LINEAR TECHNOLOGY

MAY 2004 VOLUME XIV NUMBER 2

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Single Device Tracks *and* Monitors Five Supplies

by Thomas DiGiacomo

Introduction

Multiple supply sources and multiple supply voltages have become the norm, rather than the exception, as each subsystem uses its optimum voltage to maximize performance. In fact, individual FPGA or DSP chips can have separate core and I/O power supplies requiring different voltages. Even the type of supply voltage sources may not be consistent.

Regulators (switching and linear), supply bricks, charge pumps, and batteries have varied start-up characteristics and satisfy power sourcing requirements differently. System errors or even damage can occur when loads are energized in the wrong order.

Often the best solution to avoid these problems is to ramp up all the load voltages together. The LTC2921 and LTC2922 power supply trackers do just that. These power supply trackers also include input voltage monitors for up to five supplies.

Each monitor-tracker controls the load voltages by simultaneously ramping the gates of external series N-channel FETs between the supplies and their loads. Input comparators continuously qualify up to

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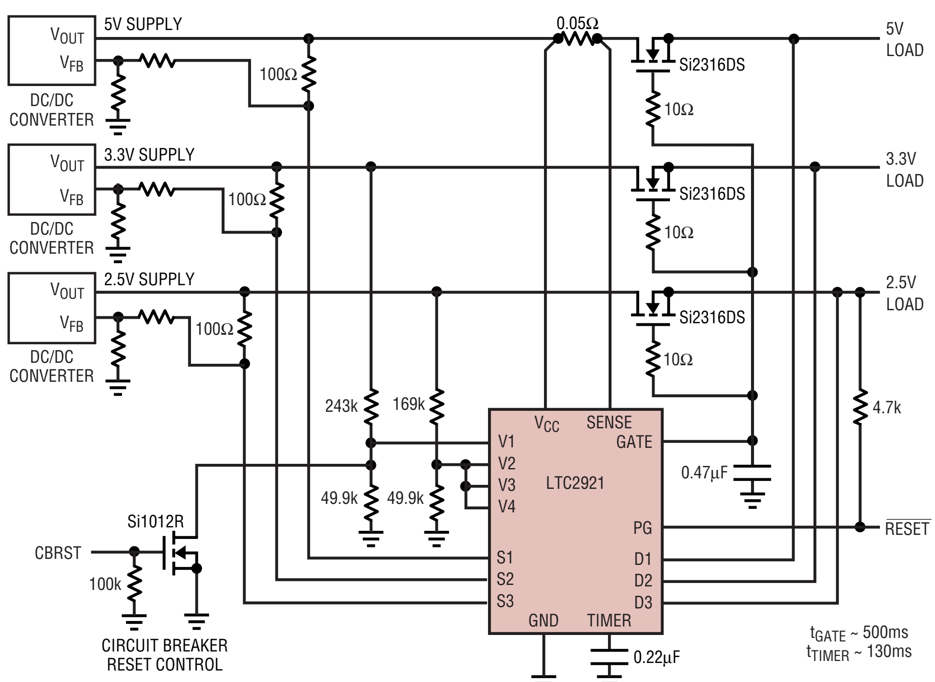

Figure 1. A 3-supply tracker and monitor including remote sensing switching, electronic circuit breaker function, and a $\overline{\text{RESET}}$ output

Issue Highlights

In multi-voltage systems, major system errors or even damage can occur when loads are energized in the wrong order. Often the best solution to avoid these problems is to ramp up all the load voltages together. Our cover article introduces two **power supply trackers** that monitor five source voltages and ramp up their loads.

Featured Devices

Below is a summary of the other devices featured in this issue.

Op Amps

The LTC2054 and LTC2055 are **single and dual low power zero-drift operational amplifiers** available in SOT-23 (LTC2054), MS8 and DD (LTC2055) packages. These are the lowest power zero-drift amplifiers available, and each offers the same high performance, including low input bias current (1pA typical), low offset (3µV max) and drift (30nV/°C max) up to 125°C while consuming only 130µA per amplifier. Similar amplifiers require 0.8mA to 1mA to achieve the same performance. (Page 6)

The LTC1992 **fully differential input/output amplifier** family provides simple amplification or level translation solutions for amplifying signals that are intrinsically differential or need to be made differential. The LTC1992 is available with uncommitted gain, or fixed gain versions with space-saving on-chip factory-trimmed resistors. (Page 16)

The LT6210 (single) and LT6211 (dual) are **programmable supply current, R-R output, current feedback amplifiers** that are flexible enough to satisfy the needs of many applications by solving a host of amplifier problems. These devices couple a high-speed, current-feedback topology with a C-Load™ stable, high current drive, rail-to-rail output stage. They have programmable supply current with a nearly constant speed to power ratio, from 10MHz at 300µA up to 200MHz at 6mA. (Page 25)

PowerPath Control

Rechargeable batteries are commonly used to power portable Universal Serial Bus (USB) devices, such as PDAs or MP3 players. The USB itself can be used to directly power the device or charge a battery. The LTC4055 **USB power controller and Li-Ion Linear Charger** uses PowerPath™ control to seamlessly and efficiently steer the load to the preferred source of power—all while remaining within the specified USB current limit. Any available leftover current is used to charge the battery. (Page 8)

The LT4351 **MOSFET diode-OR controller** turns a power N-channel MOSFET into a near ideal diode suitable for high power ORing applications. The LT4351 can improve efficiency over a Schottky by more than ten-fold in high power designs. (Page 21)

Accurate Battery Gas Guage

The LTC4150 **coulomb counter** provides an accurate battery gas guage by measuring the charge flowing into and out of the battery through a sense resistor. A voltage-to-frequency converter transforms the current sense voltage into a series of output pulses which can be used by a microcontroller to accurately determine the charge status of a battery. (Page 11)

LED and LCD Drivers

The LT3466 simplifies the task of fitting white LED driver circuitry into the latest devices by providing a **dual high efficiency, constant current white LED driver** in a space-saving 3mm × 3mm DFN package. The LT3466 can drive up to 20 white LEDs from a single cell Li-Ion battery input with greater than 80% efficiency. It also provides space and component savings with integrated Schottky diodes and internal compensation. (Page 13)

The LTC3450 **triple output power supply for small TFT-LCD displays** improves battery life and saves space by delivering a 95% efficient color LCD bias solution in a low profile (0.8mm tall), 3mm × 3mm package. (Page 19)

Design Ideas and Cameos

Starting on page 29 are six new Design Ideas including a simple solution to driving the new powerful white LEDs. At the back are six New Device Cameos. Visit www.linear.com for complete device specifications and applications information.

LTC in the News...

On April 13, Linear Technology Corporation announced its financial results for the 3rd quarter of fiscal year 2004 ended March 28. According to Robert H. Swanson, Chairman of the Board and CEO, "This was a another strong quarter for us. Sales grew 12% and profits 15% sequentially over the December quarter. Demand for our products has continued to be robust, increasing in each major end-market, led by industrial and communications, and increasing also in every major geographical area. Our return on sales was 41%. We generated approximately $83 million in cash and short-term investments, before purchasing the shares of our stock referred to above. In each of the last three quarters we have accelerated our year over year sales and profit growth. Looking forward, we are experiencing very broad based strength in our market place and, should these current trends continue, we expect to grow sales by roughly a similar percentage in the June quarter to the quarter just completed."

The Company reported net sales of $209,133,000, and net income of $85,549,000, or $0.27 diluted earnings per share. A cash dividend of $0.08 per share will be paid on May 12, 2004 to stockholders of record on April 23, 2004.

LTC2921/LTC2922, continued from page 1

five sources to ensure that all supply voltages are ready not only before load ramping begins, but also during and after ramping. If at any time during or after the turn-on sequence a monitor input fails, all the loads are disconnected immediately. When all monitors meet their thresholds again, a turn-on sequence is reinitiated.

If the monitored supplies maintain correct levels, all the supplies track up together and load ramping completes. After that, remote sense switches automatically connect the load voltages to the Kelvin sense inputs of the supply sources. Sensing the load voltage allows the sources to compensate for the voltage drops across the external series FETs. Finally, activation of the power good signal indicates that ramp-up has completed. Figure 1 shows an application with three monitored tracking supplies. A scope photo of a turn-on sequence is shown in Figure 2. Table 1 summarizes the features of these devices.

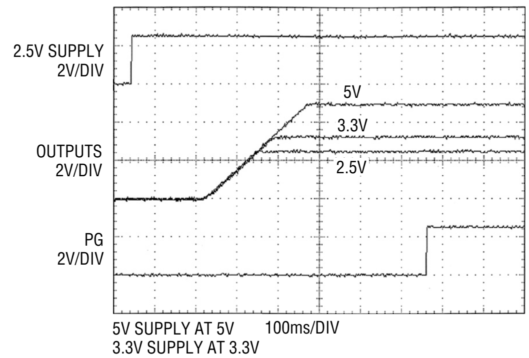

Figure 2. Scope trace of load voltage ramp-up and power good activation for the application circuit in Figure 1.

Designed for Tracking Success

The LTC2921 and LTC2922 qualify the source voltages so that the load voltages cannot begin to ramp before all the supply sources have reached operational levels. All five supplies must concurrently exceed their monitor threshold voltages before ramp-up begins. A user-adjustable timer holds off the start of load ramping, and all supplies must continuously exceed the threshold voltage levels during this period. This time delay, set by the capacitor at the TIMER pin, provides a measure of confidence in the sources' operational readiness.

Four of the five input monitor levels are adjustable by selecting resistor values for external voltage dividers. The fifth monitor level is fixed by an internal resistive voltage divider to monitor V_{CC} at 5V, 3.3V, or 2.5V—depending on device version.

The input monitors feature a threshold of 0.5V and threshold accuracy of ±1.5% over temperature, which allows tight monitoring of supply voltages to below 1V. Internal glitch filtering protects against monitoring errors due to low-energy voltage spikes around the threshold level. All five monitors include an upper threshold at 0.7V that protects the loads against supply overvoltage.

Both the LTC2921 and LTC2922 have an adjustable ramp rate, set by a capacitor at the GATE pin, allowing control of inrush currents at the loads and overall turn-on delay. During ramping, the external FETs act as source followers. As a load voltage nears its supply voltage, the still-ramping GATE pin overdrives the FET, which reduces $R_{DS(ON)}$, and therefore the voltage drop across the transistor. The higher voltage channels continue ramping upward, and each levels off in turn. This behavior is commonly called coincident tracking because the load voltages rise together. An onboard charge pump allows the LTC2921 and LTC2922 to pull the GATE pin high enough above V_{CC} to enhance fully both logic-level and sub-logic-level FETs.

Although the gates of the external N-channel FETs are overdriven to reduce $R_{DS(ON)}$, the voltage difference between supply and load may not be insignificant, especially at low supply voltages and high load currents. For example, a 10A load current drawn through a 10mΩ drain-source resistance on a 2V supply results in a load voltage that

Table 1. LTC2921 and LTC2922 summary of features

Features		LTC2921	LTC2922
V_{CC} Supply Voltage Selection	5V 3.3V 2.5V	LTC2921 LTC2921-3.3 LTC2921-2.5	LTC2922 LTC2922-3.3 LTC2922-2.5
Input Monitors		4 adjustable plus 1 dedicated to V_{CC}	4 adjustable plus 1 dedicated to V_{CC}
Monitor Threshold Voltage		0.5V	0.5V
Monitor Threshold Accuracy		±1.5% over temperature	±1.5% over temperature
Overvoltage Threshold		0.7V	0.7V
Adjustable Ramp Rate		yes	yes
Remote Sense Switches		3	5
Power Good Output		yes	yes
Adjustable Time Delay		yes	yes
Electronic Circuit Breaker		1 dedicated to V_{CC} supply	1 dedicated to V_{CC} supply
Package		16-lead Narrow SSOP	20-lead TSSOP

is 1.9V, a full 5% low. To compensate for the voltage drop, each LTC2921 and LTC2922 incorporates automatic remote sense switching.

Integrated N-channel FET switches provide remote sense paths between the loads and the supply sources' Kelvin sense pins. After the external series FETs are completely enhanced, the low resistance remote sense switches are automatically switched on, forcing the supply sources to increase enough to compensate for the series voltage drops. The LTC2921 family of parts offers three remote sense switches per package, while the LTC2922 family of parts offers five remote sense switches per package.

After the remote sense switches close, another time delay allows any switching transients to settle. The LTC2921 and LTC2922 assert the power good signal indicating that ramp-up has successfully completed, and that the sources continue to meet their monitored requirements. The addition of a pull-up resistor to the PG output generates a start signal for devices requiring a reliable $\overline{\text{RESET}}$, such as microprocessors or DSPs. Alternatively, the addition of an LED and a resistor can provide a "tracking done" indicator lamp.

Handling of Monitor Errors

The LTC2921 and LTC2922 protect the loads against invalid supply levels and supply sources that have failed outright. The failure of one or more of the input monitors deactivates power good, opens the remote sense switches, and separates the loads from the sources by quickly pulling down the gate driver. Until all supplies pass the monitoring qualifications again, the time delay cycle does not initiate, and the loads will not be ramped. Even if the source supplying V_{CC} fails, internal charge storage permits proper triggering of the load cut-off mechanisms.

Short circuits or excessive currents due to load problems can be detected indirectly in two ways. Consider first the case of a load current that exceeds the sourcing capability of its supply. The supply voltage will start collapsing. If the voltage falls enough, it trips the monitor threshold comparator. Consider next the case of a load current that creates a significant drop across the external FET. When the remote sense switches activate, the source compensates for the drop by increasing the supply voltage. If the voltage rises enough, it trips the overvoltage threshold.

The LTC2921 and LTC2922 are designed to retry on monitor errors, so that a failed source shuts down the system only as long as it is failing. Permanent source difficulties cause retry failure that keeps the loads disconnected. This tolerant control philosophy is further supported by the input monitors' glitch filters; see the "Accurate Yet Tolerant: Glitch Filtering Monitors" section in this article. Chronic short circuits or excessive loads can cause retry cycles because each disconnect eliminates the error condition, and each auto-retry eventually restores it. Repetitive retries with a period longer than the TIMER delay usually indicate a load current problem that needs to be addressed.

Oh, He's Our Short Stop: Electronic Circuit Breaker

For applications where a short circuited load needs to be handled, the LTC2921 and LTC2922 provide an adjustable electronic circuit breaker. As in the case of a monitor failure, tripping the breaker deactivates power good, opens the remote sense switches, and separates the loads from the sources. Unlike the case of the monitor failure, tripping the breaker sets a latch that prevents the retry of turn-on until the latch is reset (see Figure 3).

The electronic circuit breaker is available on the supply that powers V_{CC}. When the SENSE input pin is greater than 50mV below V_{CC}, the breaker trips and the stop latch is set. The breaker's trip current is set by choosing a resistor that creates a 50mV drop when that amount of current flows. Reaction time between a trip event and start of load disconnect is typically less than 2μs. The V1 pin monitor input doubles as the circuit breaker reset control. Pulling V1 below the monitor threshold for more than 150μs resets the circuit breaker latch. If all other monitored supplies are correct, turn-on retry begins when the V1 voltage exceeds the monitor threshold.

Accurate Yet Tolerant: Glitch Filtering Monitors

Reliable supply voltage monitoring depends on thresholds that remain accurate over temperature and supply variations. All five monitor inputs of the LTC2921 and LTC2922 have the same guaranteed threshold accuracy of ±1.5% over the full operating temperature range (see Figure 4).

In any monitoring application, supply noise riding on the monitored DC voltage can cause spurious monitor errors, particularly when the level is near the trip threshold. Having to budget for worst-case supply noise

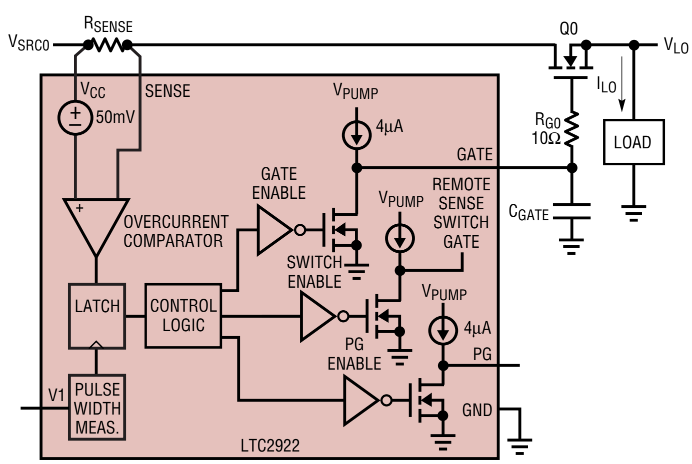

Figure 3. Functional schematic of the electronic circuit breaker function

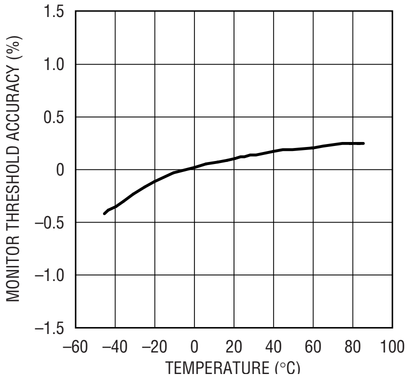

Figure 4. Typical monitor threshold accuracy versus temperature, referenced to 0.5V

directly reduces the benefit of a tight monitoring threshold.

One commonly used, but problematic, solution to this problem is the addition of hysteresis to the input comparator. The amount of hysteresis is usually specified as a percentage of the trip threshold, and typically needs to be added to the advertised accuracy of the part in order to determine the true accuracy of the trip threshold. This technique degrades accuracy, so it is not used by the LTC2921 and LTC2922.

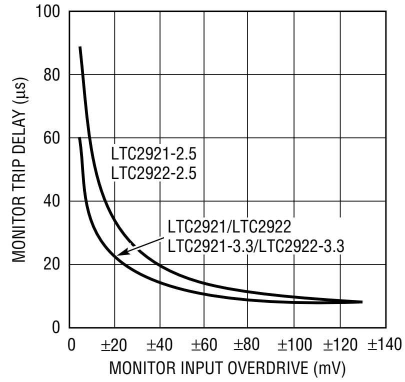

Figure 5. Typical glitch filter characteristics: trip decision delay time versus monitor input voltage delta (relative to monitor threshold)

The LTC2921 and LTC2922 employ a time-integration method of filtering glitches that accommodates low energy transients on nominally DC supply voltages. For a transient to be low energy, it can have high amplitude for short duration or low amplitude for long duration. Figure 5 shows that the response time of the monitor comparators slows significantly as the input voltage nears the threshold voltage. Small voltage differences around the threshold, if they persist, trip the monitors. Large voltage spikes around the threshold, if they

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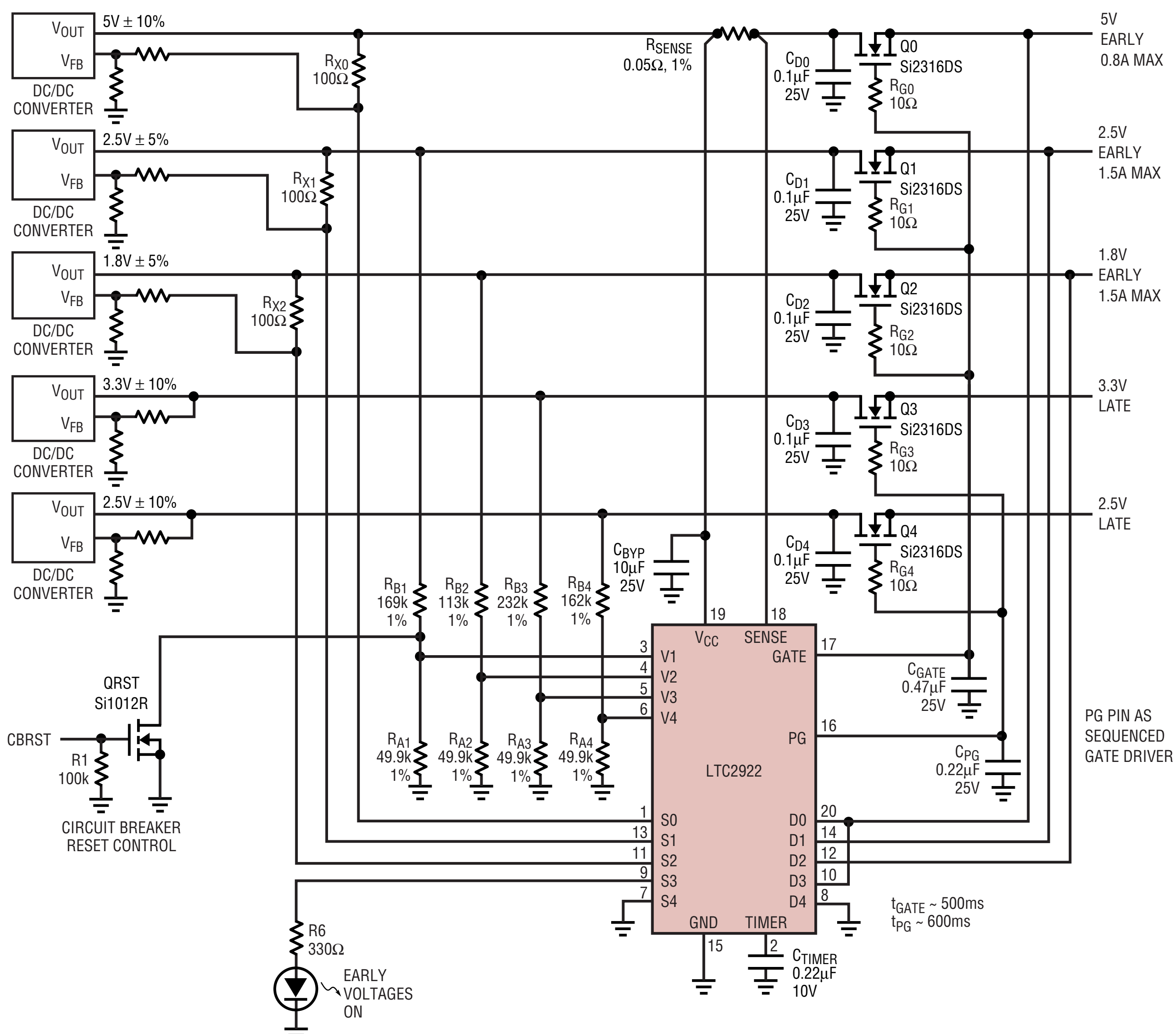

Figure 6. Supply sequencer application schematic with an LED indicating that the early voltages have turned on. Note that the late supplies do not use the remote sense switches.

Zero-Drift Op Amps Improve Performance and Save Power

by Brendan Whelan

Introduction

The LTC2054 and LTC2055 are single and dual low power zero-drift operational amplifiers available in SOT-23 (LTC2054), MS8 and DD (LTC2055) packages. These are the lowest power zero-drift amplifiers available, and each offers the same high performance, including low input bias current (1pA typical), low offset (3µV max) and drift (30nV/°C max) up to 125°C while consuming only 130µA per amplifier. Similar amplifiers require 0.8mA to 1mA to achieve the same performance. Lower power consumption enables longer battery life or a greater number of amplifier functions for any system.

The SOT-23 and DD packages allow the use of either a single or dual amplifier in just 3mm × 3mm. The wide input common-mode range extends from the negative supply to 0.5V below the positive supply while the supply range runs from 2.7V to 6V for the LTC2054 and LTC2055 and 2.7V to ±5.5V for the LTC2054HV and LTC2055HV, allowing both low and high supply voltage operation.

Performance and Features

Lowest Power Across *All* Temperatures

The LTC2054 and LTC2055 feature unprecedented low power dissipation, 150µA max over temp per amplifier for the LTC2055 and 175µA max over temp for the LTC2054. This is five to seven times lower power than similar amplifiers, and makes these amplifiers ideally suited for battery-powered applications such as remote sensing. System design is simplified since the supply current is nearly constant over temperature (Figure 1), unlike with other amplifiers that specify low room temperature supply current but allow much higher consumption at temperature extremes. Start-up current is also low, allowing the use of charge pumps or Zener diodes for supply regulation. Despite the low supply current, the LTC2054HV and LTC2055HV work just as well on ±5V supplies.

