LINEAR TECHNOLOGY

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IN THIS ISSUE…

LINEAR TECHNOLOGY

Replace Batteries in Power Ride-Through Applications with Robust Supercaps and 3mm × 3mm Capacitor Charger

by Jim Drew

Introduction

Supercapacitors (or ultracapacitors) are finding their way into an increasing number of applications for short-term energy storage and applications that require intermittent high energy pulses. One such application is a power ride-through circuit, in which a backup energy source cuts in and powers the load if the main power supply fails for a short time. This type of application has been dominated by batteries in the past, but electric double layer capacitors (EDLCs) are fast making inroads as their price-per-farad, size and effective series resistance per capacitance (ESR/C) continue to fall.

One advantage supercapacitors have over batteries is their long life. A capacitor's cycle life is quoted as greater than 500,000 cycles; batteries are specified for only a few hundred cycles. This makes the supercapacitor an ideal "set and forget" device, requiring little or no maintenance.

In a power ride-through application, series-stacked capacitors must be charged and cell-voltage balanced. Supercaps are switched into the power path when needed and the power to the load is controlled by a DC/DC converter. The LTC3225 supercapacitor charger has a number of features that make it a good choice for power ride-through applications. It comes in a small, 10-lead 3mm × 3mm DFN package and features programmable charging current, automatic cell voltage balancing, low drain current on the supercapacitors and a patent pending, low noise, constant current charger.

Supercapacitor Characteristics

Supercapacitors come in a variety of sizes, for example a 10F/2.7V supercap is available in a 10mm × 30mm 2-terminal radial can with an ESR of

continued on page 3

Linear in the News…

Linear Technology Analog Channel

Starting this month, you can tune in to the Linear Technology Analog Channel on the web. The channel kicks off with a series of video design ideas covering a broad range of topics from some of the industry's premier analog gurus. To see the videos, visit the Linear Technology website at **www.linear.com/LTchannel** or the *EDN* website at **www.edn.com/videocast/video_tech_clips.html.** New videos will be added periodically, so check in often, or sign up to receive the Linear Insider email to be notified when new videos are available at **www.linear.com/mylinear.**

Check out the following videos, now available online.

"Direct Paralleling, High Power Density LDO"
with Robert Dobkin, Vice President, Engineering and Chief Technical Officer

The LT3080 is a new architecture for linear regulators. It provides better regulation, a simple output adjustment with a single resistor where the output can be adjusted down to zero. Also, this architecture allows easy paralleling of regulators for "no heat sink" operation in all-surface-mount applications. The LT3080 video shows circuit operation and applications for paralleling, spreading the heat, general purpose power supplies and current sources.

"High Voltage, Low Noise, DC/DC Converters: A Kilovolt with 100µV of Noise"
with Jim Williams, Staff Scientist

Photomultipliers (PMT), avalanche photodiodes (APD), ultrasonic transducers, capacitance microphones, radiation detectors and similar devices require high voltage, low current bias. Additionally, the high voltage must be pristinely free of noise; well under a millivolt is a common requirement with a few hundred microvolts sometimes necessary. The video details circuits featuring outputs from 200V to 1000V with output noise below 100µV measured in a 100MHz bandwidth. Special techniques enable this performance, most notably power stages optimized to minimize high frequency harmonic content. An additional aid to achieving low noise is that load currents rarely exceed 5mA. This freedom permits output filtering methods that are usually impractical. A lab-based circuit noise measurement demonstration concludes the presentation.

"A Thermocouple Meter Reference Design Using the LTC2492 Delta Sigma ADC"
with Mark Thoren, Applications Engineering Manager, Mixed Signal Products

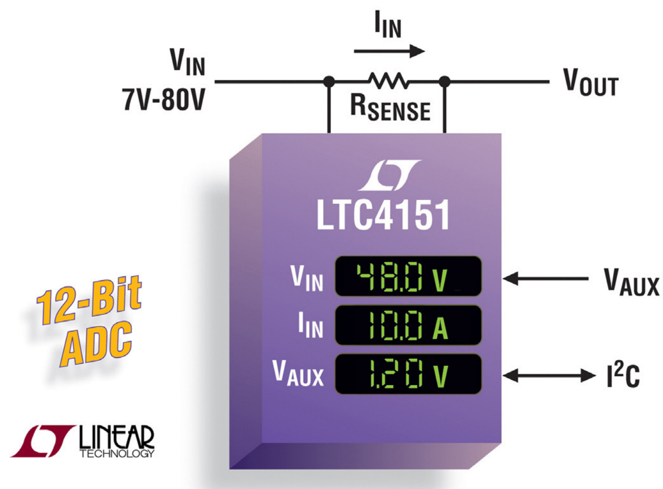
Thermocouples are perhaps the most common temperature sensor in use. And while they are extremely simple and rugged, the output is very small—tens of microvolts per degree Celsius. Traditionally, thermocouple measurement circuits use a cold junction compensation circuit to drive the thermocouple negative terminal and a low offset amplifier with enough gain to use the entire input span of a 12- or 16-bit ADC.

Linear Technology's LTC2492 greatly simplifies thermocouple instrument design. A simple filter and protection circuit is all that is required to build a rugged, ready-to-use meter. Some software tricks take care of cold junction compensation and the thermocouple's non-linear output.

Investment in Environment Award

Linear Technology's LTC4151 High Voltage I²C Current and Voltage Monitor has been selected as a finalist for an E-Legacy Investment in Environment Award by *Electronic Product Design* in the UK. This award highlights electronics companies that are devveloping environmentally responsible products.

In a world where power conservation is increasingly important, designers need to give greater consideration to the overall impact and cost of operation of their end product. Accurately monitoring power consumption provides information to understand and manage the power requirements in a high voltage system to avoid wasted resources.



The LTC4151 breaks the mold of traditional current sense solutions by combining the high voltage capability of a Hot Swap™ controller with the accuracy of a 12-bit ADC. The LTC4151 provides a true power measurement between 7V and 80V, rather than just a current reading or voltage reading on its own. This is extremely valuable data for high voltage applications, as it alerts designers to overloading and power loss in their system. The LTC4151 is ideal for a wide range of applications. By measuring up to 80V, the LTC4151 can accurately measure industrial, telecom and automotive signals at 48V, and survive transient surges up to 80V. This power monitor can also measure 72V systems with ±10% tolerances (79.2V). By measuring as low as 7V, the LTC4151 can accurately monitor 10V and 12V industrial systems.

LTC3225, continued from page 1

25mΩ while a 350F/2.5V supercapacitor with an ESR of 1.6mΩ is available in a D-cell battery form factor. One advantage supercapacitors offer over batteries is their long life. A capacitor's cycle life is quoted as greater than 500,000 cycles; batteries are specified for only a few hundred cycles. This makes the supercapacitor an ideal "set and forget" device, requiring little or no maintenance.

Two parameters of the supercapacitor that are critical to an application are cell voltage and initial leakage current. Initial leakage current is a misnomer in that the initial leakage current is really dielectric absorption current which disappears after some time. The manufacturers of supercapacitors rate their leakage current after 100 hours of applied voltage while the initial leakage current in those first 100 hours may be as much as 50 times the specified leakage current.

The voltage across the capacitor has a significant effect on its operating life. When used in series, the supercapacitors must have balanced cell voltages to prevent over-charging of one of the series capacitors. Passive cell balancing, where a resistor is placed across the capacitor, is a popular and simple technique. The disadvantage of this technique is that the capacitor discharges through the balancing resistor when the charging circuit is disabled. The rule of thumb for this scheme is to set the balancing resistor to 50 times the worst case leakage current, estimated at 2µA/Farad. Given these parameters, a 10F, 2.5V supercapacitor would require a 2.5k balancing resistor. This resistor would drain 1mA of current from the supercapacitor when the charging circuit is disabled.

An alternative is to use a non-dissipative active cell balancing circuit, such as the LTC3225, to maintain cell voltage. The LTC3225 presents less than 4µA of load to the supercapacitor when in shutdown mode and less than 1µA when input power is removed. The LTC3225 features a programmable charging current of up to 150mA, charging two series supercapacitors to either 4.8V or 5.3V while balancing the voltage on the capacitors.

Power Ride-Through Applications

To provide a constant voltage to the load, a DC/DC converter is required between the load and the supercapacitor. As the voltage across the supercapacitor decreases, the current drawn by the DC/DC converter increases to maintain constant power to the load. The DC/DC converter drops out of regulation when its input voltage reaches the minimum operating voltage (V_{UV}).

To estimate the requirements for the supercapacitor, the effective circuit resistance (R_T) needs to be determined. R_T is the sum of the capacitors' ESRs and the circuit distribution resistances.

$$R_T = ESR + R_{DIST}$$

Assuming 10% of the input power is lost in the effective circuit resistance when the DC/DC converter is at the minimum operating voltage, the worst case R_T is

$$R_{T(MAX)} = \frac{0.1 \bullet V_{UV}^2}{P_{IN}}$$

The voltage required across the supercapacitor at the undervoltage lockout threshold of the DC/DC converter is;

$$V_{C(UV)} = \frac{V_{UV}^2 + P_{IN} \bullet R_T}{V_{UV}}$$

The required effective capacitance can then be calculated based on the required ride-through time (T_{RT}), and the initial voltage on the capacitor ($V_{C(0)}$) and $V_{C(UV)}$.

$$C_{EFF} = \frac{2 \bullet P_{IN} \bullet T_{RT}}{V_{C(0)}^2 - V_{C(UV)}^2}$$

The effective capacitance of a series connected bank of capacitors is the effective capacitance of a single capacitor divided by the number of capacitors while the total ESR is the sum of all the series ESRs.

