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The New LT1425 Isolated Flyback Controller

by Kurk Matthews

Introduction

Low voltage circuitry, such as local area networks (LAN), isolation amplifiers and telephone interfaces, frequently requires isolated power supplies. The flyback converter is often the choice for these low power supplies because of its simplicity, size and low parts count. Unfortunately, designers are forced to add optocouplers and references in order to achieve the desired output regulation and transient response.

The new LT1425 provides a one-chip solution for these and other applications. The LT1425 is a 275kHz current mode controller with an integral 1.25A switch designed primarily to provide well regulated, isolated voltages from 3V–20V sources. The LT1425 is available in a 16-pin SO. Features include a new error amplifier and load compensation circuitry that eliminate the need for optocouplers while maintaining output regulation typically within a few percent.

Figure 1 shows a typical flyback LAN supply using the LT1425. Figure 1 also includes details on an alternate transformer for a complete PCMCIA type II height solution. The output voltage is within 1% of –9V for load currents of 0mA–250mA. Input current is limited to 0.35 amps in the event the output is short circuited. The output voltage droops only 300mV during a 50mA to 250mA load transient (see Figure 2). The off-the-shelf transformers provide $500V_{AC}$ of isolation. The high switching frequency allows the use of small case size, low cost, high value ceramic capacitors on the input and output of the supply.

Isolated Feedback

The heart of the LT1425 is shown in Figure 3. During S1's off-time, the voltage on the V_{SW} pin increases to $V_{IN} + (V_{OUT} + V_D)/n$, where *n* is the transformer turns ratio and V_D is the output diode voltage. Q1's collector current becomes $I_{CQ1} = (V_{OUT} + V_D)/(n \times R1)$. R2 converts I_{CQ1} into the input voltage for the transconductance feedback amplifier. C1 on the V_C pin then integrates the feedback amplifier's output current. The voltage on the V_C pin sets the current mode trip point.

Although we now have a means for generating a feedback voltage, a few problems remain. The feedback voltage is not present during S1's on-time or when the secondary current decays to zero, which is often the case with a discontinuous flyback. To make matters worse, T1's leakage inductance can cause large voltage spikes at turn-off.

These issues are taken care of by the error amplifier enable block, which incorporates enable-delay, collapse-detect and minimum-enable-time circuitry. Enable delay waits approximately 200ns after the switch turns off before enabling the feedback amplifier, thus avoiding the leakage-inductance spike. The collapse detect

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Issue Highlights

To mark the new year, we have a collection of exciting new parts from the design gurus at LTC. This issue's lead article features the new LT1425 isolated flyback converter, which provides a one-chip solution for low voltage circuitry, such as local area networks, isolation amplifiers and telephone interfaces. The LT1425 is a 275kHz current mode controller with an integral 1.25A switch, designed to provide well regulated, isolated voltages from 3V–20V sources.

Other power products featured in this issue include the LTC1474 and LTC1475 ultralow quiescent current, high efficiency step-down switching regulators. These regulators draw only 10µA at no load and require only four external components to make a complete, high efficiency (up to 92%) step-down regulator. Low component count and the parts' tiny MSOP packages provide a minimum-area solution to meet the limited space requirements of portable applications.

Another boon to the designers of portable, battery-powered equipment is the LTC1473 dual PowerPath switch driver, which simplifies the design of circuitry for switching between two batteries or a battery and an AC adapter. Presently, switching between power sources is implemented with discrete components—regulators, comparators, references, glue logic, MOSFET switches and drivers. These solutions are expensive and occupy a lot of printed circuit board space. The LTC1473 drives low loss N-channel MOSFET switches that direct power in the main power path of a single or dual rechargeable battery system, the type found in most notebook computers and other portable equipment.

In the filter department, this issue introduces the LTC1560-1, a high frequency, continuous-time, low noise filter. This device is a single-ended input and output, 5th order elliptic lowpass filter with a pin-selectable cutoff frequency of 1MHz or 500kHz. It requires no external components or clocks and provides better than 60dB of stopband attenuation and 75dB SNR, with only 0.3dB passband ripple.

In the data conversion area, we debut the LTC1594 and LTC1598, micropower 12-bit ADCs, which feature a 4- or 8-channel multiplexer, respectively. These devices include an auto shutdown feature that reduces power dissipation when the converter is inactive. Nominal power dissipation with the converter clocked at 320kHz is typically 1.6mW. Each ADC includes a simple, efficient serial interface that reduces interconnects and, thereby, possible noise sources. Reduced interconnections also reduce board size and allow the use of processors having fewer I/O pins, both of which help reduce system costs.

For data communications, this issue introduces the low cost LT1328 IrDA data receiver. This device contains all the necessary circuitry to convert current pulses from an external photodiode to a digital TTL output while rejecting unwanted lower frequency interference. The LT1328 plus six external components are all that is required to make an IrDA-compatible receiver. Power requirements for the LT1328 are minimal: a single 5V supply and 2mA of quiescent current.

This issue includes a varied selection of Design Ideas, including three power supplies, a battery charger that doubles as the main step-down converter, a voltage controlled limiter for video, a detector circuit for 470MHz signals, and an evaluation of battery life under a variety of load conditions.

Penultimately, we present Design Information on the LT2078/LT2079 and LT2178/LT2179, improved single-supply, precision surface mount op amps, and the LT1387 single 5V multiprotocol transceiver. We conclude with a selection of New Device Cameos.

LTC in the News...

Results of LTC's second fiscal quarter underscore the company's standing as an industry leader. Net sales for the second fiscal quarter of 1997, ended December 29, 1996, were $90,080,000. Although this was a decrease of 6% over net sales of $96,017,000 for the second quarter of the previous year, this actually represented phenomenally good performance, as we will see in just a moment.

LTC reported net income for the quarter of $31,631,000 or $0.40 per share, a decrease of 8% from the second quarter of the previous year. Sequentially, the results for the second quarter were essentially flat as compared to net sales and income for the quarter ended September 29, 1996 of $90,063,000 and $31,358,000 or $0.40 per share, respectively. A cash dividend of $0.05 will be paid on February 12, 1997 to shareholders of record on January 24, 1997.

According to Robert H. Swanson, president and CEO, "Although we entered the quarter with reduced backlog, we were able to achieve flat sequential sales and profits with our return on sales continuing to lead the industry. In addition, cash and short-term investments grew by approximately $20 million in the quarter. Customers' demand picked up moderately throughout the quarter and our shorter lead times enabled us to ship some of their demand within the quarter. We believe our market is improving and we are optimistic about the future."

It's becoming known around the nation's regional stock exchanges that LTC is a leading pace setter and vital indicator of the economic condition of the electronics industry. For many months, the Bloomberg Silicon Valley Index and the Dean Witter Silicon Valley Stock Index have included LTC's business performance in their assessment of the industry.

Now, the New York-based Reuters America News Service reports that the Philadelphia Stock Exchange has added two chip companies—one of which is LTC—and an equipment maker to its Semiconductor Index to replace three stocks the exchange has removed. Late last month, the exchange added Linear Technology Corp. (LLTC), Xilinx Inc. (XLNX.O) and Lam Research Corp. (LRCX.O). To us at LTC, this move is further proof that even in the realm of high finance, "it's a linear world."

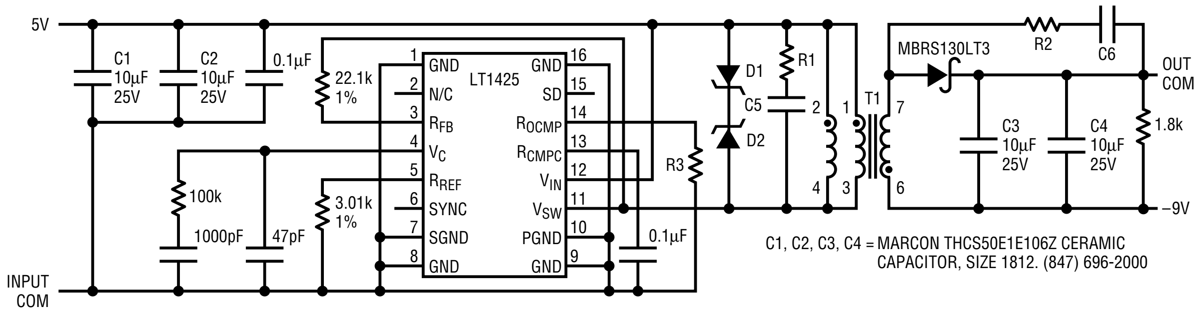
LT1425, continued from page 1

disables the feedback amplifier when the R_{REF} voltage falls below 80% of the 1.224V reference. This natural collapse of the feedback voltage occurs sometime during the off-time in the discontinuous flyback mode (see Figure 4, Trace C) or when the switch turns on in the continuous mode (see Trace A). Finally, a 200ns minimum enable time, which follows the enable delay time, ensures that the error amplifier can pump up the V_C node during start up and other conditions when V_{OUT} is low.

This unique feedback system produces controlled output voltages while maintaining fast dynamic response not found in similar isolated flyback schemes. 200ns of leading edge, current sense blanking is also included to reject turn-on spikes.

Load Compensation

If the world were a perfect place, with ideal transformers, diodes and capacitors, no additional compensation would be required to maintain perfect regulation. Unfortunately, as the load current increases, the additional voltage drop due to secondary winding resistance, the output diode and capacitor ESR results in decreased output voltage. To compensate for this change in output voltage, a current is generated in Q2 (see Figure 3), which is proportional to the average primary current. Since primary current changes with output load, the effects of nonideal components are minimized and regulation is possible over a wide load range. R3 determines the amount of load compensation. Connecting R_{CMPC} to ground defeats the load compensation.



TRANSFORMER T1

	L_{PRI}	TURNS RATIO	ISOLATION	SIZE (L × W × H)	I_{OUT}	EFFICIENCY	D1	D2	R1, R2	C5, C6	R3
DALE LPE-4841-A307	36µH	1:1:1	500VAC	10.7 × 11.5 × 6.3mm	250mA	76%	NOT USED	NOT USED	47Ω	330pF	13.3k
COILTRONICS CTX02-13483	27µH	1:1	500VAC	14 × 14 × 2.2mm	200mA	70%	1N5248	MBR0540TL1	75Ω	220pF	5.9k

Figure 1. 5V to –9V/250mA isolated LAN supply

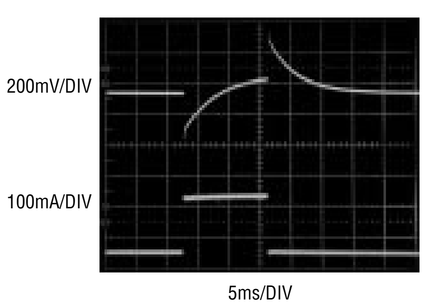


Figure 2. Transient response of LT1425 5V to –9V converter

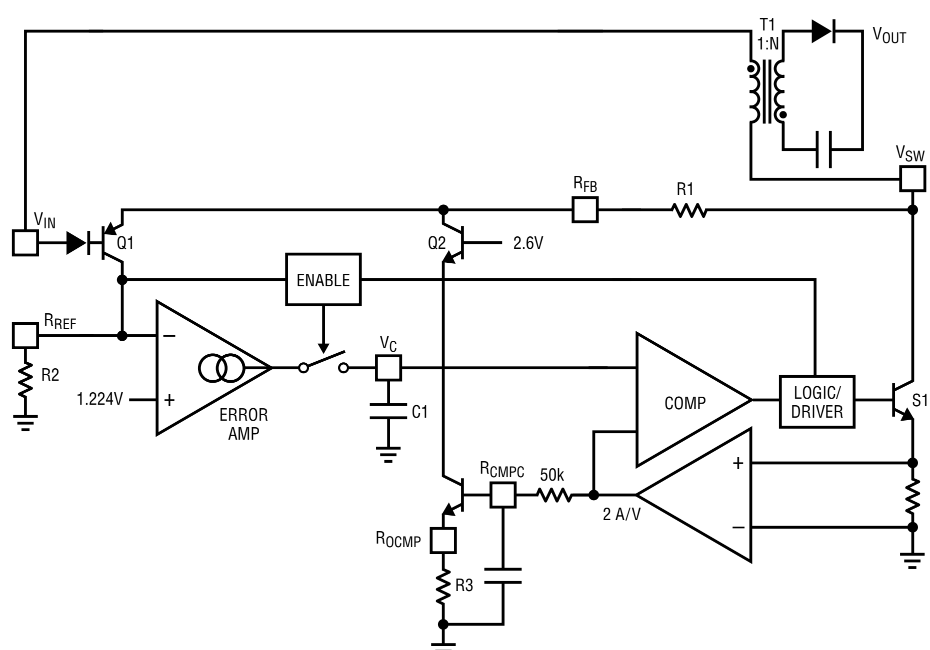


Figure 3. LT1425 isolated feedback block diagram

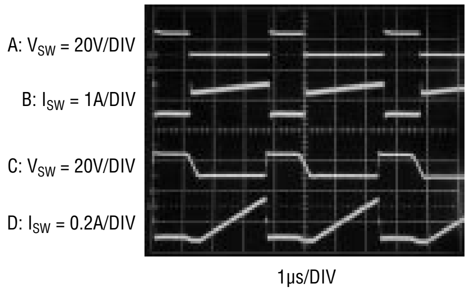


Figure 4. Switch voltage and current for Figure 1's circuit with outputs of –9V/250mA and –9V/30mA

The LT1424

The LT1424, devoted to fixed output voltage applications, is available in an 8-pin SO package. The LT1424 retains the features of the LT1425 and incorporates the feedback, reference and load compensation resistors. Figure 5 shows the LT1424 pinout. Both the LT1424 and LT1425 include shutdown and synchronization functions. Consult the factory for further information on the LT1424.

Typical Applications

Figure 6 shows a ±15V supply with 1.5kV of isolation. Output regulation remains within ±3% over the entire 5V to 15V input voltage and ±60mA output current range, even with one output fully loaded and the other unloaded (±1.5% with input voltages of 10V–15V). The isolation voltage is ultimately limited only by bobbin selection and transformer construction. The schematic shows details on building the transformer.

Figure 7 implements a 12V to 5V/1A step-down regulator with off-the-shelf magnetics. The circuit uses an external, cascoded 100V MOSFET to extend the LT1425's 35V maximum switch voltage limit. D1 and Q1 ensure the LT1425 does not start until almost 9V, guaranteeing adequate gate voltage for the MOSFET. The MUR120 prevents the source from rising above the gate at turn-off.

The circuit in Figure 8 achieves even higher input voltages, this time in the form of a –48V to 5V/2A isolated telecom supply. The input voltage is too high to directly run Q1 or the LT1425, so a bootstrap winding is used to provide feedback and power for the IC after start-up. The voltage to the V_{IN} pin is controlled by D1, D2, Q2, Q3 and associated components, which form the necessary start-up circuitry with hysteresis. Nothing happens until C1 charges through R1 to 15V. At that point, Q2 turns on Q3, pulling the shutdown pin high. Q3, in turn, latches Q2 on, setting the turn-off voltage to approximately 11V. Switching begins and, before C1 has a chance to discharge to 11V, the bootstrap winding begins to supply power. If the output is shorted, R2 prevents C1 from being charged by the transformer's leakage energy, causing the supply to continually attempt to restart. This limits input and output current during a short circuit. Feedback voltage is fed directly through a resistor divider to the R_{REF} pin. The sampling error amplifier still works, but the load compensation circuitry is bypassed. This results in a ±5% load regulation over line and load. A dedicated feedback winding referencing the feedback voltage to the V_{IN} pin could be used to include the load compensation function and improve regulation.

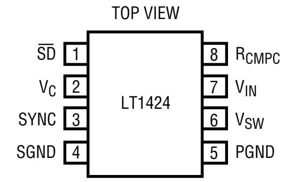


Figure 5. LT1424 pinout

Conclusion

The LT1425 offers high performance and accuracy without the additional circuitry traditionally associated with isolated DC to DC converters.

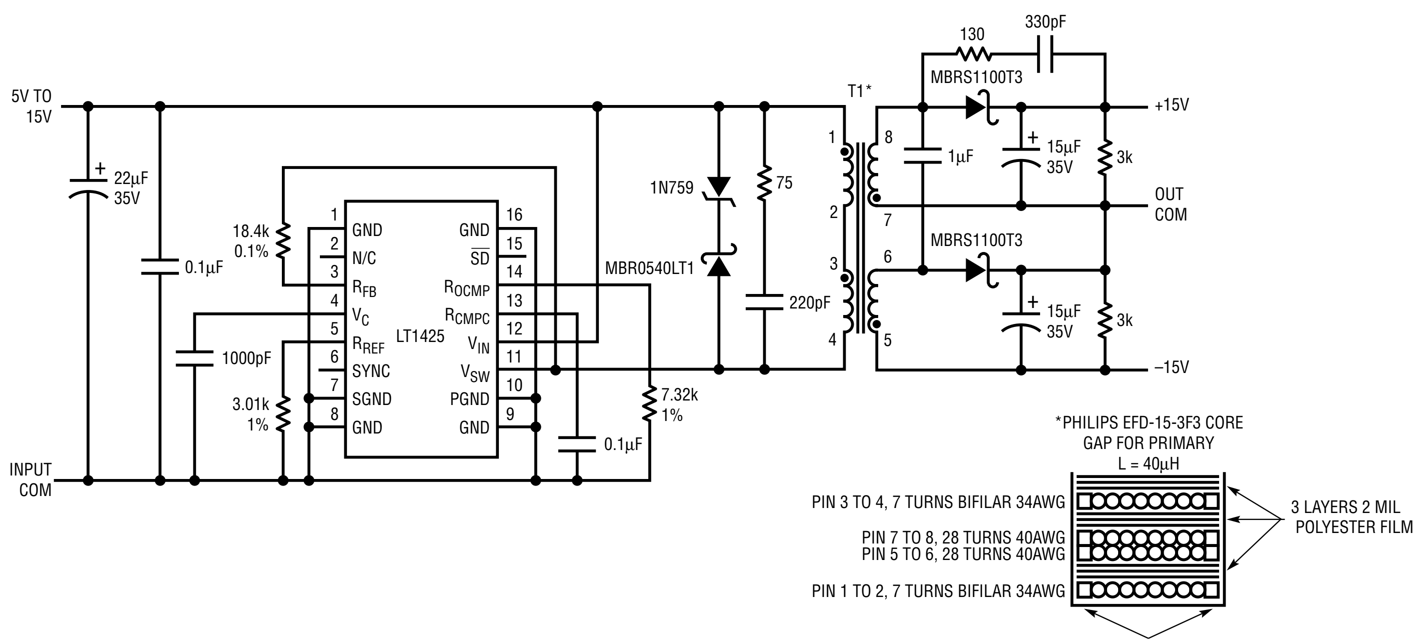


Figure 6. Fully isolated ±15V, ±60mA supply

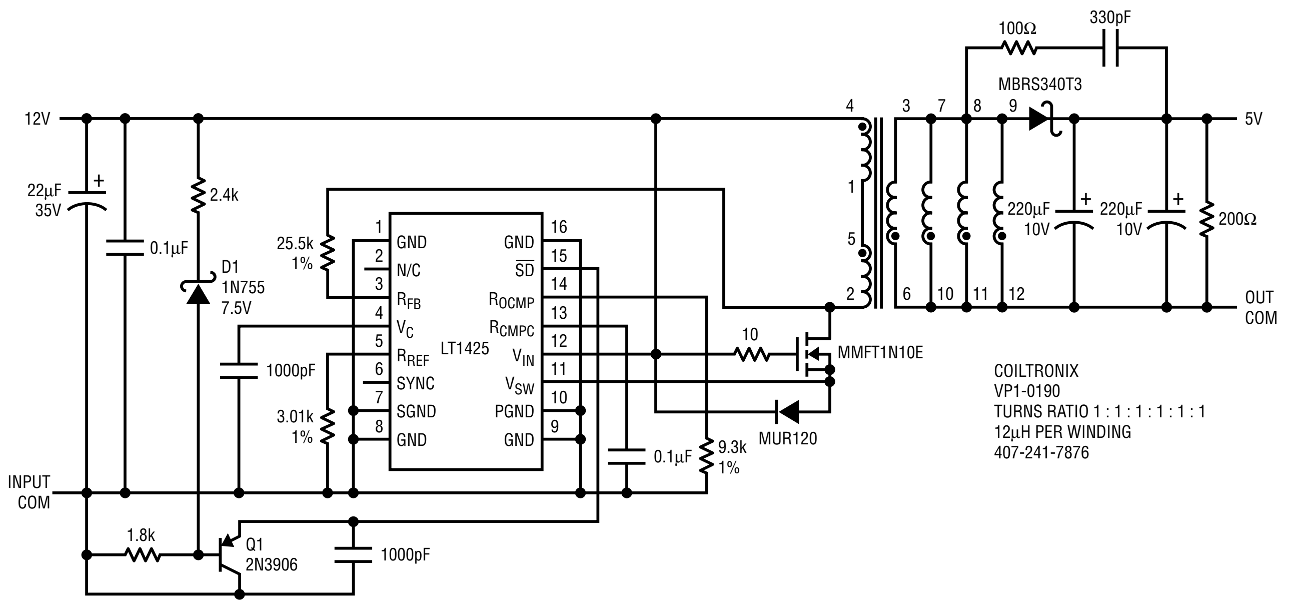


Figure 7. 5V/1A step-down, isolated supply

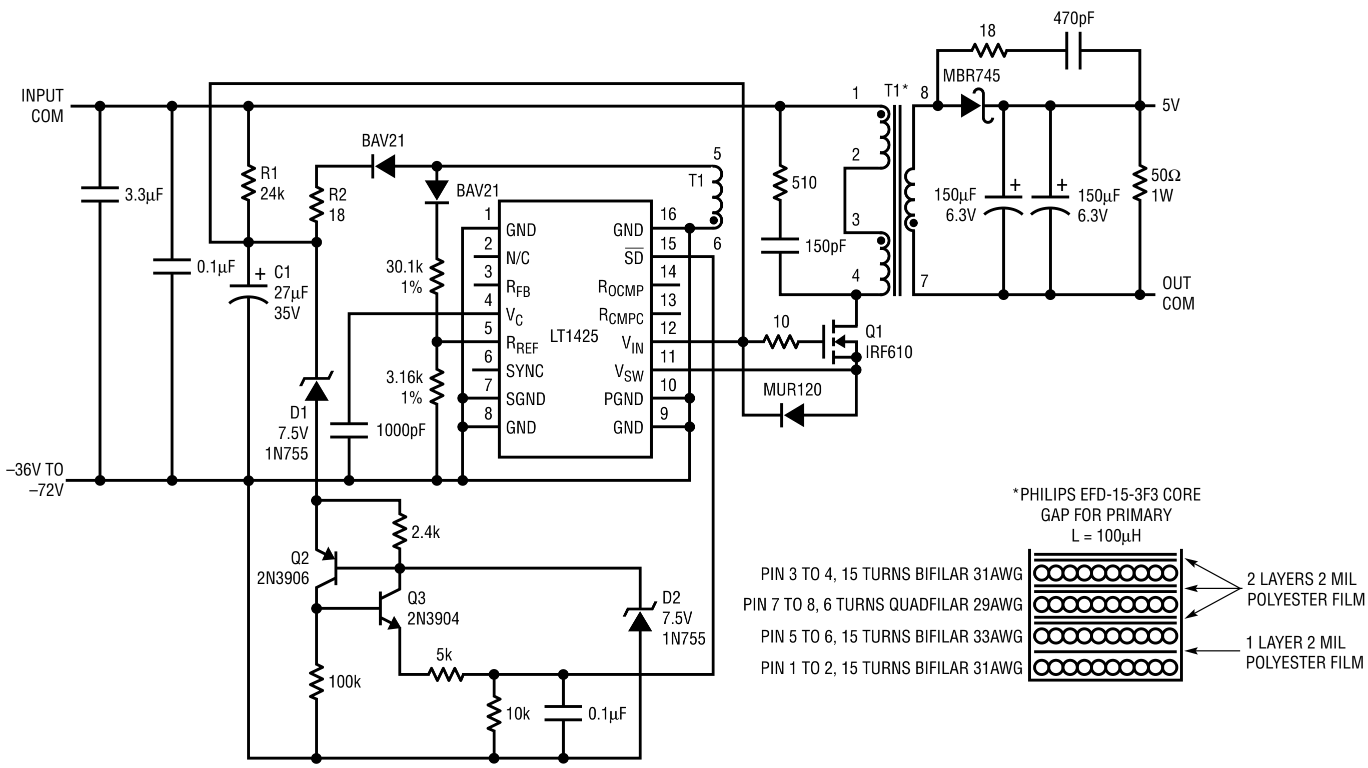


Figure 8. 5V/2A telecommunications supply

The LT1328: a Low Cost IrDA Receiver Solution for Data Rates up to 4Mbps

by Alexander Strong

Introduction

The need for ever increasing data rates required by a vast array of devices, such as notebook computers, printers, mobile phones, pagers, electronic cameras and modems, has been satisfied by the technology of infrared data transmission. The Infrared Data Association (IrDA®) standard, which covers data rates from 2400bps to 4Mbps, is the overwhelming choice for infrared data transmission. The LT1328 is a photodiode receiver that supports IrDA data rates up to 4Mbs, as well as other modulation methods, such as Sharp ASK and TV remote control.