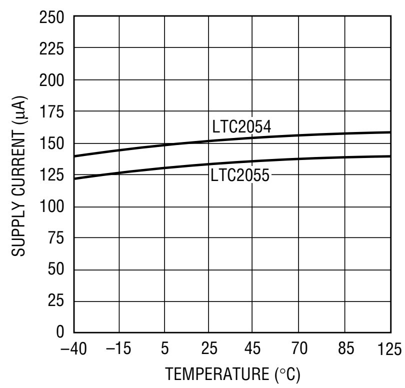

Figure 1. Supply current (per amplifier)

> ***"This level of performance is usually featured on amplifiers that require five to seven times the power of the LTC2054 and LTC2055."***

Low Input Bias Current

The LTC2054 and LTC2055 boast an incredibly low input bias current—just 1pA typical. This level of input current allows the use of large value resistors and small value capacitors without adding significantly to input offset. When used in an integrator circuit (Figure 2), the LTC2054 and LTC2055 exhibit nearly ideal DC performance. The low offset maintains output accuracy across *six orders of magnitude*. The low input current also minimizes input current noise and clock feedthrough.

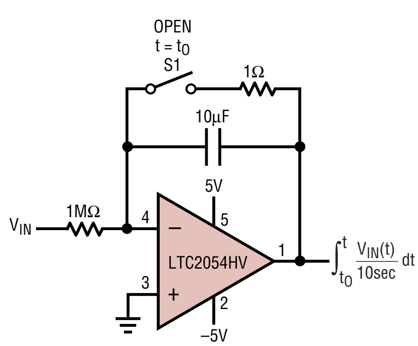

Figure 2. Precision low drift integrator

Wide Input Common-Mode Range

In order to take greatest advantage of its low offset, typically less than 1µV, the LTC2054 and LTC2055 have high CMRR (130dB typical) over a nearly rail-to-rail input common-mode range. The common-mode range extends from the negative supply to one-half volt below the positive supply. This means that even at low supply voltages there is still a large useful input range which extends from the negative supply to above the midsupply voltage. In addition, the common-mode range does not decrease substantially at temperature extremes as it does with most other amplifiers.

No Performance Trade-Offs

Normally, enhancements like those mentioned above require that the circuit designer give something up. Not with these devices. The LTC2054 and LTC2055 still maintain the high performance of their predecessors. High DC accuracy is retained with a best-in-class 3µV max offset spec and 30nV/°C drift. This low offset is combined with extraordinarily high CMRR and PSRR, 130dB each. High DC gain, 140dB typical, allows application in high gain circuits with low residual gain error. Noise performance is an exceptional 1.6µV peak-to-peak in 0.1 Hz to 10Hz band, and clock feedthrough is less than 0.2µV$_{RMS}$, due in part to the low input currents. This level of performance is usually featured on amplifiers that require five to seven

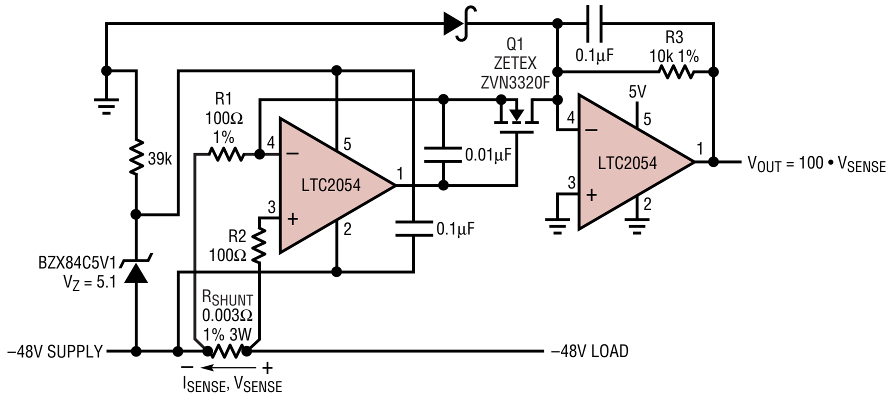

Figure 3. –48V low side precision current sense

times the power of the LTC2054 and LTC2055.

All That and Small Size, Too

Many applications don't only require precision; they need the smallest packages. In order to meet the demand for higher density, the dual LTC2055 is available in a 3mm × 3mm DD package. This allows the use of two high precision amplifiers in the same board space as a SOT-23. The LTC2054 is offered in a low-profile 5-lead SOT-23 (ThinSOT™) package. Applications with limited board space need not sacrifice performance. Where space is not such a premium, the LTC2055 is also available in an MS8 package.

Applications

Current Sense Applications

Today's drive toward portability and power conservation has led to an interest in current monitoring. Figure 3 shows a low-side current sense circuit. In this application, an LTC2054 is used to buffer the voltage across a supply shunt resistor and convert that potential to a current using Q1. Because Q1 is in the amplifier loop, the voltage across R1 is kept equal to the voltage across the shunt resistor to within 1µV. The current is then routed through R3 via Q1 in order to level shift the output.

A second LTC2054 sets the output reference level and R3 adds gain to the signal so that $V_{OUT} = V_{SENSE} \bullet R3/R1$. Resistor R2 does not affect the result directly, but serves to reduce temperature-dependent voltage offsets which occur due to thermal effects on the circuit board. These offsets are usually the result of thermocouples caused by dissimilar metal junctions, such as resistor lead to solder and solder to copper trace. Additional offset may be caused by a change in resistor values or amplifier input current over temperature. Adding a matching element such as R2 helps to cancel these changes by creating symmetrical errors at the differential inputs.

DC accuracy is preserved by the extremely low input offset of the amplifiers. In addition, the low input offset of these amplifiers allows the use of a low value sense resistor, thus conserving system power. For similar systems which have supply voltages of 10V or lower, two halves of an LTC2055 or LTC2055HV may be used instead of two LTC2054s.

A less-obvious application for these amplifiers is a high-side current sense. Figure 4 exhibits a low power, bidirectional precision high-side current sense which can run on supplies up to 60V. This circuit uses an LTC1754-5 and a 1N4686 Zener diode to generate a high-side referred low voltage supply for the LTC2054. As with the previous circuit, the sense voltage is reflected onto R1, generating a current through R3 which is proportional to the current in the sense resistor. The LTC2054 provides, with precise gain and low offset, an output voltage that is proportional to the sense current on R3.

The LT1787HV level shifts the sense output to ground, and provides bidirectional output capability. The initial gain of 125 provided by the LTC2054 ensures that the accuracy is preserved despite the use of a less accurate level-shift circuit. As in the low-side current sense circuit, the low input offset of the LTC2054 allows the use of a small sense resistor without giving up precision, even with relatively low shunt currents.

Photodiode Amplifier

Figure 5 illustrates a circuit that uses an LTC2054 as a transimpedance am-

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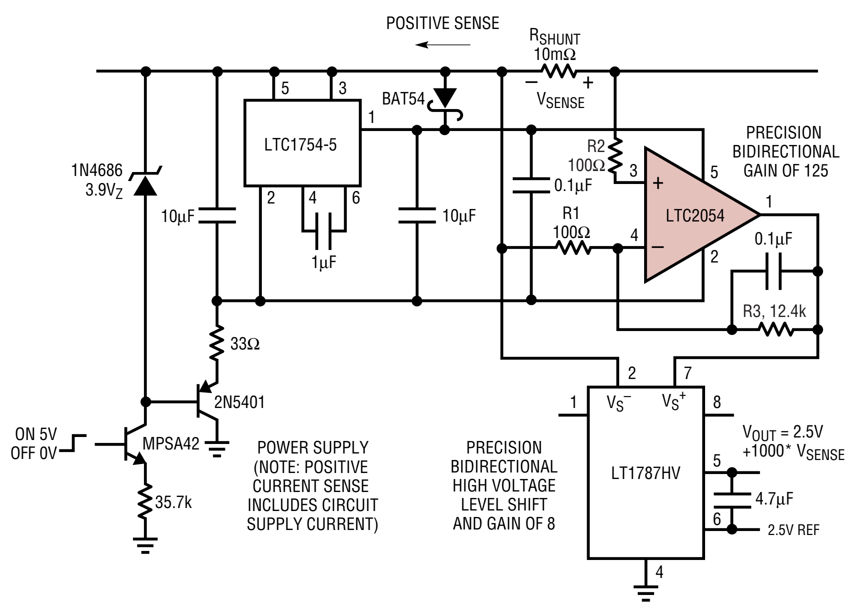


Figure 4. Low power, bidirectional 60V precision high side current sense

USB Power Controller/Charger Reduces Both Design Time and Battery Charge Time

by Roger Zemke

Introduction

Rechargeable batteries are commonly used to power portable Universal Serial Bus (USB) devices, such as PDAs or MP3 players. The USB itself can be used to directly power the device or charge a battery. The LTC4055 uses PowerPath™ control to seamlessly and efficiently steer the load to the preferred source of power; all while remaining within the specified USB current limit; and charge the battery with any available leftover current. When the USB is present, the LTC4055 connects the USB power directly to the load. When both the USB and a wall adapter are present, the LTC4055 can be configured to have the wall adapter supercede the USB as the source of power. These direct connections to the load translate to higher load voltages and greater efficiency.

USB hosts, or powered hubs, provide as much as 500mA from their nominal 5V supply. The greater efficiency of running the load at the USB supply voltage (instead of the battery voltage) means there is more current left in the 500mA USB budget for charging the battery. Because the battery is not in the power path while the application is tied to the USB or wall adapter, the application can be powered even if the battery is low or dead. The same reasoning applies for fully charged batteries. A fully charged battery, which is not in the power path until the USB or external power is removed, stays fully charged. Figure 1 shows just how simple the PowerPath control and battery charging in a USB application can be implemented using the LTC4055.

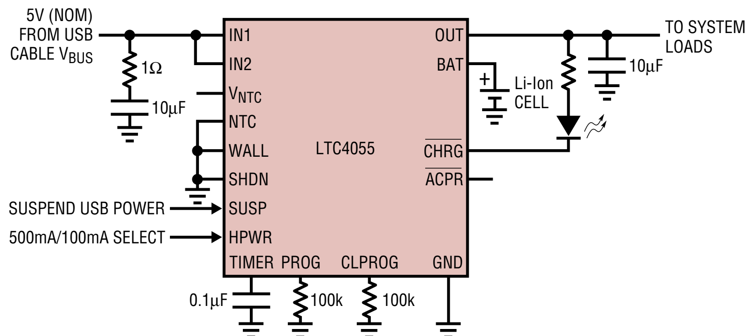
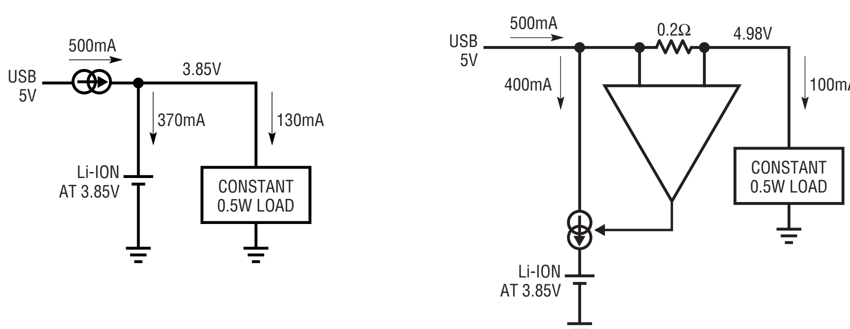


Figure 1. Standalone USB Li-Ion battery charger with PowerPath control from input to output and battery to output—configured for 500mA USB current limit and 500mA maximum charge current.

PowerPath

Let's examine how PowerPath control reduces charge time. Assume the application load is a DC/DC converter. Such converters are effectively constant power devices. The higher the input voltage to the DC/DC converter the lower the current draw. In a USB application where the current is limited, it makes sense to run the converter at as high an input voltage as possible. This minimizes the current draw from the bus—leaving more current for battery charging.

Figure 2 compares a topology that includes the battery in the power path to one that switches the battery out of the power path when it is not needed. Figure 2a shows a constant 0.5W load tied directly to the Li-Ion battery. The USB current is limited to 500mA and the nominal battery voltage is 3.85V. Thus, the current required to power the load is 0.5W/3.85V = 130mA. That



a) Without PowerPath control

b) With PowerPath control

Figure 2. PowerPath control increases available charging current (and reduces charge times) over traditional methods. In this example, the increase is 30mA (8%).

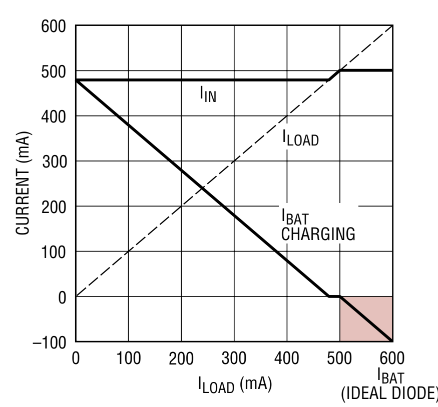


Figure 3. Input and battery currents as a function of load current in high power mode with the current limit set to 500mA (R_{CLPROG} = 100kΩ) and the charge current set to ≥ 500mA (R_{PROG} ≤ 100kΩ). Note that as load current exceeds the USB current limit, the charge current to the battery becomes negative.

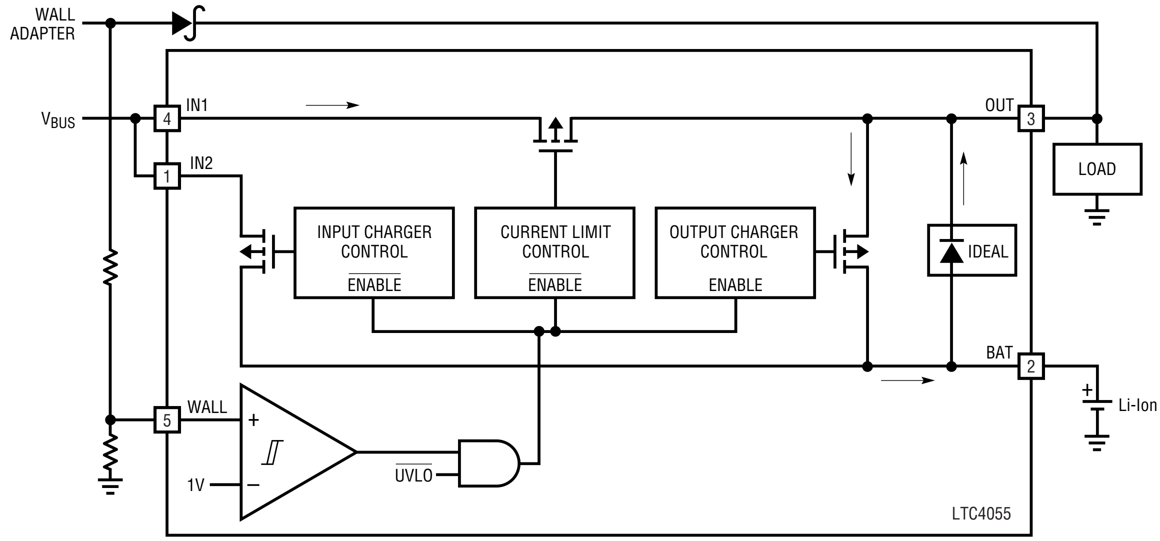


Figure 4. Simplified block diagram of the PowerPath control

leaves 370mA (500mA – 130mA) to charge the battery. Figure 2b shows a 0.5W constant power load tied directly to the USB through a sense resistor. The voltage at the load is 4.98V and the current required by the load is 100mA (0.5W/5V). The current left for battery charging is 400mA (500mA – 100mA), an 8% improvement over the 370mA available when the battery is in the power path.

The LTC4055 has an internal 200mΩ power switch that connects the USB power to the load when the USB is present. The result is the load is running off of USB voltage instead of the lower voltage of the battery. The LTC4055 has a unique current control scheme that keeps the USB current limited while charging a battery under varying load conditions. This current control scheme means that as the load current is decreased more current is available for battery charging. Figure 3 shows a plot of the LTC4055's input and battery charge currents as a function of the load current for the application shown in Figure 1.

A simplified block diagram of the PowerPath for the LTC4055 is shown in Figure 4. It consists of the internal current limited 200mΩ power switch from the inputs to the output of the LTC4055. There are two battery charger paths within the LTC4055. The first is the input charger from the input to the battery and is meant for USB charging. The other battery charger path is the output charger from the output to the battery and is meant for charging the battery when an external adapter is detected.

An internal ideal diode function prevents reverse conduction from the load to the battery when the load voltage is greater than the battery voltage. This same ideal diode function provides a low forward drop (55mV typ. at 100mA) from the battery to the load if the load current should exceed the USB limit or if the battery is the only source of power. The forward characteristics of the ideal diode compared to those of a Schottky diode are shown in Figure 5.

A wall adapter comparator is provided internal to the LTC4055 to detect the presence of an alternate external power source. When the wall adapter is detected, the comparator enables the output battery charger and disables both the power path from input to output and the input battery charger. When the wall adapter is present this comparator is important to prevent reverse conduction from the output of the LTC4055 to the input or USB. Figure 4 shows the connection of the wall adapter to the output using a power Schottky. The output of the wall adapter comparator also drives an open drain status pin ($\overline{ACPR}$). This status pin can be used to enable an external power PMOS FET to make a low impedance connection from the wall adapter to the output of the LTC4055, as shown in Figure 6.

Programmability

Input current limiting and battery charge current are both independently programmable. This allows the current limit and the charge current to be tailored to the application. An external programming resistor (R_{CLPROG}) sets the current limit for the 200mΩ switch. The battery chargers have their constant current mode current set by an external programming resistor (R_{PROG}) as well. The current limit programming resistor also sets the maximum battery charge current allowed for the input charger and does not impact the output charger current. This allows the output charger to be programmed for something greater than the cur-

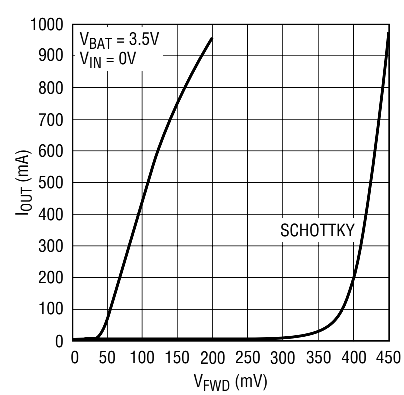


Figure 5. Ideal diode and Schottky diode forward voltage versus current

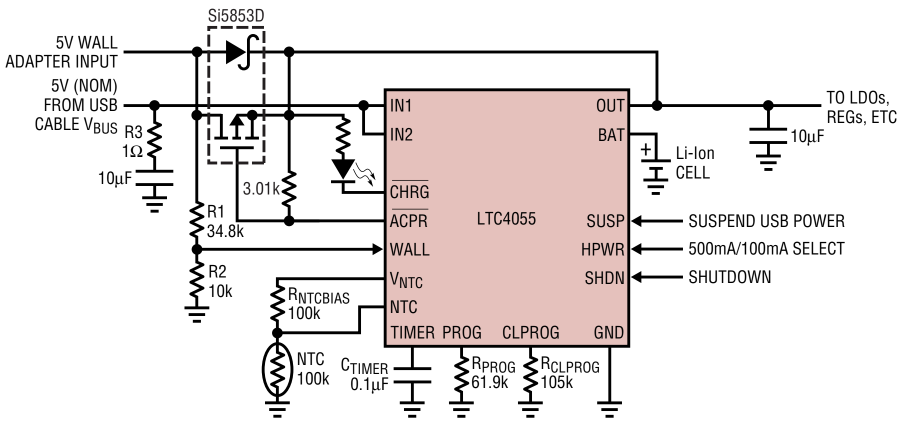


Figure 6. USB power control and battery charger application with a wall adapter input configured to charge the battery at 800mA when the adapter is present.

rent limit when an external adapter is available.

The input current limit and maximum input battery charge current (I_{CL}) is programmed as follows:

$$I_{CL} = \frac{50,000}{R_{CLPROG}}$$

The maximum battery charge current (I_{CHG}) is programmed as follows:

$$I_{CHG} = \frac{50,000}{R_{PROG}}$$

Figure 3 shows input and battery currents as a function of load current. The input current limit is set to 500mA by setting the current limit programming resistor to 100k and the charge current programming resistor to 100k or less. Figure 7 shows the input and battery charge currents for a case where the battery is programmed for something less than 500mA. In this case the battery charge current is programmed to 250mA by setting the charge current programming resistor to 200k.

USB Compatibility

The USB specification provides for two power modes, high power (500mA) and low power (100mA). The HPWR pin on the LTC4055 selects the power mode. The current limiting for the LTC4055 should be configured for the high power mode and the power mode control pin (HPWR) on the LTC4055 controls whether the current limiting is set for high or low power. When operating in low power mode (see Figure 8) the current limit is set for 20% of its programmed high power current limit and the maximum charge current is set to 16% of the programmed current limit. Note that the current limit only applies to currents from the input of the LTC4055. The output charger charges at the programmed charge current.

The USB power specification states that high power applications must operate at voltages as low as 4.5V and low power applications must operate as low as 4.35V. These voltages include resistive drops in the cables and connectors of the interface. This assumes the cables and connectors are fully USB compliant. In cases where resistive drops exceed those anticipated by the USB specification, the LTC4055 has a unique feature that allows it to work properly under these conditions. The undervoltage charge current limiting feature reduces the charge current when the voltage at the input drops below approximately 4.4V. This prevents the input from dropping too far and shutting off the charger. An abrupt shutoff of current can cause the voltage to rise again re-enabling the charger. The voltage then drops and the cycle repeats. The under-voltage charge current limiting feature prevents this drop out oscillation by adjusting the charge current in an effort to maintain a constant minimum input voltage of approximately 4.35V.

The USB specification for low power bus current is 500µA from a device while in the Suspend state. The LTC4055 is designed to allow an application to abide by this specification. A suspend mode pin has been integrated into the LTC4055 that cuts the bus current to approximately 100µA. This is accomplished by turning off input charging and the input power path to the load. If an external source is not available in this mode, the application remains active by drawing power from the battery via the LTC4055's ideal diode function.

Thermal Regulation

Thermal charge current regulation within the LTC4055 protects the part and surrounding circuitry from excessive temperature, and allows the user to push the limits of the power handling capability of a given circuit board without risk of damaging the LTC4055. The internal thermal regulation reduces the programmed charge

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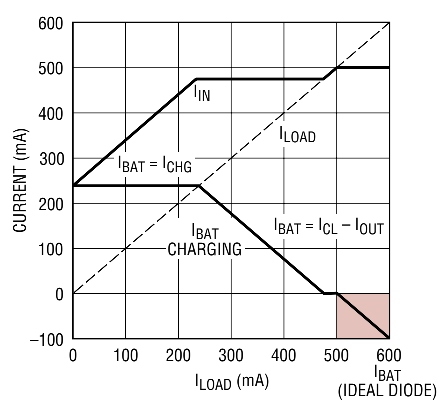

Figure 7. Input and battery currents as a function of load current in high power mode with the current limit set to 500mA and the charge current set to 250mA (R_{CLPROG} = 100k, R_{PROG} = 200k).

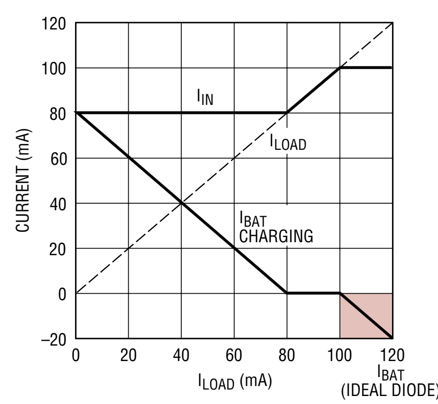

Figure 8. Input and battery currents as a function of load current in low power mode with R_{CLPROG} = 100k and R_{PROG} = 100k, the current limit is 100mA and the charge current is 80mA.