The ESR of a supercapacitor decreases with higher frequency. Manufacturers usually specify the ESR

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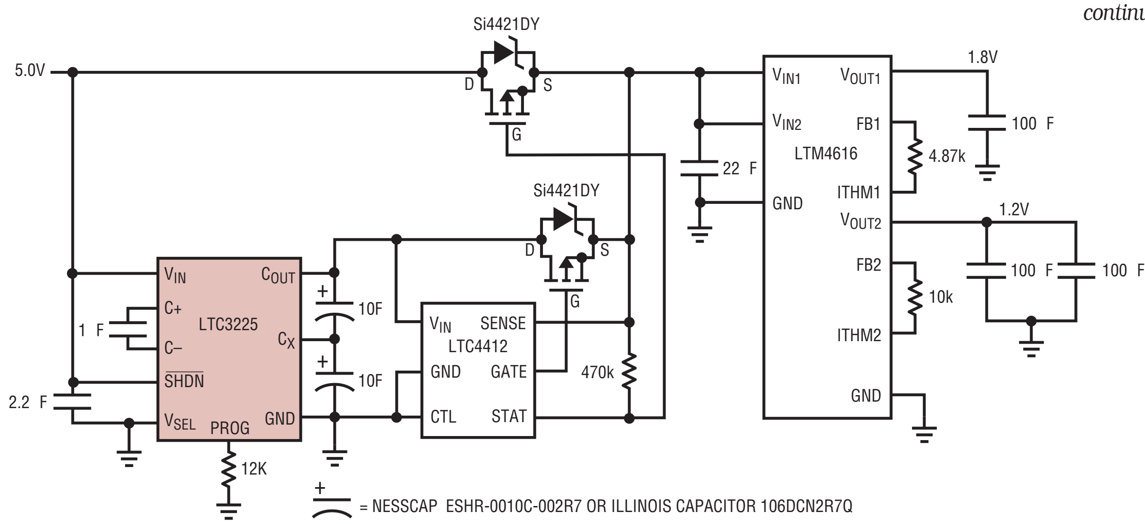


Figure 1. A 5V power ride-through application

New Family of Integrated Power Controllers Combine Fast Battery Charging, PowerPath Control and Efficient DC/DC Converters in Less Than 20mm²

by Sam Nork

Introduction

The quickest way to build an efficient power system for a battery-powered portable application is to use an IC that combines all power control functions into a single chip, namely a Power Management Integrated Circuit (PMIC). PMICs seamlessly manage power flow from various power sources (wall adapters, USB and batteries) to power loads (device systems and the charging battery), while maintaining current limits where required (such as that specified for USB). To this end, PMICs typically feature built-in PowerPath™ control, DC/DC conver-

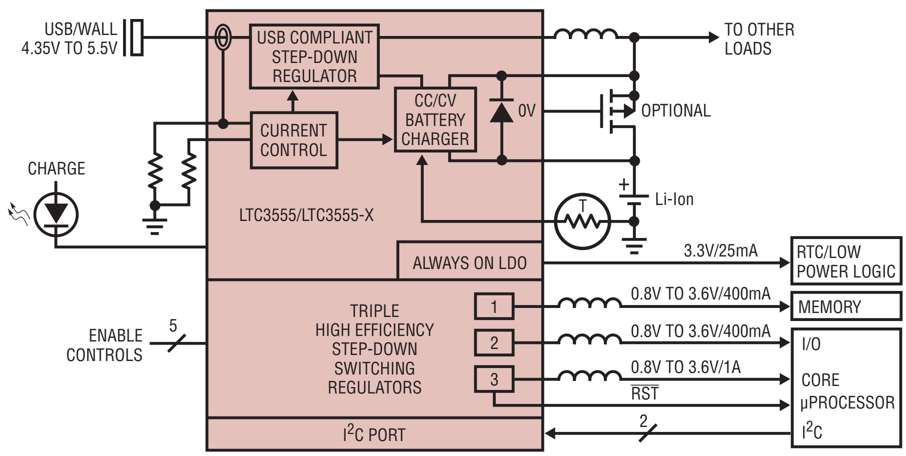


Figure 1. High efficiency PowerPath manager and triple step-down regulator

Table 1. Power management ICs with Li-ion/polymer battery chargers

Part Number	PowerPath Topology	Interface	Integrated Converters and Load Current Capabilities				Package
			Buck	Buck-Boost	Boost	LDO	
LTC3555/-1/-3	Switching	I²C	1A, 400mA × 2			25mA	4mm × 5mm QFN-28
LTC3556	Switching	I²C	400mA × 2	1A		25mA	4mm × 5mm QFN-28
LTC3566	Switching			1A		25mA	4mm × 4mm QFN-24
LTC3567	Switching	I²C		1A		25mA	4mm × 4mm QFN-24
LTC3586*	Switching		400mA × 2	1A	0.8A	20mA	4mm × 6mm QFN-38
LTC3557/-1	Linear		600mA, 400mA × 2			25mA	4mm × 4mm QFN-28
LTC3455	Linear		600mA, 400mA			Controller	4mm × 4mm QFN-24
LTC3558			400mA	400mA			3mm × 3mm QFN-20
LTC3559/-1			400mA × 2				3mm × 3mm QFN-16

*For an application of the LTC3586 see "Complete Power Solution for Digital Cameras and Other Complex Compact Portable Applications" in this issue sion and battery charging functions. PMICs can be applied in everything from consumer electronics such as MP3 players and Bluetooth headsets to specialized portable medical and industrial equipment.

Table 1 shows the wide variety of integrated charger and DC/DC combinations now available from Linear Technology. The latest additions to the family, the LTC3555, LTC3556, LTC3566, LTC3567 and LTC3586, are primarily targeted toward relatively high power Li-Ion applications and contain blocks capable of high efficiency at high current levels. (To see an application of the LTC3586, see "Complete Power Solution for Digital Cameras and Other Complex Compact Portable Applications" in the Design Ideas section of this issue.)

The most noteworthy feature of the new parts is the use of a proprietary switching PowerPath design, which improves efficiency over linear power path or battery fed solutions.

Switching PowerPath Control Efficiently Harnesses Available External Power

To speed up charging, some of Linear's new PMICs employ a unique current limited synchronous buck switching charger architecture that uses more power from the USB or adapter than other topologies. This is a big improvement over battery fed and linear PowerPath control schemes. (For a more detailed description of the switching PowerPath architecture, see the cover article in the June 2008 issue of *Linear Technology* magazine titled "Speed Up Li-ion Battery Charging and Reduce Heat with a Switching PowerPath Manager.")

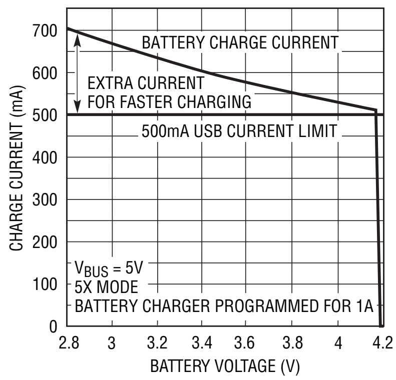


Figure 2. Switching power manager charge current vs battery voltage with a 500mA input current limit. Peak charge current = 700mA.

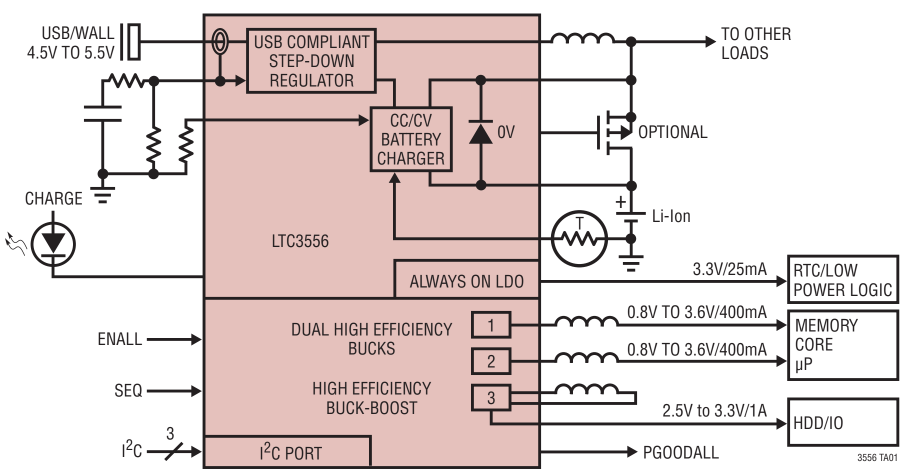
For instance, portable products with large capacity batteries (1Ahr plus) face a direct tradeoff between charge time and charger power dissipation—especially when a linear charging method is used. At relatively low charge currents, a linear charger dissipates a modest amount of power, but at currents required to quickly charge high capacity batteries, a linear charger can dissipate 2W or more.

A switching PowerPath topology is an improvement over the commonly used linear PowerPath topology, and both are an improvement over battery fed applications. A linear PowerPath powers the application directly from an external source rather than from the battery itself and provides "instant on" capability if the battery is dead or missing (as long as the load current is less than the input current limit). However, neither a linear charger nor linear power manager is well-suited for high current charging due to poor efficiency under certain conditions.

USB is now a common source of power, but charging/powering from the USB host is complicated by the host's 2.5W limit. To take advantage of the limited USB power, all components in the power path must be as efficient as possible.

A key attribute in these new PMICs is a battery-tracking (Bat-Track™) synchronous buck design with logic programmable input current limit to ensure USB compatibility. When USB or adapter power is available, the LTC35xx power manager generates a V_{OUT} supply equal to V_{BAT} + 300mV. The 300mV difference voltage is sufficient to keep the battery charger just out of dropout and deliver the programmed charge current at high efficiency. As with linear power managers, the load current is provided first, and current that is left over is directed to the battery. Input current limit is controlled via an external resistor to set absolute current and two logic pins to control the ratio (e.g. 100mA, 500mA, 1A and Suspend).

Charging efficiency of over 80% with a completely discharged battery is achievable vs 60% or so for a linear charger. Or said another way, the switching power path dissipates only 50% of the power dissipated by a linear



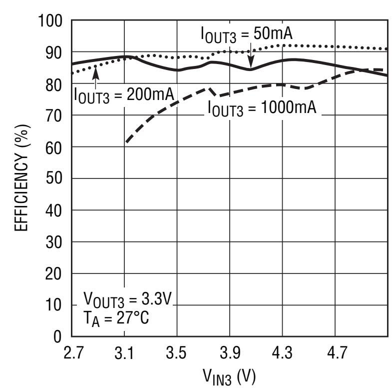


Figure 3. 1A buck-boost efficiency vs V_{IN} (LTC3556, LTC3566/7, LTC3586)

charger under worst case conditions. The LTC35xx switching power managers can charge at up to 1.2A max and provide seamless switchover to battery power when the external power is removed. In USB applications, the constant power (vs constant current) nature of the switching PowerPath controller makes it possible to charge with *more than* 500mA from a fixed 500mA USB input source, as shown in Figure 2.

Higher Current Chargers Go Hand-In-Hand with Higher Current Regulators

An obvious companion to a high performance battery charger is a corresponding set of DC/DC regulators with similar peak current handling and high efficiency. As shown in Table 1, the latest PMICs offer between one and four DC/DCs of varied topologies with peak currents reaching 1A. The new parts provide a variety of specific options to meet the high performance needs of specific applications.