The LT1328, in the MSOP package, contains all the necessary circuitry to convert current pulses from an external photodiode to a digital TTL output while rejecting unwanted lower frequency interference. The LT1328 plus six external components is all that is required to make the IrDA-compatible receiver shown in Figure 1. An IrDA- compatible transmitter can also be implemented with only six components, as shown in Figure 2. Power requirements for the LT1328 are minimal: a single 5V supply and 2mA of quiescent current.

LT1328 Functional Description

Figure 3 is a block diagram of the LT1328. Photodiode current from D1 is transformed into a voltage by feedback resistor R_{FB}. The DC level of the preamp is held at V_{BIAS} by the servo action of the transconductance amplifier's g_m. The servo action only suppresses frequencies below the R_{g_m}/C_{FILT} pole. This highpass filtering attenuates interfering signals, such as sunlight or incandescent or fluorescent lamps, and is selectable at pin 7 for low or high data rates. For high data rates, pin 7 should be held low. The highpass filter breakpoint is set by the capacitor C1 at $f = 25/(2 \times R_{g_m} \times C)$, where $R_{g_m} = 60k$. The 330pF capacitor (C1) sets a 200kHz corner frequency and is used for data rates above 115kbps. For low data rates (115kbps and below), the capacitance at pin 2 is increased by taking pin 7 to a TTL high. This switches C2 in parallel with C1, lowering the highpass filter breakpoint. A 10nF cap (C2) produces a 6.6kHz corner. Signals processed by the preamp/g_m amplifier combination cause the comparator output to swing low.

IrDA SIR

The LT1328 circuit in Figure 1 operates over the full 1cm to 1 meter range of the IrDA standard at the stipulated light levels. For IrDA data rates of 115kbs and below, a 1.6µs pulse width is used for a zero and no pulse for a one. Light levels are 40mW/sr (Watts per steradian) to 500mW/sr. Figure 4 shows a scope photo for a transmitter input (top trace) and the LT1328 output (bottom trace). Note that the input to the transmitter is inverted; that is, transmitted light produces a high at the input, which results in a zero at the output of the transmitter. The Mode pin (pin 7) should be high for these data rates.

IrDA FIR

The second fastest tier of the IrDA standard addresses 576kbps and 1.152Mbs data rates, with pulse widths of 1/4 of the bit interval for zero and no pulse for one. The 1.152Mbs rate, for example, uses a pulse width of 217ns; the total bit time is 870ns. Light levels are 100mW/sr to 500mW/sr over the 1cm to 1 meter range. A photo of a transmitted input and LT1328 output is

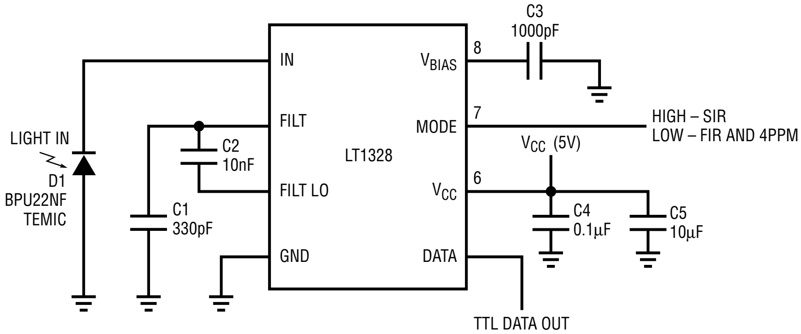


Figure 1. LT1328 IrDA receiver—typical application

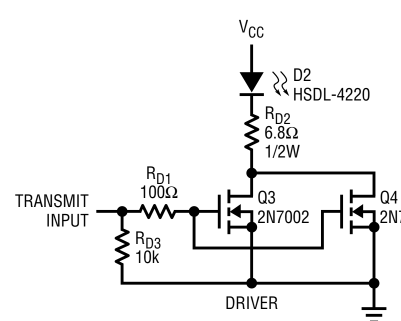


Figure 2. IrDA transmitter

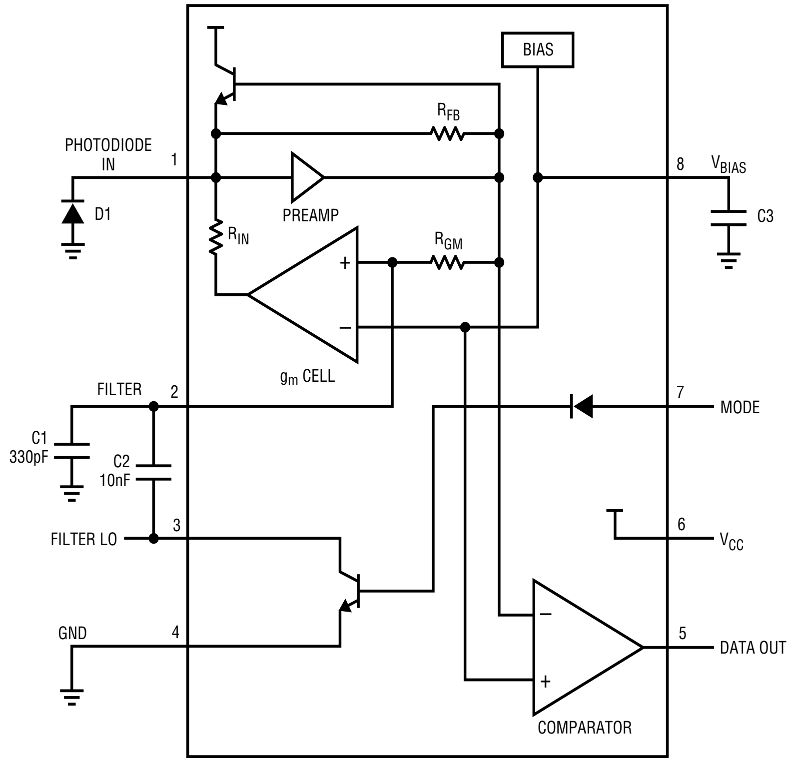


Figure 3. LT1328 block diagram

shown in Figure 5. The LT1328 output pulse width will be less than 800ns wide over all of the above conditions at 1.152Mbps. Pin 7 should be held low for these data rates and above.

4ppm

The last IrDA encoding method is for 4Mbs and uses pulse position modulation, thus its name: 4ppm. Two bits are encoded by the location of a 125ns wide pulse at one of the four positions within a 500ns interval (2 bits × 1/500ns = 4Mbps). Range and input levels are the same as for 1.152Mbs. Figure 6 shows the LT1328 reproduction of this modulation.

Conclusion

In summary, the LT1328 can be used to build a low cost receiver compatible with IrDA standards. Its ease of use and flexibility also allow it to provide solutions to numerous other photodiode receiver applications. The tiny MSOP package saves on PC board area.

IrDA is a registered trademark of the Infrared Data Association

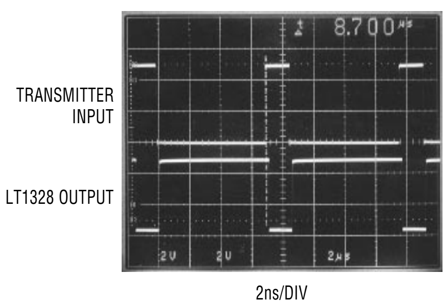


Figure 4. IrDA 115kbs modulation

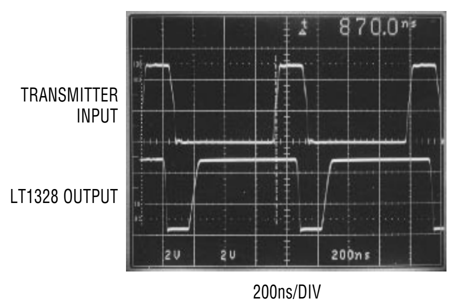


Figure 5. IrDA 1.152Mbs modulation

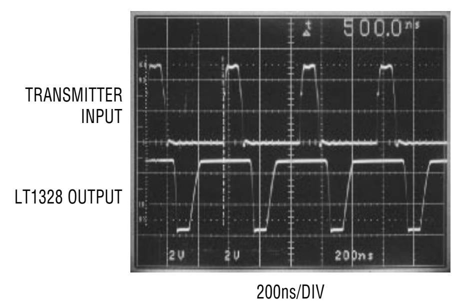


Figure 6. IrDA 4ppm modulation

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The LTC1473 Dual PowerPath Switch Driver Simplifies Portable Power Management Design

by Jaime Tseng

Introduction

The LTC1473 is the latest addition to Linear Technology's new family of power management controllers, which simplify the design of circuitry for switching between two batteries or a battery and an AC adapter. Presently, switching between power sources is implemented with discrete components—a mixture of regulators, comparators, references, glue logic, MOSFET switches and drivers. Invariably, these solutions are expensive and occupy a considerable amount of printed circuit board space. Although these circuits are frequently designed in a hurry, the problems associated with power path switching are often subtle and daunting. For example, switching from one battery to another can produce huge inrush currents between the batteries when their voltages differ. In extreme cases, system bypass capacitors can be destroyed if tantalums are used. Slowing the switch turn-on rate helps reduce the inrush current, but may cause a precipitous drop in the system supply voltage.

Solutions to these "real world" problems have been designed into our new power path switch driver. The LTC1473 dual PowerPath™ switch driver drives low loss N-channel MOSFET switches that direct power in the main power path of a single or dual rechargeable battery system, the type found in most notebook computers and other portable equipment.

Overview

The power management system in Figure 1 shows the LTC1473 driving two sets of back-to-back N-channel MOSFET switches connecting the two batteries to the system DC/DC regulator. Each of the switches is controlled by a TTL/CMOS compatible input that interfaces directly with a power management system microprocessor. An internal boost regulator provides the voltage to fully enhance the logic-level N-channel MOSFET switches.

The LTC1473 uses a current sense loop to limit current rushing in and out of the batteries and the system supply capacitor during switch-over transitions or during a fault condition. A user programmable timer monitors the time during which the MOSFET switches are in current limit and latches them off if the programmed time is exceeded. A unique "2-diode logic mode" ensures system start-up, regardless of which input receives power first.

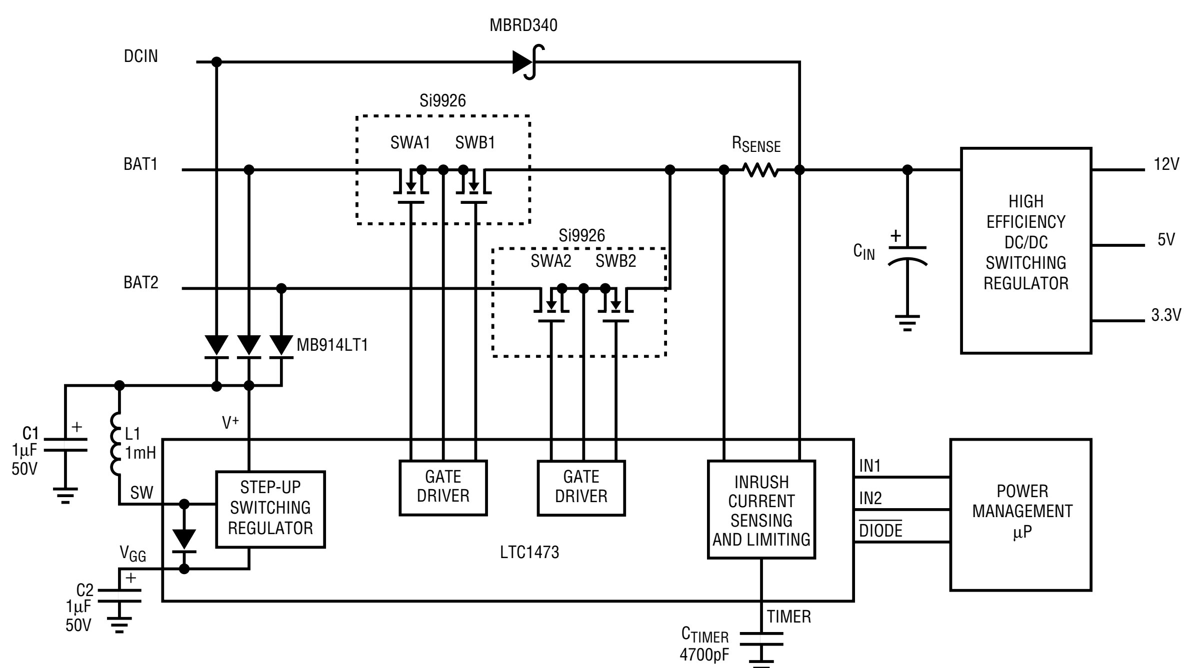

Figure 1. Dual-battery PowerPath switch driver: V_{GG} regulator, inrush limiting and switch-gate drivers

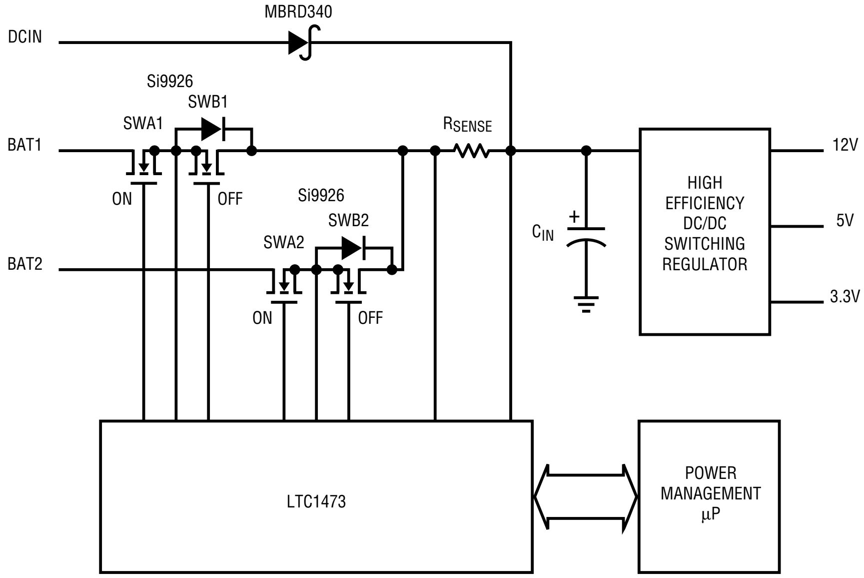

Figure 2. LTC1473 dual PowerPath switch driver in "2-diode mode"

Back-to-Back Switches

The back-to-back topology eliminates the problems associated with the inherent body diodes in power MOSFET switches and allows each switch pair to block current flow in either direction when the two switches are turned off. The low loss, N-channel switch pairs are housed in 8-pin SO and SSOP packaging and are available from a number of manufacturers. The Si9926DY, for example, houses two 20V MOSFETs rated at 0.03 with V_{GS} = 4.5V.

Inrush Current Limiting

The back-to-back topology also allows for independent control of each half of the switch pair, facilitating bidirectional inrush current limiting. The voltage across a single low value resistor, R_{SENSE}, is measured to determine the instantaneous current flowing through the two main switch pairs, SWA1/B1 and SWA2/B2. The inrush current is then controlled by the gate drivers until the transition from one power source to the other has been completed. The current flowing in and out of the two main power sources and the DC/DC converter input capacitor is dramatically reduced.

Tantalum Capacitors

Tantalum capacitors, with their high volumetric efficiency and low ESR, are the dielectric of choice for low impedance applications, such as filtering the input of a switching regulator. However, because these capacitors are exposed to uncontrolled energy supplies, they are subject to failures caused by high inrush currents unless current surges are restricted. The inrush-current limiting feature of the LTC1473 makes it feasible to use low profile tantalum surface mount capacitors in place of bulkier electrolytic capacitors.

Built-In Step-Up Regulator

The gate drive for the two low loss N-channel switches is supplied by a micropower step-up regulator that continuously generates 8.5V above V+, up to 37V maximum. The V_{GG} supply provides sufficient headroom to ensure that the logic-level MOSFET switches are fully enhanced by the gate drivers which, supply a regulated 5.7V gate-to-source voltage, V_{GS}, when turned on.

The power for the micropower boost regulator is taken from external diodes connected to each power source. The highest voltage potential is directed to V^+, where L1, an inexpensive 1mH surface mount inductor, is connected. An internal diode directs the current from L1 to the V_{GG} output capacitor, C2.

Programmable Fault Timer

A fault-timer capacitor, C_{TIMER}, is used to program the time during which the MOSFET switches are allowed to be in current limit continuously. In the event of a fault condition, the MOSFET current is limited by the inrush current-limit loop. A MOSFET switch operating in current limit is in a high dissipation mode and can fail catastrophically if this condition is not promptly terminated.

The fault-time delay is programmed with an external capacitor connected between the TIMER pin and ground. At the instant the MOSFET switch enters current limit, a 5µA current source starts charging C_{TIMER} through the TIMER pin. When the voltage across C_{TIMER} reaches 1.2V, an internal latch is set and the MOSFET switch is turned off. To reset the latch, the gate-drive input of the MOSFET switch is deselected.

The "2-Diode Mode"

Under normal operating conditions, both halves of each switch pair are turned on and off simultaneously. For example, when the input power source is switched from BAT1 to BAT2, both gates of switch pair SWA1/B1 are turned off and both gates of switch pair SWA2/B2 are turned on. The back-to-back body diodes in switch pair SWA1/B1 block current flow into or out of the BAT1 input connector.

In the "2-diode mode," only the first half of each power path switch pair, for example, SWA1 and SWA2, is turned on, and the second half, that is, SWB1 and SWB2, is turned off. These two switch pairs now simply act as two diodes connected to the two main input power sources, as illustrated in Figure 2. The power path diode with the highest input voltage passes current to the input of the DC/DC converter to ensure that the power management microprocessor is powered, even under start-up

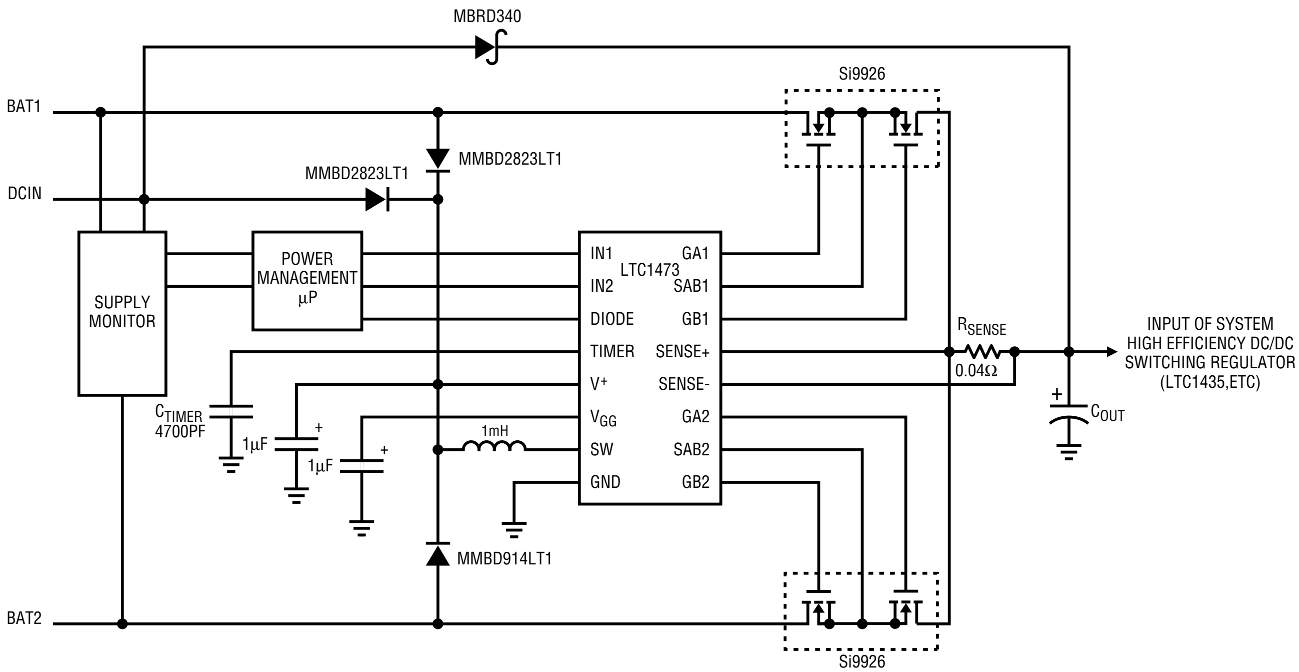

Figure 3. Dual-battery power-management system

or abnormal operating conditions. After "good" power is reconnected to one of the main inputs, the LTC1473 can be instructed to drive the appropriate switch pair on fully as the other switch is turned off, restoring normal operation.

Typical Application

A typical dual-battery system is shown in Figure 3. The LTC1473 accepts commands from a power management microprocessor to select the appropriate battery. The microprocessor monitors the presence of batteries and the AC adapter through a supply monitor block, or, in the case of some battery packs, through a thermistor sensor. This block comprises a resistor divider and a comparator for each supply. If the AC adapter is present, the two switches are turned off by the microprocessor and the power is delivered to the input of the system DC/DC switching regulator via a Schottky diode.

Conclusion

The LTC1473 dual PowerPath switch driver eases the design of the front end of the power management system. Designed to drive low cost N-channel MOSFET switches and packed with numerous protection features in a narrow, 16-lead SSOP package, the LTC1473 solves the problems of cost, space and reliability for power management system designers.