An Accurate Battery Gas Gauge

by James Herr

Introduction

A battery fuel gauge can be implemented in a variety of ways. The most popular is to derive the remaining battery capacity from the battery voltage. This method has advantages in that it is easy to implement and relatively low in cost, but it does have one major drawback: It is relatively inaccurate. Battery voltage has, at best, an inconsistent relationship to battery capacity—the relationship varies greatly depending on battery discharge rate and temperature.

The latest portable devices, though, require more accurate battery gas gauging. For instance, a portable computer or PDA may need to save data, or state information, and shut down when the battery reaches a critical discharge point. Accurate prediction of this point allows the device to safely run longer on battery power. For applications that require accurate gauging, the LTC4150 coulomb counter is a compact and easy-to-implement solution.

The LTC4150 measures the charge flowing into and out of the battery through a sense resistor. A voltage-to-frequency converter transforms the current sense voltage into a series of output pulses. Each pulse corresponds to a fixed quantity of charge flowing into or out of the battery. The device indicates the charge polarity as the battery is depleted or charged. The status of the battery can be accurately predicted by a microcontroller, connected via a simple 1-wire or 2-wire interface.

Precision Integrator Enables Charge Measurement

Charge is the time integral of current. The LTC4150 measures battery current by monitoring the voltage developed across a sense resistor and then integrates this information to determine charge. The block diagram shown in Figure 1 shows how.

The current measurement is filtered by capacitor CF connected across CF+ and CF– pins. This averages all fast changes in current arising from ripple, noise and spikes in the load, charge current, or Burst Mode® operation of a switching regulator. The filter's output is applied to an integrator with the amplifier and 100pF capacitor at its core. Switches S1 and S2 reverse the ramp direction once the integrator's output reaches the REFHI or REFLO levels. By observing the condition of S1, S2, and the ramp direction, the polarity is determined.

A counter is used to effectively increase the integration time by a factor of 1024, greatly reducing microcontroller overhead required to service the interrupts from the LTC4150. At each counter underflow or overflow, the $\overline{\text{INT}}$ output latches low, while simultaneously, the POL output is latched to indicate the polarity of the charge count. Once the interrupt is recognized, the microcontroller resets $\overline{\text{INT}}$ output with a low going pulse at $\overline{\text{CLR}}$ pin. To simplify the connections, $\overline{\text{INT}}$ and $\overline{\text{CLR}}$ pins can also be connected together. In this case, the interrupt signal lasts at least 1µs, enough time for the microcontroller to register the data, before the $\overline{\text{INT}}$ pin resets automatically.

Coulomb Counting

The LTC4150's transfer function is quantified as a voltage to frequency gain G_{VF}, where the output frequency is the number of interrupts per second and the input voltage is the voltage V_{SENSE} across the SENSE+ and SENSE– pins. The number of interrupts per second is:

$$f = G_{VF} \bullet |V_{SENSE}| \qquad (1)$$

Where:

$$V_{SENSE} = I_{BATTERY} \bullet R_{SENSE} \qquad (2)$$

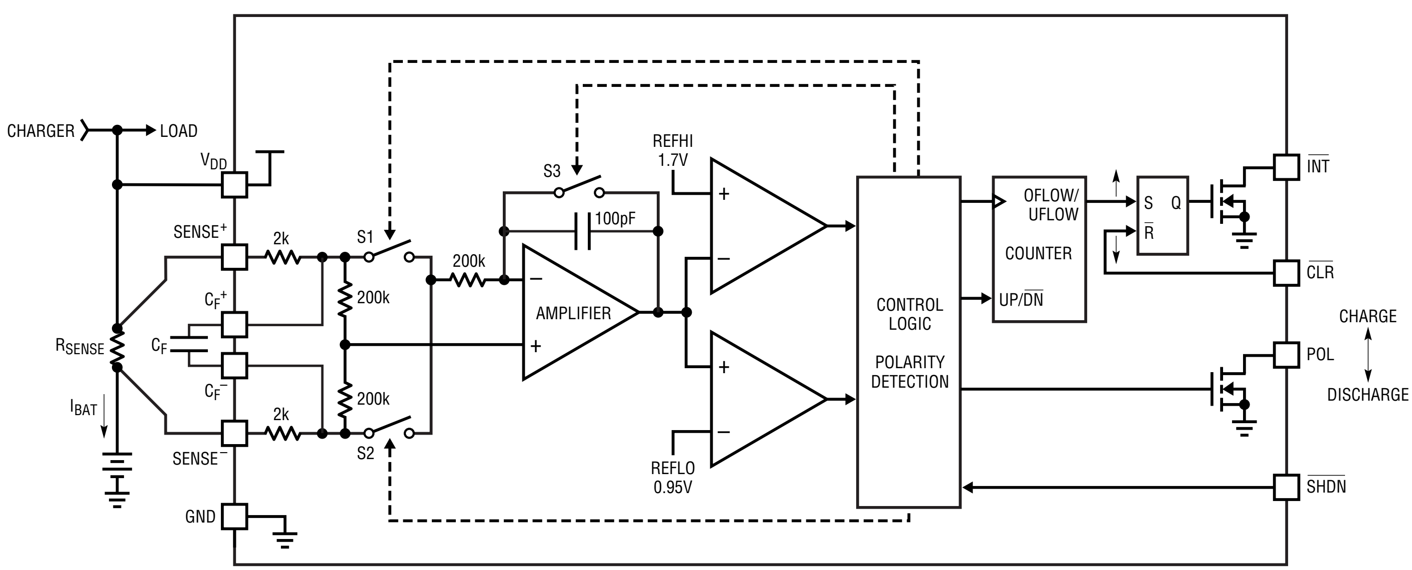

Figure 1. LTC4150 block diagram shows how measured current, at the sense resistor, is integrated and converted to an integer count of charge.

V_{SENSE} = 50mV for the LTC4150, therefore:

$$f = G_{VF} \bullet | I_{BATTERY} \bullet R_{SENSE} | \quad (3)$$

Since I • t = Q, the coulombs of battery charge per $\overline{INT}$ pulse (interrupt interval) can be derived from Equation 4:

$$\text{One } \overline{INT} = \frac{1}{G_{VF} \bullet R_{SENSE}} \text{ Coulombs} \quad (4)$$

Battery capacity is most often expressed in ampere-hours:

$$1\text{Ah} = 3600 \text{ Coulombs} \quad (5)$$

Combining Equations 4 and 5:

$$\text{One } \overline{INT} = \frac{1}{3600 \bullet G_{VF} \bullet R_{SENSE}} \text{ Ah} \quad (6)$$

or

$$1\text{Ah} = 3600 \bullet G_{VF} \bullet R_{SENSE} \text{ Interrupts} \quad (7)$$

The charge measurement can then be scaled with a microcontroller.

High Side Sensing up to 8.5V

Figure 2 shows a typical application design for a 2-cell lithium-ion battery system with 500mA of maximum load current. Using Equation 2 to calculate R_{SENSE} = 50mV/0.5A = 0.1Ω. With R_{SENSE} = 0.1Ω, Equation 6 shows that each interrupt corresponds to 0.085mAh of charge with G_{VF} = 32.55 Hz/V. A battery with 850mAh of capacity takes a total of 10,000 $\overline{INT}$ assertions to fully charge or discharge.

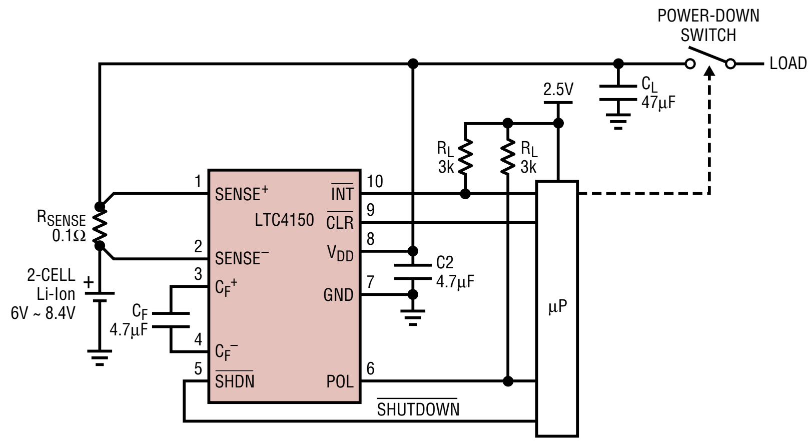

Figure 2. A 2-cell lithium-ion battery gas gauge

The LTC4150 can be shut down, when not needed, to a low current mode (1.5µA max) reducing the drain on the battery.

Accurate Prediction of Battery Capacity

The factors that affect the accuracy of the capacity prediction are the input offset voltage, the integral nonlinearity error (INL), the tolerance of the sense resistor, and the self-discharge of the battery. The self-discharge rate of a Li-Ion type of battery is around 2%–4% per month at room temperature. The LTC4150 has 0.3% of INL error across the input and common mode range, see Figure 3, and 150µV of input offset voltage.

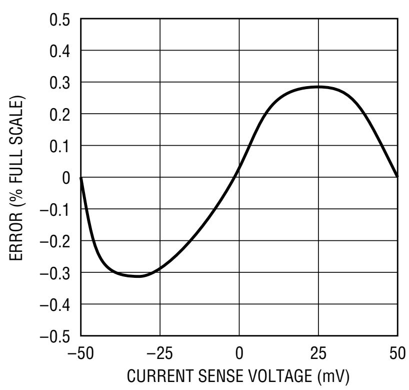

Figure 3. Integral nonlinearity of the LTC4150 is within 0.3% over the entire sense voltage range.

Conclusion

The LTC4150 offers a simple and compact solution for high side coulomb counting/battery gas gauging for battery voltages up to 8.5V(2-cell Li-Ion or 6-cell NiCd or NiMH batteries). The only required external components are the sense resistor and a filter capacitor to average out transient events and ripple current.

LTC4055, continued from page 10

current if the die temperature attempts to rise above a preset value of approximately 105°C. Another benefit of the LTC4055 thermal regulation is that charge current can be set according to typical, not worst-case, ambient temperatures for a given application with the assurance that the charger will automatically reduce the current in worst-case conditions. Thermal regulation simplifies design, maximizes charge current and prevents overheating.

Conclusion

The LTC4055 is a complete PowerPath controller and Li-Ion battery charger for portable USB applications. The LTC4055 is designed to provide device power and Li-Ion battery charging from the USB while maintaining the current limits imposed by the USB specification. This is accomplished by reducing battery charge current as output/load current is increased. The available bus current is maximized to minimize battery charge times.

The LTC4055's versatility, simplicity, high level of integration and small size makes it an ideal choice for many portable USB applications. The LTC4055 is available in a small 16-lead low profile 4mm × 4mm QFN package.

Tiny Device Drives 20 White LEDs from a Single Cell Li-Ion Battery

by Gurjit Thandi

Introduction

White LEDs are gaining popularity as the backlighting source for the LCD displays used in handheld devices, mainly due to their improved efficiency and shrinking costs. White LEDs are also making inroads into the larger LCD displays used in automotive instrument panels and car radios. The LT3466 simplifies the task of fitting the LED driver circuitry into the latest devices by providing a dual high efficiency, constant current white LED driver in a space-saving 3mm × 3mm DFN package. The LT3466 is designed to drive up to 20 white LEDs from a single cell Li-Ion battery input with greater than 80% efficiency. It also provides space- and component-savings with integrated Schottky diodes and internal compensation.

About the LT3466

Figure 1 shows a block diagram of the LT3466 with its two independent, but identical, step-up converters capable of driving asymmetric LED strings. The step-up converters are designed to drive the series connected LEDs with a constant current, thus ensuring uniform brightness and eliminating the need for ballast resistors. LT3466 incorporates internal 44V power switches and Schottky diodes. Switch current limit is guaranteed to be greater than 320mA over the full operating temperature range. A low, 200mV, high accuracy (±4%) reference voltage is provided to program the LED current.

The step-up converters use a current mode topology to provide excellent line and load transient response. Internal feedback loop compensation of LT3466 allows the use of small ceramic capacitors at the output. The built-in over-voltage protection circuit clamps the output of either converter to 42V if the LED string connected to that output fails open-circuited. Internal soft-start is provided for each step-up converter, thus minimizing inrush current during start-up.

The switching frequency of LT3466 can be programmed over a 200kHz

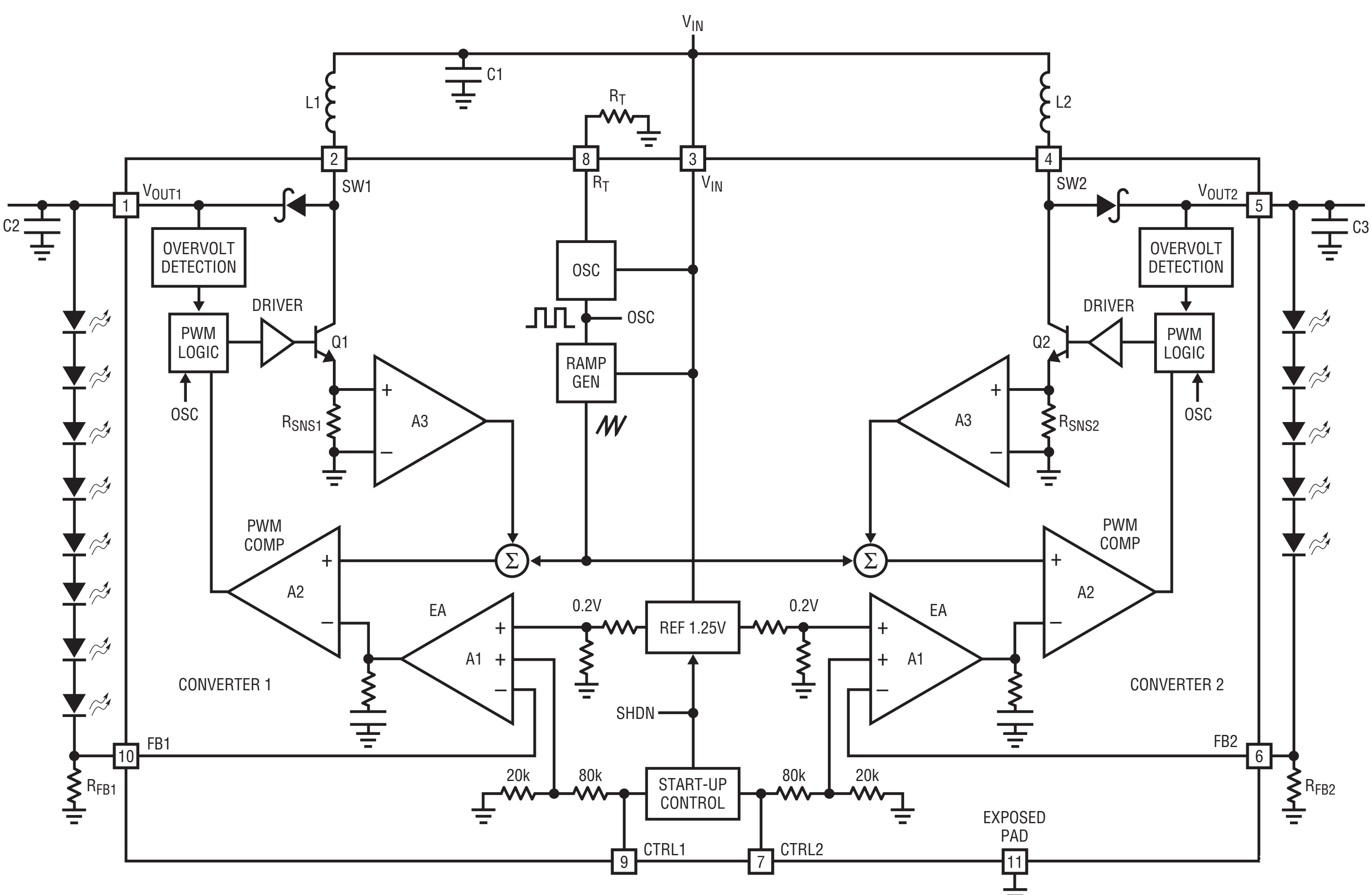

Figure 1. LT3466 block diagram

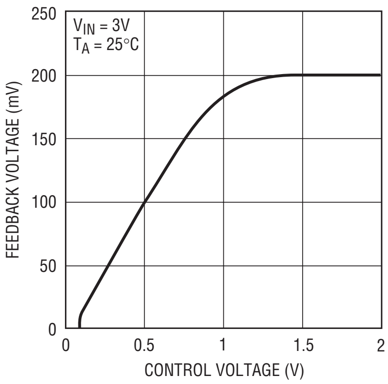

Figure 2. Correlation of feedback voltage (V_{FB}) to control voltage. The current (dimming) in the LED string is given by $I_{LED} = V_{FB}/R_{FB}$.

to 2MHz range by means of a single resistor from the R_T pin to ground. The LT3466 operates from a wide 2.7V to 24V input voltage range, making it suitable for a wide range of applications.

The device features independent shutdown and dimming control of the two LED strings. The current in each LED string can be shut off by pulling the respective control (CTRL1 or CTRL2) pin voltage below 50mV. Dimming for each LED string is achieved by applying a DC voltage to its respective control pin. When both CTRL1 and CTRL2 pin voltages are pulled below 50mV, the device enters total shutdown.The dimming feature for the LT3466 can be best understood by referring to the block diagram in Figure 1. The amplifier A1 (present in both converters) has two noninverting

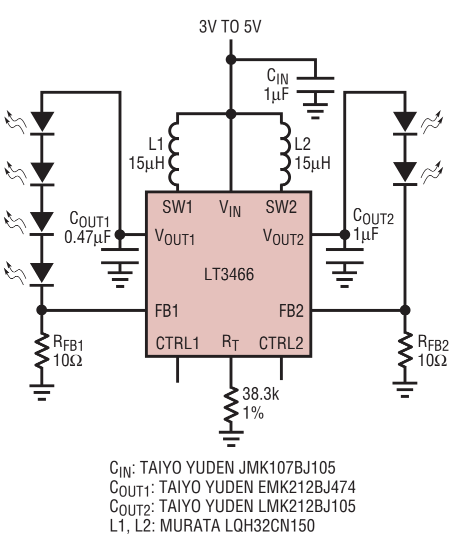

Figure 3. Low profile (max height < 1.7mm), single cell Li-Ion powered, six (4/2) white LED driver circuit

inputs and a single inverting input. An internal 200mV (±4%) reference voltage is connected to one of its noninverting inputs. An input voltage equal to $0.2 \bullet V_{CTRL}$ is connected to the second noninverting input of A1. The inverting input of A1 is connected to the cathode of the lowest LED in the string and the feedback resistor.

The LED current in each string is given by:

$$I_{LED} = \frac{V_{FB}}{R_{FB}}$$

Thus, a linear change in the feedback voltage results in a linear change in the LED current. The amplifier A1 regulates the feedback pin voltage as a function of the control voltage as given by:

$$V_{FB} = 0.2 \bullet V_{CTRL}\text{, When } 0.2V < V_{CTRL} < 1V$$

$$V_{FB} = 0.2V\text{, When } V_{CTRL} > 1.6V$$

As the voltage at the control pin is ramped from 0.2V to 1.6V, the respective feedback pin voltage changes from 40mV to 200mV. When the control voltage is taken above 1.6V, it does not affect the feedback pin voltage. Figure 2 shows the correlation between the feedback voltage and the control pin voltage.

Main and Sub-Display Backlighting for Cell Phones

A typical application of the LT3466 is as a driver for dual backlights in a cell phone. Present day, flip style cell phones typically use four white LEDs (with the phone open) for backlighting the main display and two white LEDs (with the phone closed) for a sub-display. Each of the backlights requires independent dimming and shutdown control. Figure 3 shows a Li-Ion battery powered 6-LED (4-LED main and 2-LED sub) backlight system. LT3466 allows for independent dimming control of the main and sub display via the CTRL1 and CTRL2 pins.

Board real estate is at a premium in cell phones and the circuit shown in Figure 3 minimizes the number of external components and provides a complete system solution with maximum component height under 1.7mm. The LT3466 is designed to run at a

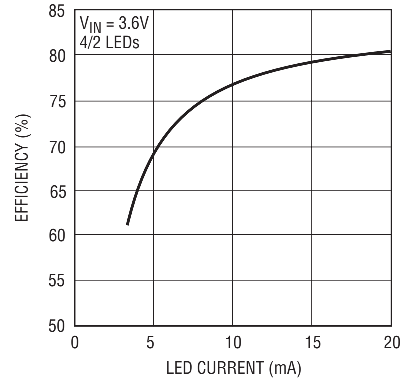

Figure 4. Efficiency for Figure 3's circuit

1.25MHz switching frequency via the selection of the R_T resistor. The choice of high 1.25MHz switching frequency allows the use of space saving low-profile inductors and tiny 0805 size ceramic capacitors, while maintaining high system efficiency. Figure 4 shows the efficiency of the circuit. The typical efficiency at 3.6V input supply is 81% with both the LED strings being run at 20mA.

Figure 5 shows the transient response of the circuit to a step in the current of the 4-LED string from 10mA to 20mA. The inductor current transition is smooth and has a well-defined steady state ripple, which results in a lower output voltage ripple. This reduces the size and cost of the output filter capacitor and allows the use of a small 0.47µF (16V, X7R dielectric) 0805 case size ceramic output capacitor.

Single Cell Li-Ion-Powered, 20-White-LED Driver Circuit Using all Ceramic Capacitors

Large color LCD displays used in present day GPS systems and other handheld devices may require up to 20 white LEDs for backlighting while

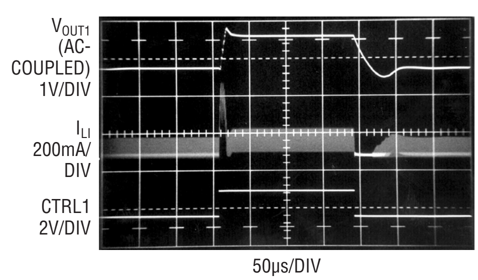

Figure 5. Transient response for Figure 3's circuit. Current in the 4-LED string is stepped from 10mA to 20mA

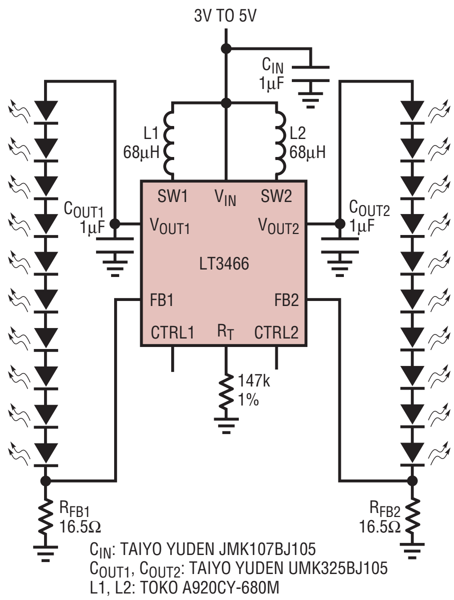

Figure 6. High efficiency, single cell Li-Ion powered twenty (10/10) white LED circuit uses all ceramic capacitors

running off a single Li-Ion cell. The LT3466, with its internal 44V power switches and Schottky diodes, is well suited to drive up to ten white LEDs in series at each output. In order to drive ten white LEDs in series, the converter needs to generate up to a 40V output voltage (the forward voltage drop of a white LED being 3V to 4V). Figure 6 shows 20 white LEDs powered by single cell Li-Ion battery.

To drive ten LEDs per output from a single Li-Ion cell, the converter must run at a high duty cycle of 94%

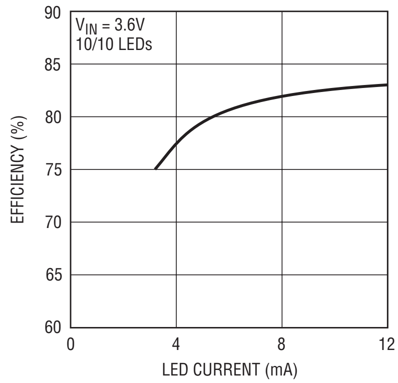

Figure 7. Efficiency for Figure 6's circuit

(typical). The unique architecture of LT3466 allows it to achieve high duty cycles by switching at a lower frequency. In the circuit shown in Figure 6, the LT3466 is designed to run at a switching frequency of 350kHz. The circuit of Figure 6 uses low profile inductors and all ceramic capacitors. Figure 7 shows the efficiency vs LED current for the circuit. The typical efficiency at 3.6V input supply is 83% with both the LED strings being run at 12mA.