Need a Buck-Boost? Not a Problem…

Most high end portable products need a minimum of three key power supplies: one for the µP core (~1.0V–1.5V), one for memory (~1.8V), and one for the I/O and main system supply (~3.3V). The LTC3555 covers all three with its built-in three synchronous bucks. However, some applications, particularly the more feature-rich variety, face occasional high peak power transients during wireless transmissions or when a hard drive spins up. The effective voltage of the battery drops during these transient currents due to the battery series resistance (BSR), trace impedance or power path losses. This poses a problem for the 3.3V supply, which can drop out of regulation even if the battery is still significantly charged. In such cases, a buck-boost regulator can save the day by riding through such battery transients—maintaining regulation as if nothing happened. Several new PMICs contain buck-boost DC/DCs specifically for this purpose. As shown in Figure 3, the PMIC buck-boosts can provide a high efficiency 3.3V output with an input that ranges from 2.7V to 5.5V.

The LTC3566 and LTC3567 products include a 1A buck-boost supply in addition to a high performance switching PowerPath controller as cornerstone high performance building blocks. The LTC3556 ups the integration further by including two 400mA buck regulators to accompany the charger and buck-boost supply. The LTC3586 contains all of the blocks of the LTC3556, but ups the integration one step further…

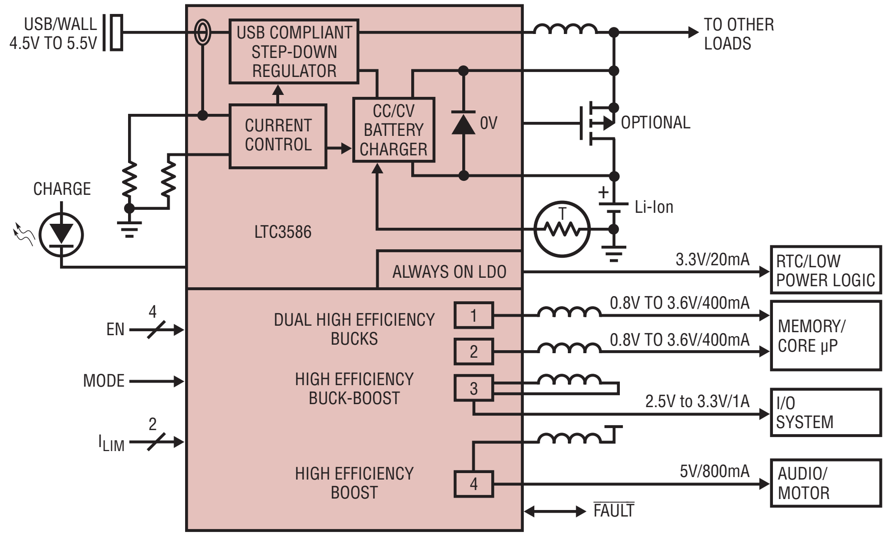


Figure 4. The LTC3586 is a high efficiency PowerPath controller, always-on LDO, dual buck, buck-boost, plus boost—all in a 4mm × 6mm package

Need an Additional 5V Boost? The LTC3586 Has It Covered

While the buck-boost regulators are capable of regulating a 5V supply, some applications require both. To meet this need, the LTC3586 includes not only a full complement of low voltage regulators, it also includes a high

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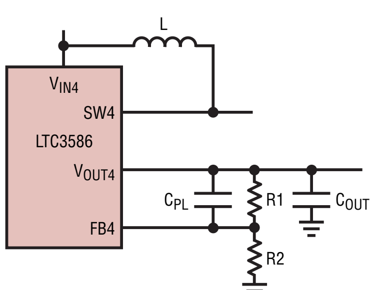

Figure 5. Boost converter application circuit

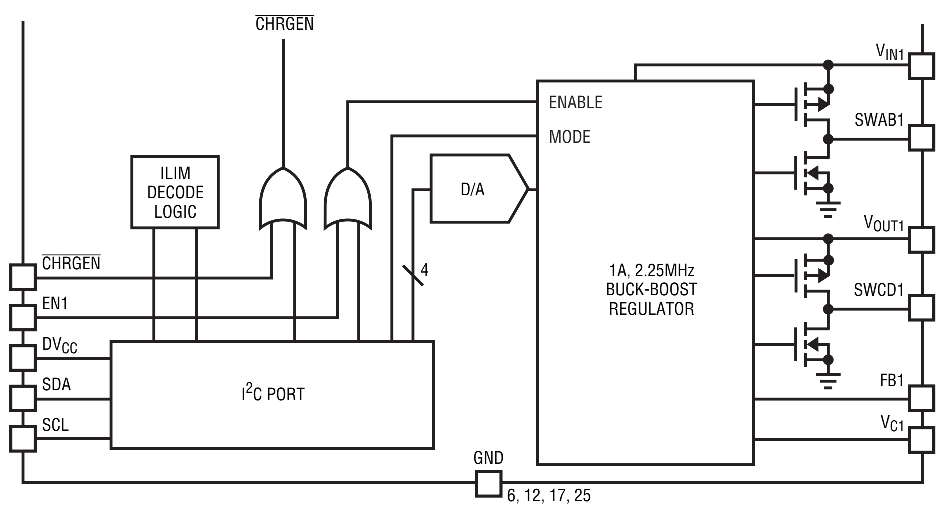

Figure 6. The LTC3567 I/O and DC/DC output voltage control interface

Charging and Discharging Methods That Extend Li-Ion Battery Life

by Fran Hoffart

Introduction

Much emphasis has been put on increasing lithium-ion battery capacity to provide the longest product run time in the smallest physical size, but there are instances where a longer battery life, an increased number of charge cycles or a safer battery is more important than battery capacity. This article presents methods relating to charging and discharging Li-ion batteries that can considerably increase battery life.

Rechargeable lithium-ion, including lithium-ion polymer batteries can be found in practically every high performance portable product and the reason for this is well justified. Compared to other rechargeable batteries, lithium-ion batteries have a higher energy density, higher cell voltage, low self-discharge, very good cycle life, are more environmentally friendly and are simple to charge and maintain. Also, because of their relatively high voltage (2.5V to 4.2V) many portable products can operate from a single cell, thereby simplifying an overall product design.

Lithium-Ion Battery Basics

Before covering the battery charger's role in extending battery life, a quick review of the lithium-ion battery is necessary. Lithium is one of the lightest metals, one of the most reactive and has the highest electrochemical potential making it the ideal material for a battery. A Li-ion battery contains no lithium in a metallic state, but instead uses lithium ions that shuttle back and forth between the positive electrode (cathode) and the negative electrode (anode) of the battery during charge and discharge.

Types of Lithium-Ion Batteries

Although there are many different types of Li-ion batteries, the most popular chemistries presently in production can be narrowed down to three, all relating to the cathode materials used in the battery. The lithium cobalt chemistry has become more popular in laptops, cameras and cell phones mainly because of its greater charge capacity. Other chemistries are used where high discharge currents are required, where safety is a concern or where cost is an issue. Also, new hybrid Li-ion batteries under development use a combination of electrode materials to take advantage of benefits of each chemistry.

Unlike a few other battery chemistries, Li-ion battery technology is not yet mature. Research is ongoing with new types of batteries that have even higher capacities, longer life and im-

The Letter "C"

The letter "C" is a battery term used to indicate the battery manufacturers stated battery discharge capacity, which is measured in mAh. For example, a 2000mAh rated battery can supply a 2000mA load for one hour before the cell voltage drops to it's zero capacity voltage. In the same example, charging the battery at a C/2 rate would mean charging at 1000mA (1A). The letter "C" becomes important in battery chargers because it determines the correct charge current required and the length of time needed to fully charge a battery. When discussing minimum charge current termination methods, a 2000mAh battery using C/10 termination ends the charge cycle when the charge current drops below 200mA.

Table 1. Most common lithium-ion batteries

Cathode Materials	Advantages	Disadvantages
Lithium Cobalt Oxide (Most Common)	❏ High Capacity	❏ Lower Charge and Discharge Rates ❏ Higher Cost
Lithium Manganese Oxide	❏ Lower ESR ❏ Higher Charge and Discharge Rates ❏ Higher Temperature Operation ❏ Inherently Safer	❏ Lower Capacity ❏ Lower Life Cycle ❏ Shorter Lifetime
Lithium Phosphate (Newest, A123 and Saphion)	❏ Very Low ESR ❏ Very High Charge and Discharge Rates ❏ High Temperature Operation ❏ Inherently Safer	❏ Lower Discharge Voltage ❏ Lower Float Voltage ❏ Lower Capacity

proved performance than present day batteries. The table shown in Table 1 includes some important characteristics of each battery type.

Lithium-Ion Polymer Batteries

A lithium-ion polymer battery is charged, discharged and has similar characteristics as a standard Li-ion battery. The main difference between the two is that a solid ion conductive polymer replaces the liquid electrolyte used in a standard Li-ion battery, although most polymer batteries also contain an electrolyte paste to lower the internal cell resistance. Eliminating the liquid electrolyte allows the polymer battery to be housed in a foil pouch rather than the heavy metal case required for standard Li-ion batteries. The ability to fabricate the battery in many different shapes, including very thin form factors, and lower production costs are making the Li-ion polymer battery very popular.

Battery Lifetime

All rechargeable batteries wear out, and Li-ion cells are no exception. Battery manufacturers usually consider end-of-life for a battery to be when the battery capacity drops to 80% of the rated capacity, although the battery can still deliver usable power below 80% charge capacity, the run time is shortened.

The number of charge/discharge cycles is commonly used when referring to battery life, but cycle life and battery life (or service life) can be different lengths of time. Charging and discharging eventually reduces the battery's active material and causes other chemistry changes that result in increased internal resistance and permanent capacity loss. Batteries can even lose permanent capacity when not used, sitting on the shelf. The permanent capacity loss is greatest at elevated temperatures with the battery voltage maintained close to 4.2V (fully charged).

> ***Perhaps one of the worst locations for a Li-ion battery is in a laptop computer when used daily on a desktop with the charger connected. Laptops typically run warm or even hot, raising the battery temperature, and the charger is maintaining the battery near 100% charge. Both of these conditions shorten battery life.***

For maximum storage life, batteries should be stored with a 40% charge (3.6V) at 40°F (refrigerator). Perhaps one of the worst locations for a Li-ion battery is in a laptop computer when used daily on a desktop with the charger connected. Laptops typically run warm or even hot, raising the battery temperature, and the charger is maintaining the battery near 100% charge. Both of these conditions shorten the battery life, which could be as short as 6 months to a year.

