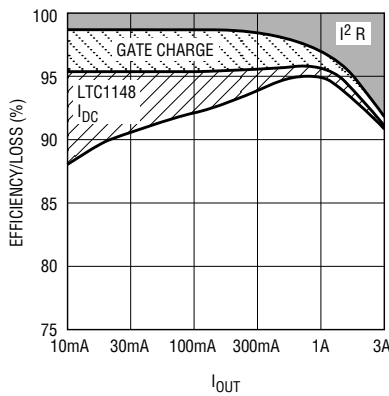
The LTC1148/LTC1149 synchronous switching regulator controllers use the constant off-time, current-

mode architecture shown in Figure 3. Current-mode operation was judged to be mandatory for its well known advantages of clean start-up, accurate current limit, and excellent line and load regulation. The constant off-time architecture adds to this list simplicity (neither an oscillator nor ramp compensation is required), inherent 100% duty cycle in dropout conditions, and constant inductor-ripple current. Because the off-time is constant, the operating frequency changes with input voltage. For example, in an LTC1149-5 application, the frequency will increase 50% when  $V_{IN}$  is doubled from 10V to 20V.

To maximize the operating efficiency over a wide current range, loss-reducing circuit techniques must be carefully applied. For example, synchronous switching (replacing the diode in a stepdown regulator with a switched transistor) may buy several percentage points in efficiency at high output currents, but will cost many more if allowed to continue at low output currents. This is the principal reason why the



**Figure 3. The LTC1148/LTC1149 architecture features constant-offtime current-mode operation, synchronous switching, and automatic transition to Burst Mode™ operation**



**Figure 4. Burst Mode™ operation limits gate charge and DC supply current at low output currents; synchronous switching limits losses at high output currents**

LTC1148 and LTC1149 change to Burst Mode™ operation as the output current drops.

The continuous mode operation is as follows: The external P-channel MOSFET switch is turned on at the end of the off-time and turned off when the inductor current has ramped up to the current-comparator threshold. During the off-time, the N-channel MOSFET synchronous switch is turned on to reduce the dissipation that would otherwise occur in the diode. At the end of the constant off-time, the P-channel MOSFET is again turned on and the cycle repeats. Adaptive anti-shoot-through circuitry prevents simultaneous conduction of the two MOSFETs regardless of their relative sizes, and gate resistors are neither required nor recommended.

### Burst Mode™ Operation—the Low-Current Efficiency Saver

The LTC1148/LTC1149 burst operating mode is automatically invoked when the current required by the load is less than the minimum current supplied by continuous operation. In Burst Mode™ operation the output voltage is regulated via a hysteretic comparator which, when tripped, shuts down both MOSFET drivers and much of the control circuitry to conserve DC supply current. From the time the comparator trips, until the lower comparator threshold is reached, the load current is supplied entirely by the charge stored

in the output capacitor. When the output capacitor discharges to the lower threshold, the main loop again turns on briefly at a low current level to recharge the capacitor. This cycle repeats at a progressively slower rate as the output current is reduced.

***The LTC1148/LTC1149 switching regulators not only beat both linear regulators and other switching regulators in efficiency, but also offer superior dropout performance***

Figure 4 shows how the efficiency in a typical LTC1148 regulator are apportioned as a result of the action of Burst Mode™ operation. The gate-charge loss deserves special attention, since it is responsible for much of the efficiency lost in the mid-current region. Each time a MOSFET gate is switched from low to high to low again, a packet of charge,  $dQ$ , moves from  $V_{IN}$  to ground. The resulting  $dQ/dt$  is a current out of  $V_{IN}$  that is typically much larger than the DC supply current. If Burst Mode™ operation was not employed at low output currents, the gate-charge loss alone would be enough to push efficiency down to unacceptable levels. With Burst Mode™ operation, the DC supply current represents the lone (and unavoidable) loss component, which continues to become a higher percentage as output current is reduced.

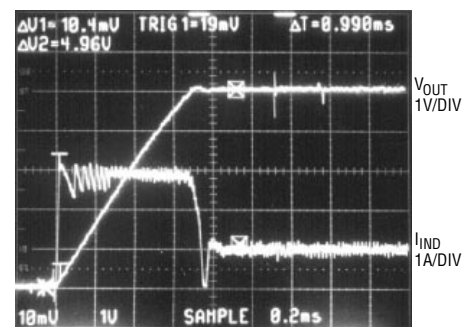
**Table 1. LTC1148/LTC1149 features**

	LTC1148	LTC1148-3.3	LTC1148-5	LTC1149	LTC1149-3.3	LTC1149-5
Continuous input voltage $\leq 48V$				✓	✓	✓
Continuous input voltage $\leq 12V$	✓	✓	✓			
Low dropout 5V			✓			✓
Adjustable/multiple output	✓			✓		
5V to 3.3V/ 4-cell to 3.3V		✓				

### Superb Start-up Manners

When starting a load from ground or recovering from a short circuit, the LTC1148 and LTC1149 offer superb control of inductor current, with no voltage overshoot when the regulated voltage is reached. This is accomplished by making the off-time proportional to the output voltage as the output capacitor charges. When  $V_{OUT} = 0$ , the off-time is lengthened to retain tight control of the peak inductor current at the very low duty cycles required. As the output voltage increases, the off-time is progressively shortened until it reaches the normal operating point. The result is the typical start-up behavior shown in Figure 5.

Line regulation can be just as vital as load regulation in battery-operated systems. This is because plugging in a wall adapter often increases the regulator input voltage to over double the battery voltage. The LTC1148/LTC1149 can handle these large steps with no effect on the output voltage.



**Figure 5. When starting up, the LTC1149/LTC1149 supply a constant current until the regulated voltage is reached. Note the lack of overshoot**

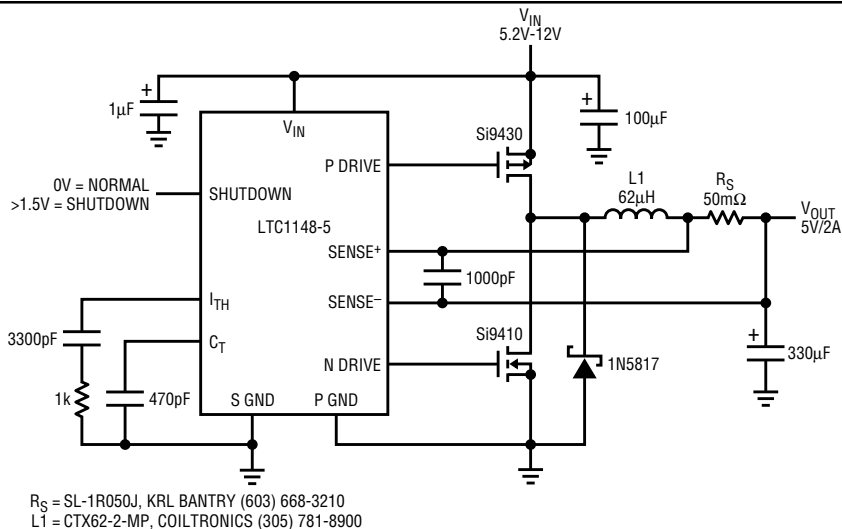
## Very Low Dropout Operation

The LTC1148/LTC1149 switching regulators not only beat both linear regulators and other switching regulators in efficiency, but also offer superior dropout performance. As the input voltage on the LTC1148 or LTC1149 drops, the loop extends the on-time for the switch (remember, the off-time is constant), thereby keeping the inductor ripple current constant. When  $V_{IN} - V_{OUT}$  drops below approximately 1.5V,  $t_{OFF}$  is reduced to compensate for the decreasing frequency. Ultimately, the LTC1148 and LTC1149 regulators drop out smoothly, with the P-channel MOSFET switch turning on at 100% duty cycle or DC.