If either of the 10-LED strings must be run at greater than 12mA, then it is necessary to power the LT3466 with a higher input supply voltage. The LT3466 is capable of driving 20 white LEDs at 20mA when powered from two Li-Ion cells connected in series. Consult the LT3466 data sheet for more details on the application circuit.

Lighting up Automotive Instrument Panels: A 50-White-LED Driver Operates from a 12V Supply

The LT3466's wide input voltage range makes it ideal for automotive applications. White LEDs are commonly used for providing the backlight for automotive instrument panels and car radio displays. In these applications, the white LEDs must be powered by a constant current to guarantee consistent light intensity and uniform brightness. Figure 8 shows the LT3466 powering 50 (two banks of 25) white LEDs from a 12V input supply. The circuit is configured as a voltage tripler to produce output voltages in excess of 90V. This allows a string of 25 LEDs to be connected at each output, resulting in constant current and uniform brightness.

In Figure 8, the LT3466 is configured to operate at a 2MHz switching frequency by the choice of the 20.5kΩ R_T resistor. This ensures that the radiated switching noise falls outside the AM radio band. High switching frequency also allows the use of low-profile inductors and surface mount ceramic capacitors. Figure 9 shows the efficiency for the circuit. In this application, LT3466 delivers 2.4W output power with 83% efficiency. The thermally enhanced 3mm × 3mm DFN packaging (with exposed pad) of the

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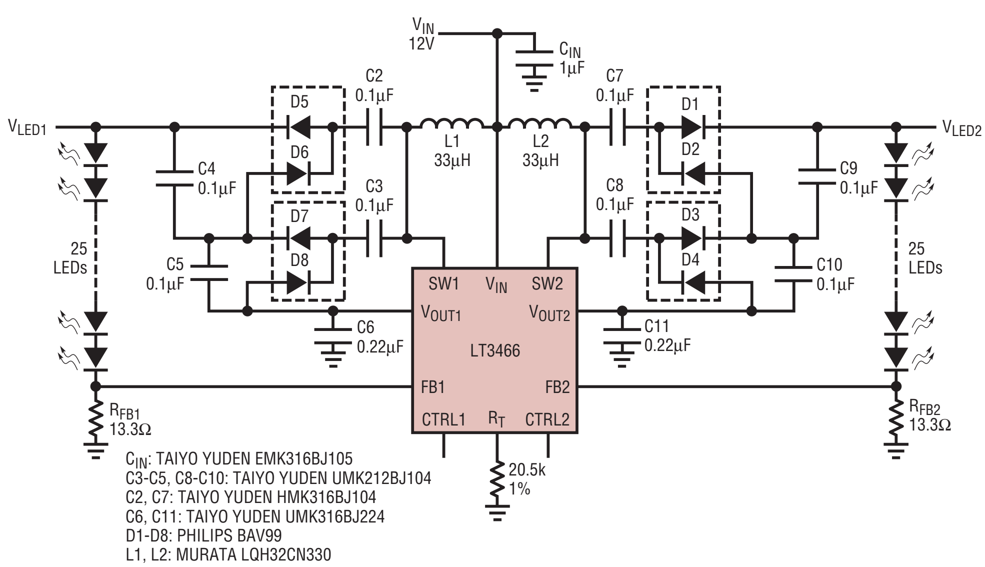


Figure 8. 50 white LEDs powered by a 12V input using low profile surface-mount components

Fully Differential Gain-Block Family Simplifies Interface Designs

by Jon Munson

Introduction

The LTC1992 product family provides simple amplification or level translation solutions for amplifying signals that are intrinsically differential or need to be made differential.

The LTC1992 is available with uncommitted gain (base LTC1992), or in fixed gain versions with space-saving on-chip factory-trimmed resistors—namely, the LTC1992-1, LTC1992-2, LTC1992-5, and LTC1992-10, where the nominal gain is indicated by the suffix dash-number.

Figure 1 shows a typical gain-of-10 application where all gain setting components are included in the tiny MSOP-8 package. The device offers output common-mode control that operates completely independent from the input common-mode of the applied signal. The inputs and outputs can be used either differentially or single-ended as needed.

The LTC1992 family operates with supply voltages from 2.7V single-supply to ±5V and typically consumes <1mA.

Easy to Use Circuit Topology

The block diagram in Figure 2 shows the general configuration of the differential-in/differential-out CMOS amplifier core, along with an output common-mode servo. The values of the on-chip gain resistors depend on the version of the device as indicated. A convenient on-chip 200kΩ voltage-divider resistor network is also provided to support applications where a source of mid-supply potential (V_{MID}) is needed.

The LTC1992 is easy to use. Any signal difference at the inputs (within the input common-mode range) is amplified and presented as a voltage difference at the output pins, with a gain bandwidth product of about 4MHz. The differential gain, A, is set by resistor values:

$$A = \frac{R_F}{R_G}$$

The configurable-gain LTC1992 (no dash suffix) provides any desired differential gain by selection of external resistors, and offers flexibility for other specialized uses. Small input common-mode induced errors, primarily caused by mismatched resistor values, appear at the output as differential error. The virtue of using the LTC1992 versions with on-chip precision resistors, besides the space savings, is that a high CMRR (>55dB) is assured without the expense of outboard precision resistor networks.

Setting the common-mode (shared offset) of the output pair is a straightforward matter of providing a V_{OCM} control voltage, and in most applications this input is simply connected to the V_{MID} pin. The output servo compares the V_{OCM} input with the $(V_{+OUT} + V_{-OUT})/2$ signal generated by the 30k resistor pair and makes a correction voltage that is applied to both outputs without disturbing the differential signal being produced. Driving V_{OCM} with V_{MID} automatically provides the greatest output dynamic-range. The output common-mode servo provides a bandwidth of about 50% of the main differential path, making it possible to use the V_{OCM} input for signal functions if desired.

Easy Conversions Between Differential and Single-Ended

The LTC1992 family is especially useful for making conversions to or from differential signaling. Analog to Digital converters (ADC's) are often optimized for differential inputs with a specific common-mode input voltage. Use of an LTC1992 amplifier makes the ADC interface very simple by using the V_{OCM} control feature to establish the requisite offset. In many cases the mid-scale potential is provided by the ADC and can be tied directly to the V_{OCM} input. In addition, the source-signal input may then be differential or single ended (by grounding the unused input) or have inverted polarity. One particularly effective use of the LTC1992 is in a situation shown in Figure 3, where a ground referenced bi-polar input signal needs level translation and possibly gain for proper operation with subsequent circuitry- and no negative supply is available.

It is not necessary to connect to both outputs, so one can treat the LTC1992 as single-ended, thereby

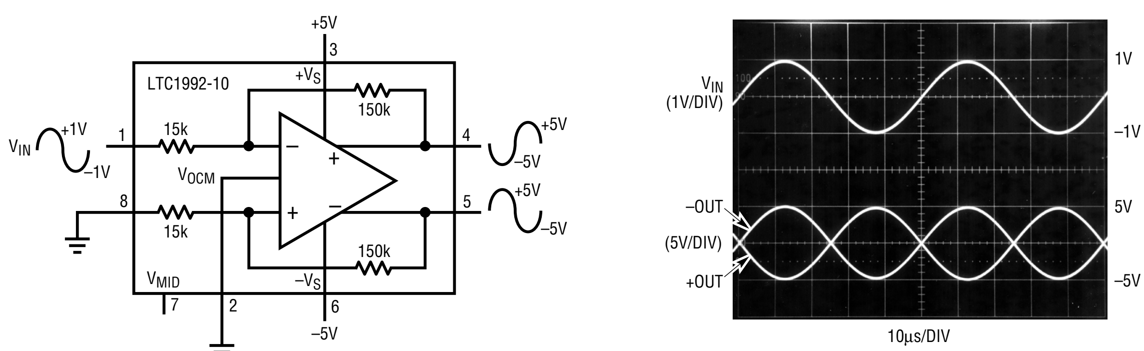
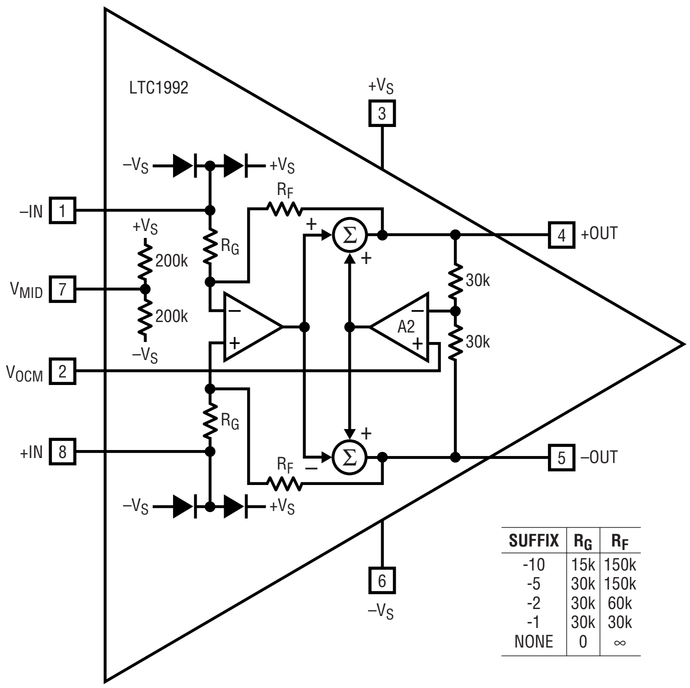


Figure 1. Single-ended to differential gain-of-10 amplifier



SUFFIX	R_G	R_F
-10	15k	150k
-5	30k	150k
-2	30k	60k
-1	30k	30k
NONE	0	∞

Figure 2. LTC1992 functional block diagram

permitting the V_{OCM} input to represent a third algebraic input term in addition to the basic differential input pair. Figure 4 shows the LTC1992-2 used for single-ended arithmetic processing of three discrete input signals with no external components. This capability is very useful in performing analog addition or simple translation functions. The LTC1992 family of devices is ideal for amplifying differential signal sources, such as acoustic transducers or power-line current monitors and, if required, converting the result to single ended.

Differential Transimpedance (TIA) Preamp

A differential TIA topology has the potential of providing an S/N improvement over a single-ended TIA with the same V/I by eliminating the common-mode component of the input noise. Figure 5 shows a photodiode TIA with a fully differential topology. The output common-mode is established with V_{OCM} as described previously, and the photodiode common-mode floats to the same value. This circuit maintains a 0V bias on the photodiode, regardless of the photocurrent flowing. As with a conventional TIA, the value of C_F is chosen to compensate for the photodiode and other stray capacitance. The circuit in Figure 5 has a bandwidth from DC to 20kHz, with a measured output noise spectral density less than twice the noise of the resistors alone (1.1μV/$\sqrt{\text{Hz}}$ at 20kHz).

Verify Operational Common-Mode Range

For a given input common-mode voltage (V_{INCM}) and output common-mode voltage (V_{OCM}), the designer needs to verify that the internal amplifier input common-mode (V_{ICM}) is within the specified operating range of $-V_S - 0.1V$ to $+V_S - 1.3V$. With a standard differential amplifier topology having gain of A, like that of the fixed gain versions of the LTC1992, the following relationship holds:

$$V_{ICM} = \frac{A}{A+1} \bullet V_{INCM} + \frac{1}{A+1} \bullet V_{OCM}$$

For example, assume an LTC1992 (no suffix) is powered from +5V, configured for a gain of 2.5, V_{OCM} is tied to V_{MID} (i.e. 2.5V), and the circuit is driven from a source with a common-mode-voltage of 0V. From the relation above,

$$V_{ICM} = \frac{2.5}{3.5} \bullet 0 + \frac{1}{3.5} \bullet 2.5 = 0.71V$$

which is well within the performance range of the part. Note in this example that the differential inputs may swing 1V below ground without clipping effects or the need for a minus rail.

The fixed-gain versions have an additional input limitation due to the possibility of forward biasing the ESD input protection diodes (shown in Figure 2), which limit the maximum allowable signal swings to about 0.3V beyond the supply voltages (while the configurable-gain LTC1992 also includes the ESD diodes, conduction can only occur outside the usable V_{ICM} range). For single-ended inputs like shown in Figure 3, the applied input common-mode voltage (V_{INCM}) is dy-

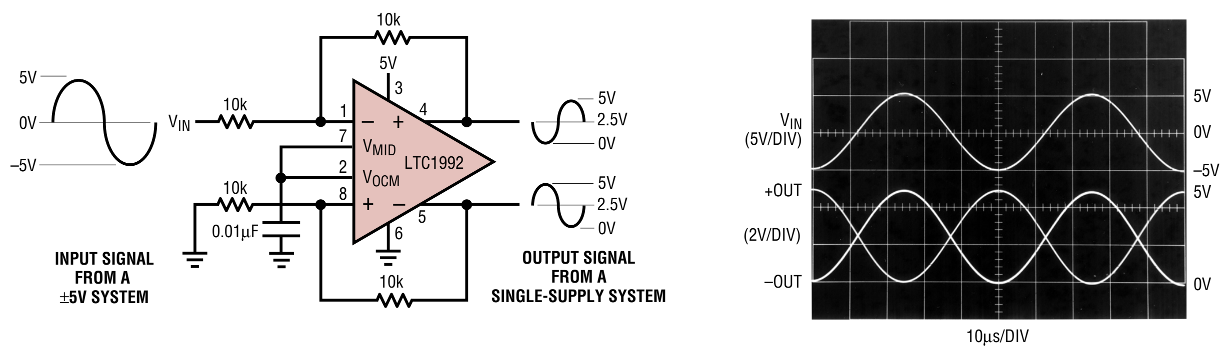


Figure 3. Handling bipolar signals with a single supply

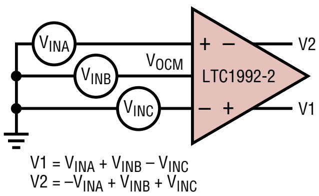


Figure 4. Easy arithmetic processing of single-ended signals

namic and has extremes that are 50% of the input swing (V_{INCM} is ±2.5V in the Figure 3 example). The V_{ICM} equation above is used with both the upper and lower dynamic V_{INCM} values to verify single-ended operability.

Common-Mode Input Range Extension

The configurable-gain LTC1992 makes it possible to extend input common-mode capability to well outside the supply range by selecting gain below unity and/or introducing common-mode shunt-resistors (see R_S in Figure 6). The drawback to the shunt-resistor method is that component tolerances of R_G and R_S become magnified by approximately the gain of the circuit, leading to reduced CMRR performance for a given resistor tolerance. For low-gain operation, common-mode extension to beyond 35V is realizable with the use of high-accuracy resistor networks.

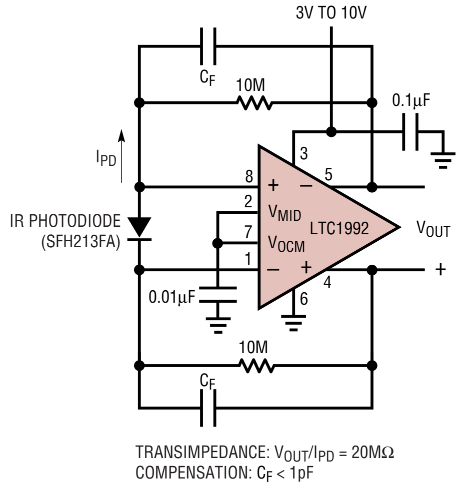


Figure 5. Fully differential transimpedance amplifier topology

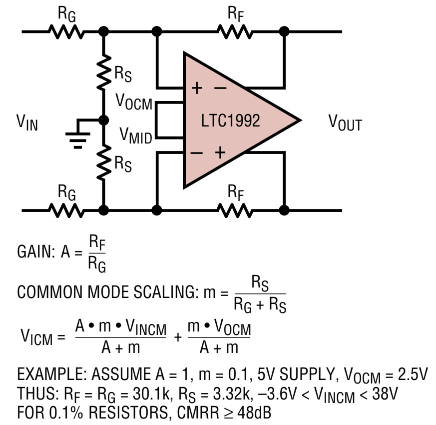


Figure 6. Extending input common-mode range

Conclusion

The LTC1992 family of differential amplifiers offers easy-to-use building blocks that provide simple, minimum component-count solutions for a wide range of applications, including convenient methods of transforming signals to/from differential form, providing component-free gain, or generating DC level-shifting functions. The versions that include on-chip precision resistors save space and reduce costs by eliminating expensive precision resistor networks. The configurable-gain LTC1992 saves cost by allowing single-supply applications to support input signal swings that exceed the supply-voltage window without additional design complexity.

LT3466, continued from page 15

LT3466 enables it to drive as many as 50 white LEDs from a 12V input supply. Figure 10 shows the switching waveforms for the circuit.

Conclusion

The LT3466 is a dual white LED driver designed to drive up to 20 white LEDs from a single Li-Ion input. Integrated power switches, Schottky diodes, and availability in a space-saving (3mm × 3mm) DFN package make LT3466 an excellent fit for handheld applications. The wide operating voltage range and high frequency capability of the LT3466 enables it to meet the backlighting needs for automotive instrument panels and car radio displays as well. Features like internal soft-start, open LED protection and internal loop compensation reduce the number of external components, thus reducing the overall cost and size of the white LED driver circuit.

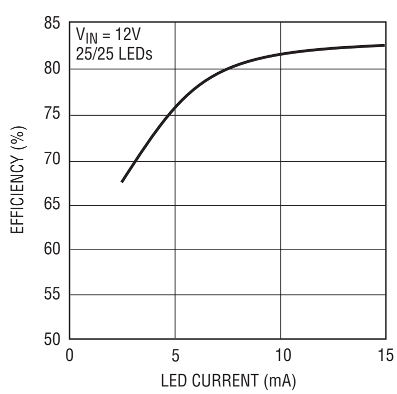


Figure 9. Efficiency for Figure 8's circuit

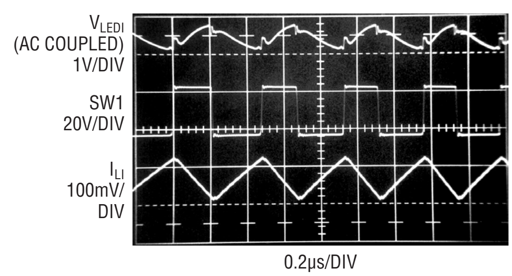


Figure 10. Switching waveforms for Figure 8's Circuit. Each set of 25 white LEDs driven at 15mA

Triple Output LCD Power Supply Delivers 95% Efficiency from a Tiny 3mm x 3mm Package

by John Bazinet

Introduction

Today's handheld products pack more functionality in less space while demanding improved battery life over products of the previous generations. The only way to achieve both is to improve power efficiency in the device wherever possible. The color LCD display system is a good place to start, since it is an increasingly popular, but power hungry feature. The LTC3450 improves battery life and saves space by delivering a 95% efficient color LCD bias solution in a low profile (0.8mm tall), 3mm × 3mm package.

Figure 1 shows a block diagram of the LTC3450—a complete triple output LCD power converter—in a low noise 5.1V, 10mA output synchronous step up DC/DC converter. The charge pump based voltage tripler develops a 15V output and a voltage inverter develops –10V. The 15V and –10V outputs are used in the LCD display for VGL and VGH supplies, while the 5.1V output is used to provide the main panel power. The 5.1V converter switches at a constant 550kHz, which enables very low AV_{DD} ripple voltage even when using tiny ceramic capacitors and one small inductor. The output voltages of the LTC3450 are sequenced to be compatible with color LCD displays with AV_{DD} powering up first followed by VGL and then VGH.

The LTC3450 also provides inrush current limiting during start-up (Figure 2), as well as output disconnect and active discharge in shutdown mode. The LTC3450 is stable with ceramic capacitors and its internal compensation eliminates the need for an external R-C compensation network. The LTC3450 also features a wide input voltage range of 1.5V to 4.6V, making it compatible with a wide variety of battery or fixed DC voltage inputs. Very low quiescent currents allow the LTC3450 to deliver excellent efficiency over the entire input voltage range (Figure 3).

Power Saving Mode

Some types of color LCD displays switch to an ultra low power state while the display is static, which allows for increased battery life. The LTC3450 supports this mode of operation by

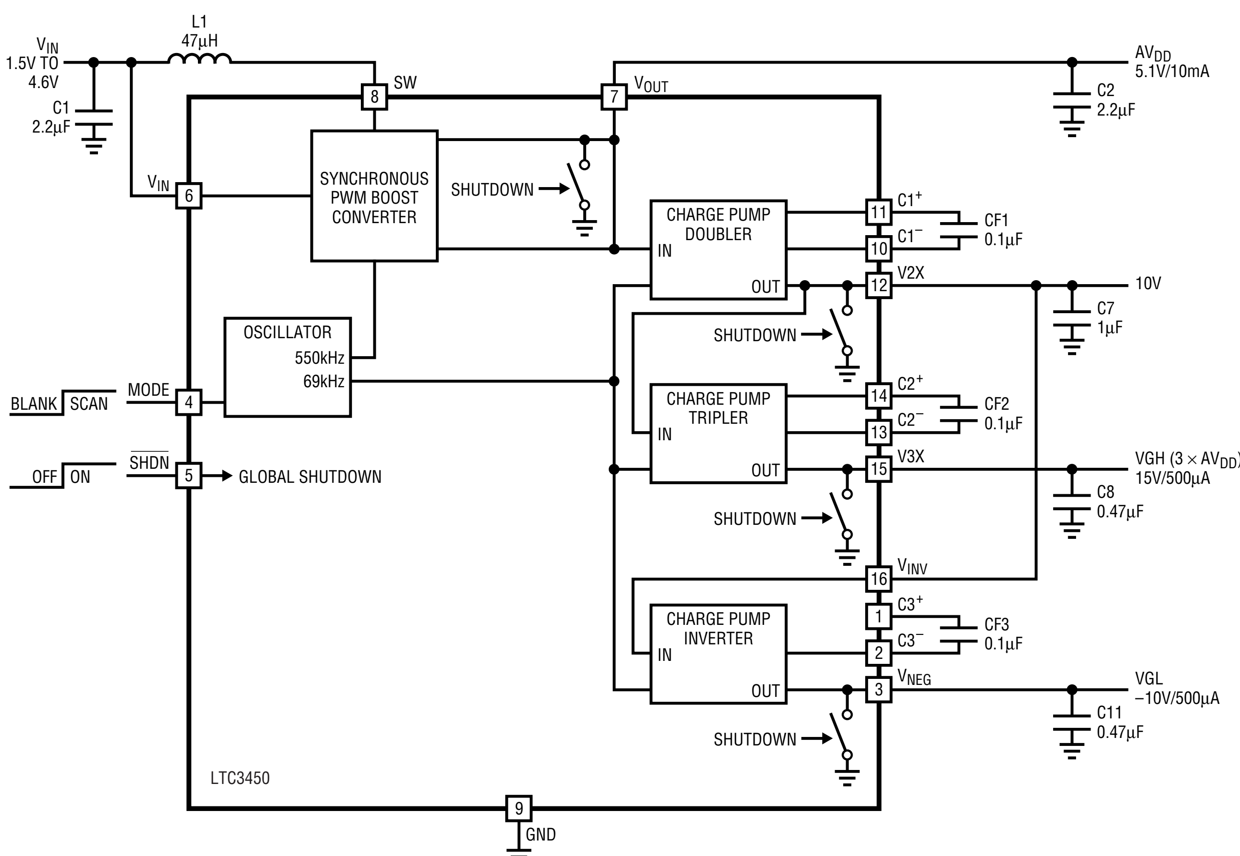


Figure 1. LTC3450 block diagram

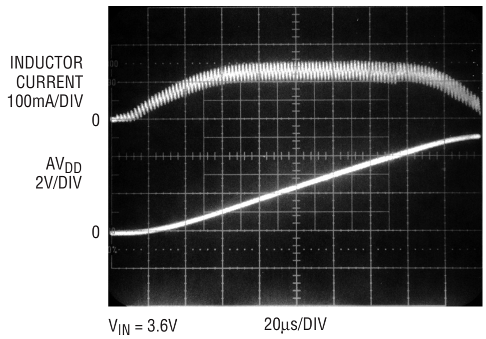


Figure 2. AV_{DD} turn on showing inrush current limiting

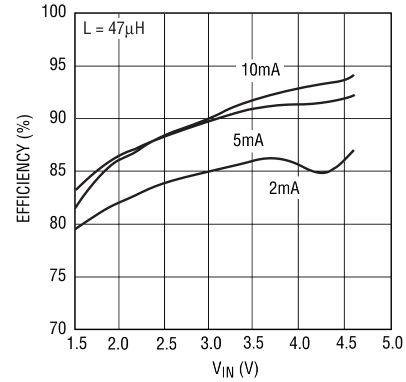


Figure 3. LTC3450 AV_{DD} efficiency vs V_{IN} and load current

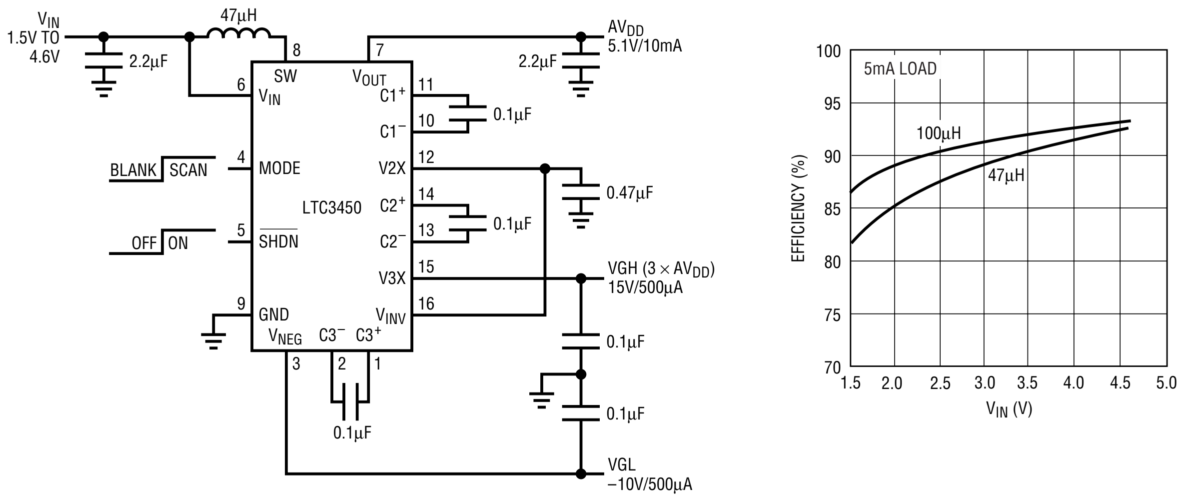


Figure 4. 5.1V, 15V, –10V application circuit and efficiency

reducing its own quiescent current to a mere 30µA from the battery while maintaining all three regulated voltage outputs. This "Blank" mode operation is programmed via the Mode pin of the LTC3450. Driving the SHDN pin low reduces the LTC3450's quiescent current to 10nA (typical) and all three voltage outputs are actively discharged to ground.