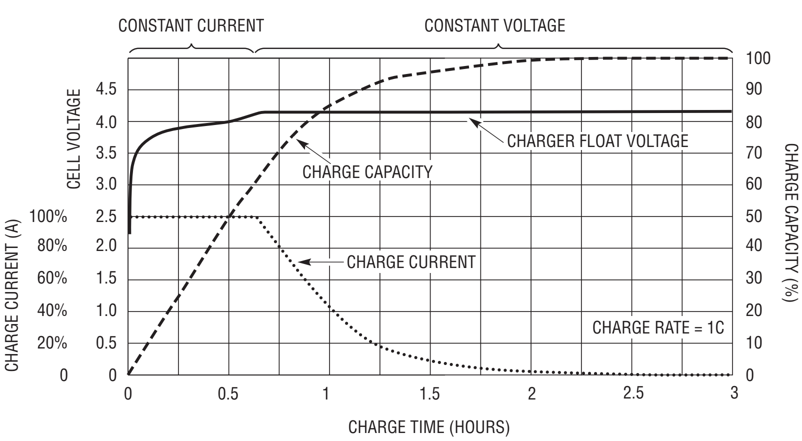

Figure 1. Typical charge profile showing charge current, voltage and capacity

If possible, remove the battery and use the AC adapter for powering the laptop when the computer is used on a desktop. A properly cared for laptop battery can have a service life of 2 to 4 years, or more.

Lithium-Ion Battery Capacity Loss

There are two types of battery capacity losses, recoverable loss and permanent loss. After a full charge, a Li-ion battery typically loses about 5% capacity in the first 24 hours, then approximately 3% per month because of self-discharge and an additional 3% per month if the battery pack has pack protection circuitry. These self-discharge losses occur when the battery remains around 20°C, but increases considerably with higher temperature and also as the battery ages. This capacity loss can be recovered by recharging the battery.

The permanent capacity loss is like the name implies, permanent, not recoverable by charging. This loss is linked to battery life because when the permanent capacity loss drops to approximately 80%, the battery is considered at the end of its life. Permanent capacity loss is mainly due to the number of full charge/discharge cycles, the battery voltage and battery temperature. The more time the battery remains near 4.2V or 100% charge level (lower voltage for Li-ion Phosphate) the faster the capacity loss occurs. This is true whether the battery is being charged or just remaining in a fully charged condition with the voltage near 4.2V. Always maintaining a Li-ion battery in a fully charged condition shortens its lifetime. The chemical changes that shorten the battery lifetime, begin when it is manufactured, and these changes are accelerated by high float voltage and high temperature. Permanent capacity loss is unavoidable, but it can be held to a minimum by observing good battery practices when charging, discharging or simply storing the battery. Using partial discharge cycles can greatly increase cycle life and charging to less than 100% capacity can increase battery life even further.

Factors That Determine Li-ion Battery Cycle Life or Service Life

Battery life is affected by a combination of several factors. To increase a battery's life, use some of the following techniques.

- ❑ Use partial discharge cycles. Using only 20% or 30% of the battery capacity before recharging extends cycle life considerably. A general rule is from 5 to 10 shallow discharge cycles are equal to one full discharge cycle. Although partial discharge cycles can number in the thousands, at the same time, keeping the battery in a fully charged state also has an effect on shortening battery life. Full discharge cycles (down to 2.5V or 3V depending on chemistry) should be avoided if possible.
- ❑ Avoid charging to 100% capacity. Selecting a lower float voltage can do this. Reducing the float voltage increases cycle life and service life at the expense of reduced battery capacity. A 100mV to 300mV drop in float voltage can increase cycle life more than 5x. Li-ion cobalt chemistries are more sensitive to a higher float voltage than other chemistries. Li-ion phosphate cells have a lower float voltage than the more common Li-ion batteries.
- ❑ Select the correct charge termination method. Selecting a charger that uses minimum charge current termination (C/10 or C/x) can also extend battery life by not charging to 100% capacity. For example, ending a charge cycle when the current drops to C/5 is similar to reducing the float voltage to 4.1V. In both instances, the battery is charged to approximately 85% of capacity, which can significantly improve overall battery life.
- ❑ Limit battery temperature. High temperatures accelerate chemical changes within the battery, which shorten battery life, while charging below 0°C promotes metal plating at the battery anode, which can develop into an internal short, producing heat and making the battery unstable and unsafe. Many battery chargers have provisions for measuring battery temperature to assure charging does not occur at temperature extremes.
- ❑ Avoid high charge and discharge currents as they reduce cycle life. High currents place excessive stress on the battery. Some chemistries are more suited for higher currents such as Li-ion manganese and Li-ion phosphate.
- ❑ Avoid very deep discharges below 2V or 2.5V, as this quickly and permanently damages a Li-ion battery. Internal metal plating can occur causing a short circuit making the battery unusable and unsafe. Most Li-ion batteries have electronic circuitry within the battery pack that opens the battery connection if the battery voltage is less than 2.5V, exceeds 4.3V or if the battery current when charging or discharging exceeds a predefined threshold.

Li-Ion Charging Methods

The recommended way to charge a Li-ion battery is to provide a ±1% voltage limited constant current to the battery until it becomes fully charged, and then stop. Methods used to determine when the battery is fully charged include timing the total charge time, monitoring the charge current or a combination of the two.

The first method applies a voltage limited constant current ranging from C/2 to 1C for 2.5 to 3 hours thus bring-

Table 2. Battery chargers that provide a lower float voltage for increased battery life

Product	Description	Float Voltage
LTC1730-4.1	Pulse Charger	4.1V
LTC1731-4.1	Linear Charger Controller	4.1V
LTC1731-8.2	2-Cell Linear Charger Controller	8.2V
LTC1732-4.1	Linear Charger Controller	4.1V
LTC1733-4.1	Linear Charger	4.1V
LTC1734-4.1	Linear Charger	4.1V
LTC3455-1	Linear Charger/DC-DC/USB Manager	4.1V
LTC3555-3	Linear Charger/DC-DC/USB Manager	4.1V
LTC3557-1	Pre-Reg Charger & USB Manager	4.1V
LTC3559-1	Linear Charger/Dual DC-DC	4.1V
LTC4001-1	Switching Charger	4.1V
LTC4007, LTC4007-1	Switching Charger Controller	12.3V & 16.4V
LTC4050-4.1	Linear Charger	4.1V
LTC4064-4.0	Linear Charger	4.0V
LTC4066-1	Linear Charger and USB Manager	4.1V
LTC4085-1	Linear Charger and USB Manager	4.1V
LTC4008	Switching Charger Controller	Adjustable
LTC1980	Switching Charger Controller	Adjustable
LTC4089-1	HV/High Efficiency Charger	4.1V
LTC4098-1	Charger/USB Manager	4.1V
LTC1760, LTC1960	Dual Smart Battery Charger Controller	Set by battery
LTC4100	Smart Battery Charger Controller	Set by battery

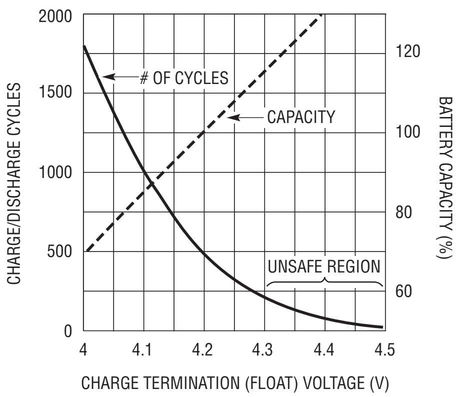

Figure 2. Charger float voltage vs battery capacity and cycle life

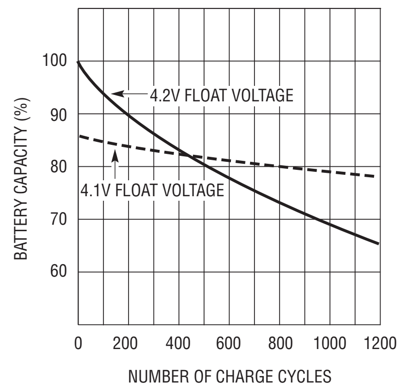

Figure 3. Cycle life and capacity vs 4.1V and 4.2V float voltages

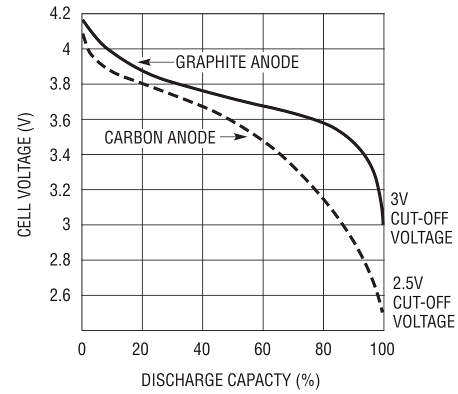

Figure 4. Li-ion discharge voltage profile for different anode materials

ing the battery up to 100% charge. A lower charge current can also be used but requires more time.

The second method is similar but it requires monitoring the charge current. As the battery charges, the voltage rises, exactly as in the first method. When it reaches the programmed voltage limit, which is also called the float voltage, the charge current begins to drop. When it first begins to drop, the battery is about 50% to 60% charged. The float voltage continues to be applied until the charge current drops to a sufficiently low level (C/10 to C/20) at which time the battery is approximately 92% to 99% charged and the charge cycle ends. Presently, there is no safe method for fast (less than one hour) charging a standard Li-ion battery to 100% capacity.

Applying a continuous voltage to a battery after it is fully charged is not recommended as this accelerates permanent capacity loss, can cause the battery to swell and may result in internal lithium metal plating. This plating can develop into an internal short circuit resulting in overheating making the battery thermally unstable. The length of time required is months.

Some Li-ion battery chargers allow a thermistor to be used to monitor battery temperature. The main purpose is to prevent charging if the battery temperature is outside the recommended window of 0°C to 40°C. Unlike NiCd or NiMH batteries, Li-ion cell temperature rises very little when charging. See Figure 1 for a typical Li-ion charge profile showing charge current, battery voltage, and battery capacity vs time.

What Determines Battery Float Voltage?

The main determining factor of a battery's float voltage is the electrochemical potential of the active materials used in the battery's cathode, which for lithium is approximately 4V. The addition of other compounds raises or lowers this voltage. The second factor is a tradeoff between cell capacity, cycle life, battery life and safety. The curve shown in Figure 2 shows the relationship between cell capacity and cycle life.

Most manufacturers of standard Li-ion cells have set a 4.2V float voltage as the best compromise of capacity and cycle life. Using 4.2V as the constant voltage limit (float voltage), a battery can typically deliver about 500 charge/discharge cycles before the battery capacity drops to 80%. A lower float voltage for Li-ion phosphate batteries allows the number of charge/discharge cycles to be much higher. One charge cycle consists of a full charge to a full discharge. Multiple shallow discharges add up to one full charge cycle.

Although charging to a capacity less than 100% using either a reduced float voltage or minimum charge current termination results in initial reduced battery capacity, as the number of cycles increases beyond 500, the battery capacity of the lower float voltage can exceed that of the higher float voltage. Figure 3 illustrates how the recommended float voltage compares with a reduced float voltage with regard to capacity and the number of charge cycles.