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The LTC1560-1: a 1MHz/500kHz Continuous-Time, Low Noise, Elliptic Lowpass Filter

by Nello Sevastopoulos

Introduction

The LTC1560-1 is a high frequency, continuous-time, low noise filter. It is a single-ended input, single-ended output, 5th order elliptic lowpass filter with a pin-selectable cutoff frequency (f_C) of 1MHz or 500kHz. Several features distinguish the LTC1560-1 from other commercially available high frequency, continuous-time monolithic filters:

- ❏ Fifth order 1MHz or 500kHz elliptic response in an SO-8 package
- ❏ No external components or clocks required
- ❏ Better than 60dB stopband attenuation
- ❏ 75dB signal-to-noise ratio (SNR)
- ❏ 0.3dB passband ripple

The LTC1560-1 delivers accurate fixed cutoff frequencies of 500kHz and 1MHz without the need for internal or external clocks. Through a simple mask change, other frequencies from 450kHz to 1.3MHz can be produced upon demand. The LTC1560-1's extremely small size makes it suitable for compact designs (see Figure1) and for a variety of applications, including communication filters, antialiasing filters and smoothing or reconstruction filters.

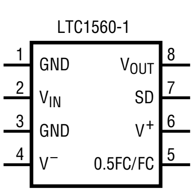

Figure 1. LTC1560-1 in an SO-8 package

DC Performance and Power Shutdown

The LTC1560-1 operates with ±5V supplies and has a power shutdown mode. The typical DC output swing of the filter is from –3V to 3.5V. The output DC offset of the filter is typically ±200mV. The operating power supply range is ±4V to ±6V.

The LTC1560-1's extremely small size makes it well suited for compact designs and a variety of applications, including communication filters, antialiasing filters and smoothing or reconstruction filters.

The LTC1560-1 provides a power shutdown option that significantly reduces current consumption when the device is not being used. The filter operation could be controlled by a TTL input together with an inverter applied to the SD pin (pin 7). A logic high input turns the device on for normal operation, whereas a logic low puts the filter into its sleep mode, in which it dissipates only 5mW of power. (Leaving pin 7 open yields the default mode of normal operation.)

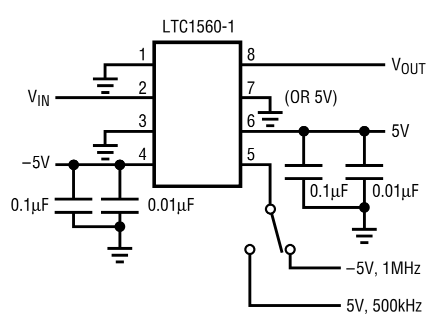

Figure 2. 1MHz or 500kHz elliptic lowpass filter with no external components

AC Performance

Frequency Response

The LTC1560-1 offers a pin-selectable cutoff frequency of either 500kHz (Figure 2; pin 5 tied to V^+) or 1MHz (pin 5 tied to V^-). The detailed passband frequency response of the 1MHz filter is shown in Figure 3. In the 1MHz mode, the passband is flat up to $0.55 \times f_C$ with a typical ripple of ±0.2dB, increasing to ±0.3dB up to $0.9 \times f_C$. The typical gain at f_C is –0.6dB. Referring to Figure 4, note that the transition band has a gain of –22dB at $1.44 \times f_C$ rolling off to –47dB

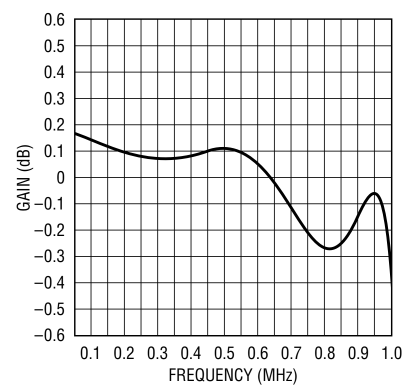

Figure 3. Expanded passband ripple for the 1MHz filter

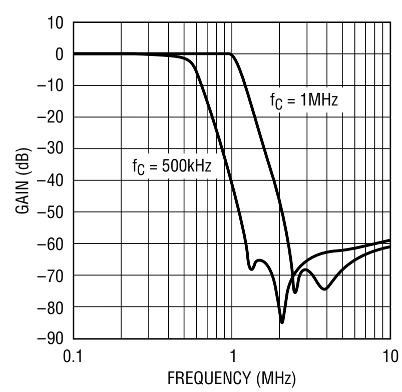

Figure 4. Gain vs frequency of the 1MHz and 500kHz filters

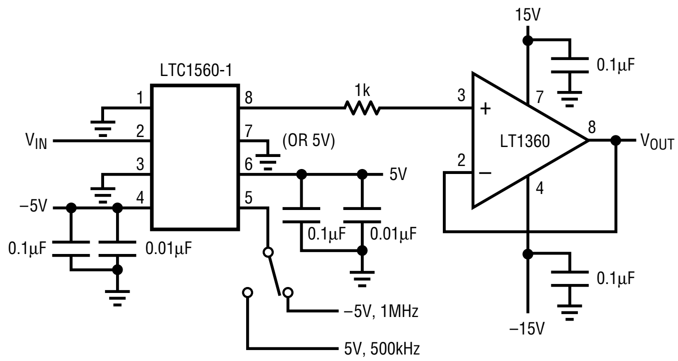

Figure 5. A typical circuit for evaluating the full performance of the LTC1560-1

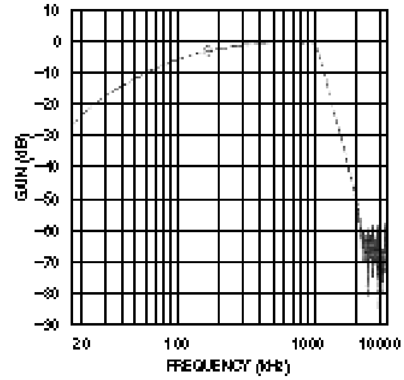

Figure 7. Measured frequency response of Figure 6's circuit

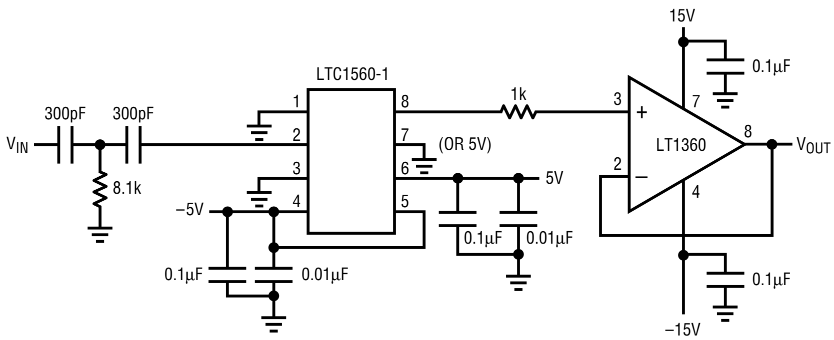

Figure 6. A highpass-lowpass filter

at $2 \times f_C$. The stopband attenuation is 63dB starting from $2.43 \times f_C$ and remains at least 60dB for input frequencies up to 10MHz. When programmed for f_C = 500kHz, the frequency response remains the same, with the exception of the gain at f_C, which is typically –1.3dB. Figure 4 compares the gain responses of the 1MHz and 500kHz filters.

Noise and Distortion Performance

The LTC1560-1 architecture offers not only low wide band noise but also low total harmonic distortion (THD). The combination of low noise and low distortion means a wide dynamic range. With a $1V_{RMS}$ input signal, the signal-to-noise ratio (SNR) is 69dB and the THD + Noise is –63dB (0.07%). The maximum SNR of 75dB is achieved with a $2.1V_{RMS}$ input signal. This results in –46dB (0.5%) THD. For the 500kHz device, the noise performance is even better, with 77dB SNR at a $1V_{RMS}$ input.

To achieve the full high frequency performance from the filter, a small resistor (about 200) should be added at the output of the device to isolate any capacitive load greater than 20pF. Figure 5 shows a typical application circuit to be used for any AC performance measurements of the LTC1560-1. Any high speed, high slew-rate operational amplifier such as the LT1360 can serve as the buffer. To correctly evaluate the high frequency distortion performance of the LTC1560-1 requires a very low distortion input signal, either from a very high quality signal generator or, if such a source is not available, from a source that has been filtered to control its harmonic content.

Applications and Experimental Results

The LTC1560-1 can be used not only as a single device (as shown in Figures 2 and 5) but also as part of a more complete frequency-shaping system. Two representative examples follow.

Highpass-Lowpass Filter

As a typical application in communication systems, where there is a need to reject DC and some low frequency signals, a 2nd order RC highpass network can be inserted in front of the LTC1560-1 to obtain a highpass-lowpass response. Figures 6 and 7 depict the network and its measured frequency response, respectively. Notice that the second resistor in the highpass filter is the input resistance of the LTC1560-1, which is about 8.1k.

Delay-Equalized Elliptic Filter

Although elliptic filters offer high Q and a sharp transition band, they lack a constant group delay in the passband, which implies more ringing in the time-domain step response. In order to minimize the delay ripple in the passband of the LTC1560-1, an allpass filter (delay equalizer) is cascaded with the LTC1560-1, as shown in Figure 8. Figures 9 and 10 illustrate the eye diagrams before and after the equalization, respectively.

An eye diagram is a qualitative representation of the time-domain response of a digital communication system. It shows how susceptible the system is to *intersymbol interference* (ISI). *Intersymbol interference* is caused by erroneous decisions in the receiver due to pulse overlapping and decaying oscillations of a previous symbol. A pseudorandom 2-level sequence has been used as the input of the LTC1560-1 to generate these eye diagrams. The larger eye opening in

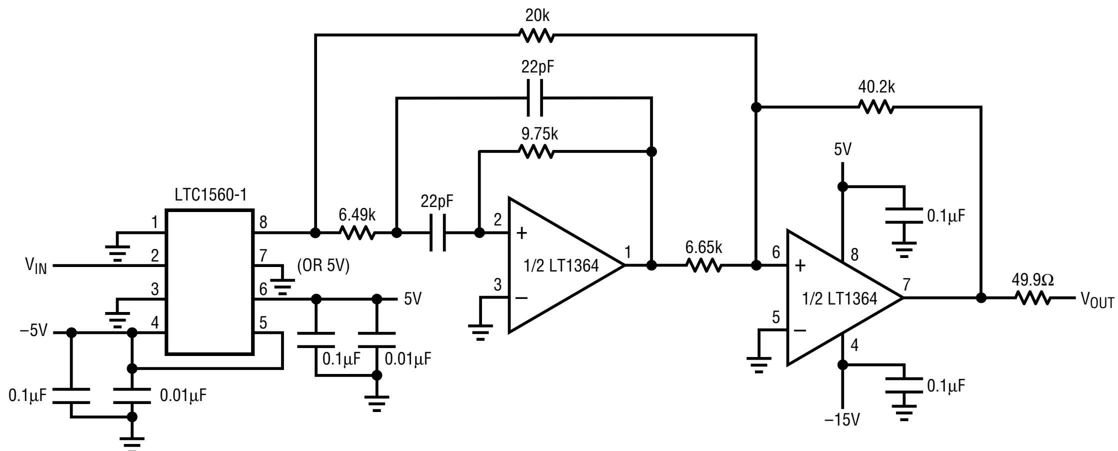

Figure 8. Augmenting the LTC1560-1 for improved delay flatness

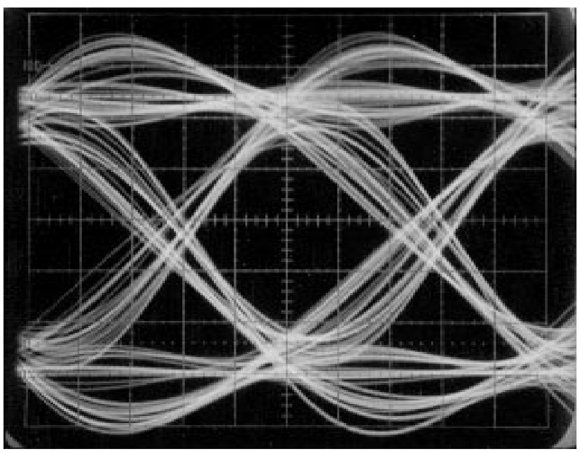

Figure 9. 2-level eye diagram of the LTC1560-1 before equalization

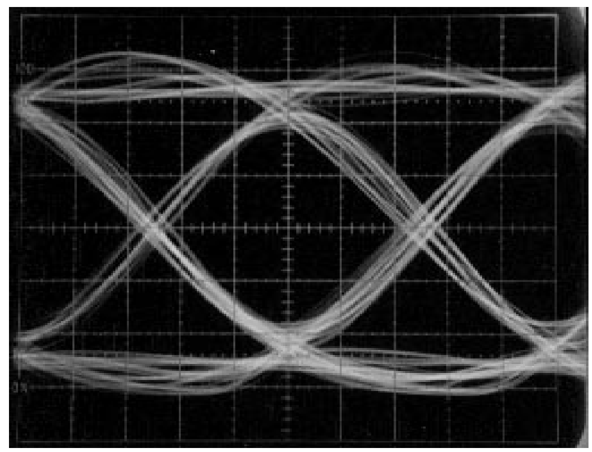

Figure 10. 2-level eye diagram of the equalized filter

Figure 10, an indication of the equalization effect, leads to reduced ISI. Note that in Figure 8, the equalizer section has a gain of 2 for driving and back-terminating 50 cable and load. For a simple unterminated gain-of-1 equalizer, the 40.2k resistor changes to 20k and the 49.9 r esistor is removed from the circuit. The 22pF capacitors are 1% or 2% dipped silver mica or COG ceramic.

Conclusions

The LTC1560-1 is a 5th order elliptic lowpass filter that features a 10-bit gain linearity at signal ranges up to 1MHz. Being small and user friendly, the LTC1560-1 is suitable for any compact design. It is a monolithic replacement for larger, more expensive and less accurate solutions in communications, data acquisitions, medical instrumentation and other applications.

Mojitaba Atarodi contributed significant portions of this article.

The LTC1594 and LTC1598: Micropower 4- and 8-Channel 12-Bit ADCs

by Kevin R. Hoskins and Marco Pan

Introduction

Data acquisition applications that require low power dissipation fall into two general areas: products that require highly efficient power use, such as battery-powered portable test equipment and remotely located data logging equipment, and products that either operate in high temperature environments or must not contribute to increasing ambient temperature. To help meet these requirements, Linear Technology has introduced the LTC1594 and LTC1598.

Micropower ADCs in Small Packages

The LTC1594 and LTC1598 are micropower 12-bit ADCs that feature a 4- and 8-channel multiplexer, respectively. The LTC1594 is available in a 16-pin SO package and the LTC1598 is available in a 24-pin SSOP package. Each ADC includes a simple, efficient serial interface that reduces interconnects and, thereby, possible sources of corrupting digital noise. Reduced interconnections also reduce board size and allow the use of processors having fewer I/O pins, both of which help reduce system costs. Small packages also shorten the distance between the ADC and its supply and voltage reference bypass components. This reduces lead inductance and allows bypass components to operate as efficiently as possible.

Conserve Power with Auto Shutdown Operation

The LTC1594 and LTC1598 include an auto shutdown feature that reduces power dissipation when the converter is inactive (whenever the $\overline{CS}$ signal is a logic high). Nominal power dissipation while either converter is clocked at 320kHz is typically 1.6mW. The curve in Figure 1 indicates the amount of current drawn by this MUXed 12-bit ADC family for sample rates up to 16.8ksps. As an example, when converting at 4ksps, the dissipation is just 450μW and 270μW for the 5V and 3V parts, respectively.

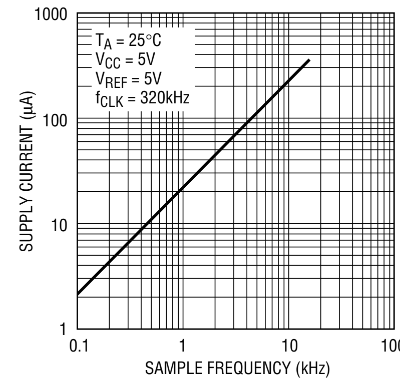

Figure 1. Supply current vs sample rate

Supply Flexibility: 2.7V or 5V

To increase applications flexibility, the LTC1594 and LTC1598 are also available as 3V parts (LTC1594L and LTC1598L), which are tested for 2.7V operation. The LTC1594L and LTC1598L typically draw 160μA at maximum conversion rate, one-half of the supply current drawn by the 5V parts. Nominal power dissipation while either converter is clocked at 200kHz (10.5ksps) is typically 800μW.

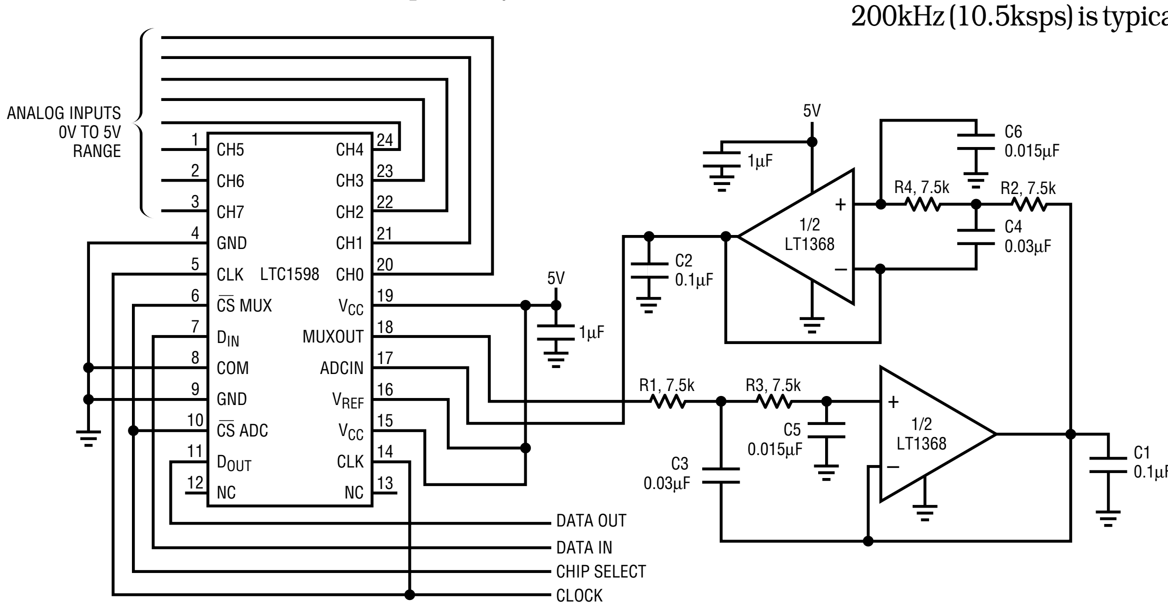

Figure 2. A simple data acquisition system takes advantage of the LTC1598's MUXOUT/ADCIN pins to filter analog signals prior to ADC conversion.

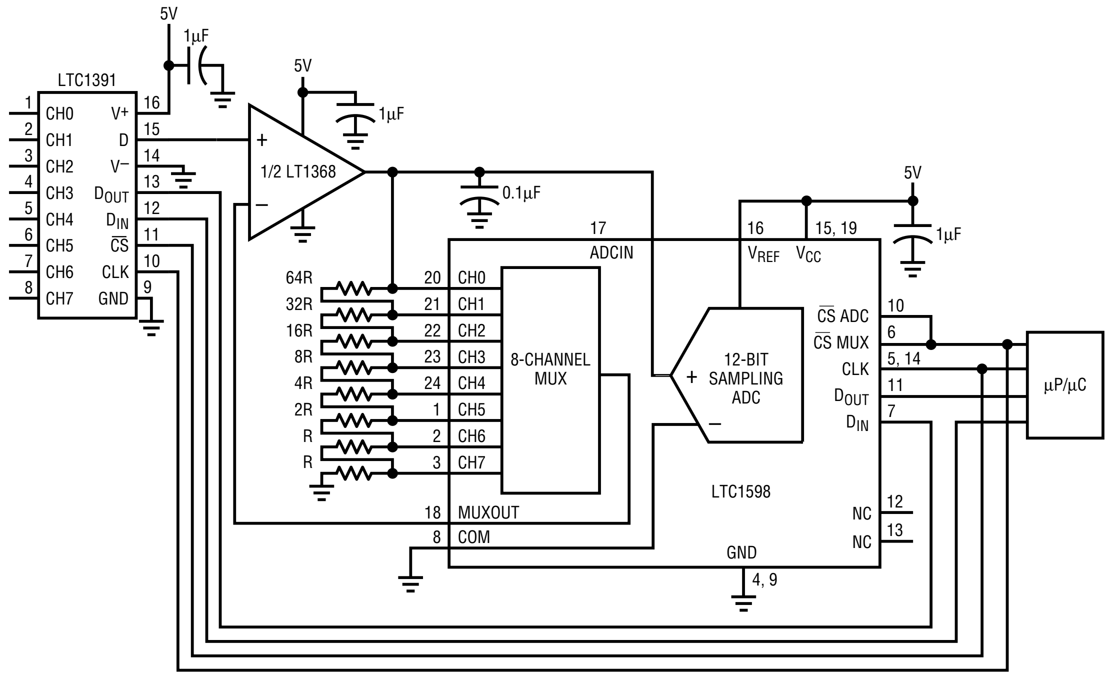

Figure 3. Using the MUXOUT/ADCIN loop of the LTC1598 to form a PGA with eight gains in a noninverting configuration

Good DC Performance

The DC specs include excellent differential nonlinearity (DNL) of ±3/4LSB, as required by pen-screen and other monitoring applications. No missing codes are guaranteed over temperature.

Versatile, Flexible Serial I/O

The serial interface found on the LTC1594 and LTC1598 is designed for ease of use, flexibility, minimal interconnections and I/O compatibility with QSPI, SPI, MICROWIRE™ and other serial interfaces. The MUX and the ADC have separate chip select ($\overline{CS}$) and serial clock inputs, which adds versatility. The remaining serial interface signals are data input (D_{IN}) and data output (D_{OUT}). The maximum serial clock frequencies are 320kHz and 200kHz for the 5V and 3V parts, respectively.

Latch-up Proof MUX Inputs

The LTC1594's and LTC1598's input MUXes are designed to handle input voltages that exceed the nominal input range, GND to the supply voltage, without latch-up. Although an overdriven, unselected channel may corrupt a selected, correctly driven channel, no latch-up occurs and correct conversion results resume when the offending input voltage is removed. The MUX inputs remain latch-up proof for input currents up to ±200mA over temperature.

Individual ADC and MUX Chip Selects Enhance Flexibility

The LTC1594 and LTC1598 feature separate chip selects for ADC and MUX. This allows the user to select a particular channel once for multiple conversions. This has the following benefits: first, it eliminates the overhead of sending D_{IN} word for the same channel each time for each conversion; second, it avoids possible glitches that may occur if a slow-settling antialiasing filter is used; and third, it sets the gain once for multiple conversions if the MUXOUT/ADCIN loop is used to create a programmable gain amplifier (PGA).