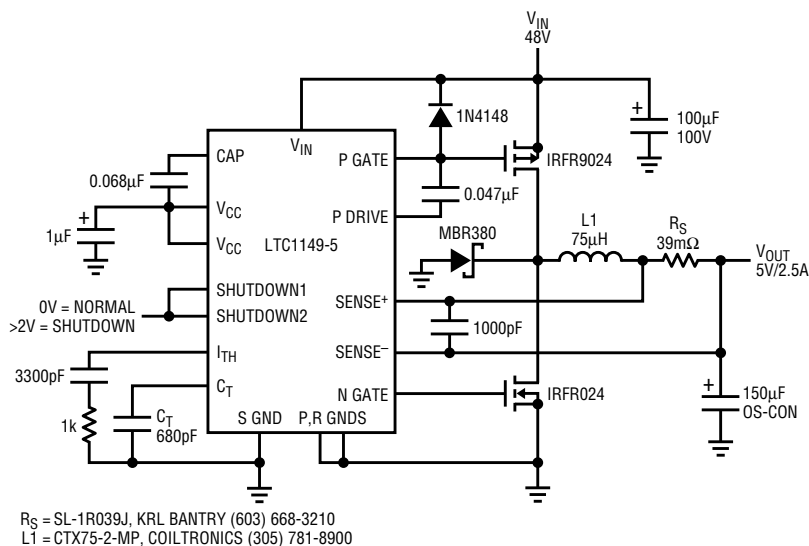
With the switch turned on at a 100% duty cycle, the dropout voltage is limited only by the load current multiplied by the total DC resistance of the MOSFET, the inductor, and the current-sense resistor. For example, the low dropout 5V regulator shown in Figure 6 has a total resistance in dropout of less than 200m $\Omega$ . This gives it a dropout voltage of less than 200mV at 1A output current. Furthermore, when the regulator is in a dropout condition, the ground current is limited to the DC supply current (1.5mA for the LTC1148 and 2.5mA for the LTC1149) independent of load current.

## High Voltage Capability

The LTC1149 versions offer an operating-voltage capability far higher than those found in other BiCMOS-based technologies. This is because the LTC1149 is actually a hybrid of a BiCMOS controller chip and a 60V bipolar companion chip that adds the low dropout regulator and P-channel drive level-shift circuits shown in Figure 3. The resulting combination, available in a narrow 16-lead SOIC package, extends LTC1148-like performance to input voltages as high as 48V (60V absolute maximum). This allows the LTC1149 to be used in such applications as automotive and distributed power, as well as portable equipment operating off high-voltage AC adapters.



**Figure 6. The LTC1148/LTC1149 architecture provides 100% duty cycle, allowing very low dropout operation. This LTC1148-5 circuit supports a 1A load with the input voltage only 200mV above the output**




**Figure 7. The LTC1149 extends high efficiency operation to high input voltages. This DC-to-DC converter achieves 87% efficiency in dropping 48V to 5V**

A 48V to 5V DC-to-DC converter that achieves 87% efficiency at 1A load current is shown in Figure 7. In this application the synchronous switch plays a vital role, since the P-channel switch duty cycle is only a little more than 10%, meaning that the N-channel synchronous switch conducts nearly 90% of the time in continuous mode. Fortunately, low  $R_{DS(ON)}$  N-channel MOSFETs that reduce losses to the point that heat sinking is not required, even during continuous short-circuit operation, are readily available. The small Schottky diode shown across the N-channel MOSFET conducts only in

the dead-time between the conduction of the two power MOSFETs and provides the highest possible operating efficiency in continuous mode.

## Conclusion

The LTC1148/LTC1149 family of synchronous, stepdown switching regulators offers breakthroughs in the areas of low-current operating efficiency, high-current operating efficiency, very low dropout, and wide input voltage compliance. This performance will be vital to extending battery life in the next generation of portable electronics. 

# A Simple, Efficient Laser Power Supply

by Jim Williams

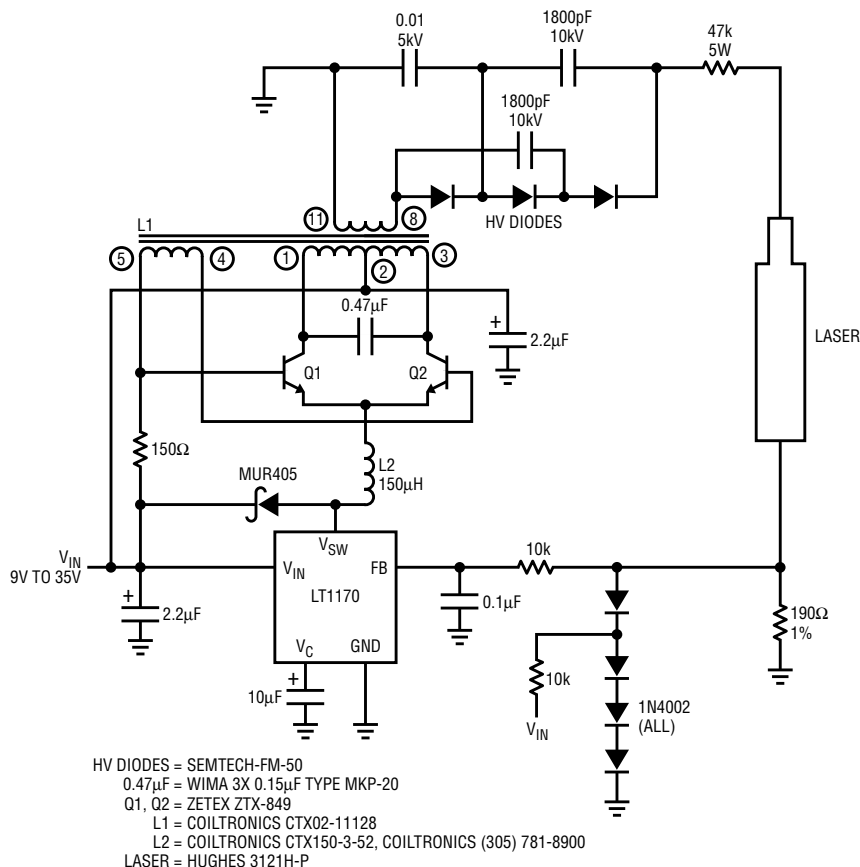
Helium-neon lasers, used for a variety of tasks, are difficult loads for a power supply. They typically need almost 10 kilovolts to start conduction although they require about 1500 volts to maintain conduction at their specified operating currents. Powering a laser usually involves some form of start-up circuitry to generate the initial breakdown voltage and a separate supply for sustaining conduction. Figure 1's circuit considerably simplifies driving the laser. The start-up and sustaining functions have been combined into a single, closed-loop current source with over 10 kilovolts of compliance. When power is applied, the laser does not conduct and the voltage across the 190 $\Omega$  resistor is zero. The LT1170 switching regulator FB pin sees no feedback voltage, and its switch pin

(V<sub>SW</sub>) provides full duty cycle pulse-width modulation to L2. Current flows from L1's center tap through Q1 and Q2 into L2 and the LT1170. This current flow causes Q1 and Q2 to switch, alternately driving L1. The 0.47μF capacitor resonates with L1, providing a boosted, sine-wave drive. L1 provides substantial step-up, causing about 3500 volts to appear at its secondary. The capacitors and diodes associated with L1's secondary form a voltage tripler, producing over 10 kilovolts across the laser. The laser breaks down and current begins to flow through it. The 47kΩ resistor limits current and isolates the laser's load characteristic. The current flow causes a voltage to appear across the 190Ω resistor. A filtered version of this voltage appears at the LT1170 FB pin, closing a control

loop. The LT1170 adjusts its pulse-width drive to L2 to maintain the FB pin at 1.23 volts, regardless of changes in operating conditions. Hence, the laser sees constant current drive, in this case 6.5mA. Other currents are obtainable by varying the 190 $\Omega$  value. The IN4002 diode string clamps excessive voltages when laser conduction first begins, protecting the LT1170. The 10 $\mu$ F capacitor at the V<sub>C</sub> pin frequency compensates the loop and the MUR405 maintains L1's current flow when the LT1170 V<sub>SW</sub> pin is not conducting. The circuit will start and run the laser over a 9–35 volt input range with an electrical efficiency of about 75%.  $\blacktriangle$

## References

1. Williams, Jim. "Illumination Circuitry for Liquid Crystal Displays" Linear Technology Application Note 49, August 1992.