Because of the different Li-ion battery chemistries and other conditions that can affect battery life, the curves shown here are only estimates of the number of charge cycles and battery capacity levels. Even similar battery chemistries from different manufacturers can have dramatically different results due to minor differences in battery materials and construction methods.

Battery manufacturers specify a charge method and a float voltage the end user must use to meet the battery specifications for capacity, cycle life and safety. Charging above the recommended float voltage is not recommended. Many batteries include a battery pack protection circuit, which temporarily opens the battery connection if the maximum battery voltage is exceeded. Once opened, connecting the battery pack to the charger normally resets the pack protection. Battery packs often have a voltage printed on the battery, such as 3.6V for a single cell battery. This voltage is not the float voltage, but rather the average battery voltage when the battery is discharging.

Selecting a Battery Charger for Extending Battery Life

Although a battery charger has no control over a battery's depth-of-discharge, discharge current and battery temperature, all of which have an effect on battery life, many chargers have features that can increase battery life, sometimes dramatically.

A battery charger's role in extending battery lifetime is mainly determined by the charger's float voltage and charge termination method. Many Linear Technology Li-ion chargers feature a ±1% (or lower) fixed float voltage of 4.2V, but there are some offerings in 4.1V and 4.0V, as well as adjustable float voltages. Table 2 lists battery chargers that feature a reduced float voltage that can increase battery life when used to charge a 4.2V Li-ion battery.

Battery chargers not offering lower float voltage options are also capable of increasing battery life. Chargers that provide minimum charge current termination methods (C/10 or C/x) can provide a longer battery life by selecting the correct charge current level at which to end the charge cycle.

Although C/10 termination brings the battery to only ~92% capacity, there is a siginificant increase in cycle life over charging the battery to full capacity. A C/5 termination level can double the cycle life, though the battery charge capacity drops to approximately 85%. Table 3 lists Linear Technology chargers that provide either C/10 (10% current threshold) or C/x (adjustable current threshold) charge termination mode.

Longer Run Time or Longer Battery Life, Can You Have Both?

With present battery technology and without increasing battery size, the answer is no. For maximum run time, the charger must charge the battery to 100% capacity. This places the battery voltage near the manufacturers recommended float voltage, which is typically 4.2V ±1%. Unfortunately, charging and maintaining the battery near these levels shortens battery life. One solution is to select a lower float voltage, which prohibits the battery from achieving 100% charge, although this means selecting a higher capacity battery to provide the same run time. Of course, in many portable products, a larger sized battery may not be an option.

Also, using a C/10 or C/x minimum charge current termination method can have the same effect on battery life as using a lower float voltage. Reducing the float voltage by 100mV reduces capacity by approximately 15% but can double the cycle life. At the same time terminating the charge cycle when the charge current has dropped to 20% (C/5) also reduces the capacity by 15% and achieves the same doubling of cycle life.

Typical Li-Ion Battery Voltage when Discharging

As expected, during discharge, the battery voltage slowly drops. The discharge voltage profile vs time depends on a number of items including discharge current, battery temperature, battery age and the type of anode material used in the battery. Presently, most Li-ion batteries use

Table 3. Battery chargers that feature minimum charge current termination method for increased battery life

Product	Description	Termination Method
LTC3550, LTC3550-1	Linear Charger & DC/DC Converter	C/x
LTC3552, LTC3552-1	Linear Charger & DC/DC Converter	C/x
LTC4001	Switching Charger	C/x
LTC4054, LTC4054X, LTC4054L	Linear Charger	C/10
LTC4058, LTC4058X	Linear Charger	C/10
LTC4061	Linear Charger	C/x or Adj. Timer
LTC4062	Linear Charger	C/x or Adj. Timer
LTC4063	Linear Charger	C/x or Adj. Timer
LTC4068, LTC4068X	Linear Charger	C/x
LTC4075	Dual Input Linear Charger	C/x
LTC4075HVX	Dual Input Linear Charger	C/x
LTC4076	Dual Input Linear Charger	C/x
LTC4077	Dual Input Linear Charger	C/10
LTC4078	Dual Input Linear Charger	C/x
LTC4088-1, LTC4088-2	Linear Charger/USB Manager	C/x
LTC4096, LTC4096X	Dual Input Linear Charger	C/x
LTC4097	Dual Input Linear Charger	C/x

either a petroleum based coke material or graphite. The voltage profiles for each are shown in Figure 4. The more widely used graphite material produces a flatter discharge voltage between 20% and 80% capacity, then drops quickly near the end, whereas the coke anode has a steeper voltage slope and a lower 2.5V cutoff voltage. The approximate remaining battery capacity is easier to determine with a coke material by simply measuring the battery voltage.

Parallel or Series Connected Cells

For increased capacity, Li-ion cells are often connected in parallel. There are no special requirements other than they should be the same chemistry, manufacturer and size. Series connected cells require more care because cell capacity matching and cell balancing circuitry is often required to assure that each cell reaches the same float voltage and the same level of charge. Connecting two cells (that have individual pack protection circuitry) in series is not recommended because a mismatch in capacity can result in one battery reaching the overvoltage limit, thus opening the battery connection. Multicell battery packs should be purchased assembled with the appropriate circuitry from a battery manufacturer.

Conclusion

The lifetime of a Li-ion battery is determined by many factors of which the most important are battery chemistry, depth of discharge, battery temperature and battery capacity termination level. The number of available charge/discharge cycles can be increased by selecting a charger that allows charging to less than 100% capacity, such as one that features a lower float voltage or one that terminates earlier in the charge cycle.

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LTC3225, continued from page 3

at 1kHz, while some manufactures publish both the value at DC and at 1kHz. The capacitance of supercapacitors also decreases as frequency increases and is usually specified at DC. The capacitance at 1kHz is about 10% of the value at DC. When using a supercapacitor in a ride-through application where the power is being sourced for seconds to minutes, use the effective capacitance and ESR measurements at a low frequency, such as 0.3Hz.

Applications

Figure 1 shows two series connected 10F, 2.7V supercapacitors charged to 4.8V that can hold up 20W. The LTC3225 is used to charge the supercapacitors at 150mA and maintain cell balancing, while the LTC4412 provides an automatic switchover function. The LTM4616 dual output switch mode µModule DC/DC converter generates the 1.8V and 1.2V outputs.

Figure 2 shows a 12V power system that uses six 10F, 2.7V supercapacitors in series charged by three LTC3225's set to 4.8V and a charging current of 150mA. The three LTC3225's are powered by three floating 5V outputs generated by the LT1737 flyback controller. The output of the stack of six supercapacitors is set up in a diode OR arrangement via the LTC4355 dual ideal diode controller. The LTM4601A µModule DC/DC regulator produces 1.8V at 11A from the OR'd outputs. The LTC4355's MON1 in this application is set for 10.8V.

Conclusion

Supercapacitors are meeting the needs of power ride-through applications where the time requirements are in the seconds to minutes range. Capacitors offer long life, low maintenance, light weight and environmentally friendly solutions when compared to batteries. To this end, the LTC3225 provides a compact, low noise solution to charging and cell balancing series connected supercapacitors.

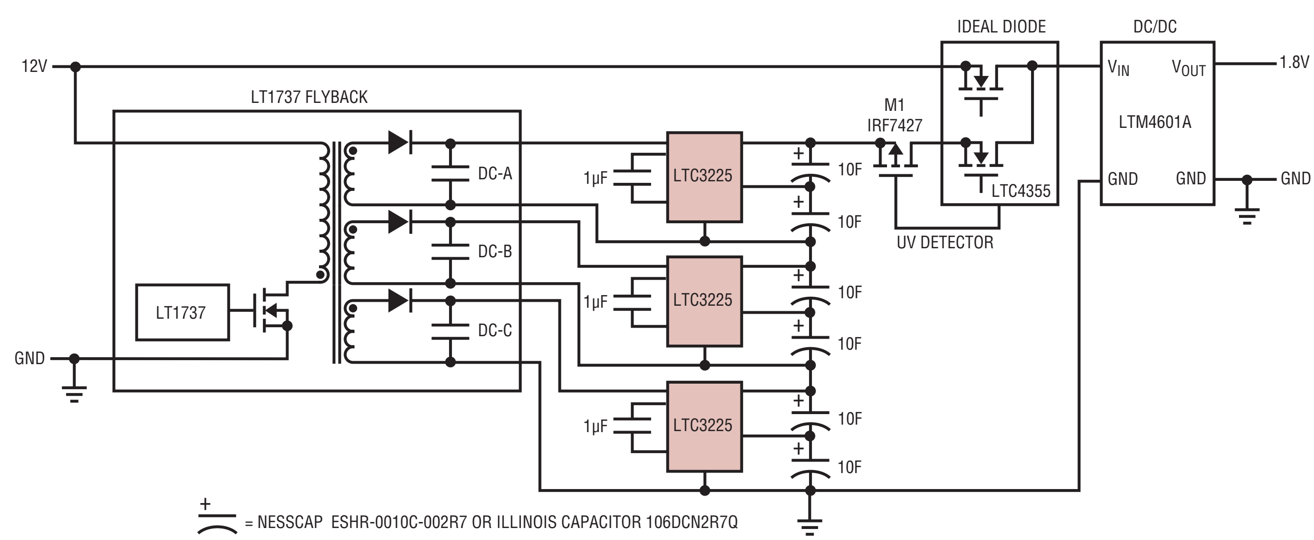


Figure 2. A 12V power ride-through application

Serial Interface for High Speed Data Converters Simplifies Layout over Traditional Parallel Devices

by Clarence Mayott

Introduction

The LTC2274 is a 105Msps, 16-bit ADC that simplifies the digital connection between the ADC and FPGA by replacing the usual parallel interface with a novel high speed serial interface, thus reducing the typical number of required data input/output (I/O) lines from 16 CMOS or 32 LVDS parallel data lines to a *single, self-clocking, differential pair* communicating at 2.1Gbps. This frees up valuable FPGA pins and board space. It also allows flexibility to route across analog and digital boundaries—in noise sensitive applications, the serial interface provides an effective isolation barrier between digital and analog circuitry and serves to eliminate coupling between the digital outputs and analog inputs to reduce digital feedback.

The LTC2274 ADC replaces the usual parallel interface with a novel high speed serial interface, thus reducing the typical number of required data input/output lines from 16 CMOS or 32 LVDS to a single, self-clocking, differential pair communicating at 2.1Gbps.