MUXOUT/ADCIN Loop Economizes Signal Conditioning

The MUXOUT and ADCIN pins form a very flexible external loop that allows PGA and/or processing analog input signals prior to conversion. This loop is also a cost effective way to perform the conditioning, because only one circuit is needed instead of one for each channel. Figure 2 shows the loop being used to antialias filter several analog inputs. The output signal of the selected MUX channel, present on the MUXOUT pin, is applied to R1 of the Sallen-Key filter. The filter band limits the analog signal and its output is applied to ADCIN. The LT1368 rail-to-rail op amps used in the filter will, when lightly loaded as in this application, swing to within 8mV of the positive supply voltage. Since only one circuit is used for all channels, each channel sees the same filter characteristics.

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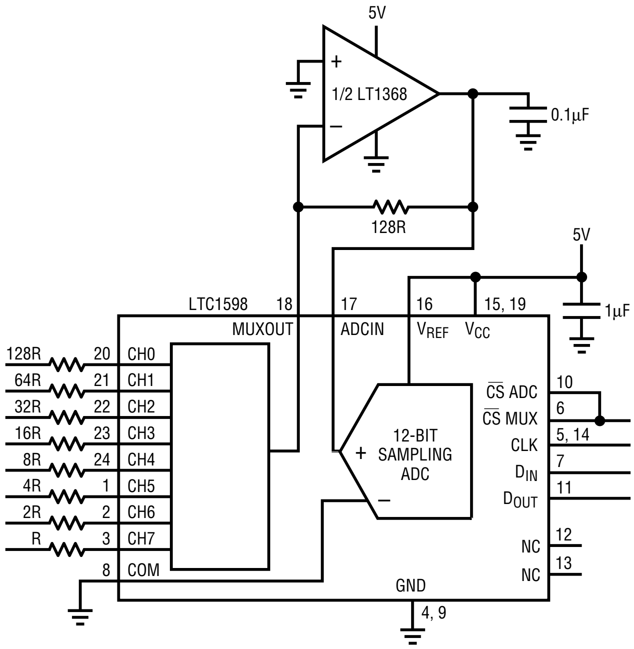

Figure 4. Using the MUXOUT/ADCIN loop of the LTC1598 to form a PGA with eight inverting gains

Using MUXOUT/ ADCIN Loop as PGA

Figure 3 shows the LTC1598's MUXOUT/ADCIN loop and an LT1368 being used to create a single-channel PGA with eight noninverting gains. Combined with the LTC1391, as shown in Figure 3, the system can expand to eight channels and eight gains for each channel. Using the LTC1594, the PGA is reduced to four gains. The output of the LT1368 drives the ADCIN and the resistor ladder. The resistors above the selected MUX channel form the feedback for the LT1368. The loop gain for this amplifier is $(R_S1/R_S2) + 1$. R_S1 is the summation of the resistors above the selected MUX channel and R_S2 is the summation of the resistors below the selected MUX channel. If CH0 is selected, the loop gain is 1 since R_S1 is 0. Table 1 shows the gain for each MUX channel. The LT1368 dual rail-to-rail op amp is designed to operate with 0.1µF load capacitors. These capacitors provide frequency compensation for the amplifiers, help reduce the amplifiers' output impedance and improve supply rejection at high frequencies. Because the LT1368's I_B is low, the R_{ON} of the selected channel will not affect the loop gain given by the formula above. In the case of the inverting configuration of Figure 4, the selected channel's R_{ON} will be added to the resistor that sets the loop gain.

Table 1. PGA gain for each MUX channel of Figures 3 and 4

MUX Channel	Noninverting Gain	Inverting Gain
0	1	–1
1	2	–2
2	4	–4
3	8	–8
4	16	–16
5	32	–32
6	64	–64
7	128	–128

8-Channel, Differential, 12-Bit A/D System Using the LTC1391 and LTC1598

The LTC1598 can be combined with the LTC1391 8-channel, serial-interface analog multiplexer to create a differential A/D system. Figure 5 shows the complete 8-channel, differential A/D circuit. The system uses the LTC1598's MUX as the noninverting input multiplexer and the LTC1391 as inverting input multiplexer. The LTC1598's MUXOUT drives the ADCIN directly. The inverting multiplexer's output is applied to the LTC1598's COM input. The LTC1598 and LTC1391 share the $\overline{CS}$, D_{IN}, and CLK control signals.

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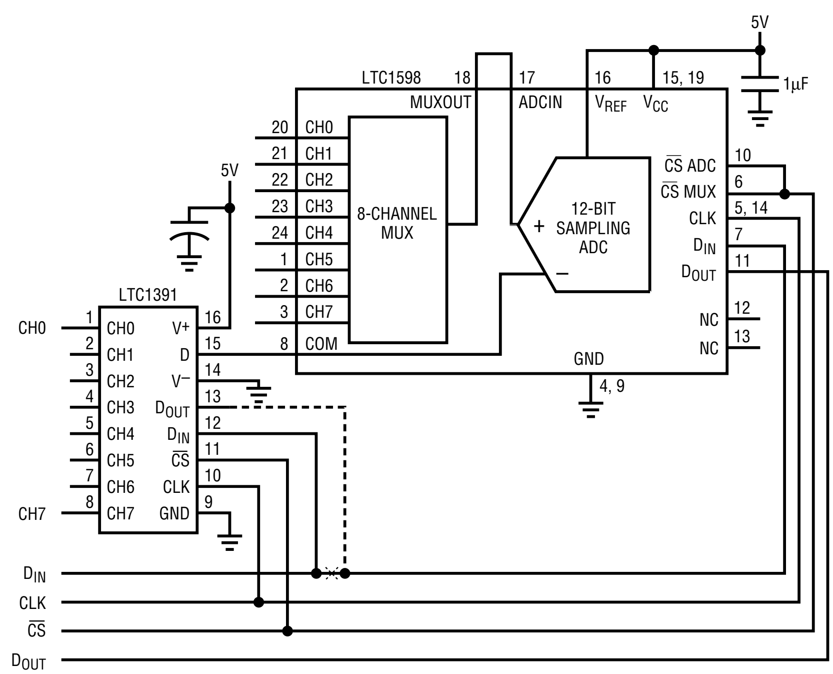

Figure 5. Using the LTC1598 and LTC1391 as an 8-channel, differential 12-bit ADC system: opening the indicated connection and shorting the dashed connection daisy-chains the external and internal MUXes, increasing channel-selection flexibility.

LTC1474 and LTC1475 High Efficiency Switching Regulators Draw Only 10µA Supply Current

by Greg Dittmer

Introduction

Maximizing battery life, one of the key design requirements for all battery-powered products, is now easier with Linear Technology's new family of ultralow quiescent current, high efficiency step-down regulator ICs, the LTC1474 and LTC1475. The LTC1474/LTC1475 are step-down regulators with on-chip P-channel MOSFET power switches. These regulators draw only 10µA supply current at no load while maintaining the output voltage. With the on-chip switch (1.3 at V_{IN} = 10V), only four external components are necessary to make a complete, high efficiency (up to 92%) step-down regulator. Low component count and the LTC1474/LTC1475's tiny MSOP packages provide a minimum-area solution to meet the limited space requirements of portable applications. Wide supply voltage range (3V–18V) and 100% duty cycle capability for low dropout allow maximum energy to be extracted from the battery, making the LTC1474/LTC1475 ideal for moderate current (up to 300mA) battery-powered applications.

The peak inductor current is programmable via an optional current sense resistor to allow the design to be optimized for a particular application and to provide short-circuit protection and excellent start-up behavior. Other features include Burst Mode™ operation to maintain high efficiency over almost four decades of load current, an on-chip low-battery comparator and a shutdown mode to further reduce supply current to 6µA. The LTC1475 provides on/off control with push-button switches for use in handheld products.

The LTC1474/LTC1475 are available in adjustable output voltage versions, in 8-pin MSOP and SO packages.

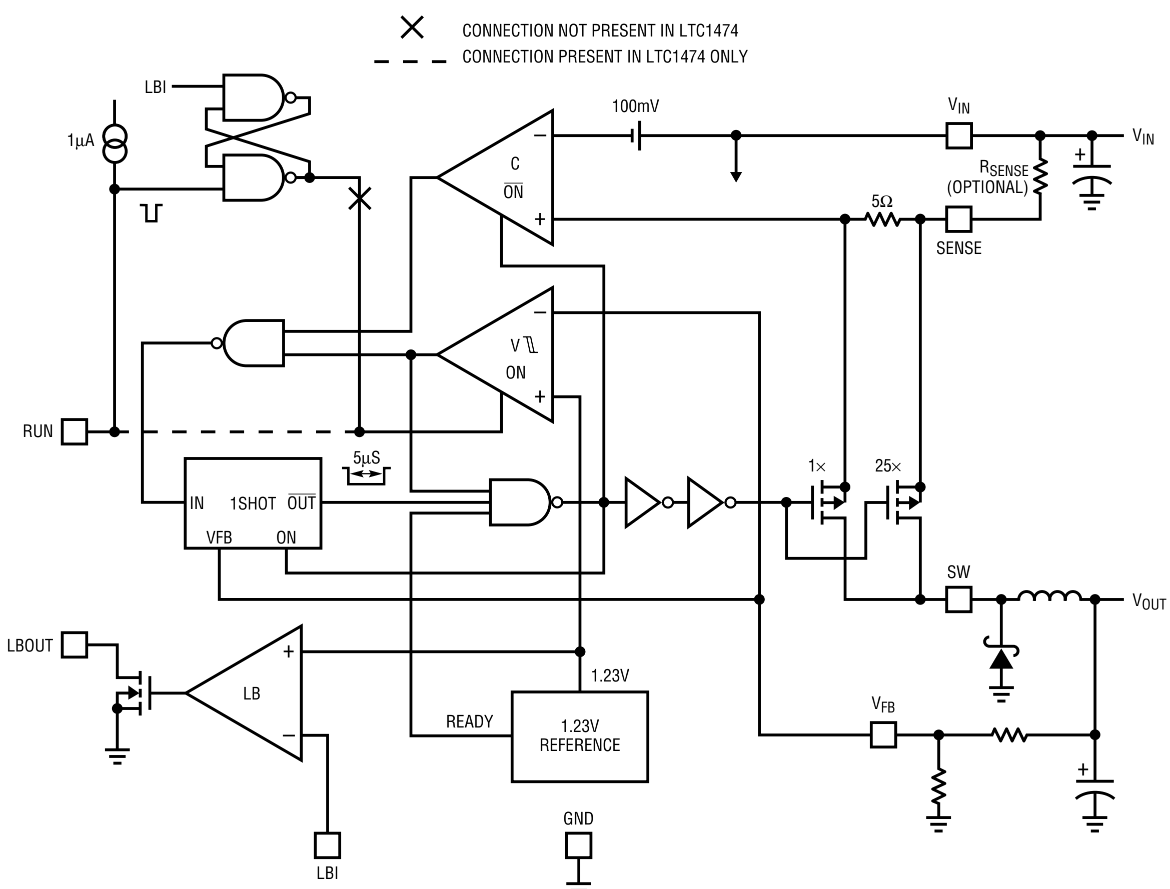

Figure 1. LTC1474/LTC1475 functional block diagram

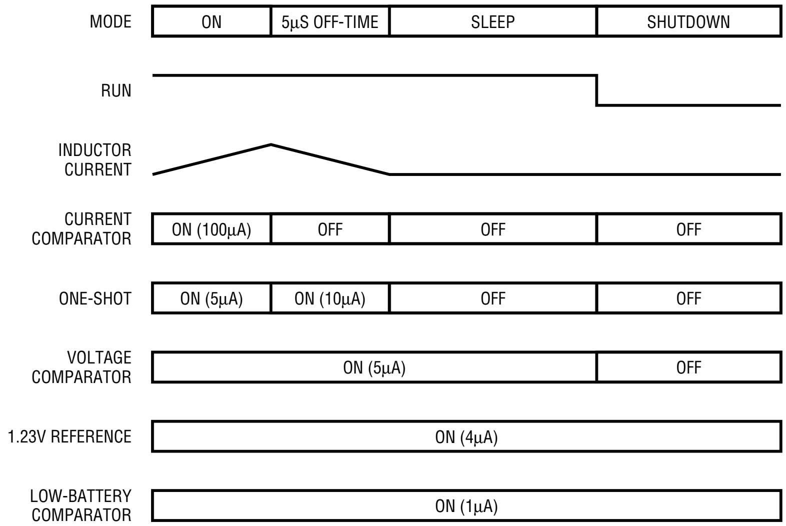

Figure 2. Supply current breakdown during each operational mode

High Performance on a Microampere Budget

The functional block diagram, shown in Figure 1, provides a study in power management. LTC1474/LTC1475 control the output voltage by charging the output capacitor in short burst cycles using Burst Mode operation. The peak current in each burst cycle (up to 400mA) is set by the external sense resistor. As the load increases, the frequency of the burst cycles increases (up to a maximum of 170kHz) to maintain the charge in the output capacitor. The burst cycle begins when the output voltage falls below the lower threshold of the voltage comparator (V). The P-channel power switch turns on to ramp the inductor current up until either the current comparator (C) trips on peak current or the voltage comparator trips on the upper voltage threshold. At this time the one-shot is triggered and begins the 5µs off-time period, during which the switch is turned off and inductor current ramps down. If, at the end of the off-time, the output voltage is below the upper voltage comparator threshold, the switch is turned on again to begin another cycle. If the upper voltage threshold is exceeded, however, the switch remains off and the output capacitor supplies the load current. The switch remains off until the load current discharges the output capacitor below the lower voltage threshold.

The ultralow supply current and very high efficiency at light loads are achieved by powering only those functions that are necessary at any given time. Figure 2 is a summary of the current used by each of the functions in each of the different operating modes. During sleep mode, when the output capacitor is supplying the load, only the 1.23V reference, the voltage comparator and low-battery comparator are on; together they draw only 10µA of supply current to perform their functions. These three functions are on at all times except during shutdown. During shutdown, the voltage comparator is turned off to save an additional 5µA. The current comparator, which, as a result of its speed requirement necessarily draws more current, is only turned on during the switch on-time, when it is needed to monitor the switch current. When the current or voltage comparator trips, the current comparator is turned off and the one-shot timer is triggered, drawing 10µA during its 5µs timeout period. When the one-shot times out it turns off, reducing the supply current to the 10µA needed for the voltage comparator, reference and low-battery comparator, until a new burst cycle begins.

In Control of Inductor Current

Excessive peak inductor current can be a liability. Lower peak current offers the advantages of smaller voltage ripple ($\Delta V = I_{PEAK} \times ESR$), lower noise and less stress on alkaline batteries and other circuit components. Also, lower peaks allow the use of inductors with smaller physical size. The LTC1474/LTC1475 provide flexibility by allowing the peak switch/inductor current to be programmed with an optional sense resistor to provide just enough to meet the load requirement. Without a sense resistor (that is, with pins 6 and 7 shorted) the current limit defaults to its maximum of 400mA. Using the default current limit eliminates the need for a sense resistor and associated decoupling capacitor.

A sense MOSFET (a portion of the main power MOSFET) is used to divert a sample (about 5%) of the switch current through the internal 5 sense resistor. The internal current comparator monitors the voltage drop across the series combination of the internal and external sense resistors and trips when this voltage drop exceeds 100mV. This results in a peak current of $I_{PEAK} = 0.1/(0.25 + R_{SENSE}) + 0.2 \times (V_{IN} - V_{OUT})/L$. The second term in the above equation is the result of overshoot of the peak current due to delays in the current comparator and must be taken into account at lower inductances and higher supply voltages to guarantee that maximum current ratings of the inductor and switch are not exceeded. Note that worst case will occur during a short circuit, when $V_{OUT} = 0$.

3.3V/200mA Step-Down Regulator

A typical application circuit using the LTC1474 is shown in Figure 3. This circuit supplies a 200mA load at 3.3V with an input supply range of 4V–18V (3.3V at no load). The 0.1 sense resistor reduces the peak current to about 285mA, which is the minimum level necessary to meet the 200mA load current requirement with a

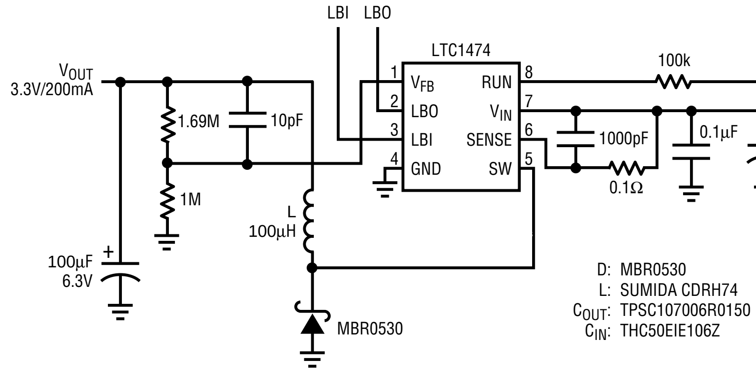

Figure 3. LTC1474 3.3V/200mA step-down regulator

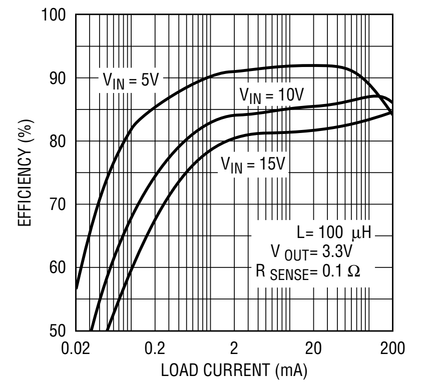

Figure 4. Efficiency vs load for Figure 3's circuit

100µH inductor. The peak can be reduced further if a higher value inductor is used. Since the output capacitor dominates the output voltage ripple, an AVX TPS series low ESR (150m) output capacitor is used to provide a good compromise between size and low ESR. With this capacitor the output ripple is less than 50mV.

Efficiency Considerations

The efficiency curves for the 3.3V/200mA regulator at various supply voltages are shown in Figure 4. Note the flatness of the curves over the upper three decades of load current and that the efficiency remains high down to extremely light loads. Efficiency at light loads depends on low quiescent current. The curves are flat because all significant sources of loss except for the 10µA standby current—I^2R losses in the switch, catch diode losses, gate charge losses to turn on the switch and burst cycle DC supply current losses—are identical during each burst cycle. The only variable is the rate at which the burst cycles occur. Since burst frequency is proportional to load, the loss as a percentage of load remains relatively constant. The efficiency drops off as the load decreases below about 1mA because the non-load-dependent 10µA standby current loss then constitutes a more significant percentage of the output power. This loss is proportional to V_{IN} and thus its effect is more pronounced at higher V_{IN}.

Care must be used in selecting the catch diode to maximize both low and high current efficiency. Low reverse leakage current is critical for maximizing low current efficiency because the leakage can potentially approach the magnitude of the LTC1474/LTC1475 supply current. Low forward drop is critical for high current efficiency because loss is proportional to forward drop. These are conflicting parameters, but the MBR0530 0.5A Schottky diode used in the Figure 3 is a good compromise. Lower inductances also help by minimizing DCR without increasing the inductor size. However, lower inductances also reduce the maximum available output power for a given I_{PEAK} due to the fixed 5µs off-time and may also increase the peak current overshoot due to high di/dt (see formula for I_{PEAK}).

LTC1475 Push-Button On/Off Operation

The LTC1475 provides the option of push-button control of run and shutdown modes for handheld products. In contrast to the LTC1474's run/shutdown mode, which is controlled by a voltage level at the RUN pin (ground = shutdown, open/high = run), the LTC1475 run/shutdown mode is controlled by an internal S/R flip-flop that is set (run mode) by a momentary ground at the RUN pin and reset (shutdown mode) by a momentary ground at the LBI pin (see Figure 5). This provides simple on/off control with two push-button switches. The simplest implementation of this function is shown in Figure 6, with normally open push-button switches connected to the RUN and LBI pins. Note that because the switch on LBI is normally open, it doesn't

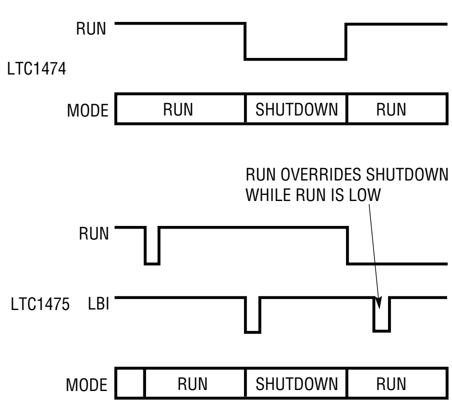

Figure 5. Comparison of RUN/SHUTDOWN operation for the LTC1474 and LTC1475

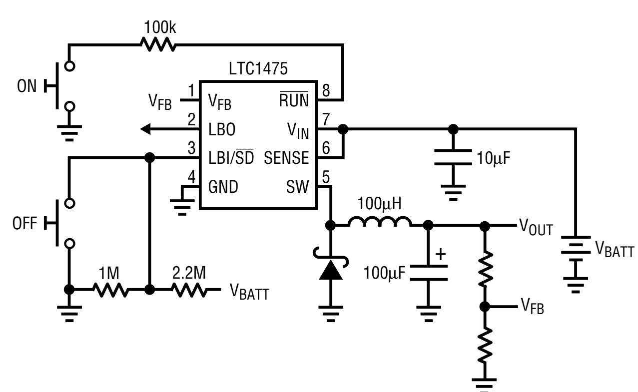

Figure 6. LTC1475 step-down regulator with push-button on/off control

affect the normal operation of this input to the low-battery comparator. With a resistor divider network connected to the LBI to monitor the input supply voltage level, the voltage at this pin will normally be above the low-battery trip threshold of 1.23V. When this pin is pulled below 0.7V by depressing the switch, the internal flip-flop is reset to invoke shutdown.

Figure 7 shows an example of push-button on/off control of a LTC1475 microcontroller application with a single push button. The push button is connected to the microcontroller as a discrete input so that the microcontroller can monitor the state of the push button. The LTC1475 LBI pin is connected to one of the microcontroller's open-drain discrete outputs so that it can force the LTC1475 off when it detects a depressed push button. Because the LTC1475 supplies power to the microcontroller, once the microcontroller is off, it can no longer turn the LTC1475 back on. However, since the push button is also connected directly to the RUN pin, the LTC1475 can be turned back on directly from the push button without the microcontroller. The LTC1475 then powers up the microcontroller. The discrete inputs of most microcontrollers have a reverse biased diode between the input and supply; thus a blocking diode with less than 1µA leakage is necessary to prevent the powered down microcontroller from pulling down on the RUN pin.

Conclusion

The LTC1474 and LTC1475 ultralow quiescent current step-down regulator ICs provide a perfect solution for low to moderate current (up to 300mA) battery-powered applications where high efficiency and maximizing battery life are critical. The 10µA no-load supply current requirement ensures that little battery energy is wasted on the regulator. The internal P-channel power switch, MSOP package and the need for as few as four additional components result in a very compact solution, and the current programmability and wide supply-voltage range provide the flexibility necessary to optimize the design for a variety of applications.