**Figure 1. Laser power supply**

# Switching Regulator Provides $\pm 15V$ Output from an 8V – 40V Input, without a Transformer

by Brian Huffman

Many systems require that  $\pm 15V$  supplies for analog circuitry be derived from an input voltage that may be above or below the 15V output. The split-supply requirement is usually fulfilled by a switcher with a multiple-secondary transformer, or by multiple switchers. An alternative approach, shown in Figure 1, uses an LT1074 switching regulator IC, two inductors, and a "flying" capacitor to generate a dual-output supply that accepts a wide range of input voltages. This solution is particularly noteworthy because it uses only one switching regulator IC and does not require a transformer. Inductors are preferred over transformers because they are readily available and more economical.

The operating waveforms for the circuit are shown in Figure 2. During the switching cycle, the LT1074's  $V_{SW}$  pin swings between the input voltage ( $V_{IN}$ ) and the negative output voltage ( $-V_{OUT}$ ).

(The ability of the LT1074's  $V_{SW}$  pin to swing below ground is unusual—most other 5-pin buck switching regulator ICs cannot do this.) Trace A shows the waveform of the  $V_{SW}$  pin voltage, and Trace B is the current flowing through the power switch.

While the LT1074 power switch is on, current flows from the input voltage source through the switch, through capacitor C2 and inductor L1 (Trace C), and into the load. A portion of the switch current also flows into inductor L2 (Trace D). This current is used to recharge C2 and C4 during the switch-off time to a potential equal to the positive output voltage ( $+V_{OUT}$ ). The current waveforms for both inductors occur on top of a DC level. The waveforms are virtually identical because the inductors have identical values, and because the same voltage potentials are applied across them during the switching cycles.

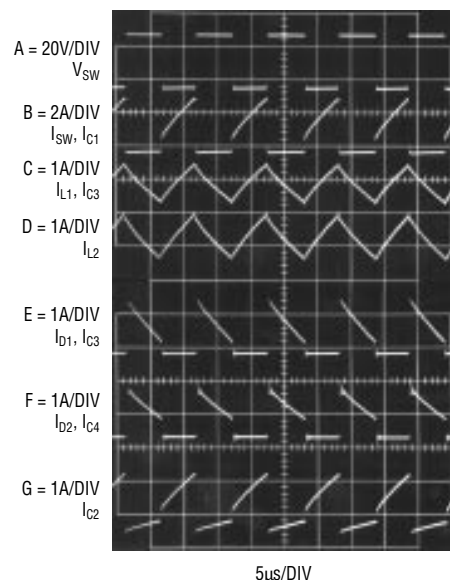


Figure 2. LT1074 switching waveforms

When the switch turns off, the current in L1 and L2 begins to ramp downward, causing the voltages across them to reverse polarity and forcing the voltage at the  $V_{SW}$  pin below ground. The  $V_{SW}$  pin voltage falls until diodes D1 (Trace E) and D2 (Trace F) are forward biased. During this interval, the voltage on the  $V_{SW}$  pin is equal to a diode drop below the negative output voltage ( $-V_{OUT}$ ). L2's current then circulates between both D1 and D2, charging C2 and C4. The energy stored in L1 is used to replace the energy lost by C2 and C4 during the switch-on time. Trace G is capacitor C2's current waveform. Capacitor C4's current waveform (Trace F) is the same as diode D2's current less the DC component. Assuming that the forward voltage drops of diodes D1 and D2 are equal, the negative output voltage ( $-V_{OUT}$ ) will be equal to the positive output voltage ( $+V_{OUT}$ ). After the switch turns on again, the cycle is repeated.

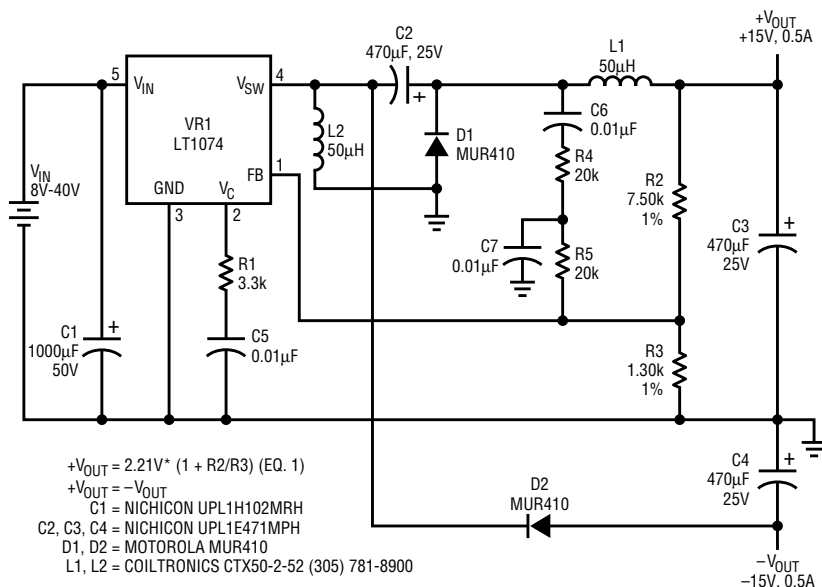


Figure 1. Schematic diagram for  $\pm 15V$  version


Figure 3 shows the excellent regulation of the negative output voltage for various output currents. The negative output voltage tracks the positive supply ( $+V_{OUT}$ ) within 200mV for load variations from 50mA to 500mA. Negative output load current should not exceed the positive output load by more than a factor of 4; the imbalance causes loop instabilities. For common load conditions the two output voltages track each other perfectly.

Another advantage of this circuit is that inductor L1 acts as both an energy storage element and as a smoothing filter for the positive output ( $+V_{OUT}$ ). The output ripple voltage has a triangular waveshape whose amplitude is determined by the inductor ripple current (see Trace C of Figure 2) and the ESR (Effective Series Resistance) of the output capacitor (C3). This type of ripple is usually small, so a post filter is not necessary.

Figure 4 shows the efficiency for a 0.5A common load at various input voltages. The two main loss elements are the output diodes (D1 and D2) and the LT1074 power switch. At low input voltages, the efficiency drops because the switch's saturation voltage becomes a higher percentage of the available input supply.

The output voltage is controlled by the LT1074 internal error amplifier. This error amplifier compares a fraction of the output voltage, via the R2-R3 divider network shown in Figure 1, with an internal 2.21V reference voltage and then varies the duty cycle until the two values are equal. The RC network (R1 and C5 in Figure 1) connected to the  $V_C$  pin along with the R4/R5 and C6/C7 network provides sufficient compensation to stabilize the control loop. Equation 1 can be used to determine the output voltage.

Figure 5 shows the circuit's -5V load-regulation characteristics, and Figure 6 shows its efficiency.

Refer to the schematic diagram in Figure 7 for modified component values to provide  $\pm 5V$  at 1 Amp. 