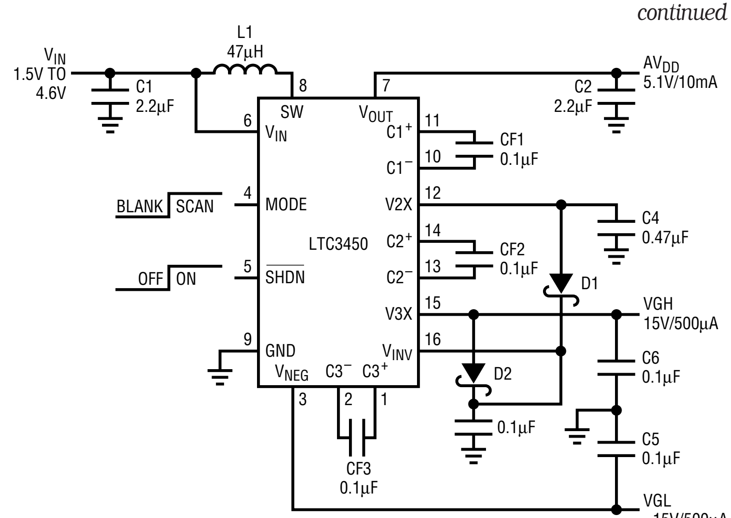
LCD Bias Power Supply Circuits

Figure 4 shows a 1.5V to 4.6V input to a triple output (5.1V/10mA, 15V/500µA and –10V/500µA) application circuit. Greater than 90% efficiency is maintained over the Li-Ion battery's voltage range. This is far superior to an all charge pump approach that can only deliver efficiency approaching the LTC3450 when V_{IN} is approximately 1/2 of AV_{DD}.

Figure 5 shows a 1.5V to 4.6V input to 5.1V/10mA, 15V/500µA and –15V/500µA converter circuit. A tiny external dual diode is added to the circuit to get the converter to deliver the –15V and 15V outputs together.

Figure 6 shows a 1.5V to 4.6V input to 5.1V/10mA, 15V and –5V circuit. Peak efficiency is greater than 90%. The magnitude of the negative output voltage (VGL) is equal to the positive voltage applied to V_{INV}. V_{INV} is connected to either AV_{DD} (for –5V), V2X (–10V), or with the dual diode (Figure 4)

continued on page 24



D1, D2: DUAL SCHOTTKY DIODE, PANASONIC MA704WKCT
L1: SUMIDA CMD4D08-470

Figure 5. 5.1V, 15V, –15V application circuit

A Low Loss Replacement for an ORing Diode

by Rick Brewster

Introduction

ORing diodes are used to connect multiple supplies together to increase reliability (through supply redundancy) or to increase total power. A diode also allows a supply to disconnect if it has insufficient voltage.

At high power levels a Schottky diode is usually chosen as the ORing diode because of its relatively low forward drop (0.35V to 0.6V). But at higher current levels even a Schottky's forward drop creates significant power loss.

A better alternative is the LT4351 controller, which turns a power N-channel MOSFET into a near ideal diode suitable for high power ORing applications. The low $R_{DS(ON)}$ of the external MOSFET provides for low on resistance when conducting, while the LT4351 maintains a scant 15mV forward voltage across the MOSFET when lightly loaded.

By way of comparison consider a 10A at 5V (50W) supply. Under these conditions, a Schottky diode with a forward voltage of 0.45 (SBG1025L) dissipates 4.5W of power—a 9% efficiency loss. The LT4351 using a power MOSFET with a 3mΩ on-resistance (Si4838DY) dissipates only 0.3W and creates a 0.03V drop. This is only a 0.6% efficiency loss and the voltage tolerance of the supply also improves. The LT4351 works with inputs down to 1.2V, where efficiency improvements are even greater

My Diode Can't Do That

Figure 1 shows the block diagram of the LT4351. In addition to its basic performance advantages over a diode, the LT4351 provides, features that a diode cannot. Input comparators serve to detect an undervoltage or overvoltage input supply and disable the MOSFET switch for an out-of-range supply. The comparators also provide a way to manually turn off power from a supply as well. The $\overline{\text{FAULT}}$ output sinks current during undervoltage or overvoltage indicating that the MOSFET is off and an input fault exists.

The LT4351 uses an amplifier to drive the MOSFET gate. This amplifier attempts to maintain approximately 15mV across the MOSFET (input to output). If the $R_{DS(ON)}$ of the MOSFET is too large it applies maximum gate voltage and the forward drop is $I \bullet R_{DS(ON)}$. The gate voltage clamps at 7.5V above the lesser of the input

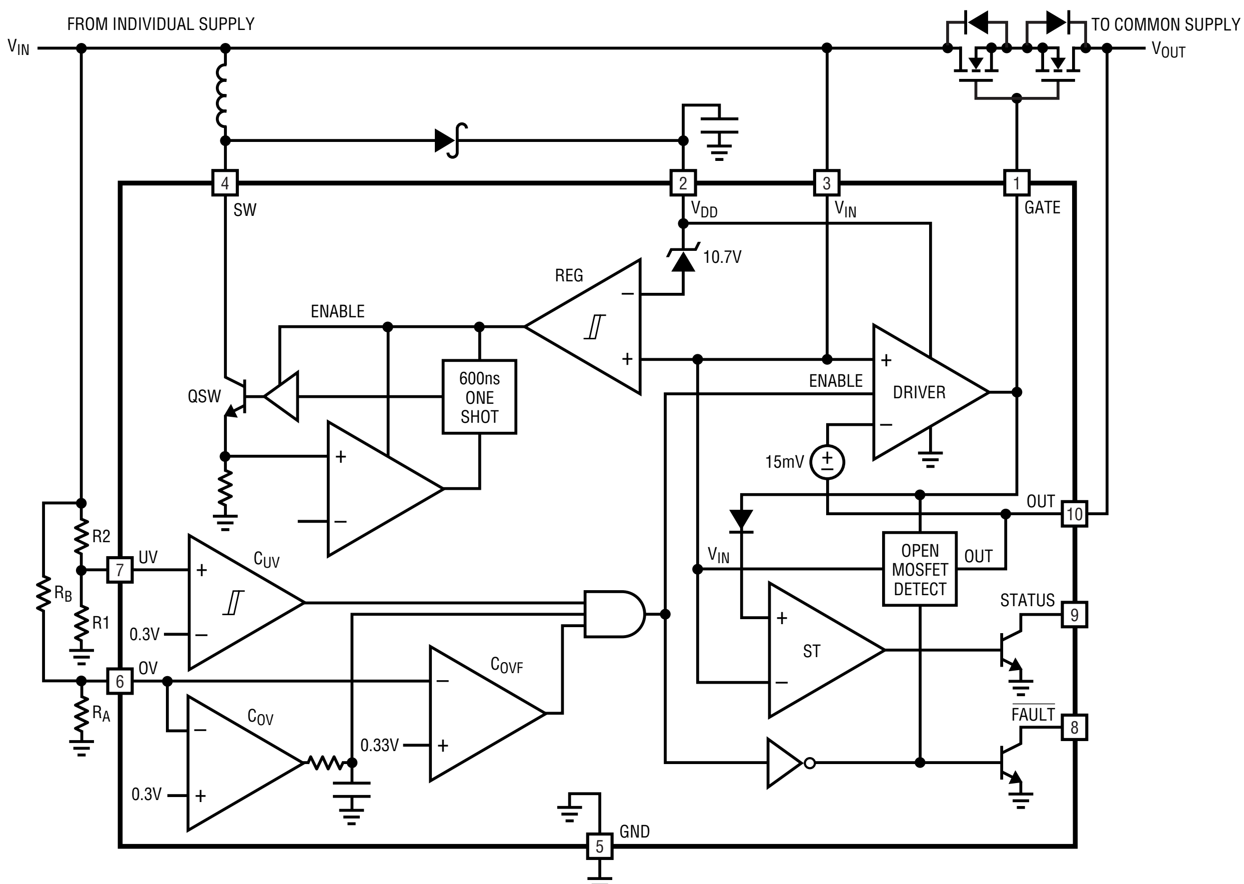


Figure 1. LT4351 block diagram

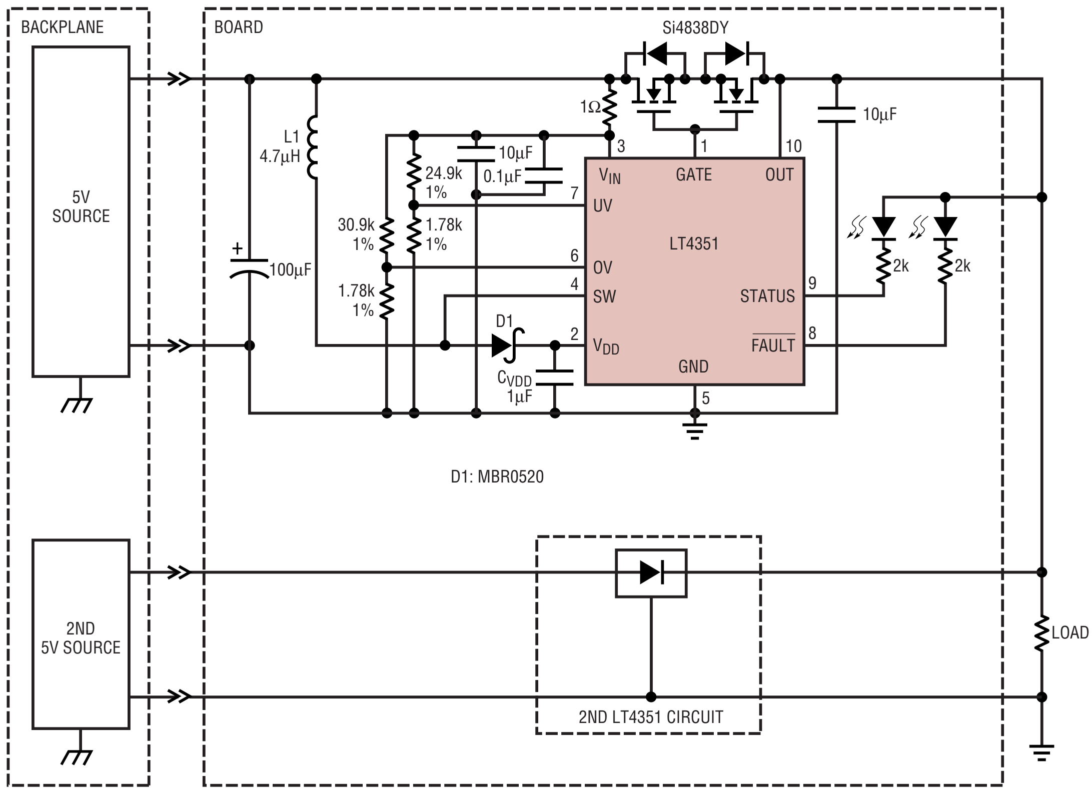


Figure 2. Dual LT4351 5V ORed supply

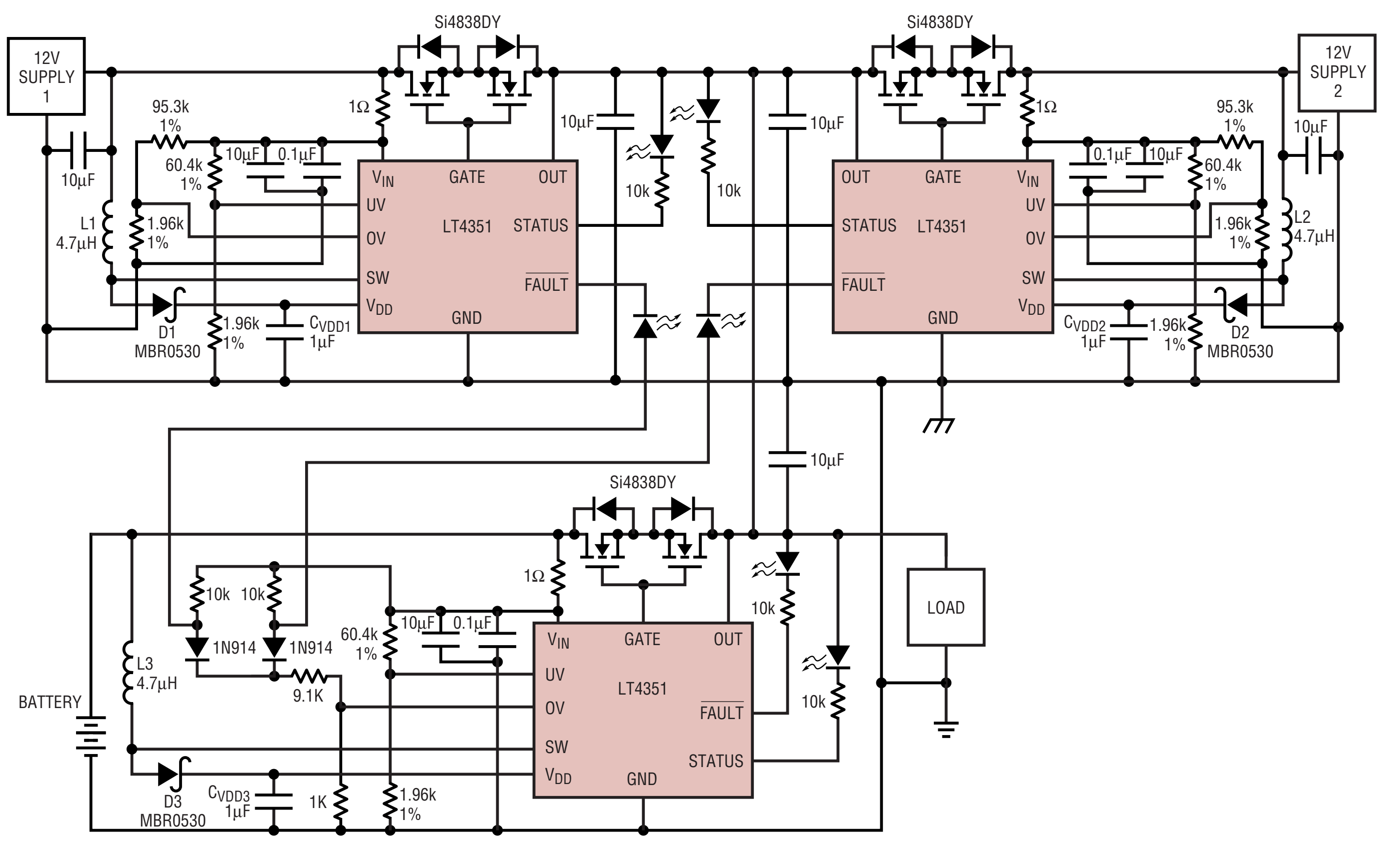


Figure 3. ORed redundant supplies with battery backup

or output to help prevent against gate oxide breakdown in the MOSFET. The strong gate drive amplifier can turn off the MOSFET in under 1µs so that minimal reverse current flows in the event of an input short. This strong amp also provides quick recovery from supply glitches.

Either single MOSFETs or back-to-back MOSFETs can be used. Back-to-back MOSFETS are used to block reverse conduction through the MOSFET body diode. A LT4351 with back-to-back MOSFETs disconnects the output from an input overvoltage condition, something a normal diode cannot do.

The UV and OV pins use hysteresis to reduce the probability of triggering a false undervoltage or overvoltage condition. The UV pin uses current hysteresis. When the UV pin drops below the UV threshold (an undervoltage fault), 10µA of current is drawn from the external resitive divider. This allows the user to set the desired hysteresis level by choosing the appropriate resistor values in the divider. The OV pin has an internal filter that reduces the response to small pulses.

The LT4351 STATUS pin provides indication of the MOSFET state. When the input is greater than the output and the gate to source/drain voltage is greater than 0.7V, STATUS sinks current indicating that the MOSFET should be on. If the input to output voltage exceeds 210mV and the GATE voltage is at its maximum (clamped), $\overline{\text{FAULT}}$ turns on indicating a possible non-functioning MOSFET.

The LT4351 also contains a boost regulator that generates the V_{DD} supply to power the MOSFET gate driver. The boost regulator output current strength allows for quick charging of the V_{DD} supply and supports higher gate drive currents. Thus, the MOSFETs can be turned on quickly during start up and can be quickly turned on and off during normal operation. The regulator only requires a small 4.7µH to 10µH inductor, Schottky diode and capacitor.

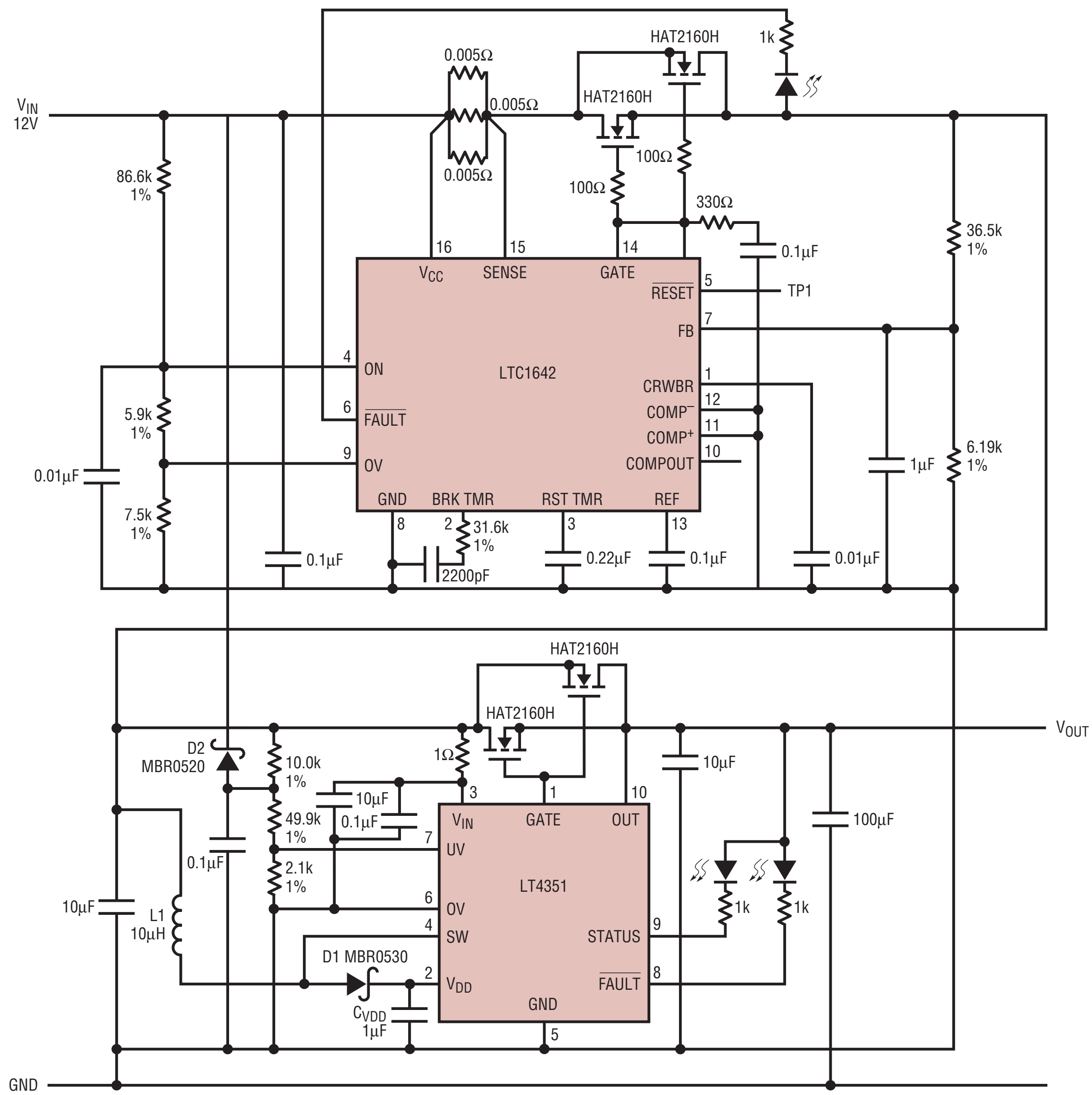


Figure 4. Hot swappable supply with ideal diode

Dual 5V Example

Figure 2 shows an example of a redundant 5V supply. In the event that one supply goes down, the back up supply would take over. In this application, back-to-back MOSFETs are used to prevent the body diode of the MOSFET from conducting in the event that a 5V supply looses regulation and goes into an overvoltage condition.

Resistive dividers from IN to UV and OV set the fault detection thresholds. In this example the UV fault occurs at 4.5V with 0.25V of hysteresis and the OV fault occurs at 5.5V.

L1 and D1 are the boost regulator components. The LT4351 creates a V_{DD} supply of 10.5V above IN. If an external supply that can provide sufficient gate drive is available, that supply can be used instead of the boost regulator.

The MOSFETs are sized based on desired voltage drop with considerations for power dissipation. In this case the Si4838DY has a worst case 4.5mΩ $R_{DS(ON)}$ (at temperature) so the back-to-back pair is 9mΩ. These MOSFETs come in SO-8 packages so if power is limited to 1W in each then they can handle 14.9A. The voltage drop across both MOSFETs at this current is 2 • 4.5mΩ • 14.9A = 0.134V. If more current is required, use MOSFETs with lower $R_{DS(ON)}$ and/or better thermal resistance, or add parallel MOSFETs.