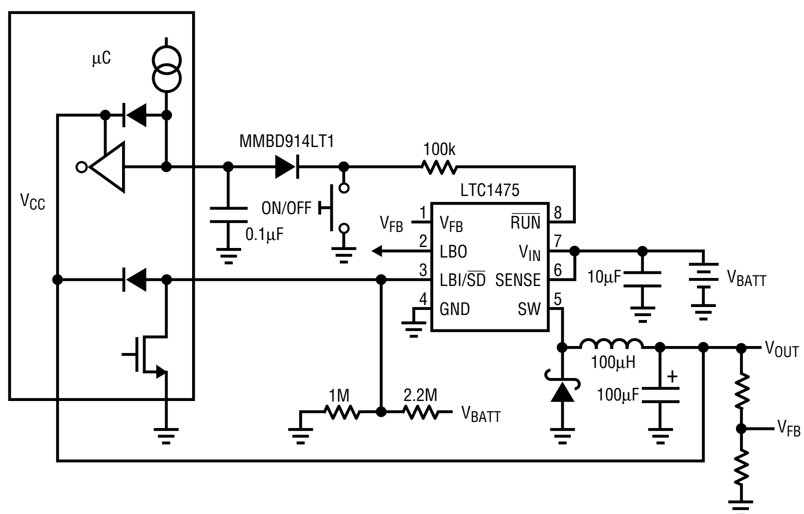

Figure 7. A single push-button controls on/off for the LTC1475 regulator and microcontroller.

LTC1594/LTC1598, continued from page 16

This arrangement simultaneously selects the same channel on each multiplexer and maximizes the system's throughput. The dotted-line connection daisy-chains the MUXes of the LTC1391 and LTC1598 together. This configuration provides the flexibility to select any channel in the noninverting input MUX with respect to any channel in the inverting input MUX. This allows any combination of signals applied to the inverting and noninverting MUX inputs to be routed to the ADC for conversion.

Conclusion

With their serial interfaces, small packages, and auto shutdown, the LTC1594(L) and LTC1598(L) achieve very low power consumption while occupying very little circuit board area. Their outstanding DC specifications make them the choice for applications that benefit from low power, battery conserving operation, multichannel inputs and space and component saving signal conditioning loop.

Biased Detector Yields High Sensitivity with Ultralow Power Consumption

by Mitchell Lee

RF ID tags, circuits that detect a "wake-up" call and return a burst of data, must operate on very low quiescent current for weeks or months, yet have enough battery power in reserve to answer an incoming call. For smallest size, most operate in the ultrahigh frequency range, where the design of a micropower receiver circuit is problematic. Familiar techniques, such as direct conversion, super regeneration or superheterodyne, consume far too much supply current for long battery life. A better method involves a technique borrowed from simple field-strength meters: a tuned circuit and a diode detector.

Figure 1 shows the complete circuit, which was tested at 470MHz. This circuit contains a couple of improvements over the standard L/C-with-whip field-strength meter. Tuned circuits aren't easily constructed or controlled at UHF, so a transmission line is used to match the detector diode (1N5711) to a 6" whip antenna. The 0.4-wavelength section presents an efficient, low impedance match to the base of the quarter-wave whip, but transforms the received energy to a relatively high voltage at the diode for good sensitivity.

Biasing the detector diode improves the sensitivity by an additional 10dB. The forward threshold is reduced to essentially zero, so a very small voltage can generate a meaningful output change. The detector diode's bias point is monitored by an LTC1440 ultralow power comparator, and by a second diode, which serves as a reference.

When a signal at the resonant frequency of the antenna is received, Schottky diode D1 rectifies the incoming carrier and creates a negative-going DC bias shift at the noninverting input of the comparator. Note that the bias shift is sensed at the base of the antenna where the impedance is low, rather than at the Schottky where the impedance is high. This introduces less disturbance into the tuned antenna and transmission-line system. The falling edge of the comparator triggers a one-shot, which temporarily enables answer-back and other pulsed functions.

Total current consumption is approximately 5µA. Monolithic one-shots draw significant load current, but the venerable '4047 is about the best in this respect. Alternatively, a discrete one-shot constructed from a quad NAND gate draws negligible power.

Sensitivity is excellent. The finished circuit can detect 200mW radiated from a reference dipole at 100'. Range, of course, depends on operating frequency, antenna orientation and surrounding obstacles; in the clear, a more reasonable distance, such as 10', can be covered at 470MHz with only a few milliwatts.

All selectivity is provided by the antenna itself. Add a quarter-wave stub (shorted with a capacitor) to the base of the antenna for better selectivity and improved rejection of low frequency signals.

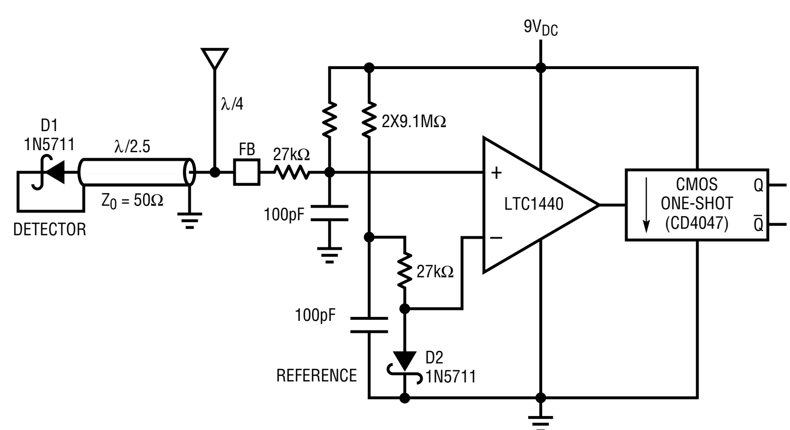

Figure 1. Micropower field detector for use at 470MHz

LT1256 Voltage-Controlled Amplitude Limiter

by Frank Cox

Amplitude-limiting circuits are useful where a signal should not exceed a predetermined maximum amplitude, such as when feeding an A/D or a modulator. A clipper, which completely removes the signal above a certain level, is useful for many applications, but there are times when it is not desirable to lose information. For instance, when video signals have amplitude peaks that exceed the dynamic range of following processing stages, simply clipping the peaks at the maximum level will result in the loss of all detail in the areas where clipping takes place. Often these well illuminated areas are the primary subject of the scene. Because these peaks usually correspond to the highest level of luminosity, they are referred to as "highlights." One way to preserve some of the detail in the highlights is to automatically reduce the gain (compress) at high signal levels.

The circuit in Figure 1 is a voltage-controlled breakpoint amplifier that can be used for highlight compression. When the input signal reaches a predetermined level (the breakpoint), the amplifier gain is reduced. As both the breakpoint and the gain for signals greater than the breakpoint are voltage programmable, this circuit is useful for systems that adapt to changing signal levels. Adaptive highlight compression finds use in CCD video cameras, which have a very large dynamic range. Although this circuit was developed for video signals, it can be used to adaptively compress any signal within the 40MHz bandwidth of the LT1256.

The LT1256 video fader is connected to mix proportional amounts of input signal and clipped signal to provide a voltage-controlled variable gain. The clipped signal is provided by a discrete circuit consisting of three transistors. Q1 acts as an emitter follower until the input voltage exceeds the voltage on the base of Q2 (the breakpoint voltage or V_{BP}). When the input voltage is greater than V_{BP}, Q1 is off and Q2 clamps the emitters of the two transistors to V_{BP} plus a V_{BE}. Q3, an NPN emitter follower, buffers the output and drops the voltage a V_{BE} and thus the DC level of the input signal is preserved to the extent allowed by the V_{BE} matching and temperature tracking of the transistors used. The breakpoint voltage at the base of Q2 must remain constant when this transistor is turning on or the signal will be distorted. The LT1363 maintains a low output impedance well beyond video frequencies and makes an excellent buffer.

Figure 2 is a multiple-exposure photograph of a single line of monochrome video, showing four different levels of compression ranging from fully limited signal to unprocessed input signal. The breakpoint is set to 40% of the peak amplitude to clearly show the effect of the circuit; normally only the top 10% of video would be compressed.

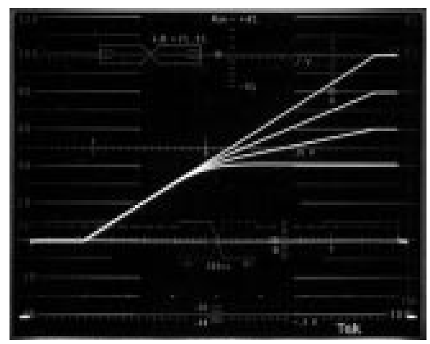

Figure 2. Multiple-exposure photograph of a single line of monochrome video, showing four different levels of compression

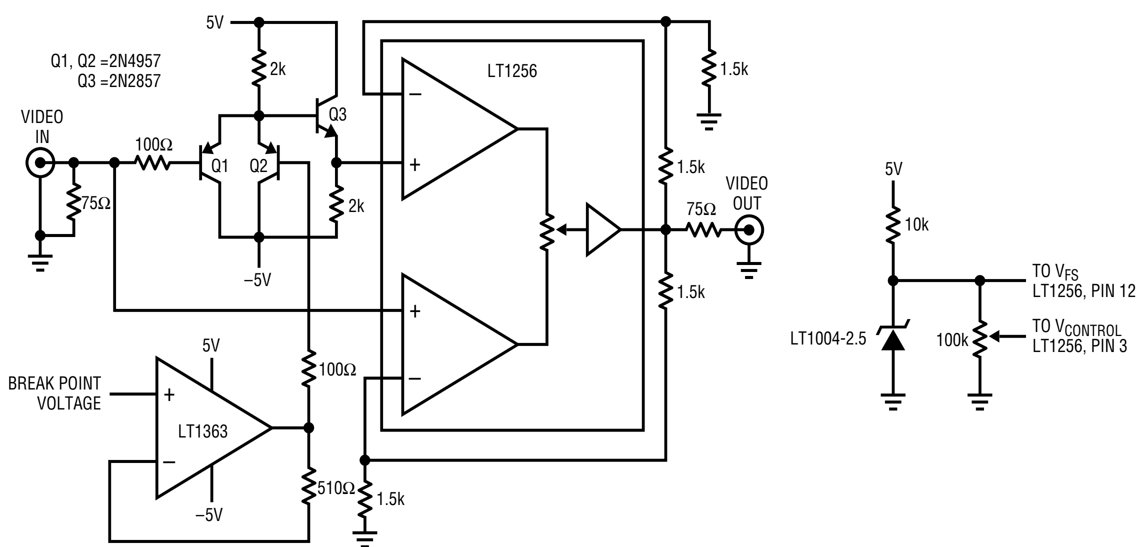

Figure 1. Voltage-controlled amplitude limiter

New IC Features Reduce EMI from Switching Regulator Circuits

by John Seago

One disadvantage of using a switching regulator is that it generates electronic noise, known as EMI (electromagnetic interference). This noise can be conducted or radiated, and it can affect other circuits in your product or interfere with the operation of nearby products. The LTC1436-PLL, LTC1437, LTC1439 and LTC1539 have features that can be used to suppress this interference.

Frequently, EMI problems don't show up until the integration phase of product development. By using this EMI suppression capability, a resistor- or capacitor-value change may be all that is required to solve an interference problem. The LTC1436-PLL shown in the circuit of Figure 1 produces a switched 5V, 3A output and a 3.3V, 0.1A linear output. The circuit is configured to provide either switch-frequency synchronization or switch-frequency modulation. Also, transistor Q3 ensures constant frequency at very low output current levels, thus eliminating audio frequencies and maintaining high efficiency using the internal Adaptive Power™ circuitry.

Switch-Frequency Synchronization

Switching regulator noise results from switching high currents on and off. This creates high energy levels at the switching frequency and all of its harmonics. A common EMI-control technique is to synchronize the switching frequency to an external clock so that all harmonic frequencies can be controlled. The LTC1436-PLL uses a phase-locked loop for synchronization to avoid the loss of slope compensation common to other synchronizing techniques. In addition, the input to the VCO in the phase-locked loop is available at the PLL LPF (phase-locked loop lowpass filter) pin so, that a lowpass filter can be used to control how fast the loop acquires lock.

Switch-Frequency Modulation

Access to the VCO input also makes it possible to modulate the regulator's switching frequency. Through frequency modulation, the peak energy of the fundamental is spread over the frequency range of modulation, thus decreasing the peak energy level at any one frequency. This frequency spreading action increases with each harmonic, so that the second harmonic has twice the bandwidth and the third harmonic has three times the bandwidth until all the harmonics blend together, decreasing the signal strength at all frequencies. This can be seen in the spectrum analyzer plots shown in Figures 2, 3 and 4.

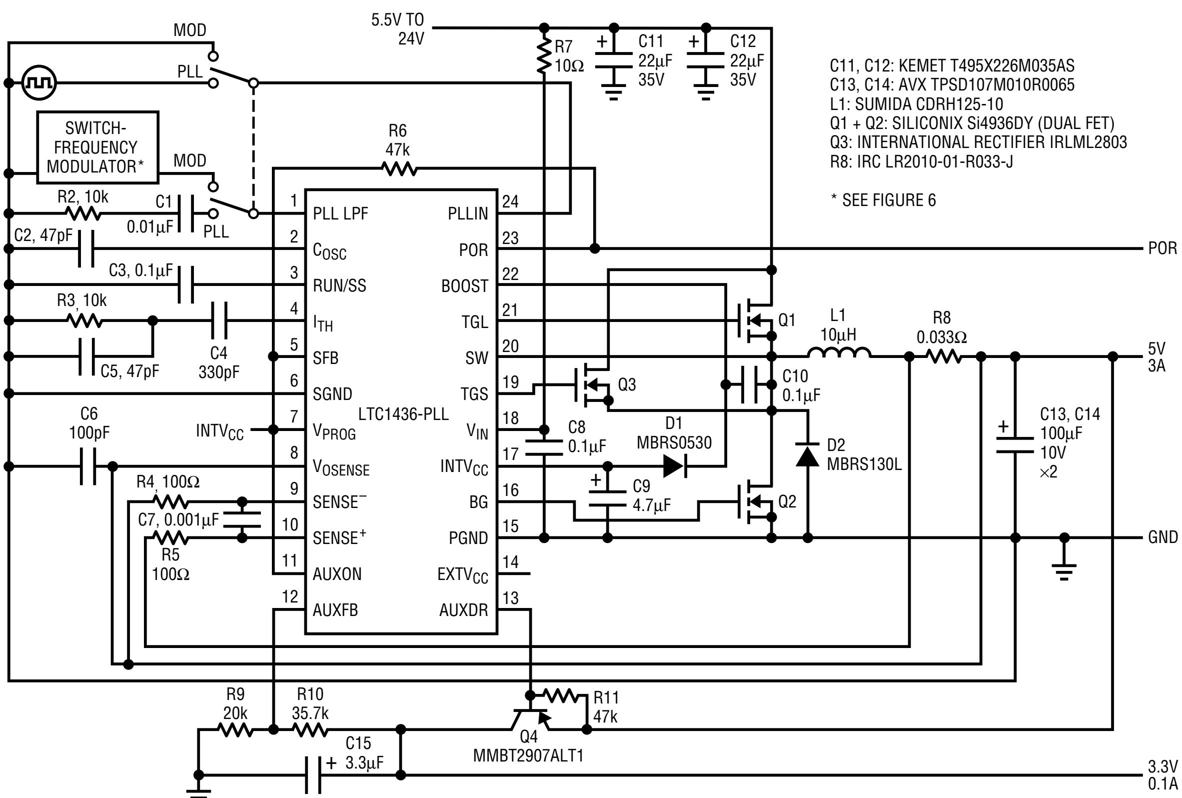

Figure 1. 2-output LTC1436-PLL test circuit

Figure 2 shows the full load output noise level from the circuit of Figure 1, before and after switch-frequency modulation. The black trace shows the normal output noise from 1kHz to 1MHz with the VCO at minimum frequency, whereas the colored trace shows output noise after modulation around the center frequency. The 228kHz unmodulated switch-frequency output noise decreased more than 30dB through modulation between 270kHz and 370kHz. Figures 3 and 4 show a 10dB to 15dB attenuation in full-load output voltage noise from 1MHz to 30MHz after modulation.

The VCO in the LTC1436-PLL has an input range from 0V to 2.4V. As shown in Figure 5, the switch frequency can be modulated at least ±30% around the center frequency f_O. The ideal modulating signal varies an equal amount above and below the center frequency voltage of 1.2V, with a constant slope. The reference circuit of Figure 6 develops a 100Hz sawtooth voltage from 0.9V to 1.5V that modulates the LTC1436-PLL in Figure 1 to generate the plots shown in Figures 2, 3 and 4. Modulator circuit complexity is largely determined by functional requirements. For most applications, a precision modulating signal is not required, because high order harmonics blend together. Consequently, modulating frequency, slope and peak-to-peak voltage are not critical.

Audio Frequency Suppression

The Adaptive Power feature of the LTC1436-PLL significantly reduces audio frequency generation, while maintaining good efficiency under very light load conditions. Figure 7 shows the audio frequencies generated by the highly efficient cycle skipping mode of the LTC1436-PLL. Figure 8 shows the decrease in audio frequencies resulting from Adaptive Power operation. Figure 9 shows efficiency curves of both the cycle skipping and Adaptive Power modes along with the traditional, forced continuous mode of operation.

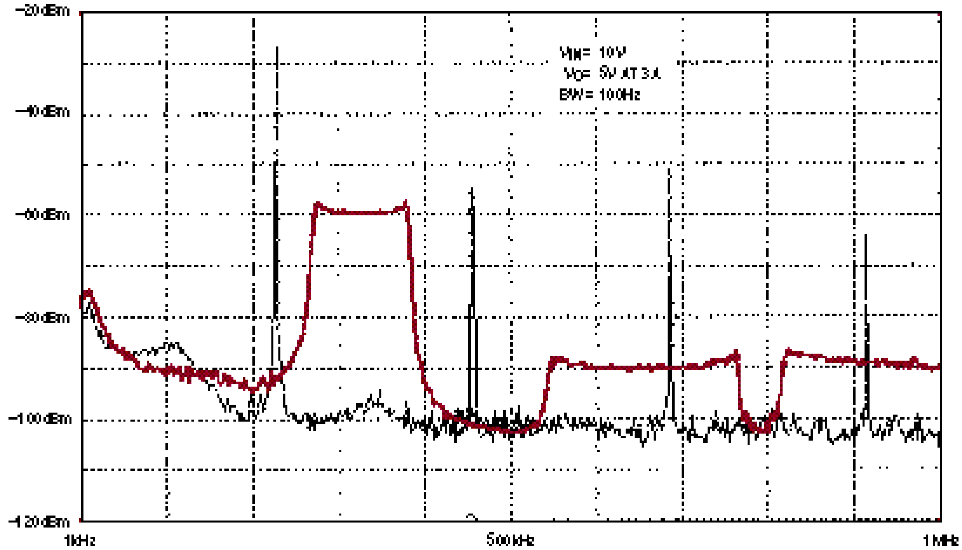

Figure 2. Output noise before and after switch-frequency modulation

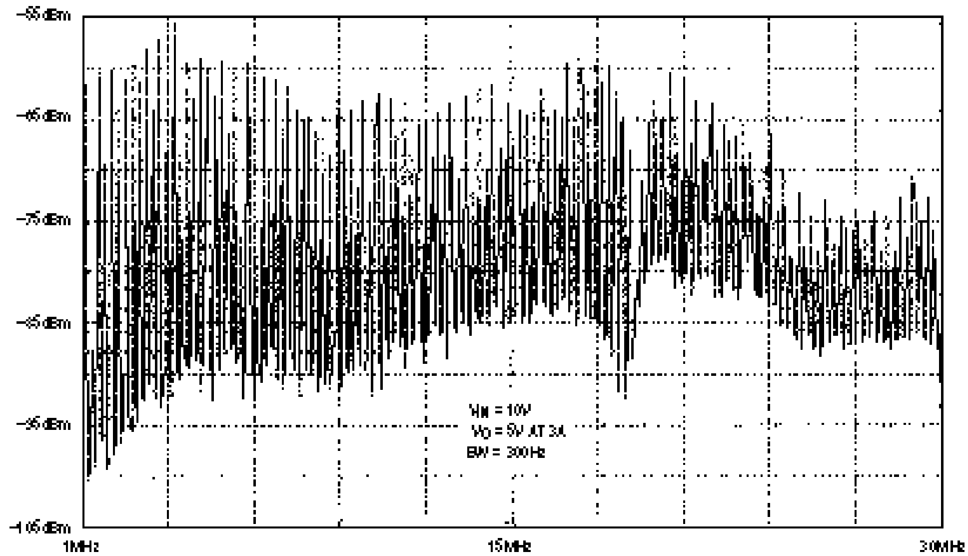

Figure 3. Output high frequency noise before switch-frequency modulation

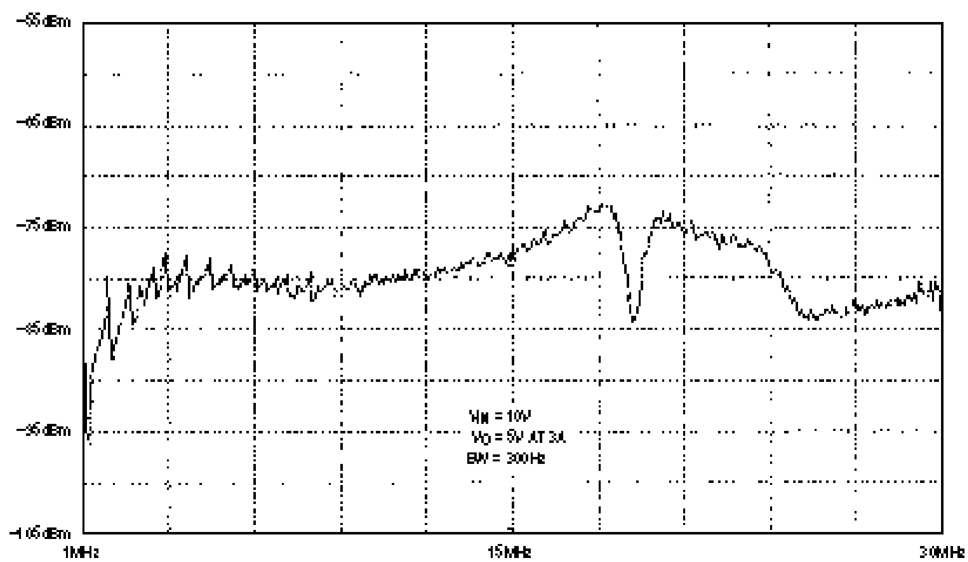

Figure 4. Output high frequency noise after switch-frequency modulation

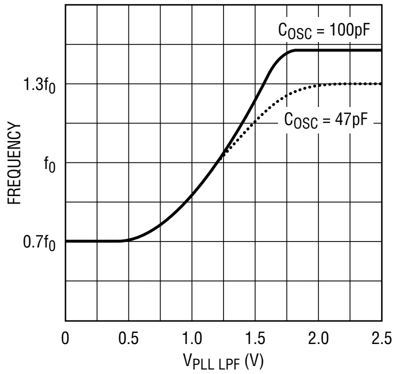

Figure 5. Operating frequency vs V_{PLLPF}

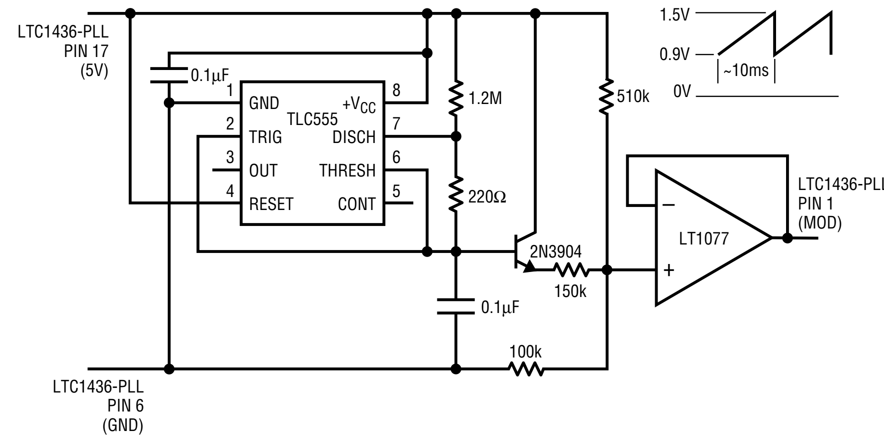

Figure 6. Switch-frequency modulator

Cycle skipping is the most efficient mode during light-load operation, where the output capacitor supplies load current most of the time and is replenished by bursts of energy at a rate determined by the load. When load current is low enough, the burst rate falls into the audio-frequency range, which can cause problems. With the addition of Q3, an inexpensive SOT-23 size MOSFET, the Adaptive Power circuitry inside the LTC1436-PLL takes control during light load conditions, turning off high current MOSFETs Q1 and Q2. Q3 and D2 are then used in a conventional constant frequency buck mode, eliminating the power loss caused by charging and discharging the large input capacitance of both power MOSFETs.