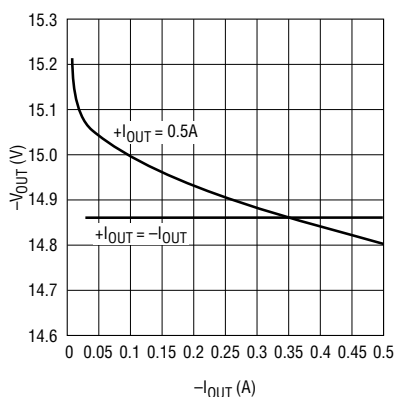


Figure 3. -15V output dropout characteristics

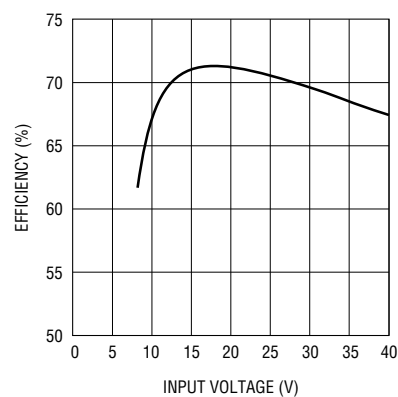


Figure 4.  $\pm 15V$  efficiency characteristics with 0.5V common load

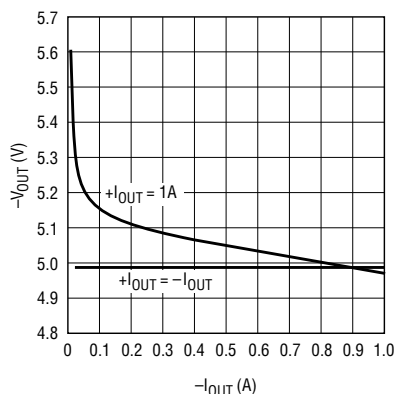


Figure 5. -5V output dropout characteristics

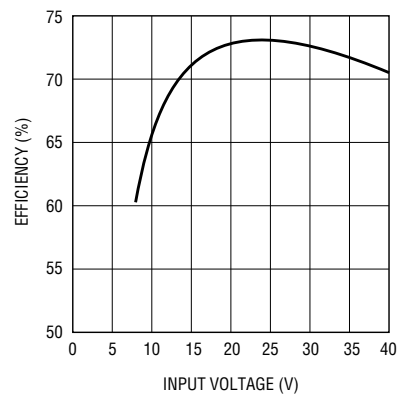


Figure 6.  $\pm 5V$  efficiency characteristics with 1A common load

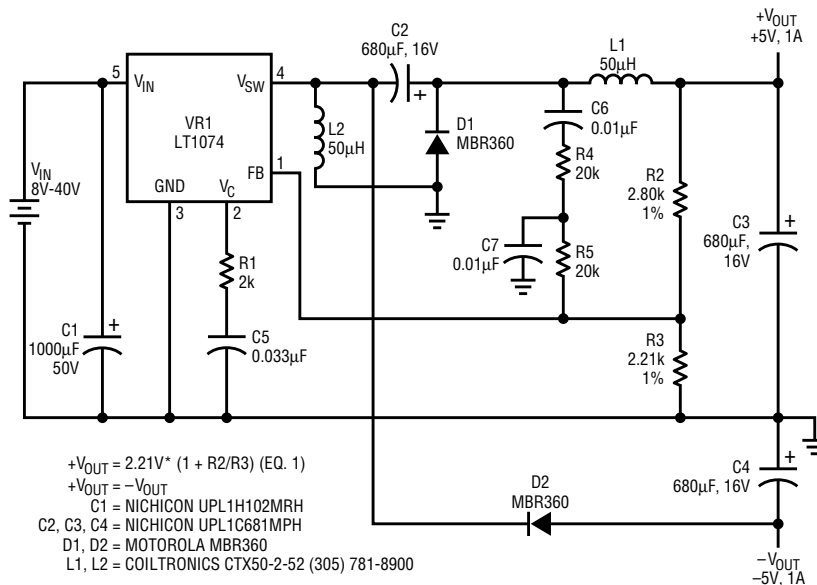


Figure 7. Schematic diagram for  $\pm 5V$  version

# A Twelve-Bit, Micropower Battery-Current Monitor

by Sammy Lum

## Introduction

The LTC1297 forms the core of the micropower battery-current monitor shown in Figure 1. This 12-bit data-acquisition system features an automatic power shutdown that is activated after each conversion. In shutdown the supply current is reduced to 6 $\mu$ A, typically. As shown in Figure 2, the average power-supply current of the LTC1297 varies from milliamperes to a few microamperes as the sampling frequency is reduced. This circuit draws only 190 $\mu$ A from a 6V to 12V battery when the sampling frequency is less than 10 samples per second. Wake-up time is limited by that required by the LTC1297 (5.5 $\mu$ s). For long periods of inactivity, the circuit's supply current can be further reduced to 20 $\mu$ A by using the shutdown feature on the LT1121. More wake-up time is required when using this mode of shutdown. It is usually determined by the amount of capacitance in the circuit

and the available charging current from the regulator.

## The Battery-Current Monitor

The battery voltage of 6V to 12V is regulated down to 5V by the LT1121 micropower regulator. A sense resistor of 0.05 $\Omega$  is placed in series with the battery to convert the battery current to a voltage. Full scale is designed for 2A, giving a resolution of 0.5mA with the 12-bit ADC. The LTC1047 amplifies the voltage across the sense resistor by 25 V/V. This goes through an RC lowpass filter before being fed into the input of the LTC1297. The RC filter serves two functions. First, it helps band-limit the input noise to the ADC. Second, the capacitor helps the LTC1047 recover from transients due to the switching input capacitor of the LTC1297. The LT1004 provides the full-scale reference for the ADC. A low battery detection circuit has been cre-

ated by using the other half of the LTC1047 as a comparator. Its trip point has been set to 5V plus the dropout voltage of the LT1121. Because data is transmitted serially to and from the microprocessor or microcontroller, this current-monitor circuit can be located close to the battery. ▀

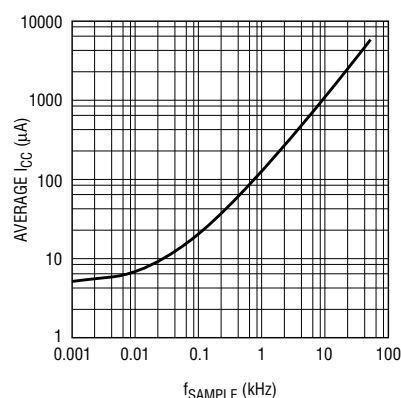


Figure 2. Power-supply current versus sampling frequency for the LTC1297

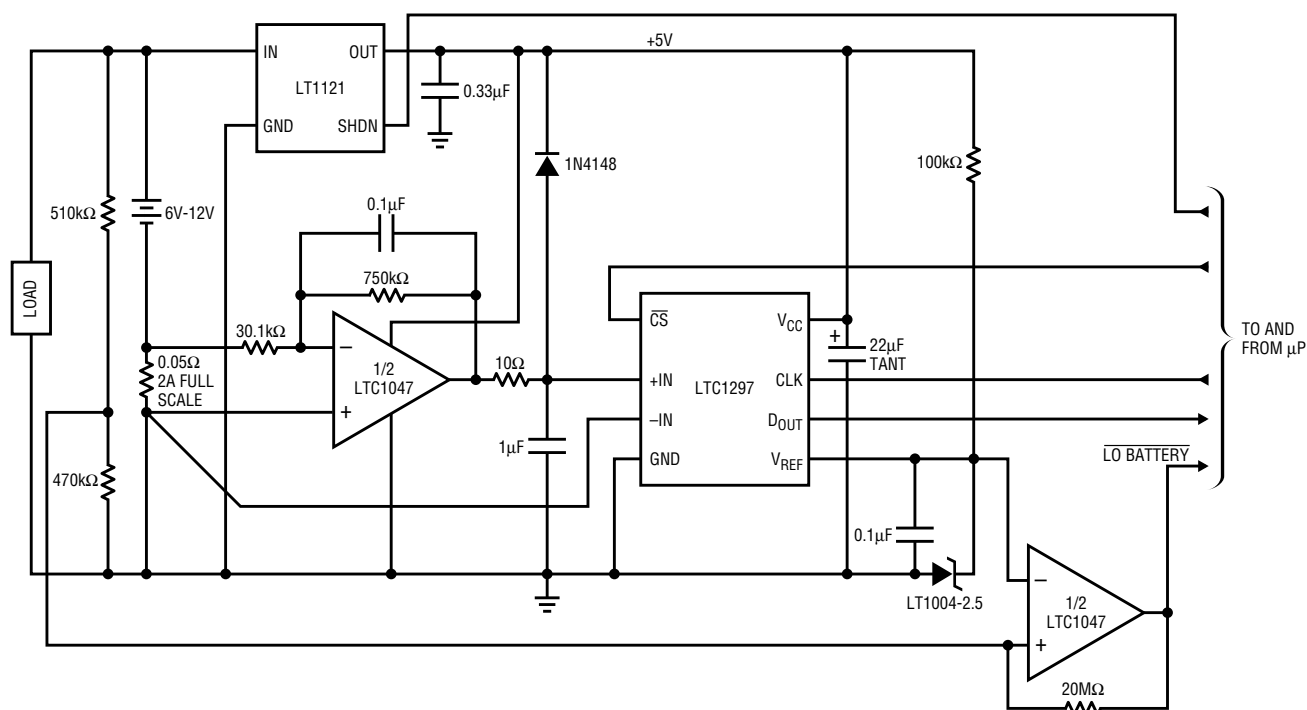


Figure 1. A micropower battery-current monitor using the LTC1297 12-bit data acquisition system



# 200mA Output, 1.5V-to-5V Converter

by Jim Williams

Some 1.5V powered systems, such as two-way survival radios, remote, transducer-fed data-acquisition systems, and the like, require much more power than stand-alone IC regulators can provide. Figure 1's design supplies a 5V output with 200mA capacity.