Current Mode Logic and 8B/10B Encoding Allows High Speed Serial Data Transfer

The LTC2274 achieves excellent signal to noise ratio (SNR) performance of 77.6dBFS and spurious free dynamic range (SFDR) of 100dB at baseband, as shown in Figure 1. The input topology of the LTC2274 family is based on its predecessor, the LTC2207 family, and achieves similar AC performance. However, the LTC2274 differs from the LTC2207 in its output structure. The LTC2274 uses an 8B/10B encoder to encode and serialize the data before it is transmitted. 8B/10B encoding is a process that takes 8 bits of data and encodes them into 10 bits to ensure zero DC offset and a limited run length. To encode a 16-bit word, the LTC2274 must transmit 20 bits of serial data. This requires that the serial data must be transmitted at 20 times the clock frequency of the ADC. Sampling at 105Msps requires the LTC2274 to transmit serial data at 2.1GHz. This is beyond the usable range of LVDS signaling, and therefore requires a faster, more robust differential signaling scheme. The LTC2274's differential signaling uses current mode logic (CML), which is capable of transmitting data in excess of 10GHz.

Current mode logic uses a differential output transistor pair (usually N-type) to steer current into resistive loads. The output swing and offset depends on the bias current and termination resistance. The output driver bias current is typically 16mA, generating a signal swing potential of $400mV_{P–P}$ ($800mV_{P–P}$ differential) across the combined internal and external termination resistance of 25Ω on each output. LVDS typically uses 3.5mA to develop its signal swing, and the capacitance of the ESD protection diodes becomes a limiting factor for transmission speed. CML uses more current, and therefore this capacitance becomes less of a limiting factor to data throughput.

CML is typically faster than LVDS. A typical LVDS output stage requires four transistors to steer current into the load, usually using both P-channel and N-channel devices. A mixture of N- and P-channel makes it difficult to produce devices that have the same characteristics. P-channel devices are often slower—that is, if an N-channel

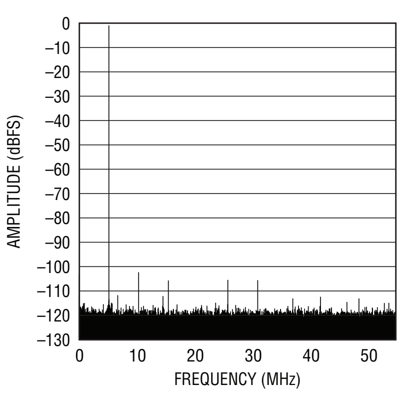
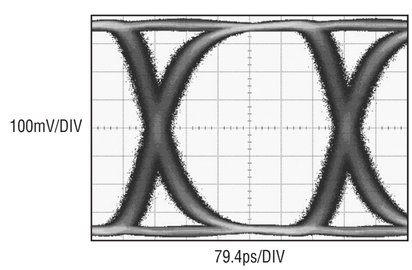
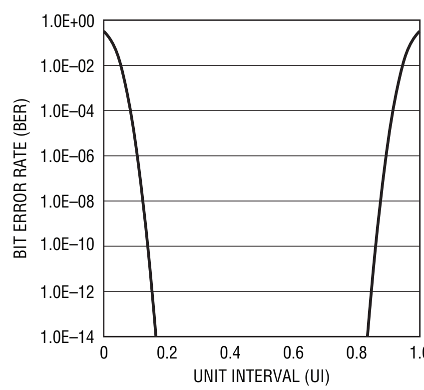


Figure 1. Typical LTC2274 performance at 105Msps f_{IN} = 4.93MHz



a. CMLOUT eye diagram 2.1GBps



b. CMLOUT Dual-Dirac BER bathtub curve, 2.1GBps

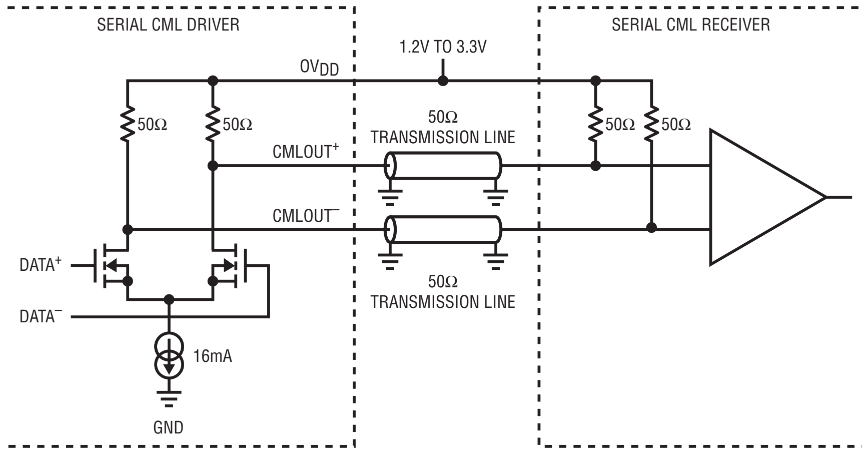
Figure 2. Signal integrity of CMLOUT

and a P-channel device are cascaded, the P-channel cannot pull up the signal as fast as the N-channel can pull down. This causes the output waveform to be distorted, which can lead to bit errors, and limits the speed at which LVDS can transfer data.

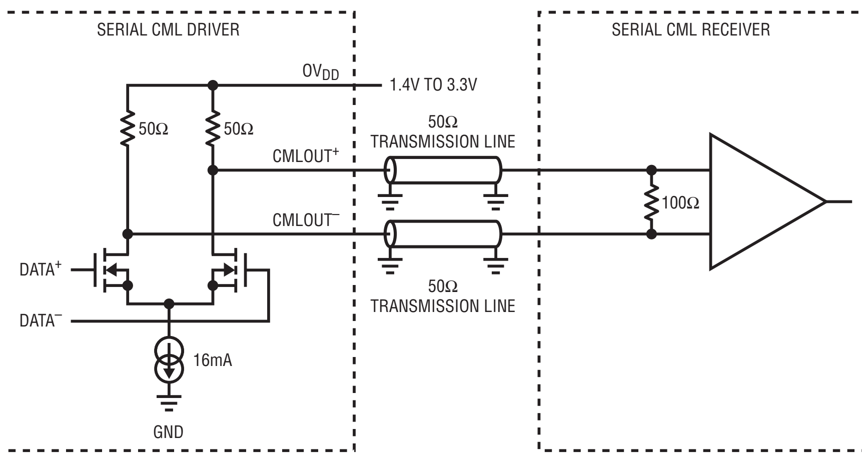
The LTC2274 CML driver is implemented with only N-channel devices, which allows faster throughput rates. Since CML only sinks current, it has true differential signal, which improves signal integrity. The eye diagram and bathtub curves of the LTC2274 are shown in Figure 2. The eye diagram shows very little variation cycle to cycle of the CML logic output, and the bathtub curve shows that total jitter in the signal is less than 0.35UI (unit interval). This equates into a very clean uniform signal that can easily received by a properly terminated receiver.

Termination of CML

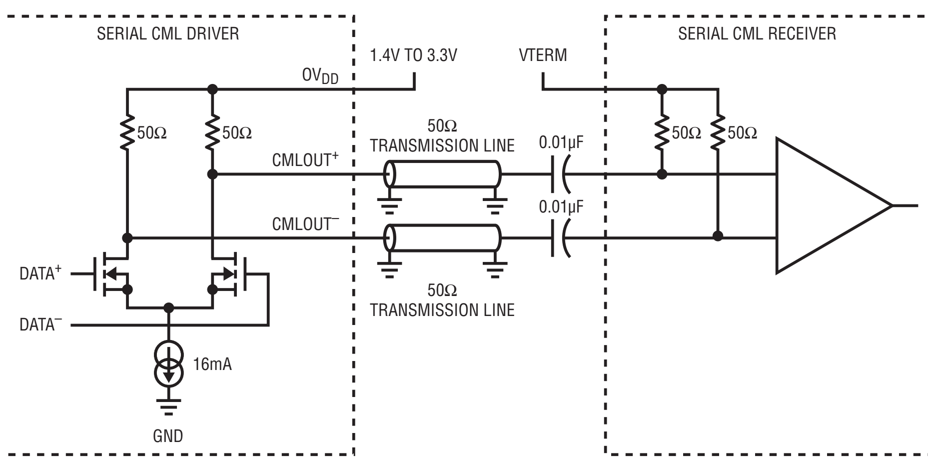
CML must be terminated for proper operation. Figure 3a shows a recommended design in which an FPGA receiver uses internal 50Ω pull up resistors for termination. These resistors pull up to the OV_{DD} of the LTC2274. OV_{DD} must be between 1.2V and 3.3V to ensure proper operation. The signal has a common mode voltage of OV_{DD} – 0.2V. The directly-coupled differential termination of Figure 3b may be used in the absence of a receiver termination voltage within the required range. In this case, the common mode voltage is shifted down to approximately 400mV below OV_{DD}, requiring an OV_{DD} in the range of 1.4V to 3.3V. If the serial receiver's common mode input requirements are not compatible with the directly-coupled termination modes, the DC balanced 8B/10B encoded data permits the addition of DC blocking capacitors as shown in Figure 3c. In this AC-coupled mode, the termination voltage is determined by the receiver's requirements. The coupling capacitors should be selected appropriately for the intended operating bit-rate, usually between 1nF and 10nF. In AC coupled mode, the output common mode voltage is approximately 400mV below OV_{DD}, so the OV_{DD} supply voltage should be in



a. Recommended CML termination, directly-coupled mode



b. CML termination, directly-coupled differential mode



c. CML termination, AC-coupled mode

Figure 3. CML termination schemes

the range of 1.4V to 3.3V. If possible, using a lower OV_{DD} can reduce power consumption. The termination scheme is largely based on the receiver. When choosing the OV_{DD} voltage, refer to the receiver's data sheet to terminate the CML lines properly.

CML uses true double termination. Generally, LVDS is only terminated at the receiver, which means that any signal reflection back to the source reflects back to the receiver with little attenuation. This limits the data rate and trace length that LVDS can drive. The truly differential nature of CML radiates less energy than LVDS and CMOS signals, allowing devices to be in closer proximity to antennas, mixers or other sensitive analog front end systems. CML also has common mode termination. This gives CML a better common mode behavior than LVDS. LVDS is only terminated differentially, which does not reject any common mode signal that may appear on the transmission line—another limiting factor in LVDS signaling.

CML Power Consumption

With a constant 16mA of bias current and a voltage swing of 800mV differential, CML logic consumes a moderate amount of power. For an equal data rate, CML logic consumes less total power than PECL and LVPECL. A single CML driver uses more power than a single LVDS driver, but only marginally more that the three pairs of LVDS drivers required for a typical LVDS serial bus.