The conventional way of avoiding audio-frequency interference is the forced current mode, where both high current MOSFETs continue to operate at full frequency and normal duty cycle under all load conditions. This causes the peak-to-peak inductor current to flow, even under no load conditions. The synchronous buck topology allows the top switch, Q1, to put current into the output capacitor, followed by the bottom switch, Q2, taking current out of the output capacitor while regulating the output voltage under no-load conditions. Although constant frequency is maintained, high current I^2R losses and high gate charge losses continue under light load conditions. LTC1436-PLL features forced-current operation to provide the fast transient response required for high di/dt loads like the Intel Pentium® processor.

Cycle skipping, Adaptive Power and forced current operation are all available on the LTC1436-PLL, so that the best operating mode can be selected for each application.

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Conclusion

The family of LTC1436-PLL parts offers very effective EMI suppression features. Reviewing the spectrum analyzer plots in Figures 2, 3 and 4 shows that the output voltage noise amplitude can be significantly reduced at frequencies to 30MHz with switch-frequency modulation. The Adaptive Power mode provides high efficiency, constant-frequency operation at very low output currents and avoids audio frequency operation.

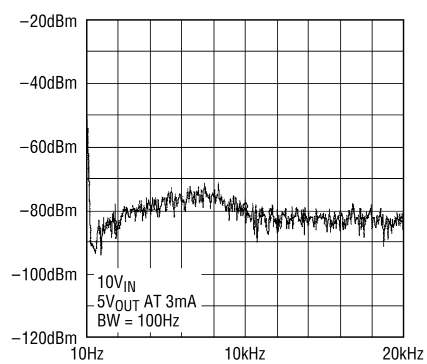

Figure 8. Output noise with Adaptive Power mode operation

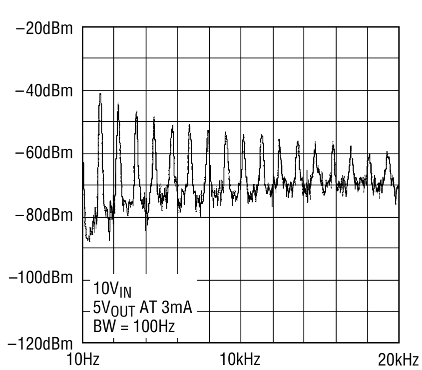

Figure 7. Audio frequencies in output noise during cycle-skipping operation

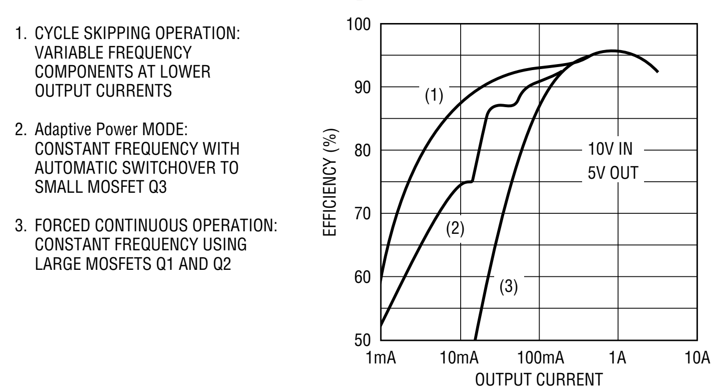

Figure 9. Efficiency curves for light load currents

Dual-Output Voltage Regulator

by Peter Guan

The LTC1266-3.3 and LTC1263 are perfect complements for one another. The combination of these two parts provides two regulated outputs of 3.3V/5A and 12V/60mA from an input range of 4.75V to 5.5V. These two outputs are perfect for notebook and palmtop computers with microprocessors that burn several amps of current from a regulated 3.3V supply, flash memories that consume milliamps of current from a regulated 12V supply and interface and logic components that still run off the 5V supply. In fact, this quick and easy combination may well be the aspirin for many of the headaches caused by the rigorous power supply demands in today's electronics.

The LTC1263, using only four external components (two 0.47µF charge capacitors, one 10µF bypass capacitor and a 10µF output capacitor), generates the regulated 12V/60mA output from a 5V input using a charge pump tripler. During every period of the 300kHz oscillator, the two charge capacitors are first charged to V_{CC} and then stacked in series, with the bottom plate of the bottom capacitor shorted to V_{CC} and the top plate of the top capacitor connected to the output capacitor. As a result, the output capacitor is slowly charged up from 5V to 12V. The 12V output is regulated by a gated oscillator scheme that turns the charge pump on when V_{OUT} is below 12V and turns it off when it exceeds 12V.

The LTC1266-3.3 then uses the 5V input along with the 12V output from the LTC1263 and various external components, including bypass capacitors, sense resistors and Schottky diodes, to switch two external N-channel MOSFETs and a 5µH inductor to charge and regulate the 3.3V/5A output. The charging scheme for this part, however, is very different from that of the LTC1263. The LTC1266-3.3 first charges the output capacitor by turning on the top N-channel MOSFET, allowing current to flow from the 5V input supply and through the inductor. By monitoring the

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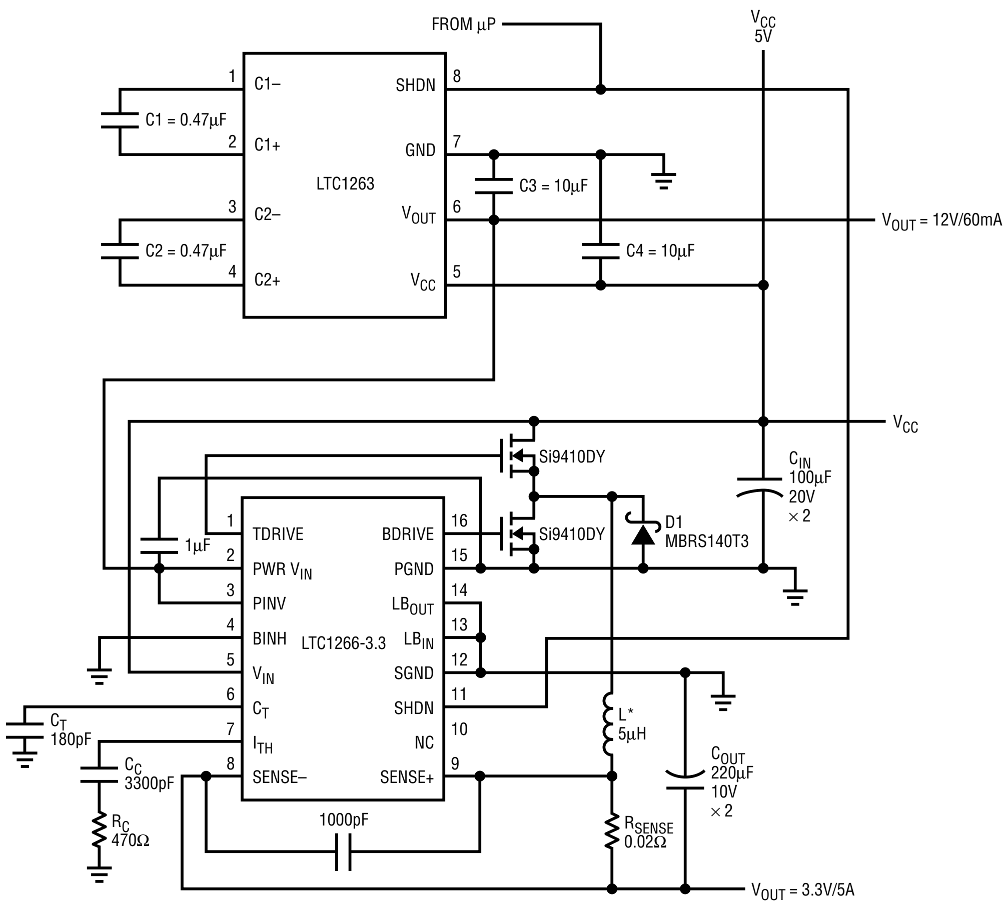

*COILTRONICS CTX0212801

Figure 1. 5V to 3.3V/5A and 12V/60mA supply

Free Digital Panel Meters from the Oppressive Yoke of Batteries

by Mitchell Lee

Digital panel meters (DPMs) have dropped in price to well under $10 for 3-1/2 digit models, even in single-piece quantities. These make excellent displays for many instruments, but suffer from one major flaw: they require a floating power supply, usually in the form of a 9V battery. This renders inexpensive meters useless for most applications because no one wants multiple 9V batteries in their product.

The circuit shown in Figure 1 powers up to five meters from a single 1.8V to 6V source. The source need not be floating, yet all five outputs are fully floating, isolated and independent in every respect. The circuit consists of an LT1303 micropower, high efficiency DC/DC converter driving a 5-output flyback converter. An off-the-shelf surface mount coil, Coiltronics' Versa-Pac™ VP1-0190, is used as the transformer. This device is hipot tested to $500V_{RMS}$—more than adequate for most applications.

Feedback is extracted from the primary by Q1, which samples the flyback pedestal during the switch off time. Typical DPMs draw approximately 1mA supply current. The primary is also loaded with 1mA for optimum regulation and ripple. Primary snubbing components, a necessity in most flyback circuits, are obviated by the primary feedback rectifier and smoothing capacitor. Although this circuit has been set up for 9V output (9.3V, to be exact), some DPMs need 5V or 7V. Use a 4.3k or 6.2k r esistor in place of R1 for these voltages. The output voltage is set by

$$R1 = (V_{OUT} – 0.7)/1mA.$$

Do not attempt to regulate the output beyond 10V or you will exceed the maximum switch rating of the LT1303. The LT1111 is better suited for higher voltage applications.

Output ripple measures $200mV_{P–P}$ and can be proportionately reduced by increasing the output capacitance. If more ripple is acceptable, the output capacitors can be reduced in value. A shutdown feature is available on the LT1303, useful where a "sleep" function is included to save power.

With each output loaded at 1mA, the input current is 16.5mA on a 5V supply. This figure rises to about 45mA on a 1.8V (2-cell) input. If the system is battery operated and if the battery voltage does not exceed 7V, operate the circuit directly from the battery for best efficiency. In line-operated equipment, use a regulated 5VDC or 3.3VDC supply.

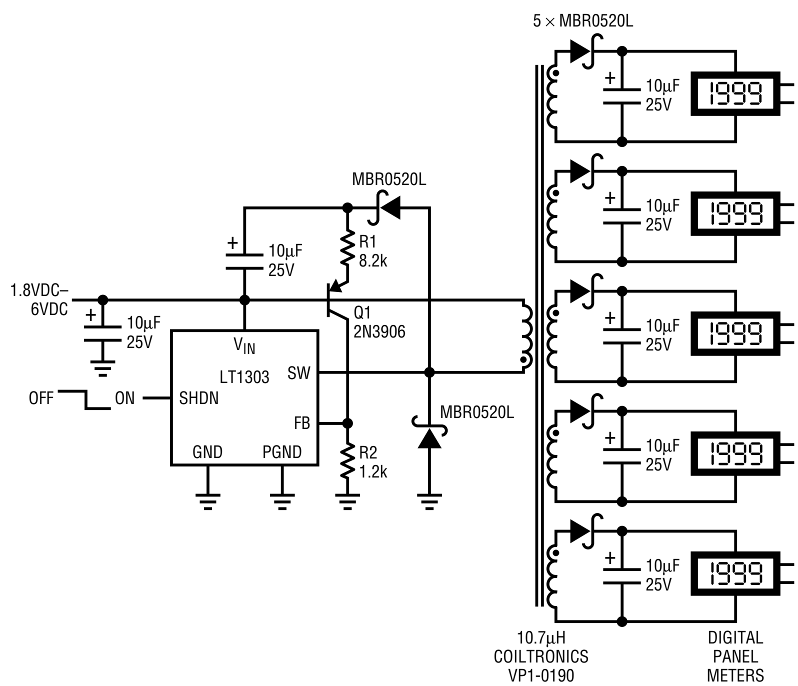

Figure 1. LT1303 flyback regulator provides fully floating and isolated 9V supplies to five independent digital panel meters. Substitute 4.3k for R1 if 5V meters are used.

Battery Charger IC Can Also Serve as Main Step-Down Converter

by Arie Ravid

Using a power adapter with the highest feasible output voltage is attractive to portable system designers for a couple of reasons. Lower current is required to maintain the same system power, which translates into a smaller cable and input connector. If the adapter output voltage is considerably higher than the battery voltage, the adapter output voltage does not need to be regulated or well filtered, resulting in lower adapter cost.

A portable system with a high output-voltage adapter, however, requires that the system's DC-to-DC converter functions over a very wide range of input voltage: from fully discharged battery voltage to the highest adapter output voltage.

This problem can be resolved by using the LT1510 as both the battery charger and the main step-down converter, as shown in Figure 1. An important feature of the circuit in Figure 1 is the glitch-free transfer from AC operation to battery operation and back.

The LT1510 battery charger IC is capable of charge current up to 1.5A and output (battery) voltage up to 20V. High efficiency and small inductor size are achieved by a saturating switch running at 200kHz. The LT1510 is capable of charging lithium-ion and sealed-lead-acid batteries in the constant-voltage/constant-current configuration, and nickel-cadmium and nickel-metal-hydride batteries in the constant-current configuration. The LT1510 contains an internal switch and current sense resistor. All the designer needs to do in order to program the current and voltage is select the current-programming resistor and the voltage-divider resistors.

In the circuit shown in Figure 1, the system's DC-to-DC converter is connected to the SENSE pin. This way, the internal sense resistor is bypassed for the system load but is active in regulating the charge current. The sum of the charge current and system current should not exceed the maximum output current allowed (limited by thermal considerations or peak switch current). Since the DC-to-DC converter circuit has a large input capacitor, it cannot be connected directly to the SENSE pin. This is because the internal sense resistor between SENSE and BAT pins will see a large capacitance across it, which will cause instability. A 2.2mH inductor, such as the DT1608C-222 by Coilcraft (L2), is used to isolate the input capacitance of the DC-to-DC converter. CR5 limits the transient current through the LT1510's internal sense resistor when the system is operating on battery and turned on. Q2 (Si9433) is required if the series resistance of 0.2 between the BA T pin and SENSE pin is too high. The Si9433's on resistance is 0.075 . The

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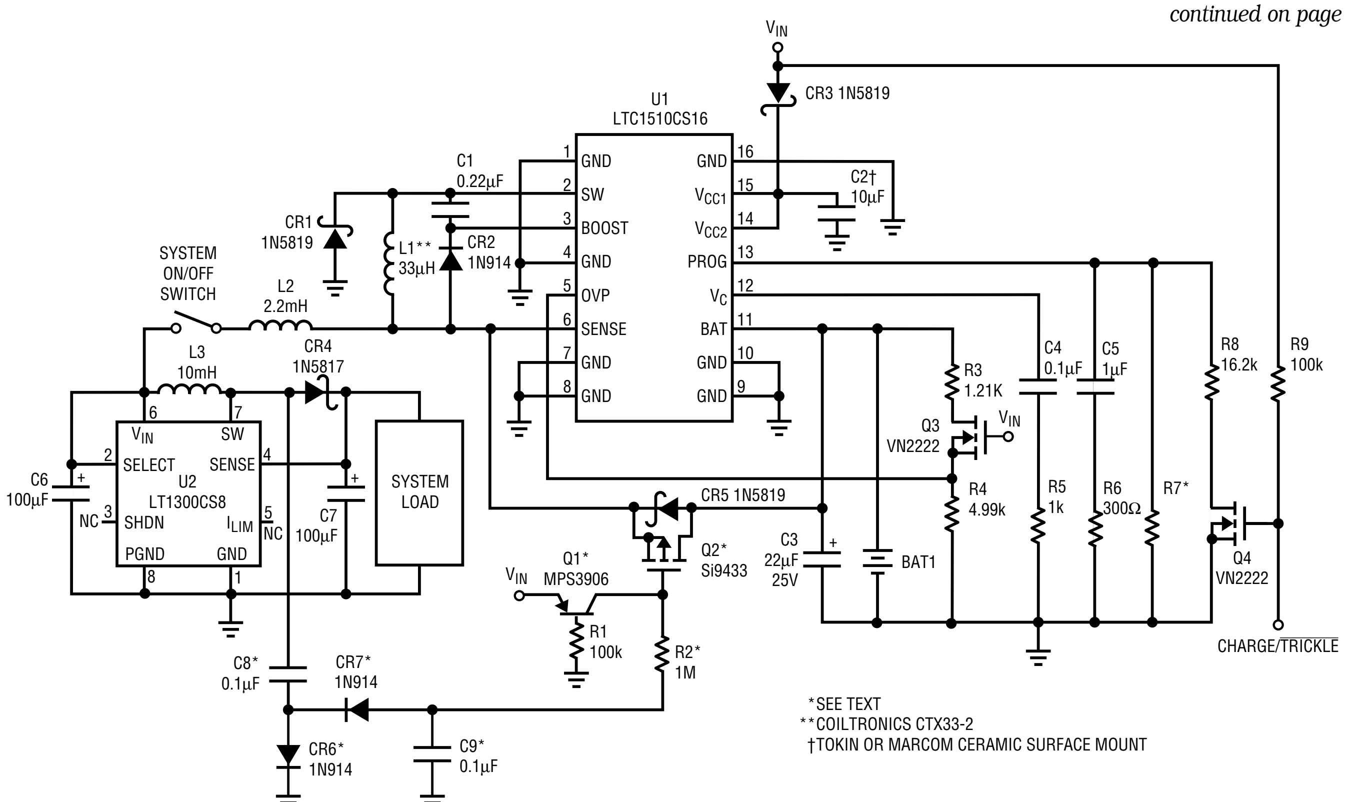

Figure 1. LT1510 battery charger/main step-down converter provides glitch-free transfer between AC and battery operation.

Combine a Switching Regulator and an UltraFast Linear Regulator for a High Performance 3.3V Supply

by Craig Varga

Introduction

It is becoming increasingly necessary to provide low voltage power to microprocessor loads at very high current levels. Many processors also exhibit high speed load transients. The Pentium® Pro processor from Intel exhibits both of these requirements. This processor requires 3.3V ±5% at approximately 14A peak (9A average) and is capable of making the transition from a low power state to full load in several clock cycles. Generally, switching regulators are used to supply such high power devices, because of the unacceptable power losses associated with linear regulators. Unfortunately, switching regulators exhibit much slower transient response than linear regulators. This greatly increases the output capacitor requirements for switchers.

Pentium is a registered trademark of Intel Corp.

Circuit Operation

The circuit shown in Figure 1 takes advantage of a new, ultrahigh speed linear regulator combined with a switching regulator to get the best of both worlds. An LTC1435 synchronous buck regulator is combined with an LT1575 linear regulator to generate a 3.3V output from a 12V input with an overall conversion efficiency of approximately 72%. The output is capable of current slew rates of approximately 20A per microsecond.

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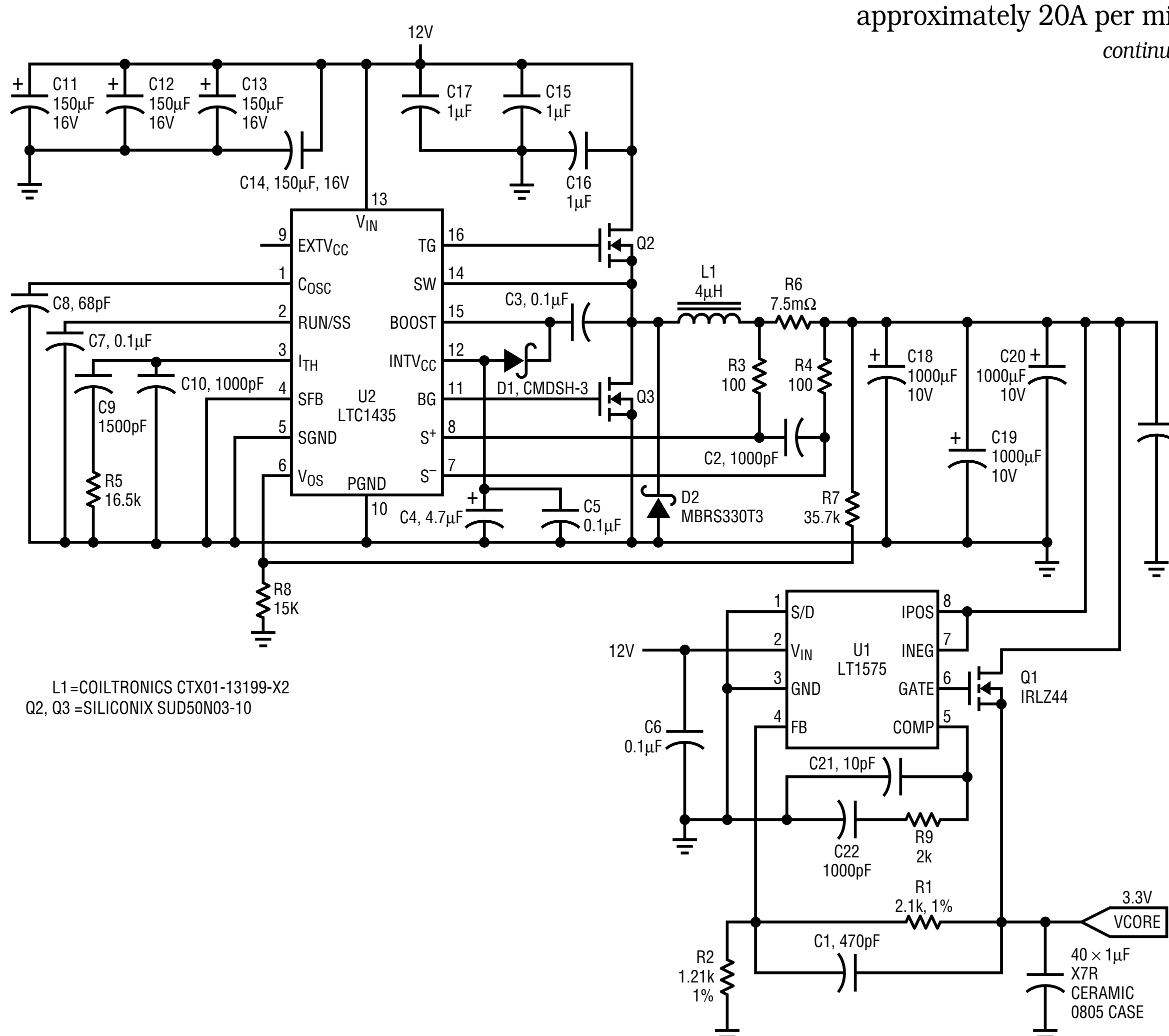

Figure 1. 12V to 3.3V/9A (14A peak) hybrid regulator

What Efficiency Curves Don't Tell

by San-Hwa Chee

Introduction

In switching regulators' data sheets, there are always efficiency curves that show how efficient the regulators are in transforming one voltage to another. Although these curves are useful in comparing one regulator to another, they don't allow a system designer to determine accurately how long batteries will last before they need to be replaced or recharged when they are used as the power source. This complication arises because the type of batteries used to power the system and the regulator load characteristic strongly affect the lifetime of the batteries.