The circuit is essentially a flyback regulator. The LT1170 switching regulator's low saturation losses and ease of use permit high power operation and design simplicity. Unfortunately this device has a 3V minimum supply requirement. Bootstrapping its supply pin from the 5V output is possible, but requires some form of start-up mechanism. The 1.5V powered LT1073 switching regulator forms a start-up loop. When power is applied, the LT1073 starts, causing its  $V_{SW}$  pin to periodically pull current through L1. L1 responds with high-voltage flyback pulses. These pulses are rectified and

stored in the 500 $\mu$ F capacitor, producing the circuit's DC output. The output-divider string is set up so the LT1073 turns off when the circuit's output crosses about 4.5V. Under these conditions the LT1073 can no longer drive L1, but the LT1170 can. When the start-up circuit turns off, the LT1170  $V_{IN}$  pin has adequate supply voltage and it can operate. There is some overlap between start-up loop turn-off and LT1170 turn-on, but this has no detrimental effect. The start-up loop must function over a wide range of loads and battery voltages. Start-up currents are about 1 ampere, necessitating attention to the LT1073's saturation and drive characteristics. The worst case is a nearly depleted battery and heavy output loading. Figure 2 plots input/output characteristics for the circuit. Note that the circuit will start into all loads with  $V_{BATT} = 1.2V$ .

Start-up is possible down to 1.0V at reduced loads. Once the circuit has started, the plot shows it will drive full 200mA loads down to  $V_{BATT} = 0.6V$  (a very dead battery). Figure 3 graphs efficiency at two supply voltages over a range of output currents. Performance is attractive, although at lower currents circuit quiescent power degrades efficiency. Fixed junction saturation losses are responsible for lower overall efficiency at the lower supply voltage.

## References

1. Williams, Jim and Brian Huffman. "Some Thoughts on DC-DC converters", pages 13-17, "1.5V to 5V Converters." Linear Technology Corporation Application Note 29, October 1988.

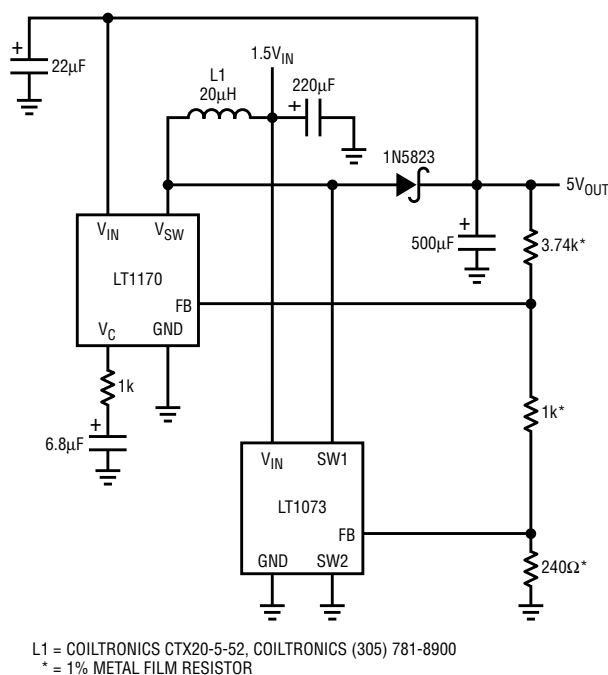


Figure 1. 200mA output, 1.5V-to-5V converter

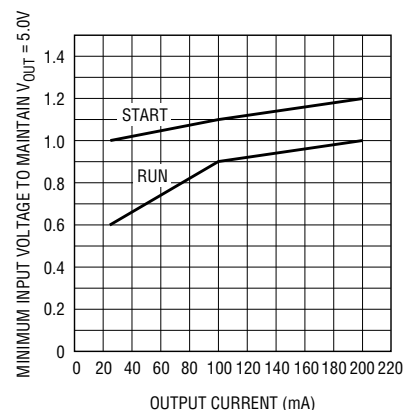


Figure 2. Input/output data for Figure 1

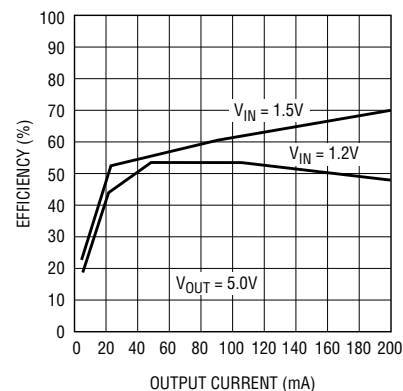


Figure 3. Efficiency versus operating point for Figure 1

# LT1158 H-Bridge uses Ground-Referenced Current Sensing for System Protection

by Peter Schwartz

The LT1158 half-bridge motor driver incorporates a number of powerful protection features. Some of these, such as its adaptive gate drive, are dedicated in function. Others are open to a variety of uses, depending upon application requirements. The circuit shown in Figure 1 takes advantage of the wide common-mode input range of the LT1158's FAULT comparator to perform ground-referenced current sensing in an H-bridge motor driver. By using ground-referenced sensing, protection can easily be provided against overloaded, stalled, or shorted motors. For overloads and stalls, the circuit becomes a constant-current chopper, regulating the motor's armature current to a preset maximum value. For shorted loads, the circuit protects itself by operating at a very low duty cycle until the short is cleared.

## Setting Up For Ground-Referenced Sensing

The circuit of Figure 1 is essentially a straightforward LT1158 H-bridge, of the "sign/magnitude" type. (See the LT1158 data sheet for a description of component functions.) In many LT1158 applications, a current-sense resistor is placed in each upper MOSFET source lead. This circuit, however, senses the IR drop across one resistor (R1) common to the sources of both lower MOSFETs. In Figure 1, U1's FAULT output activates the constant-current protection mode (for overloads and stalls), and U2's FAULT output indicates a shorted load. Hence, given a maximum continuous motor current of 15A, R1's value is easily determined:  $V_{SENSE(+)}$  of U1 must exceed  $V_{SENSE(-)}$  by the LT1158's internal threshold of 110mV in order for FAULT to go low.  $15A \times R1 = 0.110V$ , so  $R1 = (0.110V/15A) \cong 7.5m\Omega$ . The FAULT pin

of U2 should go low when  $I_{R1}$  is 24A, so a 1.6:1 voltage divider is added at U2's SENSE(+) input. R2, R3, C1, and C2 filter any switching spikes which appear across R1.

## Closing the Loop on Overloads

If the motor is overloaded or stalled, its back EMF will drop, causing the armature current to increase at a rate determined primarily by the motor's inductance. Without protection, this current could rise to a value limited only by supply voltage and circuit resistance. The necessary protection is provided via the feedback loop formed by U1's FAULT output, U3A, U4B, and U4D. When  $I_{R1}$  exceeds 15A, the FAULT pin of U1 conducts, triggering the 40 $\mu$ s monostable U3A. The "Q" output of U3A in turn forces the outputs of U4B and U4D to a logic low state, turning off Q1 or Q3, and turning on both Q2 and Q4. For the time during which U3A's "Q" output is high, the motor current decays through the path formed by the motor's resistance, plus the "on" resistance of Q2 and Q4 in series. In this application, turning both lower MOSFETs on is preferable to forcing all four MOSFETs off, as it provides a low-resistance recirculation path for the motor current. This reduces motor and supply ripple currents, as well as MOSFET dissipation. At the end of U3A's 40 $\mu$ s timeout, the H-bridge turns on again. If the overload still exists, the current quickly builds up to the U1 "FAULT" trip point again, and the 40ms timeout repeats. This feedback loop holds the motor current approximately constant at 15A for any combination of supply voltage and duty cycle that would otherwise cause an excess current condition. When the motor's current draw falls below 15A, the circuit resumes normal operation.