8B/10B Encoding Makes for Simple Connection

The 8B/10B encoding process results in an average DC offset of zero, allowing the data to be routed through transformers or fiber channel transceivers that can provide isolation between the digital and analog realm. 8B/10B encoding also does not require a framing signal or a data clock, whereas both are required in traditional serial communication. 8B/10B encoding transmits data over a single pair of data lines, whereas a typical serial ADC requires three or more pairs, and a typical parallel ADC can require more than 16 pairs.

The complexity of decoding 8B/10B lies in the receiver. Fortunately Xilinx, Altera and Lattice have solutions to receive data from the LTC2274 and decode the 8B/10B data, simplifying the collection of 8B/10B data. Other 8B/10B decoding solutions may be available. The FPGA required to receive data from the LTC2274 must be able to receive high speed serial transmissions of 2GHz or more.

Conclusion

Without sacrificing resolution or sample rate, the LTC2274 delivers full 16-bit performance at 105Msps over a single pair of transmission lines, greatly simplifying layout and saving valuable board space. This mitigates interaction with other circuitry in software defined radio, base station or industrial applications which involve many channels of an ADC routed to one FPGA.

LTC35xx, continued from page 6

power synchronous boost converter (Figure 5).

The fully integrated boost in the LTC3586 can regulate up to a 5V output with up to 800mA from a battery voltage as low as 3V. The regulator has built in output disconnect making it well-suited for USB OTG supplies or for powering motors in printer and camera applications. The current mode synchronous boost is internally compensated and operates at a fixed 2.25MHz switching frequency. Pulse-skipping at low loads achieves low noise output for driving high power audio circuits.

I^2C, Programmable Sequencing and Easy I/O

Despite the progress in new cutting edge features and design, one old problem does not go away: power supply control. Power supplies require startup and power down sequencing, fault detection/reporting/handling and voltage and operating mode adjustments. Getting it all right can be a system control nightmare depending on the complexity and limitations of the power supply circuits.

The LTC35xx family provides very simple and flexible control of all essential power supply functions. The LTC3566 and LTC3586 employ dedicated I/O control pins for enabling, disabling and changing DC/DC operating modes. Voltages on these parts are fixed and set with external resistor dividers. The LTC3555, LTC3556 and LTC3567 accommodate either I^2C control or simple I/O pins to control the supplies. The LTC3556 provides a three-state SEQ pin to allow the power up sequence of its three DC/DC converters to be programmed via pin-strapping. Those parts with I^2C V_{OUT} control power-up at their maximum V_{OUT} (as determined by the FB servo point and external dividers) when enabled via simple I/O, and can independently reduce V_{OUT} by as much as 50% in equal 16-step increments via I^2C.

All DC/DC converters in all the PMICs discussed here can survive an indefinite output fault. The parts all provide a $\overline{RST}$ output and all converters are actively pulled down in shutdown to ensure proper power-up sequencing. The LTC3586 contains an additional fault handing feature that automatically powers down all DC/DC converters whenever a valid fault is detected. In short, the entire family is designed for simple, flexible and trouble-free control and operation.

Conclusion

Linear Technology's latest PMIC products improve the performance and simplify the design of a wide variety of portable power management applications. Instead of kitchen sink alternatives with large packages, Linear Technology offers a number of devices with various feature mixes in small packages. These new PMICs are simple to use, highly integrated and high performance, allowing for shorter design times, greater PCB flexibility, and better power/thermal management than traditional solutions.

Synchronous Buck Controller in 3mm × 3mm QFN Fits Automotive and Industrial Applications with 4V–38V Input Capability

by Mark Mercer

Introduction

The LTC3851 is a versatile synchronous step-down switching regulator controller that is available in a space saving 16-lead 3mm × 3mm QFN or convenient narrow SSOP packages. Its wide input range of 4V to 38V makes it well-suited for regulating power from a variety of sources, including automotive batteries, 24V industrial supplies and unregulated wall transformers. The strong onboard drivers allow the use of high power external MOSFETs to produce output currents up to 20A with output voltages ranging from 0.8V to 5.5V.

The constant frequency peak current mode control architecture provides excellent line and load regulation along with load current sharing capability and dependable cycle-by-cycle current limiting. OPTI-LOOP® compensation simplifies loop stability design and provides well-behaved regulation over a broad range of operating conditions. The LTC3851 has ±1% output voltage tolerance over temperature. The part's low minimum on-time (90ns, typical) allows for low duty cycle operation even with switching frequencies as high as 750kHz.

Two Current Sensing Options

The LTC3851 features a high input impedance current sense comparator. This allows the use of the inductor's DC resistance (DCR) as the current sense element in conjunction with an RC filter. DCR current sensing allows the designer to eliminate the need for a discrete sense resistor, thereby maximizing efficiency and lowering solution cost. Alternately, higher current sense accuracy may be achieved by connecting the SENSE$^+$ and SENSE$^-$ pins to a precision sense resistor in series with the inductor. The LTC3851 offers the choice of three pin-selectable maximum current sense thresholds (30mV, 50mV and 75mV) to accommodate a wide range of DCR values and output current levels.

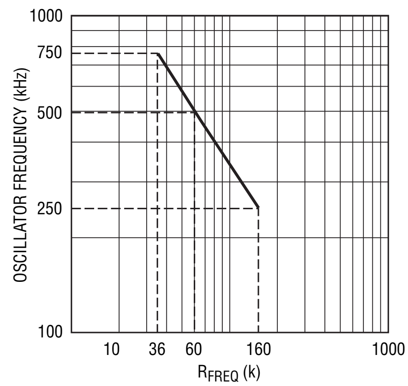


Figure 1. Relationship between oscillator frequency and resistor connected between FREQ/PLLFLTR and GND

As with all constant frequency, peak current mode control switching regulators, the LTC3851 utilizes slope compensation to prevent sub-harmonic oscillations at high duty cycles. This

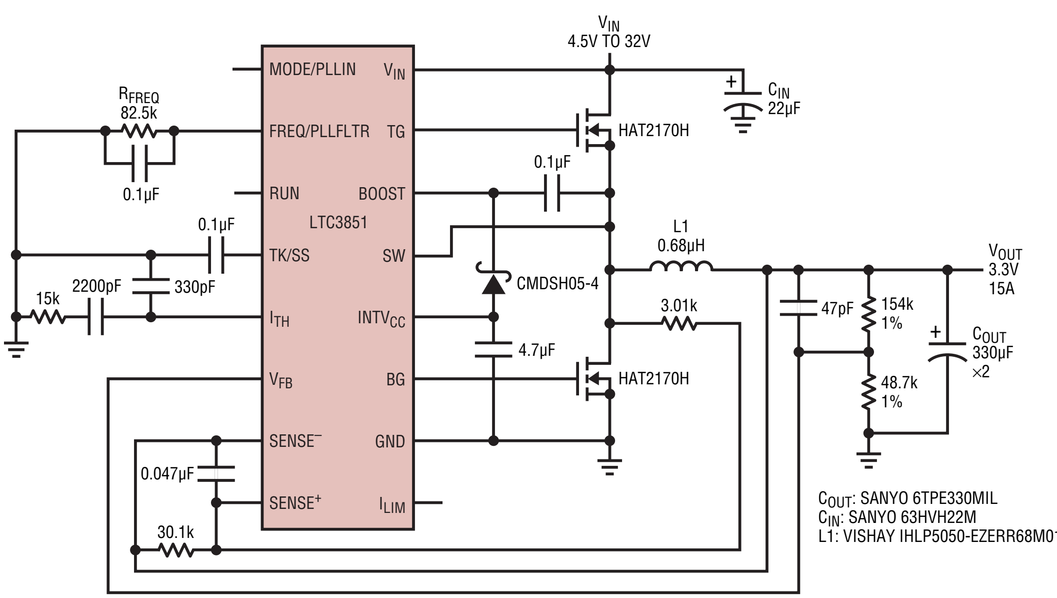


Figure 2. High efficiency 3.3V/15A power supply with DCR sensing

is accomplished internally by adding a compensating ramp to the inductor current signal. Normally, this results in a >40% reduction of maximum inductor peak current at high duty cycles. However, the LTC3851 uses a novel scheme that allows the maximum peak inductor current to remain stable throughout all duty cycles.

Versatility

During heavy load operation, the LTC3851 operates in constant frequency, continuous conduction mode. At light loads, it can be configured to operate in high efficiency Burst Mode® operation, constant frequency pulse-skipping mode or forced continuous conduction mode. Burst Mode operation offers the highest efficiency because energy is transferred from the input to the output in pulse trains of one to several cycles. During the intervening period between pulse trains, the top and bottom MOSFETs are turned off and only the output capacitor provides current to the load. Forced continuous conduction mode results in the lowest output voltage ripple, but is the least efficient at light loads. Pulse-skipping mode offers a compromise—lower output ripple than Burst Mode operation and more efficiency than continuous conduction mode.

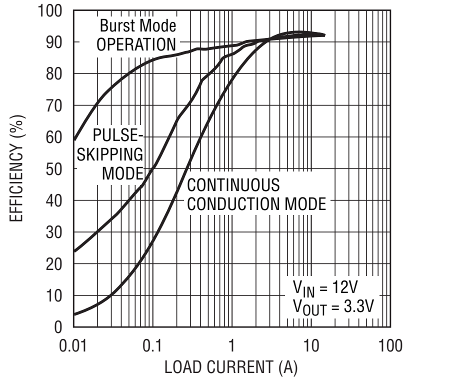


Figure 3. Efficiency vs load current with three modes of operation for the circuit of Figure 2

The switching frequency of the LTC3851 may be programmed from 250kHz to 750kHz by the resistor, R_{FREQ}, connected to the FREQ/PLLFLTR pin. This provides the flexibility needed to optimize efficiency. Figure 1 shows a plot of the switching frequency vs R_{FREQ}. Additionally, the switching frequency may be synchronized to an external clock. While doing so, the LTC3851 will operate in forced continuous conduction mode.

The output voltage can be ramped during start-up by means of an adjustable soft-start function, or it can track an external ramp signal. Track and soft-start control are combined in a single pin, TK/SS. Whenever TK/SS is less than 0.64V, the LTC3851 operates in pulse-skipping mode. This feature allows for starting up into a pre-biased load. When TK/SS is between 0.64V and 0.74V, the regulator operates in forced continuous mode to ensure a smooth transition from start-up to steady state. Once TK/SS exceeds 0.74V, the mode of operation is determined by the state of the MODE/PLLIN pin.

The RUN pin enables or disables the LTC3851. This pin has a precision 1.22V turn-on threshold which is useful for power supply sequencing. The turn-off threshold is 1.10V. There is an internal 2µA pull-up current source on the RUN pin.