In this article, battery lifetime curves are obtained for the LTC1174 and the LTC1433.

A Short Introduction to the LTC1174 and LTC1433

The LTC1174 uses a constant off-time architecture to switch its internal P-channel power MOSFET. The input-to-output voltage ratio sets the on time and requires the inductor current to reach a preset limit. Even at low load current, the LTC1174 still requires the inductor current to reach the preset limit before it initiates the off-time cycle. Burst Mode operation of the LTC1174 enhances efficiency throughout the load-current range by switching only the required number of cycles to bring the output into regulation and then stopping switching (going into sleep mode). When the output voltage has dropped slightly, the switching sequence resumes. By doing this, switching losses are reduced and are minimized when the load current is low, because the sleep duration is long.

The LTC1433 is a constant-frequency, current mode, monolithic switching regulator in which the inductor peak current varies according to the load current. In place of Burst Mode operation, the LTC1433 has an Adaptive Power output stage to enhance its efficiency at low load current. Under low load conditions, the LTC1433 uses only a fraction of its power MOSFET, effectively reducing switching losses without introducing low frequency noise components.

For more information on both parts, consult the data sheets.

The Setup

The circuits in Figures 1a, 1b and 1c were used to obtain the lifetime data. All outputs were set at 3.3V and the power was supplied by either four AA alkaline (Eveready No. EN91) or four AA NiCd (Eveready No. CH15) cells or a single 9V alkaline (Eveready No. EN22) battery. A current-sink load was set up to either draw a constant 400mA or provide a load-step characteristic. The load stepping operated at 0.05Hz, going from 10mA to 410mA with a duty cycle of 10%, providing an average load current of 50mA.

In Figure 1b, the LTC1433 was set up to optimize low load current efficiency by configuring the Adaptive Power output stage with separate inductors for low and high current operation.

Efficiency curves for each circuit are shown in Figure 2a and 2b. Figures 3 through 8 show the battery voltage and regulator output voltage versus time for various battery and load combinations.

4-Cell to 3.3V Configuration

Figures 3 and 4 were obtained with a load current of 400mA. For Figure 3, the input power to the regulator was provided by four AA alkaline batteries, whereas four AA NiCds were used in Figure 4. The alkaline batteries lasted longer than the NiCds, due to

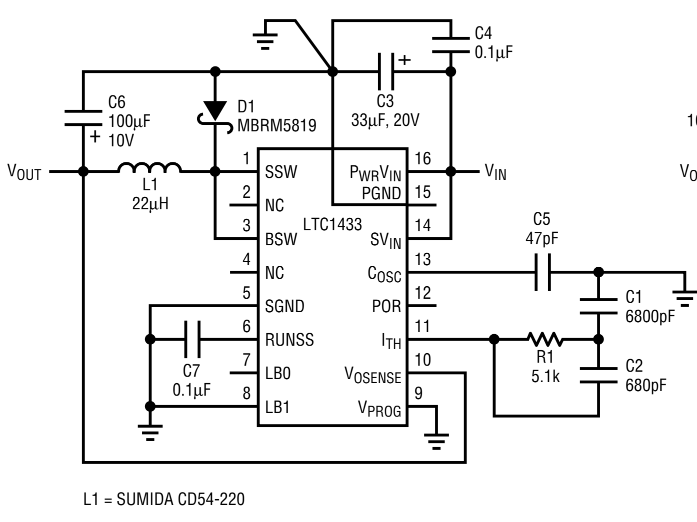

Figure 1a. LTC1433 single-inductor configuration

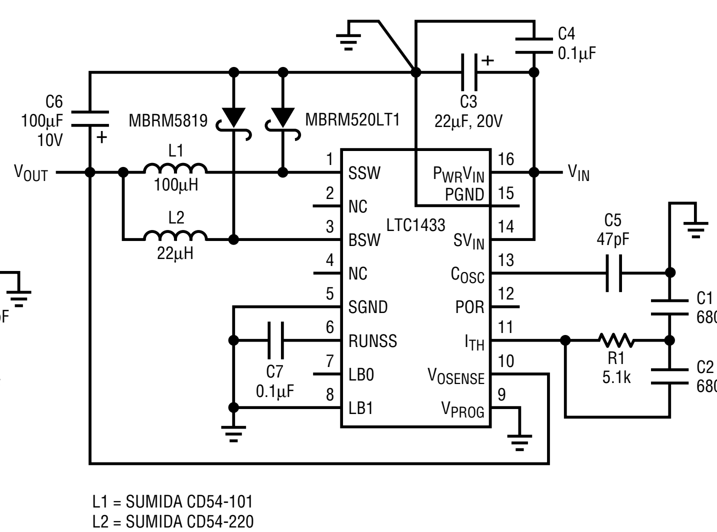

Figure 1b. LTC1433 dual-inductor configuration

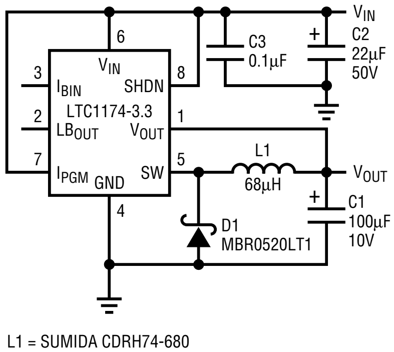

Figure 1c. LTC1174 test circuit

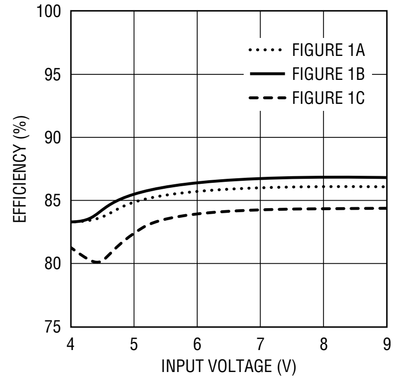

Figure 2a. Efficiency curves for Figure 1's circuits, I_{LOAD} = 400mA

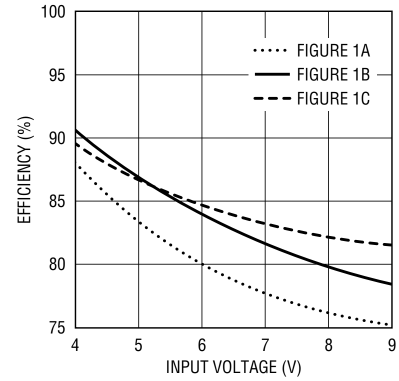

Figure 2b. Efficiency curves for Figure 1's circuits, I_{LOAD} = 10mA

their higher energy capacity. From Figure 4, it is apparent when the NiCd gives up, from the cliff-like shape of the output voltage.

For Figures 5 and 6, a step load was applied to the regulators instead of a DC load. Figure 5 and 6 are the data obtained for alkaline and NiCd AA cells, respectively. With the average load one-eighth of the previous experiment, it would be expected that the lifetime of the alkaline batteries would be eight times longer or approximately 18 hours, but Figure 5 shows a significantly better result. The main reason for this improvement has to do with the internal resistance of the alkaline cell. At high constant DC load current, heat is dissipated by the internal resistance of the alkaline batteries. The internal resistance increases as the batteries voltage decreases, and hence causes more heat to be dissipated, thus lowering the lifetime.

For the NiCd battery, internal resistance is low and remains relatively constant over its life span. Therefore, the lifetime of the NiCd batteries for the load step case comes out to be approximately the expected eight times that of a constant DC load current.

The above result indicates that if the load is intermittent in nature, the user can operate the device much longer if the power is provided by

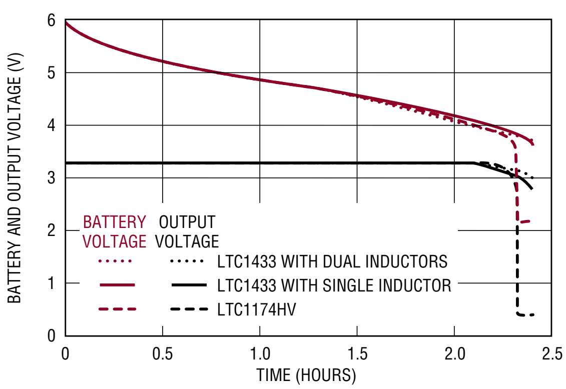

Figure 3. Lifetime at I_{LOAD} = 400mA—four AA alkaline batteries

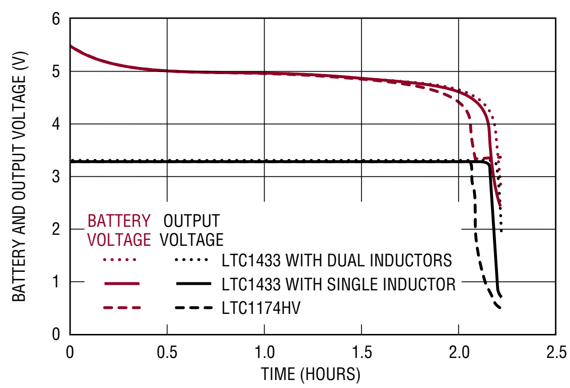

Figure 4. Lifetime at I_{LOAD} = 400mA—four AA NiCd batteries

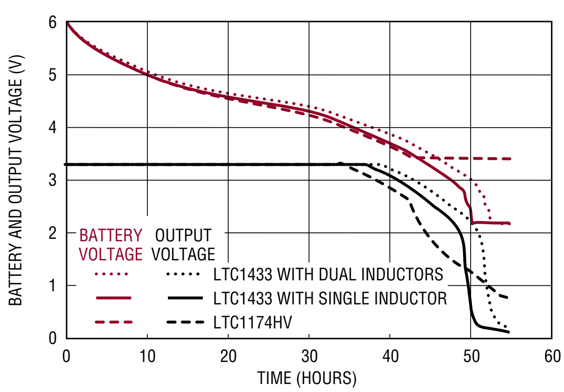

Figure 5. Lifetime with load step from 10mA to 410mA, 10% duty cycle, T_{PERIOD} = 20s—four AA alkaline batteries

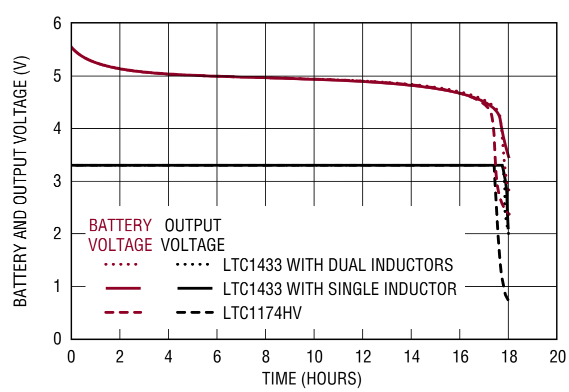

Figure 6. Lifetime with load step from 10mA to 410mA, 10% duty cycle, T_{PERIOD} = 20s—four AA NiCd batteries

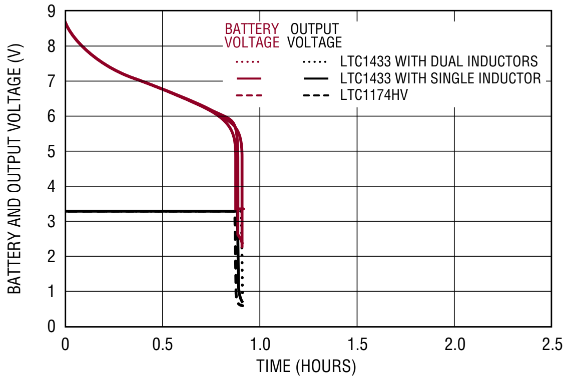

Figure 7. Lifetime at I_{LOAD} = 400mA—one 9V alkaline battery

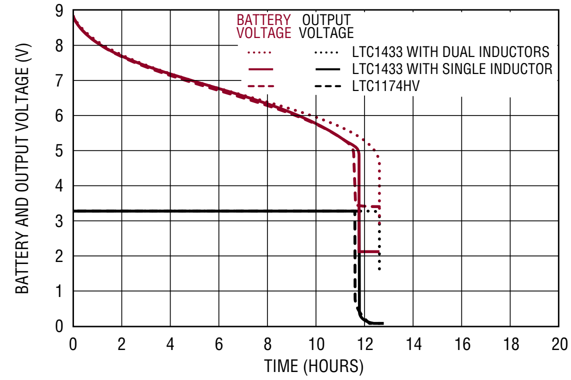

Figure 8. Lifetime with load step from 10mA to 410mA—one 9V alkaline battery (10% duty cycle, T_{PERIOD} = 20s)

alkaline batteries. Again, the NiCd exhibits a sudden "death" at the end of its life, whereas the alkaline shows a much gentler decay. The gentle sloping of the output voltage of Figure 5 towards the end of the battery life can be attributed to the on-resistance of the switch when the regulator is in dropout.

For the above load characteristic, where the load is light most of the time, making full use of the Adaptive Power mode of the LTC1433 by means of the dual inductor configuration helps to squeeze an additional 1.5 hours of life compared to the single inductor LTC1433 configuration.

Another important point to note is that although the efficiency for the LTC1174 is better than that of the single inductor configuration of the LTC1433 at 10mA load current, the LTC1433 lasted 2.9 hours longer than the LTC1174 in Figure 5. The reason for this is that the LTC1174 inductor's current always ramps up to the preset value of 600mA whether the load current is at 10mA or at 410mA. This high peak inductor current, combined with the high internal resistance of the alkaline AA cells, shortens the lifetime. Figure 6 shows that the use time is about the same for the LTC1174 and the LTC1433 because of the low, constant internal resistance of the NiCd batteries.

9V-to-3.3V

The lifetime graphs are shown in Figures 7 and 8. Comparing the data between the 9V and the AA alkaline cells, the lifetime of the AA cells is about 2.5 times longer. This is because the energy capacity of the 9V alkaline is much smaller than that of the AA cells. In addition, the internal resistance of the 9V alkaline is much higher than the AA cells, causing more energy to be dissipated as heat. For the load step case, the battery lasted 13.8 times longer than a constant 400mA load. The dual inductor configuration of the LTC1433 lasted about an hour longer than the single inductor one.

Conclusion

Although a switching regulator can be highly efficient, its architecture, the type of load it is driving and its power source can have a significant effect on how long batteries will last. For a load that varies from low load to heavy load at low duty cycle, it is worthwhile to consider powering your system with alkaline batteries, because they last longer. For a constant heavy load, NiCd and alkaline come out to be about the same but NiCds, of course, can be recharged.

Dual-Output, continued from page 26

amount of current flow in the inductor with a sense resistor, the 3.3V output is regulated by turning on and off the top and bottom N-channel MOSFETs to charge and discharge the output capacitor.

If we replaced the top external N-channel MOSFET with a P-channel, the LTC1266-3.3 could generate the same 3.3V/5A output without the help of the LTC1263. But, since N-channel MOSFETs have lower gate capacitance and lower $R_{DS(ON)}$, their higher efficiency at high currents more than compensates for the extra complexity in bringing in another higher input voltage, especially if that second input voltage is readily available.

Since both of these devices are very stingy on quiescent current, their combination is also very gentle to the main power supply, especially if that power supply is a battery. In standby mode, the LTC1263 and the LTC1266-3.3 have a total quiescent current of about 500µA. To conserve even more current, both of these parts can be put into shutdown mode by floating their shutdown pins or pulling them high. The total shutdown current is less than 40µA. When loaded, the LTC1263 has a 76% efficiency, whereas the LTC1266-3.3 can squeeze out more than 90%. Together, with a 60mA load at the 12V output and a 5A load at the 3.3V output, the overall efficiency is 87%.

The LTC1266-3.3 is available in the 16-pin SO package and the LTC1263 is available in the 8-pin SO package. Together, these two parts provide an easy and efficient solution for multiple power supply demands.

Introducing the LT2078/LT2079 and LT2178/LT2179 Single Supply, Micropower, Precision Amplifiers in Surface Mount Packages

by Raj Ramchandani

Introduction

Circuit designers seldom have an opportunity to revisit a product as successful as the LT1078/LT1079 and LT1178/LT1179 dual and quad micropower precision op amps. In the last decade, these amplifiers have become true industry standards, with outstanding DC precision and only 55µA and 21µA of supply current per op amp, respectively. A look at the data sheet shows that the LT1078 and LT1178 have much better offset voltage and offset voltage drift in the dual in-line package (DIP) than in the small outline surface mount package (SO) (see Table 1). Since the introduction of these parts, the demand for surface mount packages has grown dramatically; today, the majority of ICs sold are in surface mount packages. The new LT2078 and LT2178 deliver the precision performance of the LT1078 and LT1178 in SO packages without changing any of the other characteristics that made these parts so popular.

Package Limitations of Precision Specs

An inherent problem with precision ICs is that as circuit design and process innovations improve the performance, packaging issues can become the major limitation in achieving precision specifications. Typically, the best precision is in metal-can packages; this is because there is very little mechanical stress on the die. Plastic packages exert stress on the top and sides of the die as the mold compound cools, causing changes in the offset voltage. A solution that has been used for many years is to put a jelly-like coating all over the die before molding; this keeps the plastic (and its stress) off the die. This works well in the DIP package but in the small SO package there is not enough room for this coating.

Optimizing Performance in Surface Mount

A new coating with much lower viscosity before curing was developed so that a thin (about 50 micron) coat would cover the top of the die. The coating runs to the edge of the die, where it stops due to capillary action. This coating is cured to a jelly-like consistency before the plastic is molded, keeping the stress off the top of the die. A new dispensing system was developed to control the quantity of "thin coat" on each die, since it must be controlled more accurately than the old DIP coating. Unfortunately, the sides of the die in the SO package are still stressed by the molding compound, although several new molding compounds have become available in the last few years that exert less stress on the die, making this problem less severe.

We designed a new die in order to take full advantage of these new surface mount packaging technologies. The circuit design and process used for the LT2078 and LT2178 are the same as their predecessors; only the die has been changed, resulting in identical AC performance. The mask

continued on page 36

Table 1. LT1078/LT1079 and LT2078/LT2079 offset voltage performance comparison

Parameter	LT1078S8 (plastic SO-8)	LT2078CS8 (plastic SO-8)	LT2078ACS8 (plastic SO-8)
Maximum V_{OS}	180µV	120µV	70µV
Maximum V_{OS}Drift	3.5µV/°C	2.5µV/°C	1.8µV/°C
	LT1079S (plastic SO-16)	**LT2079C** (plastic SO-14)	**LT2079AC** (plastic SO-14)
Maximum V_{OS}	300µV	150µV	100µV
Maximum V_{OS}Drift	4.0µV/°C	3.5µV/°C	3.0µV/°C

Table 2. LT1178/LT1179 and LT2178/LT2179 offset voltage performance comparison

Parameter	LT1178AS8 (plastic SO-8)	LT2178CS8 (plastic SO-8)	LT2178ACS8 (plastic SO-14)
Maximum V_{OS}	180µV0	12 µV	70µV
Maximum V_{OS} Drift	3.5µV/°C	2.5µV/°C	1.8µV/°C
	LT1179S (plastic SO-16)	**LT2179CS** (plastic SO-14)	**LT2179ACS** (plastic SO-14)
Maximum V_{OS}	600µV	150µV	100µV
Maximum V_{OS} Drift	4.5µV/°C	3.5µV/°C	3.0µV/°C

LTC1387 Single 5V RS232/RS485 Multiprotocol Transceiver

by Y.K. Sim

Introduction

The LTC1387 is a new addition to Linear Technology's family of multiprotocol transceivers. It is a single 5V supply, logic-configurable, single-port RS232 or RS485 transceiver. This part is targeted at handheld computers or point-of-sale terminals and features software-controlled multiprotocol operation with an emphasis on flexibility and minimum pin count.

Positioning and Key Features

The LTC1387 complements the dual-port LTC1334 by providing a single port in a smaller 20-pin SO or SSOP package. The LTC1387 offers a flexible combination of two RS232 drivers, two RS232 receivers, an RS485 driver, an RS485 receiver and an onboard charge pump to generate boosted voltages for true RS232 levels from a single 5V supply. The RS232 transceivers and RS485 transceiver are designed to share the same port I/O pins for both single-ended and differential signal communication modes. The RS232 transceiver supports both RS232 and EIA562 standards, whereas the RS485 transceiver supports both RS485 and RS422 standards. Both half-duplex and full-duplex communication are supported.