The LT4351 is useful in any ORing situation benefiting from low power dissipation—not just redundant supplies. Different types of power sources can also be ORed together, and because the LT4351 diode function is gated, power sequencing of different supplies is relatively easy.

For example, Figure 3 shows a system with two redundant supplies and a battery backup. The two redundant supplies are ORed via the ideal diodes, so power is delivered from the higher of the in-range supplies. Their undervoltage and overvoltage thresholds are set based on the input supply range. The LT4351 circuit for the battery disconnects the battery when power is supplied from either system supply. Its OV pin is above threshold if the $\overline{\text{FAULT}}$ is off on either system supply (UV is set above threshold). If both system supplies are disabled ($\overline{\text{FAULT}}$ of both systems are low) then the battery's LT4351 OV pin is pulled below threshold to allow the battery to provide power .

Figure 4 shows an example of combining the LT4351 ideal diode function with a Hot Swap controller. This can be used to create ORed redundant supplies on a plug-in board. The Hot Swap controller provides current limiting, circuit breaker functions and reset timing while the LT4351 provides the ideal diode behavior.

Conclusion

The trend in today's power supplies is toward higher currents, lower voltages, higher efficiency and increased reliability. These needs are forcing designers away from traditional Schottky ORing diodes. The LT4351 provides an improved ORing solution by controlling low $R_{DS(ON)}$ MOSFETs to create a near ideal diode. In addition the LT4351 adds increased functionality with supply monitoring that can disable power path conduction. An LT4351 solution has significantly lower power dissipation than a Schottky diode and offers protection features that a Schottky cannot.

LTC3450, continued from page 20

for –15V. If desired, an independent positive voltage source between 5V and 15V can be connected to V_{INV} to produce any desired negative voltage between –5 and –15V.

Conclusion

The LTC3450 delivers a highly compact and efficient power supply solution for small LCD displays. Its wide input voltage range makes it easy to drop into a variety of applications. Built-in inrush current limiting, output disconnect and power saving controls simplify the task of implementing power friendly LCD displays.

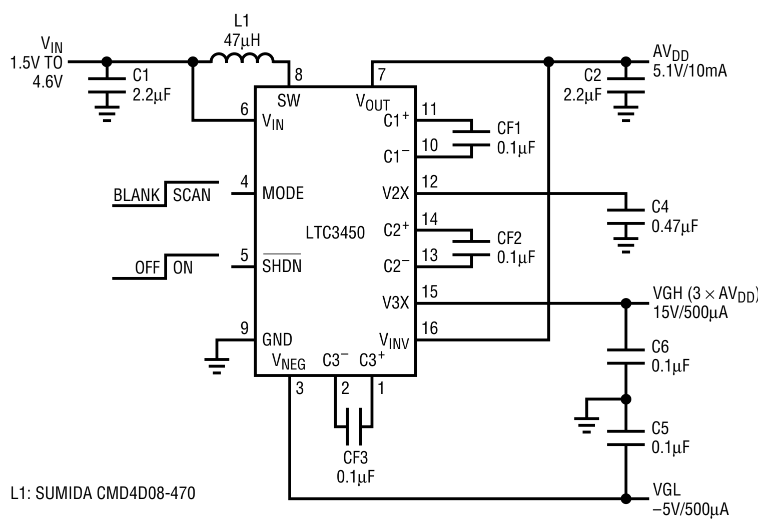


Figure 6. 5.1V, 15V, –5V application circuit

Flexible, High Speed Amplifiers Fit Many Roles

by John Morris and Glen Brisebois

Introduction

Selecting the best operational amplifier for a particular application can be difficult. Fast amplifiers rarely have enough input or output range. Many can't handle difficult capacitive loads, or if they can, they're usually too slow or use too much supply current for the application at hand. But now there is a simple solution: the LT6210 (single) and LT6211 (dual) are flexible enough to satisfy the needs of many applications by solving all of these problems.

These devices couple a high-speed, current-feedback topology with a C-Load™ stable, high current drive, rail-to-rail output stage. They have programmable supply current with a nearly constant speed to power ratio, from 10MHz at 300µA up to 200MHz at 6mA. The LT6210 and LT6211 can fit into such a wide variety of different applications—ranging from power-sensitive, battery-powered applications to high-bandwidth video drivers—that it may be possible to stock just one amplifier for every use.

The single-amplifier LT6210 is available in the SOT-23 6-pin package, while the dual-amplifier LT6211 is available in both an MSOP-10 package and a tiny 3mm × 4mm DFN-10 package. The LT6211 allows independent switching of each amplifier from a high speed to a low power mode.

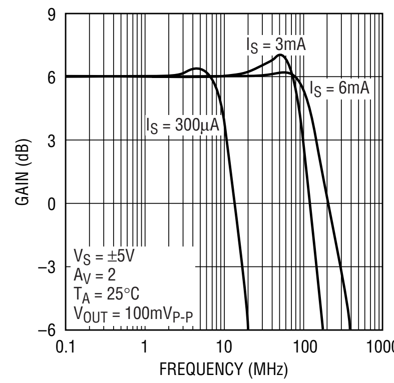


Figure 1. Small signal response vs supply current (per amplifier)

Performance

Table 1 summarizes the performance of the LT6210 and LT6211 at three selected quiescent current levels. The majority of AC specifications improve linearly with supply current. Table 2 shows the resistor values used to achieve these performance values. The frequency response with a 100mV_{P-P} signal at the three selected supply currents is shown in Figure 1. Transient response of a 3.5V_{P-P} signal at the three selected supply currents is shown in Figures 2, 3 and 4.

Circuit Operation

Figure 5 shows the simplified schematic of a single amplifier. Transistors Q1 and Q2 mirror a current from the

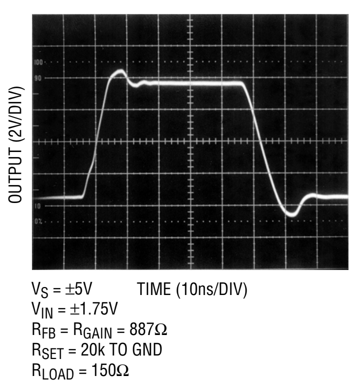


Figure 2. Large signal transient response (I_S = 6mA per amplifier)

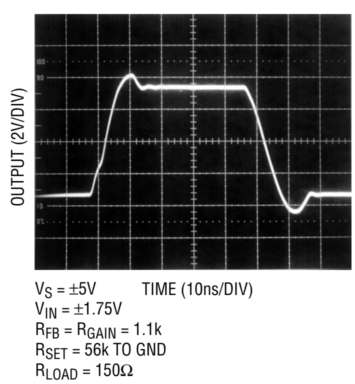


Figure 3. Large signal transient response (I_S = 3mA per amplifier)

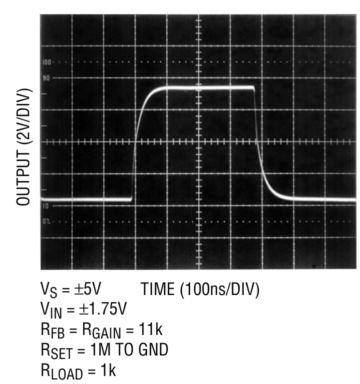


Figure 4. Large signal transient response (I_S = 300µA per amplifier)

Table 1. LT6210 performance at three quiescent current levels on ±5 supplies

Parameter	Conditions	I_S = 6mA	I_S = 3mA	I_S = 300µA	Units
–3dB Bandwidth	A_V = 2, V_{OUT} = 200m$V_{P–P}$	200	100	10	MHz
Slew Rate	A_V = 2, V_{OUT} = 7$V_{P–P}$	700	600	170	V/µs
2nd Harmonic Distortion	A_V = 2, V_{OUT} = 2$V_{P–P}$, f = 1MHz	–70	–65	–40	dBc
3rd Harmonic Distortion	A_V = 2, V_{OUT} = 2$V_{P–P}$, f = 1MHz	–75	–65	–45	dBc
Maximum Output Current	V_{IN+} = 0V, $V_{IN–}$ = ±50mV, R_L = 0Ω	±75	±70	±30	mA

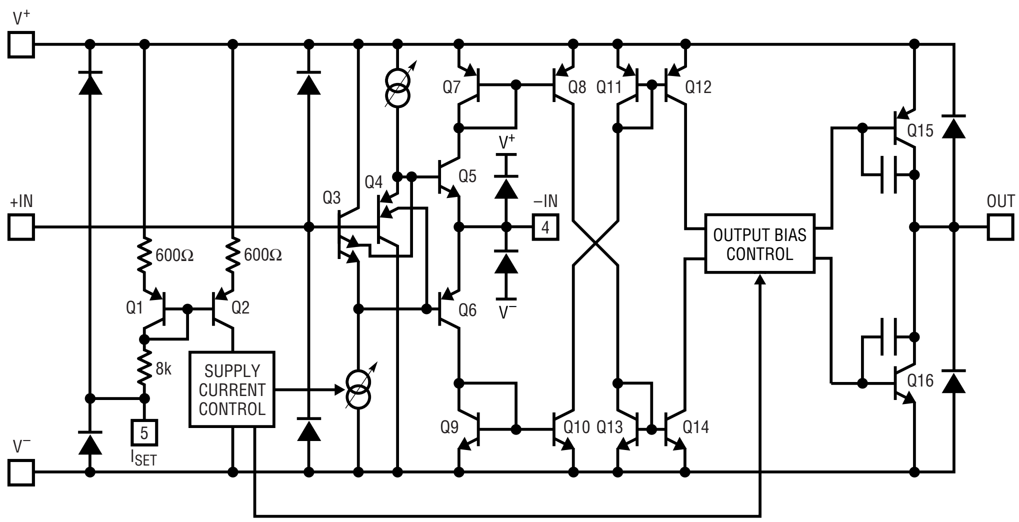


Figure 5. Simplified schematic of single amplifier

I_{SET} pin to a bias distribution network feeding the input stage. The internal 8k resistor sets the bias current when the I_{SET} pin is directly shorted to ground, and internal clamping circuitry within the supply current control ensures that the current is never high enough to damage the device.

The input stage uses a current-feedback diamond topology with two complementary pairs of emitter followers (Q3–Q6) between the noninverting and inverting inputs. Q3 and Q4 each have additional emitters that diode-clamp to the opposing positive input devices to prevent damage in case of large differential input voltages. The current outputs of the diamond circuit at the collectors of Q5 and Q6 are fed into current mirrors (Q7/Q8 and Q9/Q10) that would feed a high-impedance node in a typical current feedback amplifier. In the rail-to-rail topology of the LT6210 and LT6211, though, the signal currents are inverted by a second set of current mirrors (Q11/Q12 and Q13/Q14) and then directed into output transistors Q15 and Q16 along with an output bias current, derived from the variable supply current control. The primary frequency compensation is at the output, enhancing the amplifier's ability to drive capacitive loads.

Table 2. LT6210 configuration for A_V = +2 at various current levels

I_S	R_{SET}	R_{FB}, R_{GAIN}	R_{LOAD}
6mA	20k	887Ω	150Ω
3mA	56k	1.1k	150Ω
300µA	1M	11k	1k

Applications

Optimizing the Response of a Differential Cable Driver

Using a differential twisted pair instead of coaxial cable to transmit signals over longer distances can reduce both cost and bulk. In addition, transmitting signals differentially eliminates common mode noise pickup that can occur in longer routings. The LT6211 is ideal for these applications since the amplifier's bandwidth can be altered without changing the gain both by scaling the feedback and gain resistors and by tweaking the quiescent current of the amplifier. Therefore, the response can be optimized for a specific application, and the inverting and noninverting amplifiers can be programmed to have nearly identical frequency responses.

The C-Load stability of the LT6211 provides an additional benefit in twisted pair applications. If the differential cables are disconnected or not properly terminated the LT6211 remains stable (of course, if the line is left unterminated, signal fidelity will suffer).

The following explains how to obtain a desired response for a specific twisted pair application, in this case, for a flat response with approximately 100MHz of –3dB bandwidth. The circuit with its final values is shown in Figure 6.

Since the inverting gain amplifier gain of –2 is not shown in the Typical AC Performance table of the LT6210/LT6211 data sheet, an educated guess for the starting resistor values is required. A 1k feedback resistor is a good starting point, roughly halfway between the 1200Ω resistor suggested for a gain of –1 at the 3mA, 80MHz level and the 698Ω resistor suggested at 6mA and 140MHz. This fixes the gain resistor value at 499Ω for a gain of –2. With the gain network complete, the potentiometer at the I_{SET} pin can be tweaked while viewing the small signal frequency response on a network analyzer until the desired, flat response is achieved. With an R_{SET} value of 40.7k, the frequency response is entirely first order, with a –3dB bandwidth of 97MHz and a ±0.05dB bandwidth of 39MHz.

The approach for setting the resistor values on the noninverting channel is similar. 1k resistors are initially selected to get the desired response, but after adjusting the quiescent current to achieve a flat response, the –3dB bandwidth is significantly higher than the inverting channel. Therefore, 1.21k feedback and gain resistors are swapped in and the R_{SET} potentiometer tweaked again. This makes sense since the A_V = 2, I_S = 3mA in the "Typical AC Performance" section shows a 100MHz bandwidth with R_{FB}, R_G = 1.1k. The

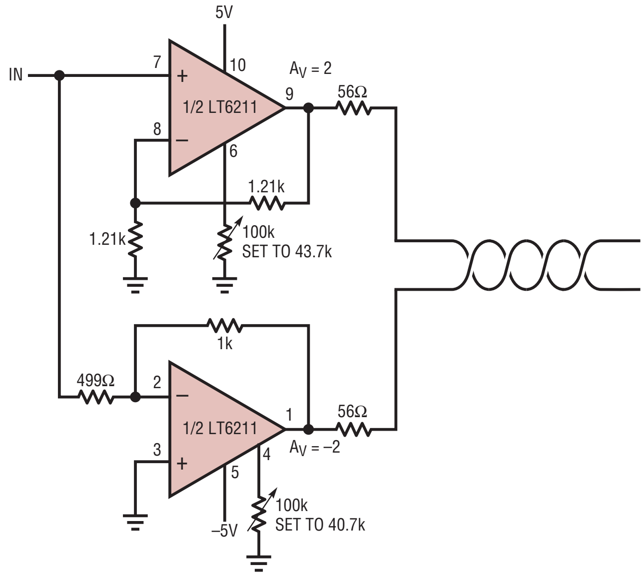


Figure 6. Differential cable driver application using LT6211

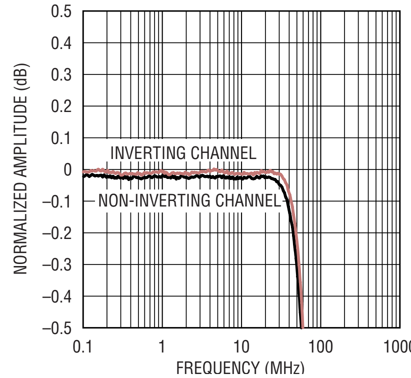


Figure 7. LT6211 differential cable driver has 0.02db gain flatness

slightly larger feedback resistor and higher quiescent current flatten the AC response from the 1dB peaking shown in the data sheet curves.

With the 1.21k resistors, bandwidth and response of the noninverting channel closely matches the inverting channel with a ±0.05dB bandwidth of 35MHz and a –3dB bandwidth of 101MHz. The final R_{SET} resistance for the noninverting amplifier is 43.7k, setting the total supply current for both amplifiers to 7.8mA. Figure 7 shows the gain flatness and ±0.1dB response of the two channels.

3V Cable Driver with Active Termination

Driving back-terminated cables on single supplies usually results in very limited signal amplitude at the receiving end of the cable. While the rail-to-rail output of the LT6210 and LT6211 already provides a larger swing than typical current feedback amplifiers, positive feedback can be used to further improve swing at the load by reducing the size of the series back termination resistor, decreasing the attenuation between the series and load termination resistors. The positive feedback also maintains controlled output impedance from the line-driving amplifier, allowing the amplifier to drive long cables without signal degradation.

Figure 8 shows the LT6210 using this "active termination" scheme on a single 3V supply. The amplifier is AC-coupled and in an inverting gain configuration to maximize the input signal range. The gain from V_{IN} to the receiving end of the cable, V_{OUT}, is set to –1. The effective impedance looking back into the amplifier circuit from the cable is 50Ω throughout the usable bandwidth.

The response of the cable driver with a 1MHz sinusoid is shown in Figure 9. The circuit is capable of transmitting a $1.5V_{P-P}$ undistorted sinusoid to the 50Ω termination resistor and has a full power ($1V_{P-P}$) bandwidth of 50MHz. Small signal –3dB bandwidth extends from 1kHz to 56MHz with the selected coupling capacitors.

Line Driver with Low Power Mode

In applications where low distortion or high slew rate are desirable but not necessary at all times, the LT6210 or LT6211's quiescent current can be decreased when the higher power performance is not required. Figure 10 illustrates a method of setting quiescent current with a FET switch. In the 5V dual supply case pictured, shorting the I_{SET} pin through an effective 20k to ground sets the supply current to 6mA, while the 240k resistor at the I_{SET} pin with the FET turned off sets the supply current to approximately 1mA. The feedback resistor of 4.02k is selected to minimize peaking in low power mode. The bandwidth of the LT6210 in this circuit increases from just over 40MHz in low power mode to over 200MHz in full speed mode, as illustrated in Figure 11. Other AC

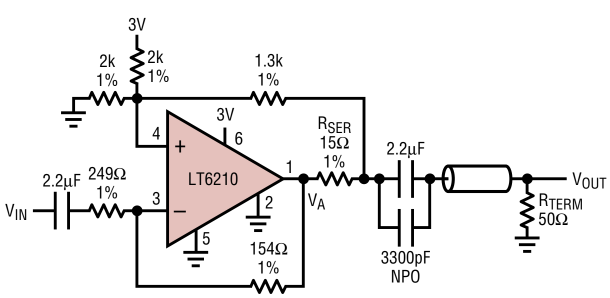


Figure 8. 3V cable driver with active termination

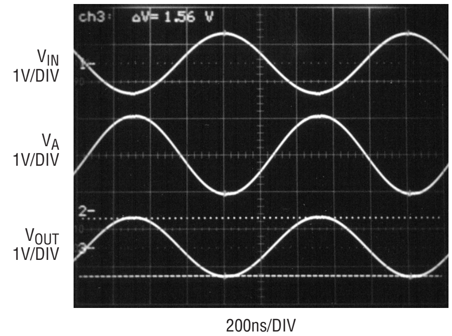


Figure 9. Response of 3V cable driver circuit at 1MHz

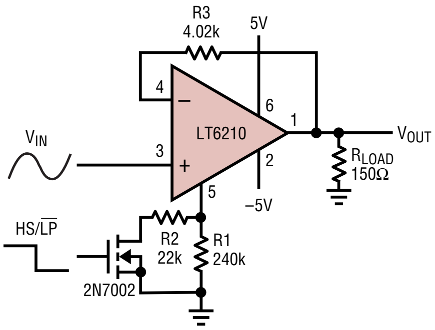


Figure 10. LT6210 line driver with low power mode

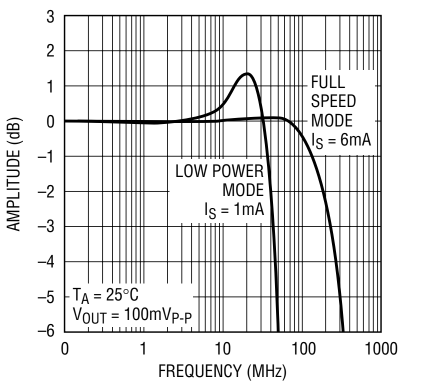


Figure 11. Frequency response of line driver for full speed and low power modes

performance also improves significantly at the higher current setting. Table 3 shows harmonic distortion at 1MHz with a $2V_{P-P}$ sinusoid at the two selected current levels.

In a system with multiple LT6211's, it is possible to use a single FET to change the supply current of all the amplifiers in parallel, as shown in Figure 12. While a single FET can be used to control numerous I_{SET} pins due to its connection to ground, individual resistors from the FET to each amplifier's I_{SET} pin are recommended to ensure consistent current programming.

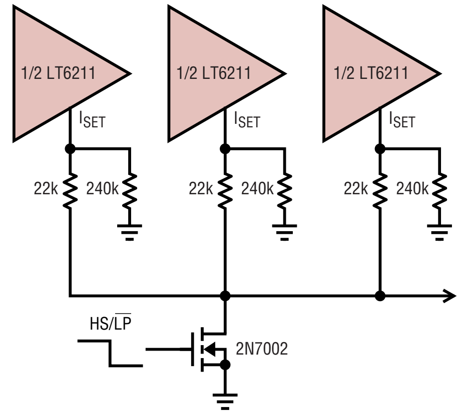


Figure 12. Using a single FET to switch multiple LT6211 quiescent currents

Conclusion

The LT6210 / LT6211 family offers impressive, high speed versatility. With a rail-to-rail, C-Load stable output stage and programmable speed and supply current, the part can be tuned to fit most applications. Whether the application is supply current sensitive or requires high speed with high output drive, the LT6210 and LT6211 are suited to the task.

Table 3. Harmonic distortion of line driver with low power mode

Low Power		Full Speed	
HD2	–53dBc	HD2	–68dBc
HD3	–46dBc	HD3	–77dBc

LTC2921/LTC2922, continued from page 5

are short-lived, do not trip the monitors. Thus momentary load transients and electronic noise do not affect the continuous monitoring operation, but a supply voltage consistently outside of the designed range, even a small amount, does. Allowing time to factor into the threshold comparison affords glitch tolerance without degrading monitoring accuracy.

Bonus Functionality: Sequencing

Whereas tracking satisfies the requirements for many multiple-supply systems, sequencing is sometimes necessary. The LTC2921 and LTC2922 offer a single-chip solution to simple sequencing via the power good output. The PG pin has a weak pull-up current to the same voltage rail that allows the GATE pin to pull well above V_{CC}. By connecting one or more external FET gates and a capacitor to the PG output, it functions as an auxiliary gate driver with an independently selectable ramp rate. The time period set by the capacitor at TIMER provides the sequencing delay between the ramps. It is important to note that because the automatic remote sense switches activate before the power good signal activates, sources ramped by PG cannot take advantage of remote sense switching. Figure 6 shows a schematic of an application that takes advantage of the sequencing capability of the LTC2921 and LTC2922 to create early-on and late-on supplies.

Conclusion

The LTC2921 and LTC2922 monitor up to five supply sources and ramps their loads up together. When any source fails its monitoring threshold, all loads are disconnected. Once all monitors are again satisfied, the turn-on sequence is attempted again. The LTC2921 and LTC2922 combine a guaranteed threshold accuracy of ±1.5% over temperature (which facilitates tight monitoring limits) with input glitch filtering (which allows the customer to take full advantage of the threshold accuracy). The low 0.5V monitor threshold allows even sub-1V supplies to be tracked. The parts feature remote sense switching that automatically connects the loads to the Kelvin sense inputs of the supply sources after the loads have fully ramped. The integrated switches and control circuitry allow the supply sources to compensate the load levels for any voltage drops due to currents through the external tracking FETs.

Dual Regulators Offer Flexibility with Independent Shutdown Control and Adjustable Start-Up Timing

by Todd Owen

Introduction

Desktop computers to digital cameras demand more from their power supplies than ever before. Some devices require more than seven supplies, often complicated further by a unique set of vital conditions and specifications for power supply start-up timing, tracking and voltage differentials. In many cases, the power supplies must start up in specific order, and track each other in concert, to avoid the risk of damage to critical components that run from the multiple supply rails.

To help meet these conditions, Linear Technology introduces the LT3023 and LT3024. Both parts are dual low dropout, low noise, micropower regulators based on the LT1761 and LT1763, single regulators delivering 100mA and 500mA respectively. The LT3023 combines a pair of 100mA regulators while the LT3024 combines a 500mA regulator with a 100mA regulator. Both regulators operate over an input voltage range of 1.8V to 20V with a dropout of 300mV at full load current. Quiescent current is less than 30µA for each regulator, dropping to less than 0.1µA in shutdown. Individual shutdown controls for each regulator allow for flexibility in power management. Both devices are available as adjustable parts with a 1.22V reference.