## Opening the Loop on Shorts

In the event of a short across the motor terminals, the current through the H-bridge rises faster than the U1/U3A loop can regulate it. This could easily exceed the safe operating area limits of the MOSFETs. The solution is simple: when the FAULT comparator of U2 detects that  $I_{R1} \geq 24A$ , monostable U3B is triggered. The "Q" output of U3B will then hold the ENABLE line of the two LT1158s "low" for 10ms, resulting in a rapid shutdown and a very low duty cycle. After the 10ms shutdown interval, U3B's "Q" output will return high, and the bridge will be re-enabled. If the motor remains shorted, U3B is triggered again, causing another 10ms shutdown. When the short is cleared, circuit operation returns to that described above.

## A Final Note

As a class, sign/magnitude H-bridge systems are susceptible to MOSFET and/or motor damage if the motor velocity is accelerated rapidly, or the state of the DIRECTION line is switched while the motor is rotating. This is especially true if the motor/load system has high inertia. The circuit of Figure 1 is designed to provide protection under these conditions: the motor may be commanded to accelerate and to change direction with no precautions. For the case of deceleration, however, it's generally best to use a controlled velocity profile. If a specific application requires the ability to operate with no restrictions upon the rate of change of duty cycle, there are straightforward modifications to Figure 1 which allow this. Please contact the factory for more information. **LT**