A logic input selects between RS485 and RS232 modes. Three additional control inputs allow the LTC1387 to be reconfigured easily via software to adapt to various communication needs, including a one-signal line

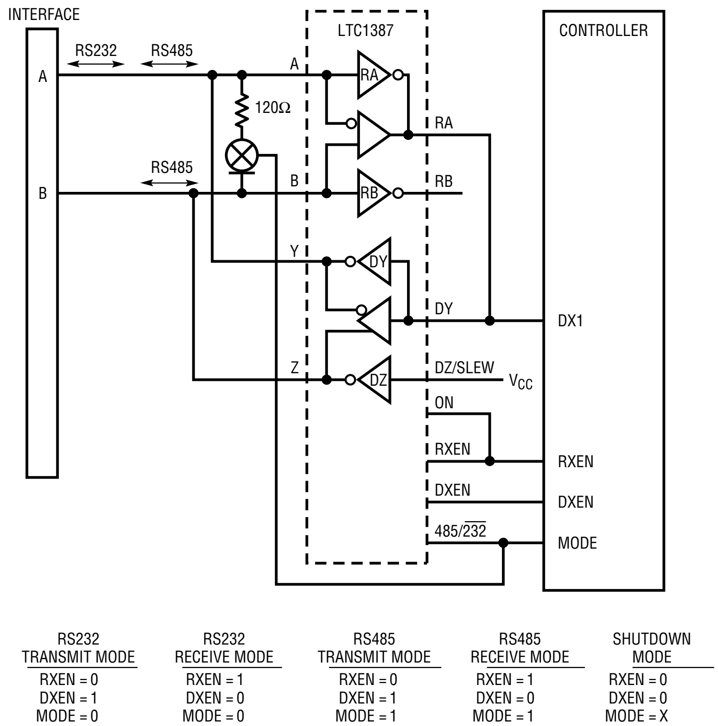

Figure 1. Half-duplex RS232, half-duplex RS485

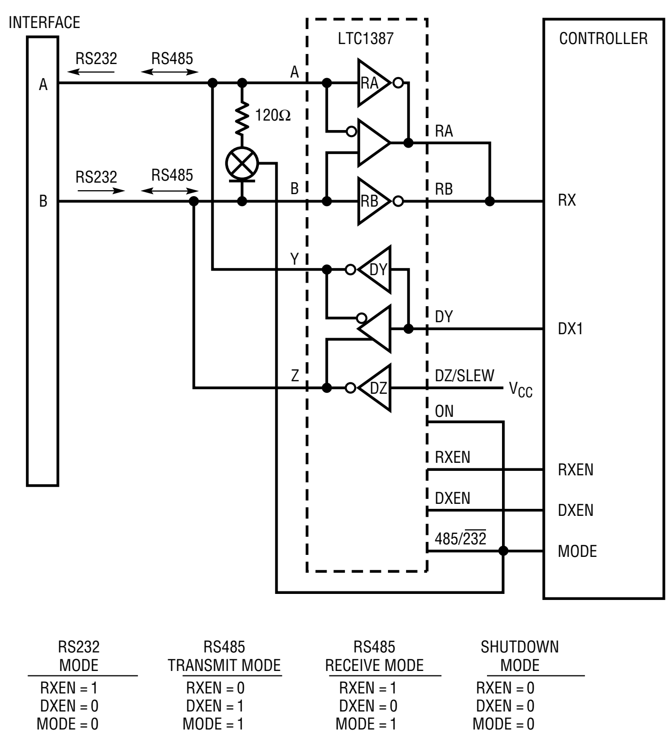

Figure 2. Full-duplex RS232, half-duplex RS485

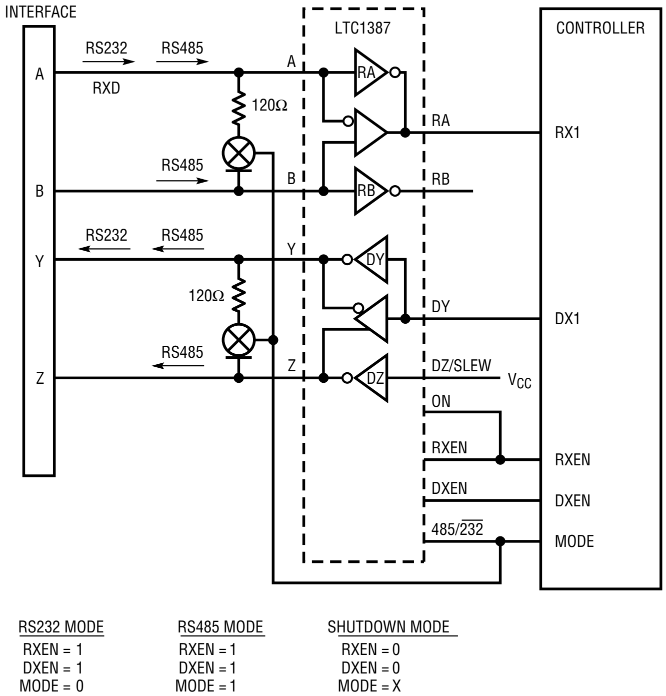

Figure 3. Full-duplex RS232 (1-channel), full-duplex RS422

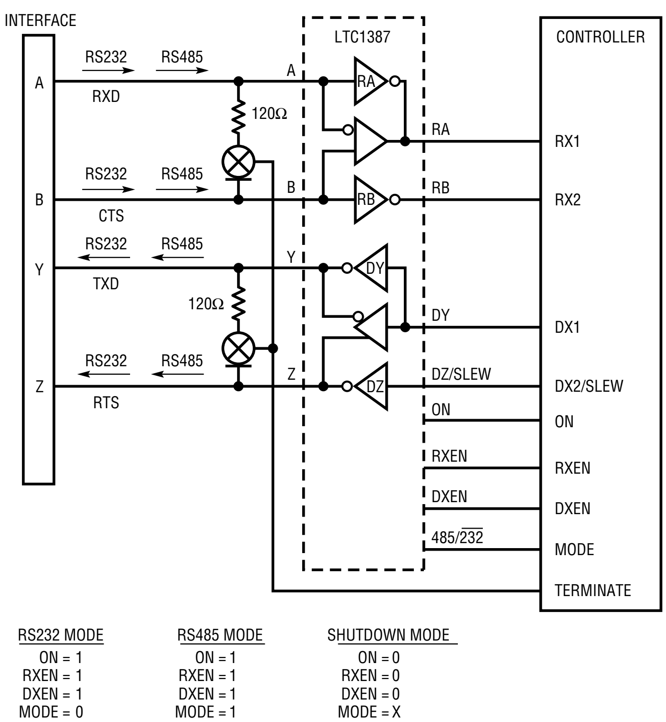

Figure 4. Full-duplex RS232 (2-channel), full-duplex RS485 with slew and termination control

RS232 I/O mode (see function tables in figures). Four examples of interface port connections are shown in Figures 1–4.

A SLEW input pin, active in RS485 mode, changes the driver transition between normal and slow slew-rate modes. In normal RS485 slew mode, the twisted pair cable must be terminated at both ends to minimized signal reflection. In slow-slew mode, the maximum signal bandwidth is reduced, minimizing EMI and signal reflection problems. Slow-slew-rate systems can often use improperly terminated or even unterminated cables with acceptable results. If cable termination is required, external termination resistors can be connected through switches or relays.

The LTC1387 features micropower shutdown mode, loopback mode for self-test, high data rates (120kbaud for RS232 and 5Mbaud for RS485) and 7kV ESD protection at the driver outputs and receiver inputs.

Conclusion

The LTC1387 is ideal for point-of-sale terminals, computers, multiplexers, networks or peripherals that need to adapt on the fly to various I/O configuration requirements without any hardware adjustments. The LTC1387, along with the rest of the LTC multiprotocol interface line, makes dedicated single-protocol communication ports obsolete.

Battery Charger, continued from page 28

charge pump comprising C8, C9, CR6, CR7 and R2 biases the gate of Q2. Q1 and R1 turn Q2 off on AC operation (V_{IN} active). R7 programs the trickle-charge current (maximum value is about 100k) and the equivalent value of R7 and R8 programs the charge current. The Charge input must be pulled low at the end of the charge.

The charger in Figure 1 is connected to a 2-cell NiCd battery, BAT1.

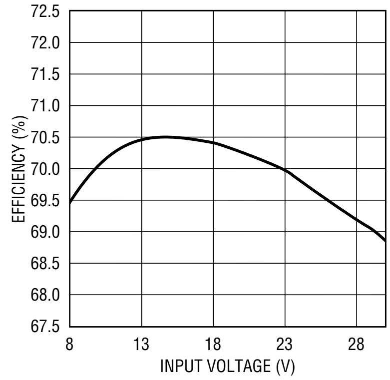

Figure 2. System efficiency vs input voltage

The system switching regulator is LT1300 (U2) based and powers a 5V/250mA load. The efficiency, h, of the complete system is defined as:

$$h = \frac{\text{LT1300 Output Power + Battery Charger Power}}{\text{LT1510 Input Power}}$$

The efficiency plot is shown in Figure 2. For the purpose of measurement, the battery voltage is 3.2V and the charge current is 0.3A.

3.3V Supply, continued from page 29

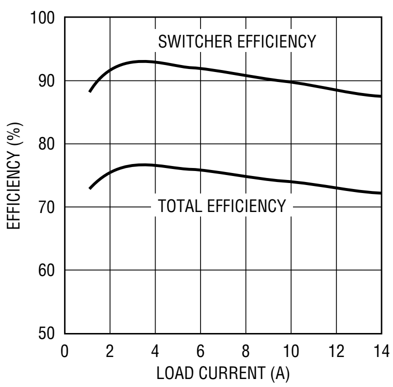

Figure 2. Efficiency of Figure 1's circuit

The LT1575 uses an IRLZ44 MOSFET as the pass transistor, allowing the dropout voltage to be less than 550mV. Setting the switching supply's output to only 700mV above the output of the linear regulator ensures output regulation. The switcher is therefore set up to deliver 4.0V at 14A from the 12V supply. Conversion efficiency of the switcher is around 90% (depending on load), whereas the LT1575's efficiency is 82.5% (see Figure 2). The 12V input current is only about 5.5A. At an average current of 9A, the power dissipation in the linear pass transistor is only 6.3W. A small stamped aluminum heat sink is adequate.

Figure 3 shows the transient response to a 10A load step with a rise time of approximately 50ns. The only output capacitance is 40 1µF ceramic capacitors. No additional bulk capacitance is required at the processor. The circuit eliminates approximately a dozen low ESR tantalum capacitors at the load, which would be required without the linear post-regulator. The switching supply's output is decoupled with three aluminum electrolytic capacitors. Because the transient response at this point is much less critical than at the load, the long-term degradation of the aluminum capacitors will not be as detrimental to the circuit's performance as it would be if they were used for load decoupling.

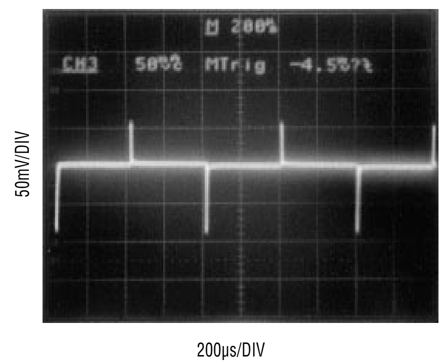

Figure 3. Transient response of Figure 1's circuit to a 10A load step

Conclusion

By combining a high efficiency switching regulator and an UltraFast™ linear regulator, it is possible to achieve reasonable efficiencies with superior transient dynamics. Power dissipation can be held down to easily manageable levels while eliminating the need for very large amounts of bulk decoupling capacitance.

LT2078/LT2079, continued from page 33

design (layout) of the new ICs carefully placed the input transistors in the area of the die where the package-induced stress is most uniform. Further, the input transistors are "cross-coupled" to cancel out any nonuniform stresses. The wafer level trimming was tightened so that assembled parts have less offset variation. Postpackage trimming was optimized for the new SO packages. (Postpackage trimming is done by taking an input pin above the supply pin to forward bias a diode and "zap" a trim Zener.)

The result is that the LT2078/LT2079 and LT2178/LT2179 are the best single supply, precision op amps available in the standard-pinout surface mount packages. Table 1 compares the dual LT2078 and quad LT2079 to their predecessors, the LT1078/LT1079, whereas Table 2 compares the LT2178/LT2179 to the LT1178/LT1179 in surface mount packages. These new parts are available in the SO-8 and SO-14 packages for operation over commercial, industrial and extended temperature ranges.

New Device Cameos

LT1118 Adjustable Sink/Source Regulator

The LT1118 adjustable regulator joins the LT1118-2.5, LT1118-2.85 and LT1118-5 fixed-output versions of the sink/source regulator. The output voltage is programmed by customer selected feedback resistors to provide any output voltage between 2.0V and V_{IN} – 1.0V, for V_{IN} up to 15V. The regulator maintains regulation for load currents between 800mA sourced into the load to 400mA sunk from the load.

The adjustable regulator is especially useful for data bus terminations, similar to the use of the 2.85V fixed version in SCSI applications.

A fused-lead SO-8 package provides a low thermal resistance to PC board traces. In most applications, no further heat sinking is required for the regulator.

A Shutdown pin places the output in a high impedance state, effectively disconnecting the load from the regulator. Fault tolerance is provided by current limiting of both sunk and sourced output current in addition to on-chip thermal shutdown.

LT1141A 3-Driver, 5-Receiver RS232 Transceiver Meets IEC-1000-4-2 ESD Protection Standards

The LT1141A 3-driver, 5-receiver RS232 transceiver is the latest Linear Technology RS232 transceiver to be upgraded to pass the IEC-1000-4-2 level 4 ESD test. The chip is internally protected against ±15kV air-gap or ±8kV contact-mode discharges. The IEC-1000-4-2 test, formerly known as IEC-801-2, must be passed by all equipment sold in Europe. The chip also passes up to ±15kV ESD as tested by MIL-STD-883, Method 3015. The on-chip protection of the LT1141A frees the user from the cost and board area required by external transient-suppression devices that are usually required to successfully meet the IEC ESD protection requirements.

The enhanced ESD protection has been achieved without compromising the electrical performance of the device. Present LT1141A users will see no change in electrical performance. The 3-driver, 5-receiver device retains all of the electrical performance features which make it popular. The enhanced ESD protection devices do not degrade operation at rates of up to 120kbaud with full 2500pF loads or to 250kbaud with 1000pF loads.

The LT1141A is available in 24-pin DIP, SO and SSOP packages.

LT1180A/LT1181A 2-Driver, 2-Receiver RS232 Transceivers Meet IEC-1000-4-2 ESD Protection Standards

The LT1180A and LT1181A, Linear Technology's popular 2-driver, 2-receiver RS232 transceivers, have been upgraded to meet the IEC-1000-4-2 level 4 ESD standards. The circuits are internally protected against ±15kV air-gap or ±8kV contact-mode discharges. The IEC-1000-4-2 test, formerly known as IEC-801-2, must be passed by all equipment sold in Europe. The chip also passes up to ±15kV ESD as tested by MIL-STD-883 Method 3015. The on-chip protection of the LT1181A frees the user from the cost and board area required by external transient-suppression devices that are usually required to successfully meet the IEC ESD protection requirements.

Enhanced ESD protection has been achieved without compromising the electrical performance of the devices. Present LT1180A/LT1181A users will see no change in electrical performance. The devices retain all of the electrical performance features that make them popular. The enhanced ESD protection devices do not degrade operation at rates of up to 120kbaud with full 2500pF loads or to 250kbaud with 1000pF loads.

The LT1181A is available in 16-pin DIP, SW and SO packages. The LT1180A, which includes a shutdown control, is available in 18-pin DIP and SW packages.

LTC1438-ADJ: High Efficiency, Dual, Adjustable Output Voltage Synchronous Switching Power Supply Controller for Portable Applications

The LTC1438-ADJ is a dual, adjustable output voltage, synchronous step-down switching regulator controller that drives external N-channel power MOSFETs in a fixed frequency architecture.

The LTC1438-ADJ differs from the LTC1438 in its ability to set both controller output voltages using external resistive dividers, for output voltages as low as 1.2V. External-feedback voltage setting provides remote sensing of each output voltage at the load—often required in higher current applications.

A 1% voltage reference and load regulation of ±0.8% are guaranteed over the full temperature range, eliminating output voltage adjustment in most applications. The operating current levels are user-programmable via external current sense resistors. Wide input supply range allows operation from 3.5V to 30V (36V maximum).

A secondary feedback input can be used in conjunction with a flyback winding on the first controller to generate a third output voltage that can supply power regardless of the load on the first controller's primary winding. This feedback forces continuous operation on the first controller using a simple voltage mode loop. The input can also be used as a logic input to force continuous operation, thereby suppressing Burst Mode operation on the first controller.

A hysteretic comparator, which has its inverting input tied to the internal 1.19V reference, is included. The output is an open-drain type and can be pulled up to any available supply of up to 10V. A power-on reset timer (POR) generates a logic-low output signal during controller start-up, which persists for 65,536 clock cycles after the output reaches 7.5% of the regulated output voltage.

The part is available in a 28-lead plastic SSOP package.

LTC1605 Single 5V 100ksps Sampling 16-Bit ADC

The LTC1605 is a complete 100ksps sampling 16-bit ADC that operates on a single 5V supply and typically dissipates 55mW. Its input range is an industrial standard ±10V. This gives the user a large input LSB size of 305μV, which can help ease noise requirements for the input conditioning circuitry. The input signal is captured by an onboard sample-and-hold and digitized by a differential, switched capacitor SAR ADC. The LTC1605 achieves 16-bit performance without the autocalibration overhead required with other types of ADCs. Maximum DC specifications include ±2.0LSB INL and 16 bits with no missing codes guaranteed over temperature. The part has an internal 2.5V bandgap reference. An external reference can also be used.

The ADC has a microprocessor-compatible 16-bit parallel output port that can provide data as a 16-bit word or as two bytes. The LTC1605 is easily connected to FIFOs, DSPs and microprocessors using its convert start input and data ready signal (BUSY).

LT1039A RS232 Transceiver Meets IEC-1000-4-2 ESD Protection Standards

The popular LT1039 3-driver 3-receiver RS232 transceiver has been upgraded to pass the IEC-1000-4-2 level 4 ESD test. The chip is internally protected against ±15kV air-gap or ±8kV contact-mode discharges. The IEC-1000-4-2 test, formerly known as IEC-801-2, must be passed by all equipment sold in Europe. LT1039A's on-chip protection eliminates the cost and board area required by external transient-suppression devices, which are usually needed to successfully meet the IEC ESD protection requirements.

The enhanced ESD protection is achieved without compromising the electrical performance of the device.

Present LT1039 users will see no change in electrical performance. The 3-driver, 3-receiver device retains all of the electrical performance features that make it popular. Operation to 120kbaud with full 2500pF loads, and up to 250kbaud with 1000pF loads, is not degraded by the enhanced ESD protection devices.

The LT1039A is available in 16-pin and 18-pin DIP and SO packages. The 18-pin versions include ON-OFF control and a BIAS pin to power one receiver when the device is shut down.

DESIGN TOOLS

Applications on Disk

Noise Disk — 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.

SwitcherCAD™ — The SwitcherCAD program is a powerful PC software tool that aids in the design and optimization of switching regulators. The program can cut days off the design cycle by selecting topologies, calculating operating points and specifying component values and manufacturer's part numbers. 144 page manual included. $20.00

SwitcherCAD supports the following parts: LT1070 series: LT1070, LT1071, LT1072, LT1074 and LT1076. LT1082. LT1170 series: LT1170, LT1171, LT1172 and LT1176. It also supports: LT1268, LT1269 and LT1507. LT1270 series: LT1270 and LT1271. LT1371 series: LT1371, LT1372, LT1373, LT1375, LT1376 and LT1377.

Micropower SwitcherCAD™ — The MicropowerSCAD program is a powerful tool for designing DC/DC converters based on Linear Technology's micropower switching regulator ICs. Given basic design parameters, MicropowerSCAD selects a circuit topology and offers you a selection of appropriate Linear Technology switching regulator ICs. MicropowerSCAD also performs circuit simulations to select the other components which surround the DC/DC converter. In the case of a battery supply, MicropowerSCAD can perform a battery life simulation. 44 page manual included. $20.00

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Technical Books

1990 Linear Databook, Vol I —This 1440 page collection of data sheets covers op amps, voltage regulators, references, comparators, filters, PWMs, data conversion and interface products (bipolar and CMOS), in both commercial and military grades. The catalog features well over 300 devices. $10.00

1992 Linear Databook, Vol II — This 1248 page supplement to the 1990 Linear Databook is a collection of all products introduced in 1991 and 1992. The catalog contains full data sheets for over 140 devices. The 1992 Linear Databook, Vol II is a companion to the 1990 Linear Databook, which should not be discarded. $10.00

1994 Linear Databook, Vol III —This 1826 page supplement to the 1990 and 1992 Linear Databooks is a collection of all products introduced since 1992. A total of 152 product data sheets are included with updated selection guides. The 1994 Linear Databook Vol III is a companion to the 1990 and 1992 Linear Databooks, which should not be discarded. $10.00

1995 Linear Databook, Vol IV —This 1152 page supplement to the 1990, 1992 and 1994 Linear Databooks is a collection of all products introduced since 1994. A total of 80 product data sheets are included with updated selection guides. The 1995 Linear Databook Vol IV is a companion to the 1990, 1992 and 1994 Linear Databooks, which should not be discarded. $10.00

1996 Linear Databook, Vol V —This 1152 page supplement to the 1990, 1992, 1994 and 1995 Linear Databooks is a collection of all products introduced since 1995. A total of 65 product data sheets are included with updated selection guides. The 1996 Linear Databook Vol V is a companion to the 1990, 1992, 1994 and 1995 Linear Databooks, which should not be discarded. $10.00

1990 Linear Applications Handbook, Volume I — 928 pages full of application ideas covered in depth by 40 Application Notes and 33 Design Notes. This catalog covers a broad range of "real world" linear circuitry. In addition to detailed, systems-oriented circuits, this handbook contains broad tutorial content together with liberal use of schematics and scope photography. A special feature in this edition includes a 22-page section on SPICE macromodels. $20.00

1993 Linear Applications Handbook, Volume II — Continues the stream of "real world" linear circuitry initiated by the 1990 Handbook. Similar in scope to the 1990 edition, the new book covers Application Notes 40 through 54 and Design Notes 33 through 69. References and articles from non-LTC publications that we have found useful are also included. $20.00

1997 Linear Applications Handbook, Volume III — This 976 page handbook maintains the practical outlook and tutorial nature of previous efforts, while broadening topic selection. This new book includes Application Notes 55 through 69 and Design Notes 70 through 144. Subjects include switching regulators, measurement and control circuits, filters, video designs, interface, data converters, power products, battery chargers and CCFL inverters. An extensive subject index references circuits in LTC data sheets, design notes, application notes and *Linear Technology* magazines. $20.00

Interface Product Handbook — This 424 page handbook features LTC's complete line of line driver and receiver products for RS232, RS485, RS423, RS422, V.35 and AppleTalk® applications. Linear's particular expertise in this area involves low power consumption, high numbers of drivers and receivers in one package, mixed RS232 and RS485 devices, 10kV ESD protection of RS232 devices and surface mount packages. Available at no charge

Power Solutions Brochure — This 84 page collection of circuits contains real-life solutions for common power supply design problems. There are over 88 circuits, including descriptions, graphs and performance specifications. Topics covered include battery chargers, PCMCIA power management, microprocessor power supplies, portable equipment power supplies, micropower DC/DC, step-up and step-down switching regulators, off-line switching regulators, linear regulators and switched capacitor conversion. Available at no charge.

High Speed Amplifier Solutions Brochure — This 72 page collection of circuits contains real-life solutions for problems that require high speed amplifiers. There are 82 circuits including descriptions, graphs and performance specifications. Topics covered include basic amplifiers, video-related applications circuits, instrumentation, DAC and photodiode amplifiers, filters, variable gain, oscillators and current sources and other unusual application circuits. Available at no charge

Data Conversion Solutions Brochure — This 52 page collection of data conversion circuits, products and selection guides serves as excellent reference for the data acquisition system designer. Over 60 products are showcased, solving problems in low power, small size and high performance data conversion applications—with performance graphs and specifications. Topics covered include ADCs, DACs, voltage references and analog multiplexers. A complete glossary defines data conversion specifications; a list of selected application and design notes is also included. Available at no charge

Telecommunications Solutions Brochure — This 72 page collection of circuits, new products and selection guides covers a wide variety of products targeted for the telecommunications industry. Circuits solving real life problems are shown for central office switching, cellular phone, base station and other telecom applications. New products introduced include high speed amplifiers, A/D converters, power products, interface transceivers and filters. Reference material includes a telecommunications glossary, serial interface standards, protocol information and a complete list of key application notes and design notes. Available at no charge

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DESIGN TOOLS, continued from page 39

CD-ROM

LinearView — LinearView™ CD-ROM is Linear Technology's interactive PC-based CD-ROM. It allows you to instantly access thousands of pages of product and applications information, covering Linear Technology's complete line of high performance analog products, with easy-to-use search tools.

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