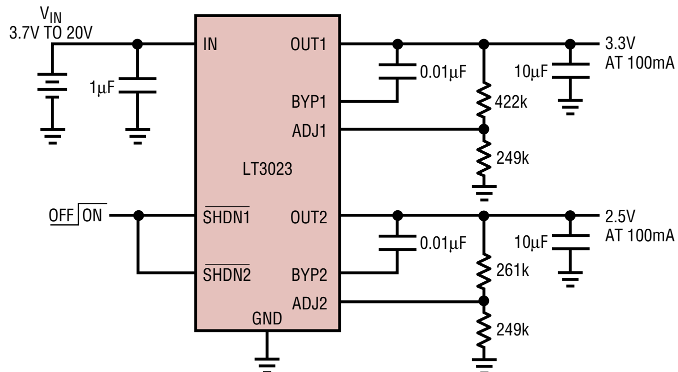


Figure 1. Noise bypassing slows start-up, allows outputs to track

The small size of these regulators simplifies system design. The LT3023 is packaged in the 3mm × 3mm 10-lead DFN, maintaining the same footprint as a SOT-23. The LT3023 is also available in the thermally enhanced 10-lead MSOP package. The LT3024 is offered in the 4mm × 3mm 12-lead DFN, with a footprint only 33% larger than a SOT-23, and also in the thermally enhanced 16-lead TSSOP. These regulators also help minimize external component size. The 100mA regulators are stable with output capacitors as low as 1µF; the 500mA regulator in the LT3024 requires a minimum of 3.3µF. Small ceramic capacitors can be used without the series resistance required by other regulators.

Tracking Supplies

Adding external 0.01µF bypass capacitors to the LT3023 or LT3024 devices drops output voltage noise for each regulator to 20µV_{RMS} over a 10Hz to 100kHz bandwidth. This capacitor improves transient performance of the regulators and also slows start-up of the regulator. Figure 1 shows

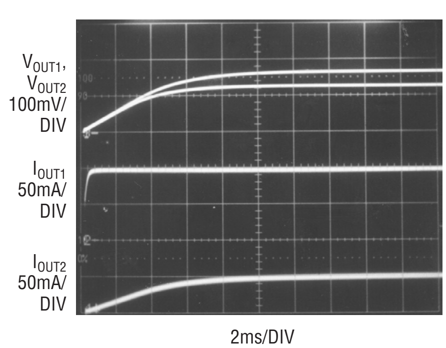


Figure 2. Output voltages track independent of load

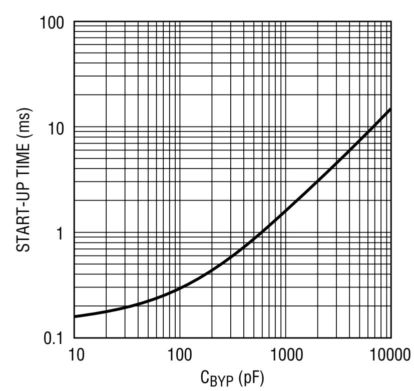


Figure 3. Start-up time

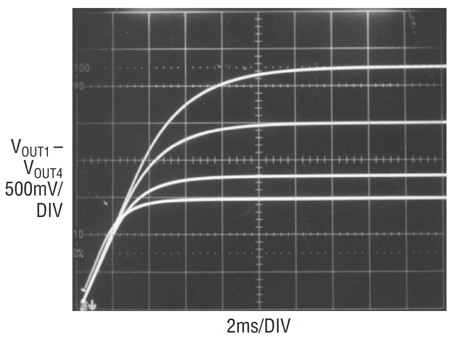


Figure 4. Multiple parts provide consistent start-up

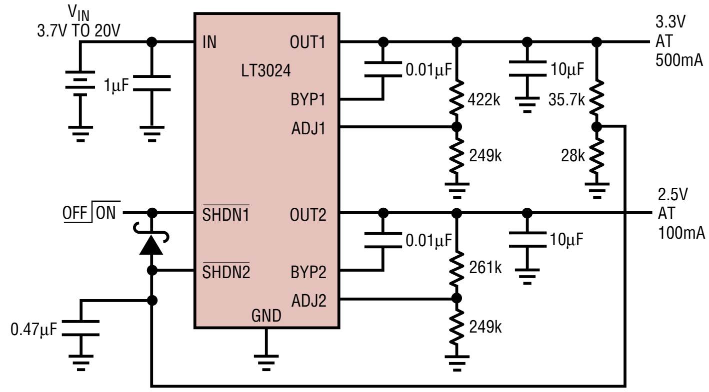


Figure 5. Start-up sequencing

an application that takes advantage of this slowed start-up in a soft-start circuit.

In this circuit, two different supply rails are generated by an LT3023. Both the $\overline{\text{SHDN1}}$ and $\overline{\text{SHDN2}}$ pins are tied together, driving the regulators simultaneously. As the two regulators are brought out of shutdown, their output voltages rise at the same rates. The rate at which the output voltages rise is independent of load current—the regulators can deliver up to the full rated output current at the intermediate voltages. The size of the output capacitor also drops out of the equation when its charging current added to the load current is less than the regulator current limit. Figure 2 shows the output voltages and currents of the regulators as they are brought out of shutdown.

Figure 3 shows the time for the regulators to start as the value of the noise bypass capacitor varies. Minimum time for start-up is 150µs with no bypass capacitor. Start-up time is roughly proportional to the size of the noise bypass capacitor, with 0.01µF of capacitance giving a time of 15ms. Two more supply rails are provided by an LT3024: a 1.5V rail at 500mA, and a 1.8V rail at 100mA. As shown in Figure 4, start-up times are consistent between the two regulators.

Flexibility is an important feature of this circuit. The regulators can be operated with differing sizes of noise capacitor to slew one regulator on faster and the $\overline{\text{SHDN1}}$ and $\overline{\text{SHDN2}}$ pins can also be separated as needed for independent shutdown control. Since these regulators are based on the LT1761/LT1763, the same design techniques and characteristics apply to those parts. Supply rails can be generated in any number, not just even multiples.

Start-Up Sequencing

Figure 5 shows an LT3024 being used to sequence the start-up of the regulators. In this circuit, the 500mA regulator is turned on and begins to rise at the rate determined by the noise bypass capacitor. As the output lifts, it begins to pull up the $\overline{\text{SHDN2}}$ pin to turn on the 100mA side. The 0.47µF capacitor slows the rise of this pin, keeping it from turning on until several milliseconds after the 500mA side begins turning on (see Figure 6).

When the circuit is turned off, the Schottky diode between $\overline{\text{SHDN1}}$ and $\overline{\text{SHDN2}}$ allows both outputs to be shutdown simultaneously. This is a precaution to prevent voltage differences between OUT1 and OUT2 that may cause application problems or damage. Figure 7 shows both outputs turning off together. The resistor divider between OUT1 and $\overline{\text{SHDN2}}$ is designed to account for the threshold voltage of the $\overline{\text{SHDN2}}$ pin and the current of this pin as well (typically 1µA at 0.8V, maximum 3µA at 1.4V).

Conclusion

The LT3023 and LT3024 are dual high performance regulators available in tiny packages. Both offer independent channel shutdown control and adjustable start-up timing. These features offer a high degree of flexibility that makes it easy to meet demanding system requirements.

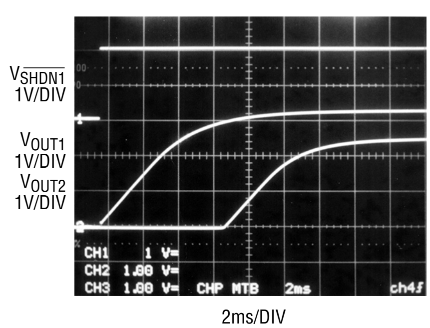


Figure 6. Turn-on waveforms

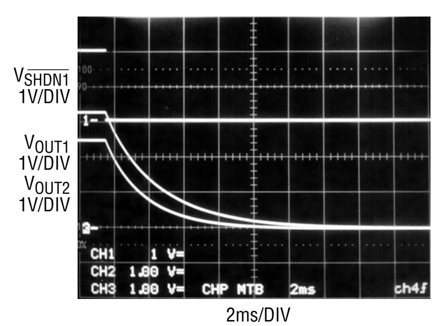


Figure 7. Turn-off waveforms

4A, 4MHz Monolithic Synchronous Regulator with Tracking offers a Compact Solution for Power Supply Sequencing

by Joey M. Esteves

Introduction

The LTC3416 offers a compact and efficient voltage regulator solution for systems that require power supply sequencing between different supply voltages. Many microprocessors and DSP chips need a core power supply and an I/O power supply that must be sequenced during start-up. Without proper power supply sequencing, latch-up or excessive current draw may occur that could lead to damage to the microprocessor's I/O ports or the I/O ports of a supporting device such as memory, logic, FPGAs, or data converters. The LTC3416 operates from an input voltage range of 2.25V to 5.5V and can generate an output voltage between 0.8V to 5V. The internal power MOSFET switches have a low 67mΩ on-resistance, thus allowing the LTC3416 to deliver up to 4A of output current while achieving efficiencies as high as 91%.

The LTC3416 employs a constant frequency, current-mode architecture with a frequency range of 300KHz to 4MHz. Forced continuous operation allows the LTC3416 to maintain a constant frequency throughout the entire load range, making it easier to filter the switching noise and reduce the RF interference—important for EMI-sensitive applications.

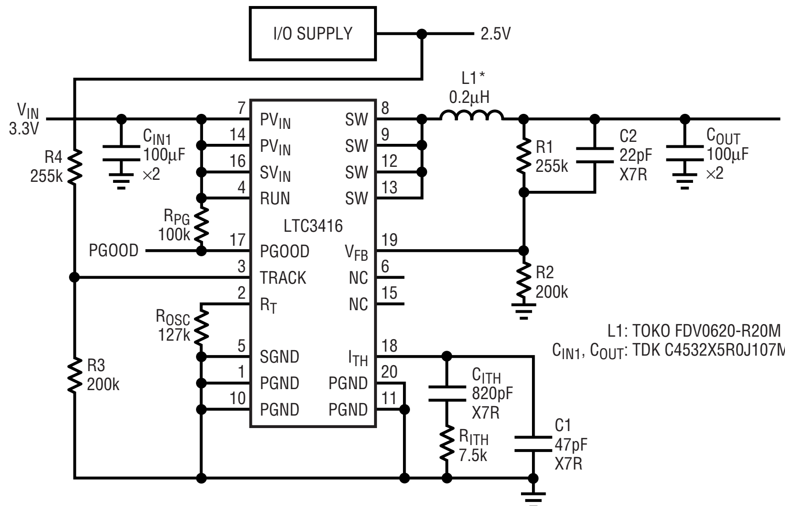


Figure 1. A 1.8V/4A step-down regulator with tracking

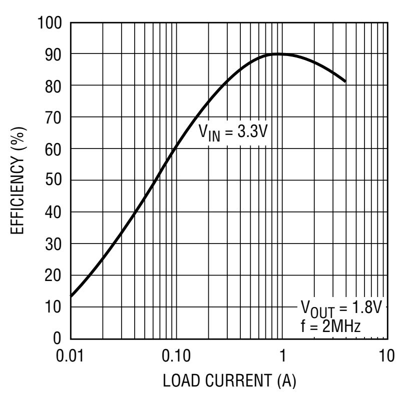


Figure 2. Efficiency vs load current

The switching frequency can be set externally with a resistor or synchronized to an external clock, where each switching cycle begins at the falling edge of the external clock signal. Since the output voltage ripple is inversely proportional to switching frequency and inductor value, a designer can take advantage of the LTC3416's high switching frequency to use smaller inductors without compromising the output voltage ripple. Lower inductor values translate directly to smaller case sizes, reducing the overall size of the system. OPTI-LOOP® compensation allows the transient response to be optimized over a wide range of loads and output capacitors, including ceramics. For increased thermal handling, the LTC3416 is offered in a 20-Lead TSSOP package with an exposed pad to facilitate heat sinking.

Authors can be contacted at (408) 432-1900

Voltage tracking is enabled by applying a ramp voltage to the TRACK pin. When the voltage on the TRACK pin is below 0.8V, the feedback voltage regulates to this tracking voltage. When the tracking voltage exceeds 0.8V, tracking is disabled and the feedback voltage regulates to the internal reference voltage. Tracking is implemented by connecting an extra resistor divider to the I/O supply voltage. The ratio of this divider should be selected to be the same as that of the LTC3416's feedback resistor divider.

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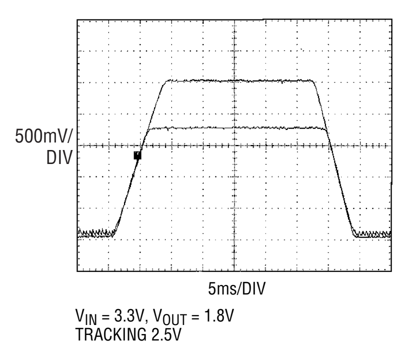


Figure 3. Start-up and shut-down tracking

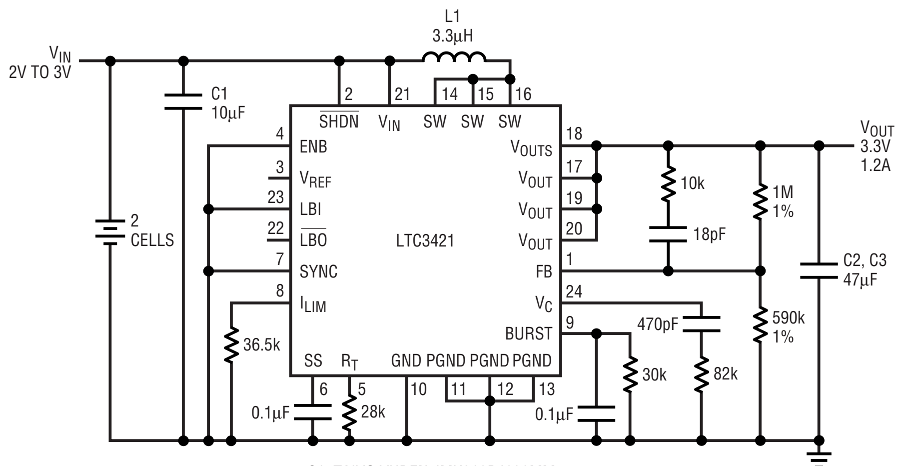
Synchronous Boost Converter with Output Disconnect Delivers 4W from Two Cells

by Dongyan Zhou

Introduction

Portable, battery-powered devices require power supplies that are efficient and small. The LTC3421 synchronous boost converter offers both. It features a low, 12µA quiescent current in Burst Mode operation, greatly improving battery life in applications that spend much of their time in low power mode. The LTC3421 itself is small, available in a small 4mm × 4mm QFN package, and its oscillator frequency can be programmed or synchronized up to 3MHz, which minimizes the size of external components. It can drive power hungry circuits with its 3A guaranteed switch current—up to 4W output power from two NiCd or NiMH cells.

In a conventional synchronous boost converter, the internal body diode of the synchronous rectifier connects the input supply through the inductor to the load. The peak inrush current when the input supply is first applied to the boost converter is only limited by the resistance in the loop consisting of the input source, inductor, diode, and output capacitor. The large surge current during initial plug-in can cause sufficient input voltage drop to possibly trigger a low-battery detector. The direct path from the input to the output also leaves the load connected to the input even when the boost converter is in shutdown. This can cause additional power loss due to leakage current. With true output disconnect, by eliminating body diode conduction of the internal PMOS rectifier, the LTC3421 eliminates these problems.



C1: TAIYO YUDEN JMK212BJ106MM
C5: TAIYO YUDEN JMK325BJ476MM
L1: TDK RLF7030T-3R3M4R1

Figure 1. A 1MHz, 2-cell to 3.3V at 1.2A boost converter

2-Cell to 3.3V/1.2A Synchronous Boost Converter

The circuit in Figure 1 shows a 2-cell to 3.3V converter that can provide up to 1.2A of load current. The switching frequency is set at 1MHz by having 28kΩ at R_T pin. This gives a good tradeoff between efficiency and circuit size. The footprint of this converter is about 0.35inch^2, as shown in Figure 2. The LTC3421 has a bottom metal pad to improve thermal performance. The entire metal pad can be soldered directly to the PC board copper area and through multiple thermal vias to internal and backside copper layers to optimize efficiency and thermal performance.

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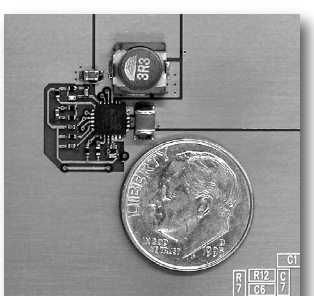
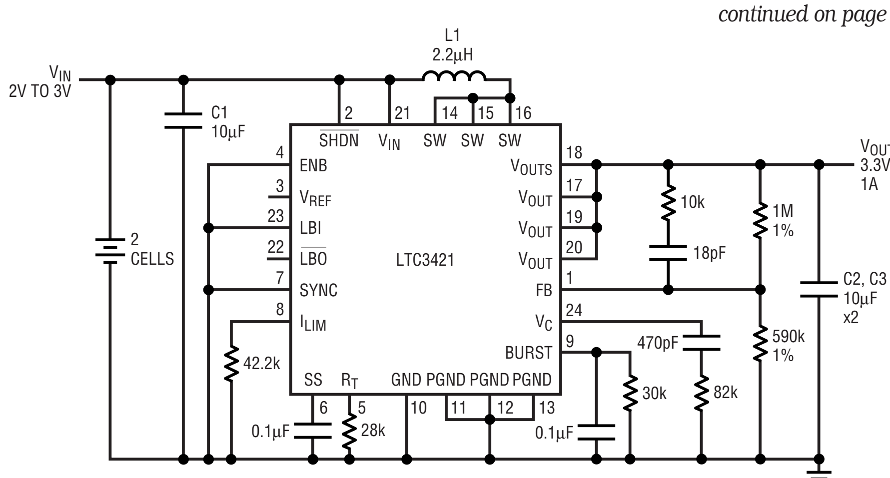


Figure 2. The circuit of Figure 1 fits in a mere 0.35in²



C1, C2, C3: TAIYO YUDEN JMK212BJ106MG
L1: Sumida CDRH6D12-2R2

Figure 3. A 1.5mm height, 1MHz, 2-cell to 3.3V at 1A boost converter

Boost Converter Drives 1A White LEDs

by Keith Szolusha

White LEDs are brighter and more powerful than ever. High-power white LEDs, because of their extreme luminous density and ultra-compact size, are replacing conventional bulbs in flashlights, headlamps, streetlights, and many automotive applications—anywhere a conventional bulb might be found. Some new white LEDs, such as Lumileds' Luxeon™ series, improve on conventional bulbs in several characteristics, including greater luminescence, improved response time, and increased durability with decreased size and cost.

The challenge in using white LEDs in portable applications is powering them with the wide input voltage range that batteries present, such as 3.3V to 4.2V from a lithium-ion. LEDs require constant current to maintain constant luminosity. The battery-LED DC/DC converter must both step up and step down the source voltage to a 3.0V to 3.6V LED forward voltage range at a constant LED current such as 1A.

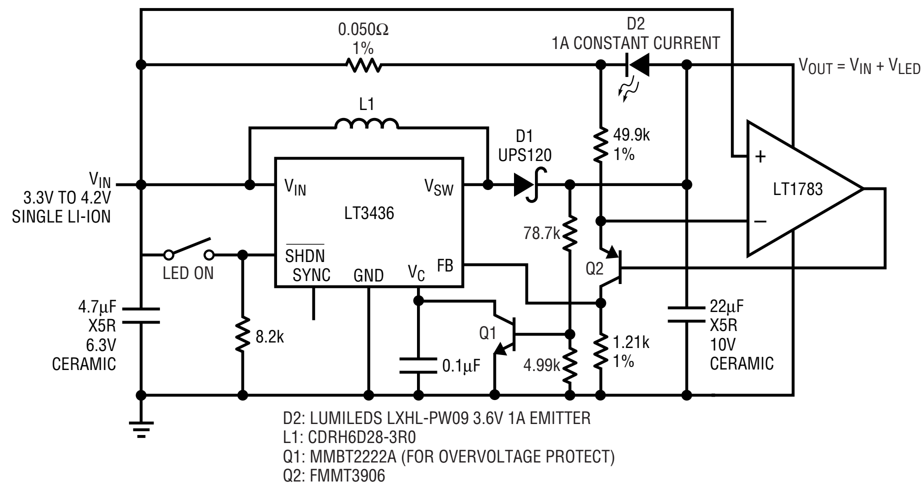


Figure 1. LT3436EFE boost converter drives Luxeon III 1A 3.6V white LED with 70% efficiency.

The LT3436EFE 800kHz boost converter in Figure 1 provides 1A driving current for the Luxeon III series white LED LXHL-PW09 from a lithium-ion battery. The Luxeon III white LED has a forward voltage range from 3.0V to 3.6V. By tying the LED from the output of the boost converter back to the input, as opposed to ground, the boost converter is capable of both stepping-up and stepping-down its input voltage to the LED. The effective output voltage of the converter is a boosted voltage of V_{IN} plus V_{LED} as shown in the schematic.

The LT1783 1.25MHz SOT-23 rail-to-rail op amp provides the current-sense capability and regulates the diode current to 1A when the LED ON switch is closed. When the switch is open, the LT3436 consumes only 6µA in shutdown.

Luxeon is a trademark of Lumileds Lighting.

LTC3416, continued from page 31

1.8V/4A Converter Tracks a 2.5V I/O Supply

Figure 1 shows a 1.8V step-down DC/DC converter tracking an I/O supply voltage of 2.5V. This circuit operates from an input voltage of 3.3V and provides a regulated 1.8V output at up to 4A of load current. Efficiency is as high as 90% and is shown in Figure 2.

The switching frequency for this circuit is set at 2MHz by a single external resistor, R_{OSC}. Operating at a frequency this high allows the use of a lower valued and physically smaller inductor. During start-up, the output of the LTC3416 coincidentally tracks the I/O supply voltage. Once the I/O supply voltage exceeds 1.8V, tracking is disabled and the LTC3416 regulates its output voltage to 1.8V. Figure 3 shows the relationship between the output voltage waveform of the LTC3416 and the I/O supply voltage during start-up.

Ceramic capacitors offer low cost and low ESR, but many switching regulators have difficulty operating with them because the extremely low ESR can lead to loop instability. The phase margin of the control loop can drop to inadequate levels without the aid of the zero that is normally generated from the higher ESR of tantalum capacitors. The LTC3416, however, includes OPTI-LOOP compensation, which allows it to operate properly with ceramic input and output capacitors. The LTC3416 allows loop stability to be achieved over a wide range of loads and output capacitors with proper selection of the compensation components on the I_{TH} pin.

Conclusion

The LTC3416 with its tracking ability is well suited to applications involving microcontroller-based circuits with dual supply architectures. It's high switching frequency and internal low $R_{DS(ON)}$ power switches allow the LTC3416 to provide a small solution size with high efficiency for systems with power supply sequencing requirements.

Smart Card Interfaces Made Easy

by Steven Martin

Introduction

Smart Card interfaces must comply with extensive, and often difficult, software and hardware standards to produce robust card reading systems. The LTC4556 makes it easy to comply with Smart Card interface requirements by integrating all required power management, control, ESD and fault protection circuitry into a single device, precluding the need for a complicated array of discrete components.

The LTC4556 employs a voltage doubling charge pump and a low dropout linear regulator to generate an output voltage of 5V, 3V or 1.8V from a 2.7V to 5.5V input. It supports custom Smart Card systems—in addition to the EMV (Europay, MasterCard, Visa) and ISO7816 standards—by providing control for the C4 and C8 pins and a bidirectional clock mode for clock stretching in I²C™- or SMBus-like Smart Cards. A microcontroller compatible serial interface controls the entire device. Above all, a complete solution takes little space. The LTC4556 is available in a small 4mm × 4mm × 0.75mm leadless package and requires a minimum of external components.