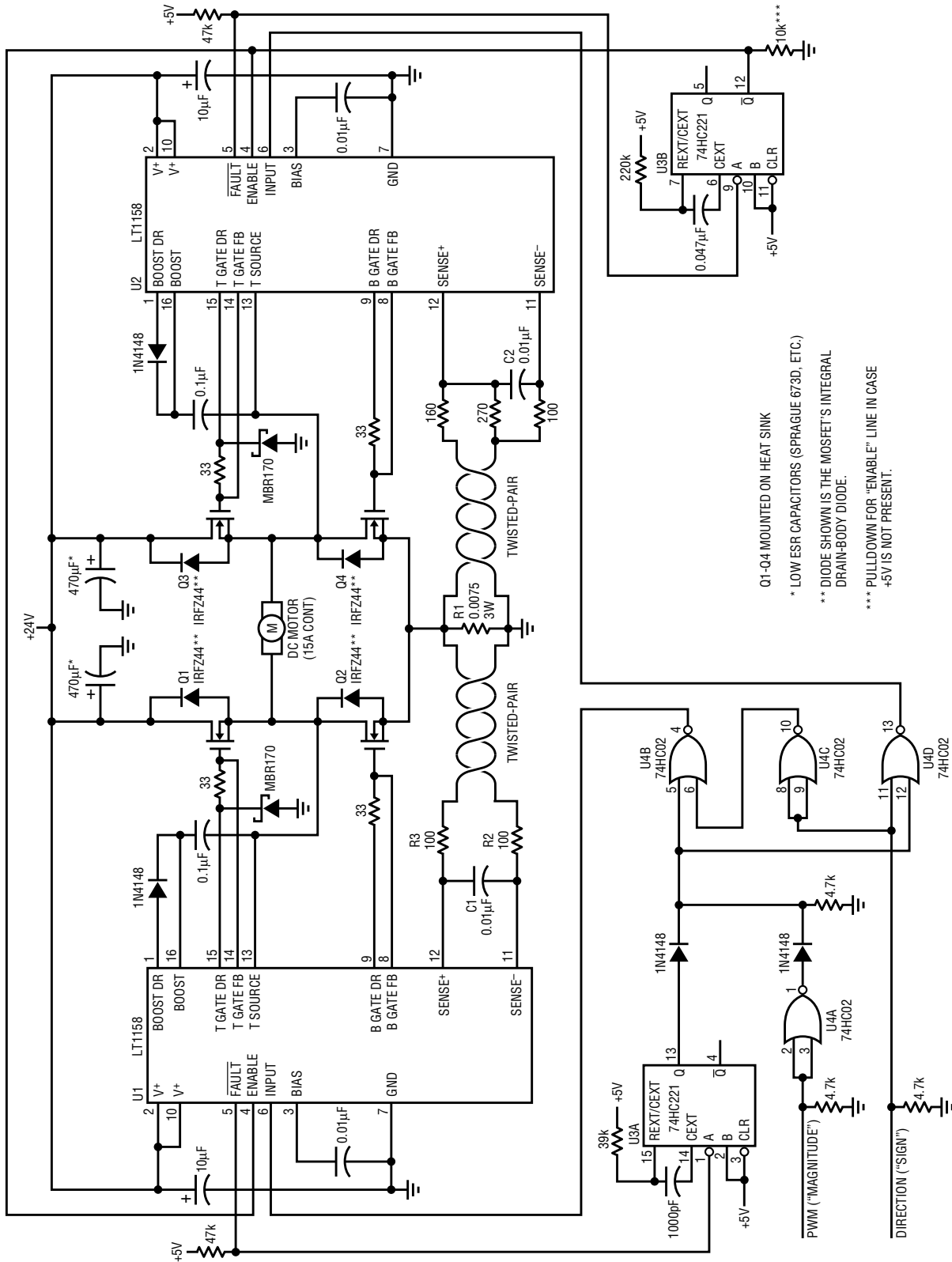


Figure 1. H-bridge motor driver with ground referenced current sensing

# Multi-Output Three-Watt Power Supply Operates from Two AA Cells

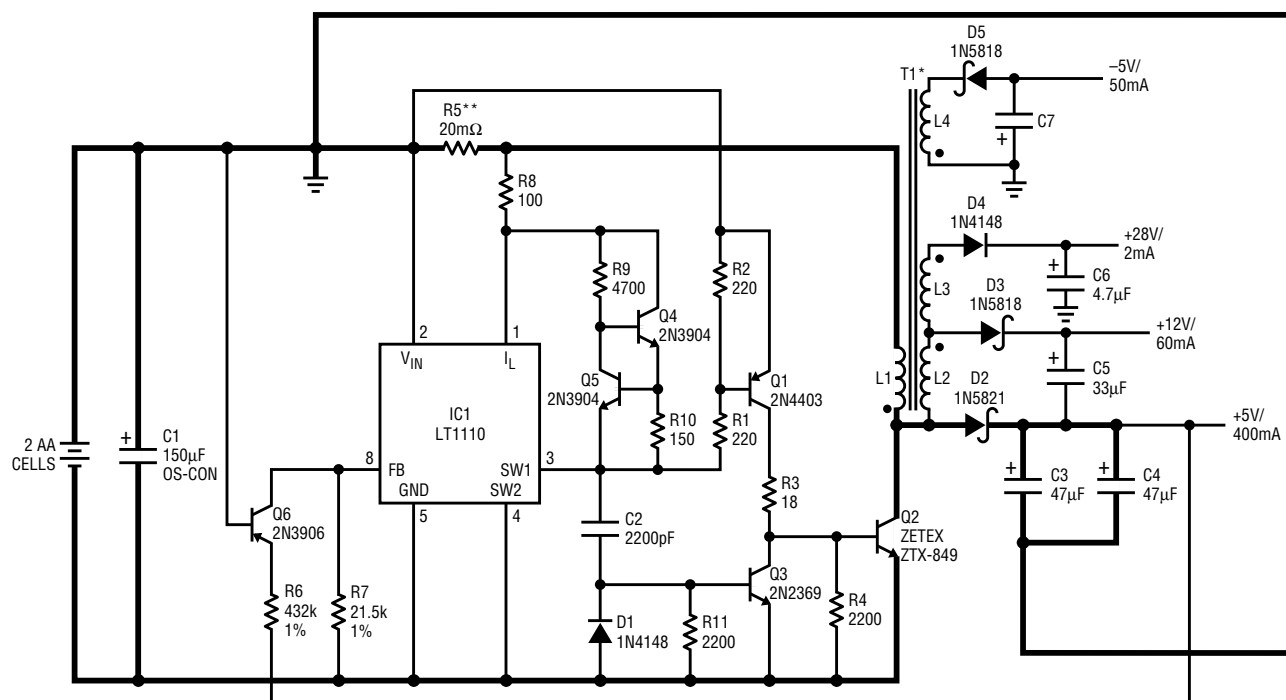
Steve Pietkiewicz

Portable, battery-operated microprocessor systems often have power supply requirements beyond what existing low-voltage IC switching regulators can deliver. Also, a multiplicity of voltages are usually required to supply sub-systems such as main logic, flash memory VPP supply, LCD contrast, and modem. Previous approaches to this problem used a separate DC-DC converter circuit for each output, increasing system cost and complexity. The approach described in this article combines the classic multi-output flyback topology with an LT1110 micropower, low-voltage DC-DC converter. The negative-to-positive topology provides for operation from a

1.8V to 7.5V input, a key provision for systems that must operate with either an AC adaptor or two AA cells. Micropower circuitry reduces quiescent current to 400 $\mu$ A no-load. The circuit can provide 5V at up to 400mA, 12V at 60mA, +28V at 2mA and -5V at 50mA from an input voltage as low as 2.0V.

The LT1110 micropower, Burst Mode™ DC-DC converter IC functions as the controller in the circuit (Figure 1). The LT1110 toggles its SW1 pin when the voltage at its FB pin drops below 220mV. The power device in the circuit is Q2, a Zetex ZTX-849. This remarkable device, which comes in a small TO-92-type package, can handle collector currents exceeding 6A with

guaranteed beta of 100. Saturation voltage of the device with a forced beta of 50 is 250mV at 5A  $I_C$ . Base drive for Q2 is provided by Q1, whose drive is supplied by the SW1 pin of the LT1110. Q2 is turned off by Q3, whose base is AC coupled to the SW1 pin by the 2200pF capacitor. Q3, a 2N2369, is a very fast device; it pulls the base charge out of Q2 in 50ns. Q2 is kept off by the 2200 $\Omega$  base-emitter resistor R4. The primary winding of the transformer, L1, functions as the regulated (main) secondary winding during the flyback phase. The voltage across L1 is forced to 5V during this phase. Hence, other indirectly regulated voltages can be achieved by the use of secondary wind-



\*T1 = TDK EPC-15 CORE, PC40 MATERIAL, 6 MIL GAP OR  
FERROXCUBE EFD 15 CORE, 3C85 MATERIAL, 6 MIL GAP  
L1 = 6T #20  
L2 = 7T #32  
L3 = 16T #38  
L4 = 6T #34

\*\*R5 = DALE LVR-3

C1, C3, C4, C5 = SANYO OS-CON

ZETEX: (516) 543-7100

— = HEAVY, HIGH CURRENT TRACES

Figure 1. Multi-output power supply delivers +5V at 400mA, +12V at 60mA, -5V at 50mA and +28V at 2mA from 2AA cells

ings with appropriate turns ratios. The 12V output does not possess 5% regulation from zero to full load, but a micropower, linear, low-dropout regulator such as the LT1121 can be used to achieve the desired voltage regulation. Negative outputs can be generated merely by reversing the phasing of additional secondary windings, as is done with L4 to obtain -5V output. Feedback is accomplished by the level-shift network comprising Q6 and R6. Q6's collector is fed into R7, closing the loop.

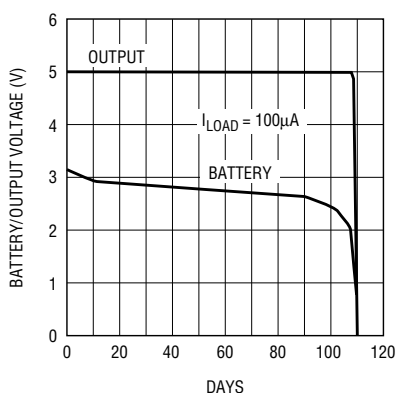
Switch-current sensing and control is essential when throwing lots of amperes around. Variations in  $V_{IN}$  and  $t_{ON}$  due to manufacturing spread can result in large peak current changes if sensing and control are not implemented. Many Burst Mode™ regulators contain no provision for current sensing, but the LT1110 is an

exception. The LT1110 switch will turn off when the voltage at the  $I_L$  pin reaches 600mV less than the voltage at the  $V_{IN}$  pin. A 600mV shunt would reduce system efficiency severely in a 2.0V input converter, so a pre-bias voltage drop is developed by current source Q4-Q5 flowing through resistor R8. Approximately 480mV is developed across R8, reducing the drop across sense resistor R5 to 120mV. This voltage drop represents 6% of the 2V input, causing some loss of efficiency, but the current sense function allows operation with inputs as high as 7.5V.

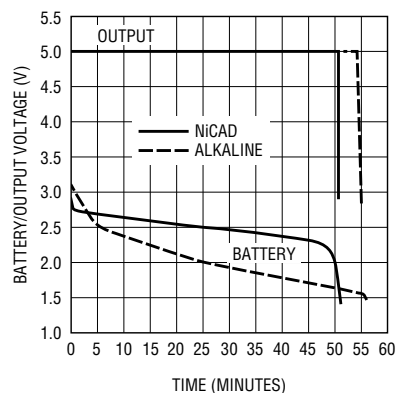
Bypass capacitor C1 should be placed close to the DC-DC converter circuitry. The low-ESR OS-CON type should be used. An inexpensive, high-ESR unit can result in poor efficiency. The main 5V output capacitors should also be OS-CON types. The peak cur-

rent into these units is over 4A. Skimping on output capacitors can result in costly field failures. High peak currents also necessitate careful printed-circuit layout. The high-current paths (highlighted in Figure 1) should be made extra-wide and as short as possible.

Efficiency for the circuit is approximately 70% over an input range of 2 to 3.2V and .5W to 2W total output power. The circuit will supply a 5V, 100μA "sleep" mode load for over 3 months from a pair of alkaline AA cells (Figure 2). A 5V, 1mA load lasts 28 days with alkalines. However, NiCad cells are recommended for the power source, as the relatively high internal impedance of the alkaline cells deliver only 8% more operating time than a pair of 600mAh NiCad cells when delivering 5V at 200mA load, as detailed in Figure 3. **LT**



**Figure 2.** Sleep mode lifetime, 5V output, 100μA load current



**Figure 3.** Battery lifetime for  $I_{LOAD} = 200mA$

# LTC1157 Switch for 3.3V PC Card Power

by Tim Skovmand

Computers designed to accept PC cards—plug-in modules specified by the Personal Computer Memory Card International Association (PCMCIA)—have special hardware features to accommodate these pocket-sized cards. PCMCIA-compliant cards require power management electronics which conform to the height restrictions of the three standard configurations: 3.3mm, 5mm and 10.5mm. These height limitations dramatically reduce the available options for power management on the card itself. For example, high-efficiency switching regulators to convert the incoming 5V down to 3.3V for the on-card 3.3V logic require relatively large magnetics and filter capacitors, which are not always available in packaging thin enough to meet the tight height requirements.

One possible approach to the problem of supplying power to a 3.3V PC

card is to switch the input supply voltage from 5V to 3.3V after the card has been inserted and the attribute ROM has informed the computer of the card's voltage and current requirements. The switching regulator, housed in the computer, switches the power supplied to the connector from 5V to 3.3V.

A window comparator and ultra-low drop switch on the PC card, Q1 in Figure 1, closes after the supply voltage drops from 5V to 3.3V, ensuring that the sensitive 3.3V logic on the card is never powered by more than 3.6V or less than 2.4V. A second switch, Q2, is provided on the card to interrupt power to 3.3V loads that can be idled when not in use.