I²C is a trademark of Philips Electronics N.V.

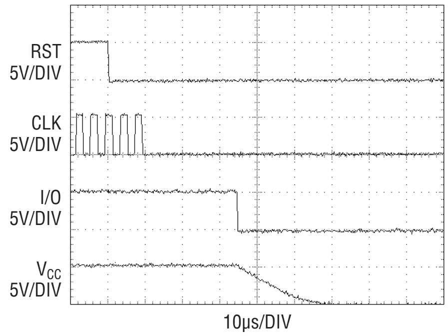


Figure 1. Smart Card deactivation sequence

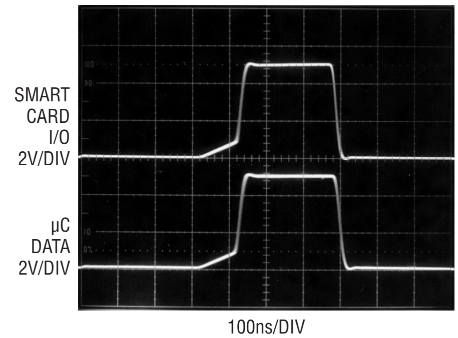


Figure 2. Bidirectional pin waveforms

Features

The LTC4556 includes a considerable number of features and yet remains

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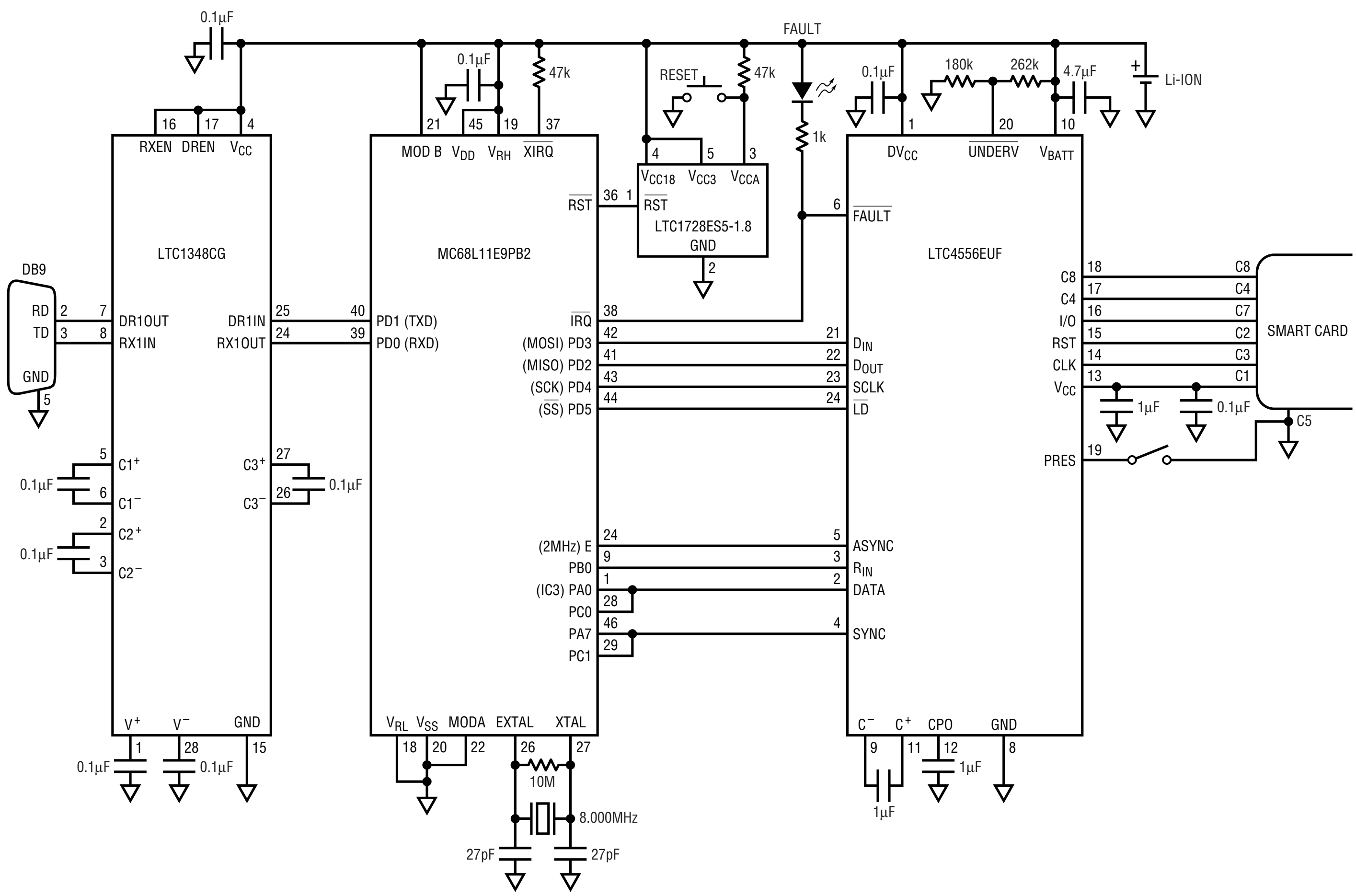

Figure 3. Battery powered RS232 to Smart Card interface

LCD Power Supply Provides ±15V Plus LED Driver

by Mike Shriver

A typical LCD application requires both a positive and a negative voltage to drive the glass and, in some cases, a means of illuminating the back panel. The LT3463 circuit shown in Figure 1 provides all three. The outputs of this circuit are 15V, –15V and a 15mA LED driver. The –15V rail is generated from an inverting charge pump regulated by channel 2 of the LT3463. A quasi-regulated charge pump tapped from the switch node of channel 2 forms the 15V rail. Channel 1 is configured as current source boost converter and supplies current to the LEDs. The advantages offered by this circuit are low quiescent current and minimal parts count.

The on-demand power delivery provided by the Burst Mode operation of the LT3463 allows the ±15V rails to have a no-load quiescent current of 76µA and an efficiency of over 73% from 5% load to 100% load for an input voltage of 3.6V. The full load efficiency is 77% at 3.6V. (See Figure 2.) Because a charge pump is used for both the positive and negative output, the load is disconnected from the output during shutdown which increases battery run time. The slave charge pump for the +15V rail does require more parts than a slave boost converter, but the extra parts are offset by the internal Schottky diodes of the LT3463.

The LED driver is best suited for applications that require only a single level of backlighting or partial dimming. The time constant formed by C_{LED} and R1 does not allow PWM dimming over the entire range of brightness. The LED driver has an efficiency of 76% at an input voltage of 3.6V. During shutdown, less than 1µA flows through the LEDs from V_{IN}.

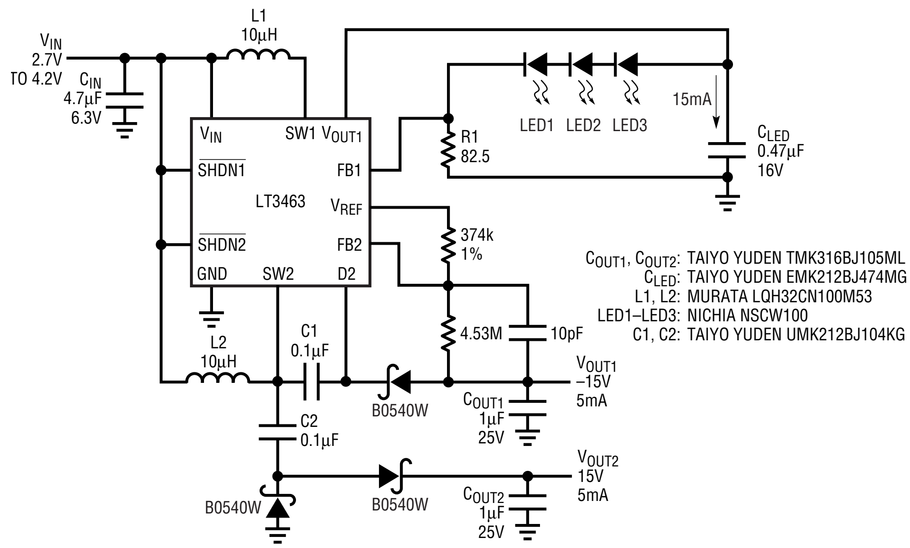

Figure 1. ±15V converter plus LED driver

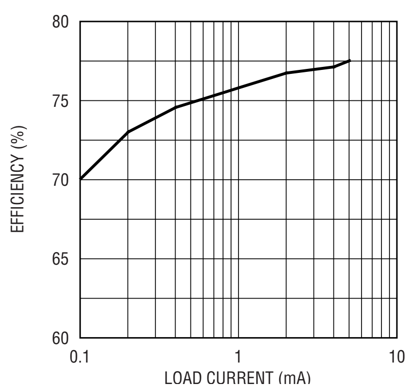

Figure 2. Total efficiency of ±15V converter at V_{IN} = 3.6V

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1.5mm Height, 2-Cell to 3.3V/1A Converter

Low-profile is required in many handheld devices, such as cellular phones, and MP3 players. Figure 3 shows how to make a 2-NiCd, or 2-NiMH cell to 3.3V output converter with 1.5mm maximum height by using a lower profile inductor and output capacitor. This circuit can provide up to 1A load current for 2V minimum input battery voltage and 900mA load if the battery cutoff voltage is 1.8V. Figure 4 shows the efficiency of this circuit. With Burst Mode enabled, the efficiency stays above 85% over three decades of load current.

Conclusion

With output disconnect, inrush current limiting and 12µA quiescent current, the LTC3421 synchronous boost converter is an ideal fit for many portable applications. Its guaranteed 1V start-up input voltage works with a large variety of battery configurations. It is available in a small 4mm × 4mm QFN package with exposed copper on the backside, making it possible to provide up to 1.2A at 3.3V from 2-cell input without taking much space.

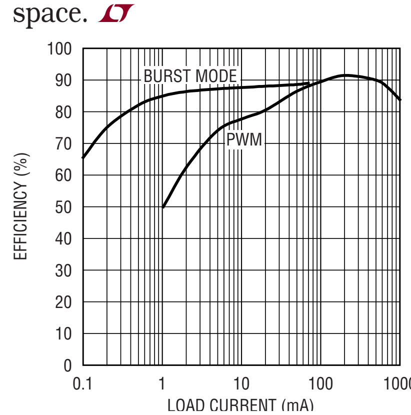

Figure 4. Efficiency curves for the converter in Figure 3 (V_{IN} = 2.4V)

New Device Cameos

Quad 802.3af Power over Ethernet Controllers

The LTC4258 and LTC4259A each provide all the circuitry to control four ports of IEEE 802.3af Power over Ethernet, utilizing the ubiquitous CAT-5 data cables to also distribute power. The availability of 13W direct from the Ethernet cable frees network peripherals from the added tether of an AC adapter.

At the delivery end of the Ethernet cable, the LTC4258 and LTC4259A manage—with strict adherence to the 802.3af™ standard—the distribution of power to four separate Ethernet ports. Multiple LTC4258s or LTC4259As can be used together to build systems with 24, 48 or more powered ports.

Power over Ethernet systems apply 48V common mode to the Ethernet cables while peacefully coexisting with non-powered Ethernet devices. Consequently the Power Sourcing Equipment (PSE) must be very careful to only apply power to devices that require it. The LTC4258 and LTC4259A meet this and other requirements of the 802.3af standard.

These devices include an array of complex analog functions—data converters, precision current measurement and current limiting, voltage regulation, and Hot Swap™ along with digital logic and an I^2C interface—in one 36-pin SSOP package. This high level of integration simplifies the design of IEEE 802.3af compliant PSEs.

Detection and classification are completely handled within the LTC4258 and LTC4259A. Measurements are automatically decoded into IEEE defined results such as "Valid Detection Signature," and "Class 2." The LTC4258 and LTC4259A can act autonomously on these results, applying power when a Powered Device (PD) is connected to the Ethernet port. All power control and monitoring functions (over current cutoff, current limit, power off when the PD is unplugged) are also handled automatically. The LTC4259A also offers an IEEE compliant AC method for determining when a PD is unplugged.

802.3af is a trademark of the IEEE.

The LTC4258 and LTC4259A perform all these functions with a minimum of external components, yielding compact circuit board layouts.

The LTC4258 and LTC4259A provide advanced features that go beyond the IEEE standard. Fast gate pull down, foldback, and duty cycle limitation protect the external MOSFETs from damage due to fault conditions, power dissipation or thermal cycling. The detection circuitry rejects 50Hz/60Hz interference, and the low impedance of classification output voltage is stable under any load. The LTC4259A's AC disconnect sensing circuitry operates independently of DC current flow and has low sensitivity to stray capacitance. An internal control engine allows the LTC4258/4259A to perform all 802.3af PSE functions without microcontroller support. Used in larger systems, the programmable $\overline{\text{INT}}$ pin, I^2C/SMBus interface and semi-autonomous mode of the LTC4258/59A eliminates software polling and minimizes the load on the host controller.

High Voltage Ideal Diode Controller Eliminates Energy Wasting Diodes in Power ORing Applications

Many electronic devices need a means to automatically switch between power sources when prompted by the insertion, removal or loss of any power source. The LTC4412-HV simplifies PowerPath management and control by providing an automatic, low-loss and near ideal diode controller function. Any circuit that could use a diode OR to switch between power sources can benefit from the LTC4412-HV. The forward voltage drop of an LTC4412-HV ideal diode is far less than that of a conventional diode and the reverse current leakage can be smaller for the ideal diode as well. The tiny forward voltage drop of only 20mV minimizes power losses and self-heating. The low component count helps keep overall system cost low and the ThinSOT 6-pin package permits a compact design solution.

Operation is specified over a wide supply operating range of 2.5V to 36V (40V absolute maximum) and over a wide temperature range of –40°C to 125°C ambient, which is suitable for automotive and industrial applications. Quiescent current is only 18µA with a 36V supply and is independent of the load current. A status pin can be used to indicate that an auxiliary supply is present.

This high voltage version of the LTC4412 is versatile enough to be used in a variety of diode ORing applications by controlling external P-channel MOSFET power switches to create a near ideal diode functions for power switchover or load sharing power path management applications. Two or more LTC4412-HVs ganged together allow load sharing between two or more power sources or the charging of two or more batteries from a single battery charger. The LTC4412-HV also has built in reverse supply protection.

Supply Independent Hot Swappable 2-Wire Bus Buffer Allows Backplane Bus Voltages to be Above or Below Card Side Bus Voltages

The LTC4301 is a supply independent hot swappable 2-wire bus buffer used in I^2C and SMBus systems. In a typical application, the LTC4301 is located on the edge of peripheral card, with SDAOUT and SCLOUT connected to the card side bus. SDAIN and SCLIN are connected to the card connector and pulled-up to the voltage of the backplane data and clock bus after the card is plugged in. The LTC4301's unique architecture allows the backplane and the card bus pull-up voltages to be higher or lower than each other and the supply voltage of the part. Therefore, busses operating at different voltages can communicate seamlessly through the LTC4301. As a result, the backplane does not have to pass its bus voltage through the connector to the card, saving a valuable connector pin.

The LTC4301 also supports hot swapping of the data and clock busses (SDA and SCL). The LTC4301's hot swap feature allows an I/O card to be plugged into a live backplane without corruption of SDA and SCL busses. SDA and SCL pins are precharged to 1V to minimize the amount of disturbance caused by the I/O card. Control circuitry looks for a bus idle or a stop bit on the backplane side and verifies that data and clock are high on the card side. When these conditions are met, the connection circuitry is activated, joining the SDA and SCL bus on the I/O card side with those on the backplane side.

Another key feature of the LTC4301 is that once the connection circuitry is activated, capacitive buffering is provided between the input and output busses. This means the backplane side bus only sees the capacitance of the backplane and the LTC4301 (<10pF), as the capacitance on the card is isolated from the backplane. The LTC4301 is available in small 8-pin MSOP and low profile, 3mm × 3mm DFN packages.

2A, 600Khz Buck-Boost Converter Achieves 96% Efficiency Without Schottky Diodes

The LTC3443 is a high efficiency single inductor buck-boost converter that is pin-for-pin compatible with its predecessor, the LTC3441. The LTC3443 is intended for applications where a lower operating frequency (and resulting larger inductor value) is traded off for an increase in converter efficiency. The IC incorporates an internal VC pin clamp during Burst Mode operation, which minimizes perturbations to the output voltage during Burst to Fixed Frequency mode changes.

The LTC3443 can provide up to 1.2A of output current at 3.3V from a single Li-Ion battery or multicell NiMH or NiCad batteries. Efficiencies up to 96% are achieved without the use of Schottky rectifier diodes. The device operates in forced continuous mode sinking up to 400mA to optimize the load transient response and maintain constant switching frequency at light loads when fixed frequency operation is selected. The input voltage range is 2.5V to 5.5V and the output voltage is specified for 2.4V to 5.25V. The output voltage can be programmed as low as 0.4V with the addition of a Schottky diode to provide a low impedance conduction path to the output.

The low 28µA quiescent current in Burst Mode operation maximizes battery life at low power. Burst Mode operation is user controlled and enabled when the MODE/SYNC pin is driven high. If the MODE/SYNC pin is driven low, or driven by an external clock, fixed frequency switching is enabled. The LTC3443 has a synchronization range of 690kHz to 1.2 MHz.

The Linear Technology family of buck-boost converters provides the most compact and efficient solution for applications requiring an output voltage within the input supply range. The LTC3443 augments this family by providing higher efficiency operation and an enhanced MODE transient response.

6-Supply Monitors in 8-Lead TSOT and DFN

The LTC2908-A1 and LTC2908-B1 are 6-supply monitors with 5% tolerance in tiny 8-pin ThinSOT and DFN packages. The LTC2908-A1 is designed to monitor 5V, 3.3V, 2.5V, 1.8V and two positive adjustable voltages, while the LTC2908-B1 is designed to monitor 3.3V, 2.5V, 1.8V, 1.5V and two positive adjustable voltages. These new devices are intended as precise and cost-effective voltage monitoring solutions for systems with any number of supply voltages.

The LTC2908-A1 and LTC2908-B1 feature ultra-low voltage pull downs on the $\overline{\text{RST}}$ pin. The open drain $\overline{\text{RST}}$ output is guaranteed to be in the correct state as long as either V1 or V2 is 0.5V or greater. These new parts also feature a tight 1.5% threshold accuracy over the whole operating temperature range (–40°C to 85°C), and glitch-immunity to ensure reliable reset operation without false triggering. The common $\overline{\text{RST}}$ output remains low until all six inputs have been above their respective thresholds for 200ms.

The LTC2908-A1 and LTC2908-B1 also feature two low voltage positive adjustable inputs (+ADJ) with nominal threshold level at 0.5V, and a low quiescent current on the main supply (the greater of V1 or V2) of 25µA typical.

–48V Hot Swap Controller Protects Boards from Slow Transients to Short-Circuit Faults

The LTC4252A is a negative voltage Hot Swap controller that provides three levels of inrush and short-circuit protection for servers and –48V distributed power systems.

The Hot Swap controller features a circuit breaker that controls the current to the board in three stages. A slight overcurrent trips the circuit breaker only if it persists beyond a user-programmed time period. Larger overcurrent conditions are controlled through active current limiting, which maintains a safe power level in the MOSFET. Catastrophic overcurrent conditions from short-circuits cause the fast comparator to trip immediately, protecting the load and the MOSFET more quickly than the active current limit loop. Separate soft-start circuitry limits inrush currents when a board is inserted or removed from the power bus.

Two voltage monitors with ±1% threshold accuracy are included to allow an accurate user-defined operating range. The LTC4252A is shunt regulated, allowing it to be operated from supplies lower than –15V.

The LTC4252A is offered in the 10-pin MSOP package and is screened to commercial and industrial temperature ranges. This part is available in two configurations: the LTC4252A-1 for automatic retry and the LTC4252A-2 for latch-off after a circuit breaker trip.

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LTC2054, continued from page 7

plifier. The current in a photodiode is converted to a voltage at the output. The low input bias current and input noise current, combined with low voltage offset, provide a precision signal monitor. A high degree of input sensitivity is provided to the circuit by the large dynamic range, characterized by low input offset and high DC gain of the LTC2054. In addition, the LTC2054HV allows ±5V supply operation, further increasing dynamic range.

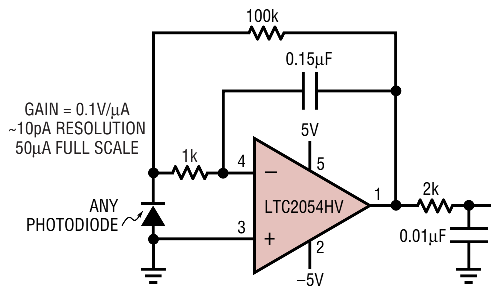

Figure 5. Ultra-precision, wide dynamic range 10Hz bandwidth photodiode amplifier

Conclusion

The LTC2054 and LTC2055 low drift operational amplifiers couple low power consumption with high precision DC specifications. They require little board area, available in small footprint packages including SOT-23-5 for the LTC2054 and the industry-leading 3mm × 3mm DD package for the LTC2055. A wide input common-mode range and a wide supply range that allows operation between 2.7V and ±5V provide flexibility.

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easy to use. Its simple 8-wire serial port provides maximum control with a minimum number of wires.

A detection circuit indicates the presence or absence of the Smart Card. Card insertion is debounced with a 40ms delay to ensure that the contacts are well seated before the card is activated. If the card is removed from its socket during a transaction, the LTC4556 cleanly deactivates it before its pads leave the connector's contact pins. Figure 1 shows the sequencing of the Smart Card pads during an automatic deactivation. RST is brought low first. On the next available edge, CLK is brought low. After CLK goes low, I/O goes low, followed by V_{CC}.

When providing power to 5V cards from a lower voltage supply, the charge pump operates in constant frequency mode under heavy load, and features Burst Mode operation for power savings when lightly loaded. The constant frequency operation allows the use of small capacitors. The charge pump is powerful enough to supply the Smart Card at rated current requirements for all 3 V_{CC} voltages.

A low dropout linear regulator controls the voltage of the Smart Card. The LTC4556 supports all three Smart Card classes (1.8V, 3V and 5V). The Smart Card signals are level shifted to the appropriate microcontroller supply voltage (which can range from 1.7V to 5.5V).

The data communication pins (I/O and DATA) are bidirectional and full duplex. This feature allows true *acknowledge* data to be returned to the microcontroller interface. These bidirectional pins also have special accelerating pull-up sources to ensure fast rise times. These sources are faster than a resistor, and don't suffer the power dissipation of a resistor when the pin is held low. They sense the edge rate on the pin and compare it to a preset limit. If the limit is exceeded, an additional current source is applied to the pin, thereby accelerating it. Once the pin reaches its local supply level, the acceleration current is disabled. Figure 2 shows an example of the data waveforms on a Smart Card pin and a microcontroller pin.

For further information on any of the devices mentioned in this issue of *Linear Technology*, use the reader service card or call the LTC literature service number:

1-800-4-LINEAR

Ask for the pertinent data sheets and Application Notes.

For the Smart Card clock pins, special clock divider and synchronization circuitry allows easy interfacing to a microcontroller. Separate clock input pins are available to support either asynchronous Smart Cards or synchronous memory cards. A true bidirectional mode is available to allow clock stretching for custom Smart Card applications. In this mode, the clock channel is identical to the data channel with its bus accelerators.

Ease of Use

Figure 3 shows an example of the LTC4556 used in a Smart Card to RS232 application powered by only a single Li-Ion battery. A simple 4-wire command and status interface plus a 4-wire Smart Card communications interface are all that is required. The command/status serial port can be easily daisy-chained, and the Smart Card communications port paralleled, to expand this application to virtually any number of Smart Cards while maintaining the same number of wires to the microcontroller.

Conclusion

The LTC4556 provides a compact, simple and cost effective solution to the difficult problems facing Smart Card system designers.

DESIGN TOOLS

Databooks

Linear Technology currently has a set of seven databooks organized by product family. This set supersedes all previous Linear databooks. Each databook contains all related product data sheets, selection guides, QML/space information, package information, appendices, and a complete reference to all of the other family databooks.

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