The built-in charge pumps in the LTC1157 drive the gates of the low  $R_{DS(ON)}$  N-channel MOSFETs to 8.7V when powered from a 3.3V supply.

(P-channels cannot be used at 3.3V because they do not have guaranteed  $R_{DS(ON)}$  with  $V_{GS} < 3.3V$ .) The LT1017 and the LTC1157 are both micropower and are supplied by a filter, R5 and C2, which holds the supply pins high long enough to ensure that the MOSFET gates are fully discharged immediately after the card is disconnected from the power supply. A large bleed resistor, R6, further ensures that the high-impedance gate of Q1 is not inadvertently charged-up when the card is removed or when it is stored.

All of the components shown in Figure 1 are available in thin, surface-mount packaging and occupy a very small amount of surface area. Further, the power dissipation is extremely low because the LTC1157 and LT1017 are micropower and the MOSFET switches are very low  $R_{DS(ON)}$ .

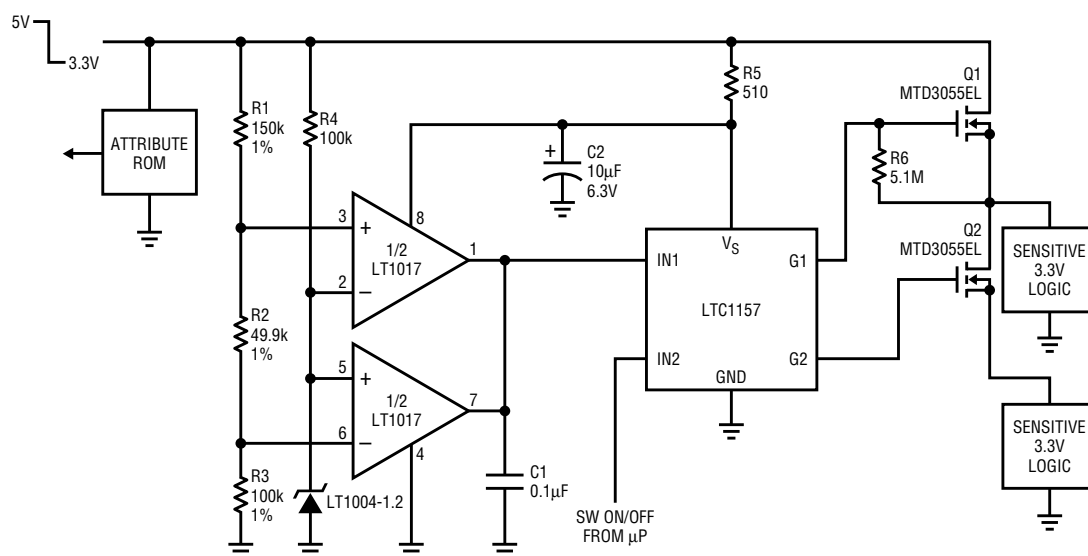


Figure 1. 3.3V PCMCIA card power switching

# New Device Cameos

## LT1116 12ns, Single-Supply, Ground-Sensing Comparator

The LT1116 is a high-speed (12ns) comparator capable of sensing signals down to ground while operating from a single +5V supply rail. The comparator can also operate from split  $\pm 5V$  supply rails, where the input common-mode range extends from 2 volts below the positive rail to the negative supply rail.

The LT1116 is pin-compatible with the industry standard LT1016. Like the LT1016, the LT1116 is stable through its output-transition region, which makes it easy to use over a wide range of operating conditions. The device's complementary output stages provide active drive in both directions for increased speed when driving TTL logic or passive loads. The LT1116 has a latch pin for synchronizing or retaining data. Latch setup and hold times are typically 2ns—commensurate with the device's propagation delay.

The LT1116's tight offset (1mV typical) and high gain specifications (3000V/V typical) make it an ideal choice for high-speed applications such as zero-crossing detectors, triggers, sampling circuits, A/D converters, current sensing for switching regulators, and line receivers for data communication. Linear Technology's Application Note 13 describes practical design techniques for high-speed comparators.

The LT1116 is available in 8-lead SOIC and 8-pin mini-DIP packages.

## The LTC1255 Dual, 24V High-Side MOSFET Driver

The LTC1255 dual, 24V high-side gate driver is designed to drive two standard N-channel power MOSFETs in a high-side switch configuration. The LTC1255 contains two independent, on-chip charge pumps so that less expensive, lower  $R_{DS(ON)}$  N-channel MOSFETs can be used in place of P-channel MOSFETs. The charge pumps require no external components and have been designed to be very efficient.

All of the circuitry to drive, control, and protect the power MOSFET and

load is provided by the LTC1255. The input is compatible with both TTL and CMOS logic families and the standby current with the input switched off is only 12 microamps from a 12V supply. The quiescent current rises to 240 microamps with the switch turned on and the charge pump producing 24V from a 12V supply.

The MOSFET and load are protected by a sense circuit that trips when an over-current condition is detected at the drain end of the power MOSFET. A built-in 10-microsecond delay ensures that the LTC1255 protection circuitry is not false-triggered by transient load or power supply conditions. A longer RC delay can be added externally to accommodate loads with large transient start-up current requirements, such as lamps or DC motors.

The 9–24V operating range of the LTC1255 makes it the ideal choice for many automotive and industrial applications, as well as 8–12 cell notebook-computer battery switching applications. The LTC1255 is available in both 8-lead SO and 8-lead DIP packaging and is rated over both the industrial and commercial operating temperature ranges.

## LT1331, LT1341, and LT1342 RS232 Transceivers

Three new RS232 transceivers expand LTC's line of interface circuits for PC-compatible applications. Each of these transceivers contains three drivers and five receivers to support the serial interface requirements of personal computers. All three feature  $\pm 10kV$  ESD protection on the RS232 line pins, operate to 120kbaud, and contain on-chip charge-pump circuitry to allow operation from standard logic power supplies. Pin-outs are compatible with the LT1137, and each transceiver has low-power SHUTDOWN and DRIVER DISABLE operating modes to allow optimization of system power consumption based upon signal requirements.

The LT1341 features one low-power receiver that remains active while the circuit is in SHUTDOWN mode. Drawing only 60 $\mu A$  of power, the keep-alive receiver may be used to monitor a data line to control system wake-up. This is especially useful in battery-operated systems.

The LT1342 matches LT1137A performance with the addition of 3V logic-interface capability. The circuit is ideal for systems with both 3V and 5V power supplies. Power consumption is 12mA from the 5V supply and 0.1mA from the 3V power supply. In SHUTDOWN, power consumption drops to near zero.

The LT1331 provides more flexible power management features for mixed 5V/3V systems, and delivers RS562 level outputs when used in 3V-only systems. Two power supply pins,  $V_{CC}$  and  $V_L$ , are used to power the circuit. Either may be used at 3V or 5V. The  $V_{CC}$  supply powers the charge pump and driver circuits and may be turned off in SHUTDOWN. With  $V_{CC} = 5V$ , full RS232 output levels are supported. With  $V_{CC} = 3.3V$ , outputs are at RS562 levels. The receivers are powered from supply  $V_L$ .  $V_L$  current drain is 3mA with all receivers active or 60 $\mu A$  in SHUTDOWN with one receiver active.

All three circuits are available in 28-pin DIP, SOIC, and SSOP packages.



**For further information on the above or any other devices mentioned in this issue of Linear Technology, use the reader service card or call the LTC literature-service number: (800) 637-5545. Ask for the pertinent data sheets and application notes.**

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This IBM-PC (or compatible) program allows the user to calculate circuit noise using LTC op amps, determine the best LTC op amp for a low noise application, display the noise data for LTC op amps, calculate resistor noise, and calculate noise using specs for any op amp. Available at no charge.

#### SPICE MACROMODEL DISK

This IBM-PC (or compatible) high density diskette contains the library of LTC op amp SPICE macromodels. The models can be used with any version of SPICE for general analog circuit simulations. The diskette also contains working circuit examples using the models, and a demonstration copy of PSPICE™ by MicroSim. Available at no charge.

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