The LTC3851's fault protection features include foldback current limiting, output overvoltage detection and input undervoltage detection. If an overload event causes the output to fall to less than 40% of the target regulation value, then the LTC3851 folds back the maximum current sense threshold. This reduces the on-time in order to minimize power dissipation in the top MOSFET. If the output voltage is more than 10% above the target regulation value, the bottom MOSFET turns on until the output falls back into regulation. If the input voltage is allowed to fall low enough such than the output of the internal linear regulator falls below 3.2V, then switching operation is disabled. This feature

continued on page 36

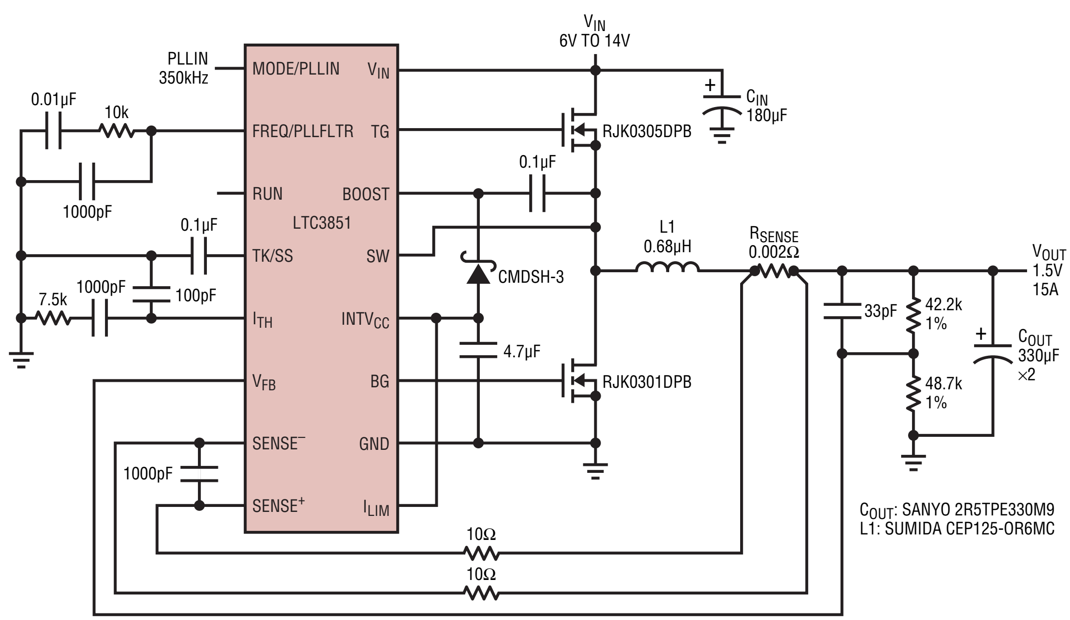


Figure 4. High efficiency 1.5V/15A power supply synchronized to 350kHz

Feature-Packed Charger Handles All Battery Chemistries and Produces 3A/50W for Fast Charging from a 4mm × 4mm QFN

by James A. McKenzie

Introduction

The LTC4009, LTC4009-1 and LTC4009-2 are a family of high power battery charger ICs that achieve a small circuit size and high performance without compromising functionality. The family operates with high efficiency while packing the most desirable charging and protection features into a space-efficient 20-lead 4mm × 4mm QFN package. When combined with just a few external components and termination control, the LTC4009 family facilitates construction of chargers capable of delivering up to 3A to batteries with output power levels approaching 50W. These ICs are especially well-suited to implementing microprocessor-controlled chargers for all chemistry types, including smart batteries.

High Performance

The LTC4009 family builds upon the proven quasi-constant frequency, constant off-time PWM control architecture found in other Linear Technology battery chargers such as the LTC4006, LTC4007, LTC4008, and LTC4011. This buck topology provides continuous switching with synchronous rectification, even with no load current.

Normally the charger operates over a wide duty cycle range in a manner similar to a fixed-frequency PWM controller running at 550kHz. However, if the input or output voltage drives the duty cycle to extremes, below 20% or above 80%, the LTC4009 smoothly adjusts the operating frequency downward to avoid pulse-skipping that might otherwise begin to occur at 550kHz. Under very low dropout conditions requiring high duty cycle operation, the internal watchdog timer on the LTC4009 prevents the charger from switching below 25kHz. This allows the charger to achieve a

Table 1. LTC4009 family features

Feature	LTC4009	LTC4009-1	LTC4009-2	LTC4008
Output Voltage Selection	External Resistor Divider	Pin Programmable at 4.1V/cell	Pin Programmable at 4.2V/cell	External Resistor Divider
Output Voltage Accuracy (Room Temperature)	±0.5% + Divider Error	±0.6%	±0.6%	±0.8% + Divider Error
Maximum Charge Current	3A	3A	3A	4A
Charge Current Accuracy	±5%	±5%	±5%	±5%
Input Current Limit Accuracy	±4%	±4%	±4%	±7%
Input Current Limit/Indicator	✓	✓	✓	✓
External PWM Switching MOSFETs	All NFET	All NFET	All NFET	PFET/NFET
Nominal PWM Frequency	550kHz	550kHz	550kHz	300kHz
Shutdown Pin	✓	✓	✓	Merged with ACP
C/10 Indicator	✓	✓	✓	✓
Charge Current Monitor	✓	✓	✓	✓
Termination Method	External	External	External	External
Fault Indicator				✓
Thermistor Interface				✓
INFET Control				✓

maximum duty cycle of 98% or higher without producing frequencies that could extend down into the audible range.

With a synchronous rectifier, not only are high current applications supported at efficiency levels greater than 90%, but switching activity is continuous and independent of the load current. Maintaining full continuous conduction mode in the inductor at final output voltage, under no-load conditions, avoids pulse-skipping which can generate audible noise and provide poor load regulation.

The input current limit accuracy is typically ±3% and a maximum of ±4% over the full operating temperature range. Output voltage accuracy is typically ±0.5% and a maximum of ±0.8% over temperature.

Small PCB Footprint

Besides its small surface mount package size, the LTC4009 family offers other features that drive down the total solution size.

For instance, as shown in Figure 1, the family supports direct drive of both an N-channel MOSFET power switch and N-channel MOSFET synchronous rectifier. N-channel MOSFETs are desirable in high current applications because of their lower $R_{DS(ON)}$, and the LTC4009 family uses a novel adaptive gate drive that is insensitive to MOSFET inertial delays to avoid overlap conduction losses. Many suppliers now source dual N-channel MOSFETs in a single space-efficient package, often with individual drive capabilities tailored to synchronous buck PWM switching topologies.

When combined with just a few external components and termination control, the LTC4009 family facilitates construction of chargers capable of delivering up to 3A to batteries with output power levels approaching 50W. These ICs are especially well suited to implementing microprocessor-controlled chargers for all chemistry types, including smart batteries.

Increasing the switching frequency to 550kHz and adjusting internal bias circuits to allow higher charge current ripple minimize both the inductor size and output capacitance requirements. This is particularly important because these components tend to dominate the overall solution size due to continual improvements in IC and passive SMD packaging technology.

The physical layout of a typical 3A application is shown in Figure 3, requiring only 240mm^2 of board space.

A Rich Tradition

The LTC4009 family builds upon the general purpose features offered by the LTC4008 and the output voltage programming convenience afforded by the LTC4006. Each member of the LTC4009 family contains the same charge current and input current limit programming features, along with a full complement of charge monitoring, safety and fault management functions. The LTC4009 has a fully adjustable output voltage, which is set with a simple resistor divider. Charge

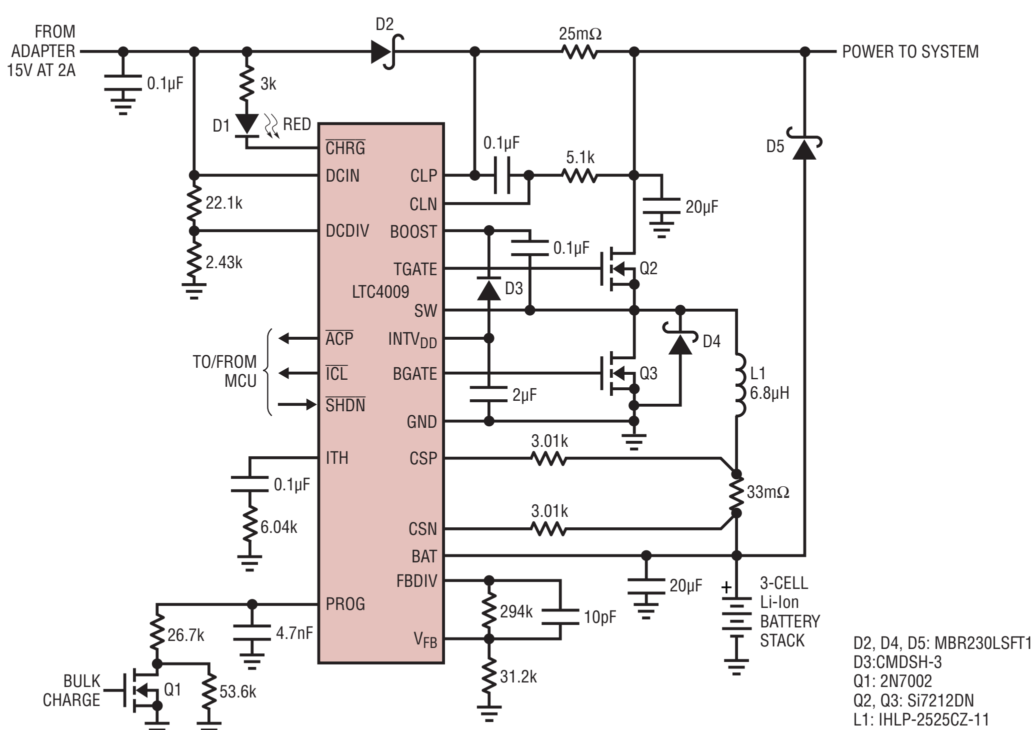


Figure 1. A 12.6V, 3A lithium-ion charger

current accuracy is maintained at output voltages below 6V, making the LTC4009 ideal for charging nickel-based chemistries or supercaps.

The LTC4009-1 and LTC4009-2 are easy to use in lithium-based battery products containing one to four series cells. Each has a range of output voltages that can be selected simply by strapping two pins to either ground or the output of the onboard 5V regulator, as shown for the LTC4009-1 in Figure 2. No other external components are required to set this precision voltage. The LTC4009-1 provides 4.1V/cell settings in support of evolving consumer product safety standards or coke-anode cells, while the LTC4009-2 utilizes 4.2V/cell for conventional full-capacity charging of graphite-anode lithium-ion packs. The ICs contain a dedicated PMOS switch that during shutdown removes the additional current drained from the battery by the resistive feedback divider, whether external or internal. Table 1 compares the features of the LTC4009 family to the LTC4008.

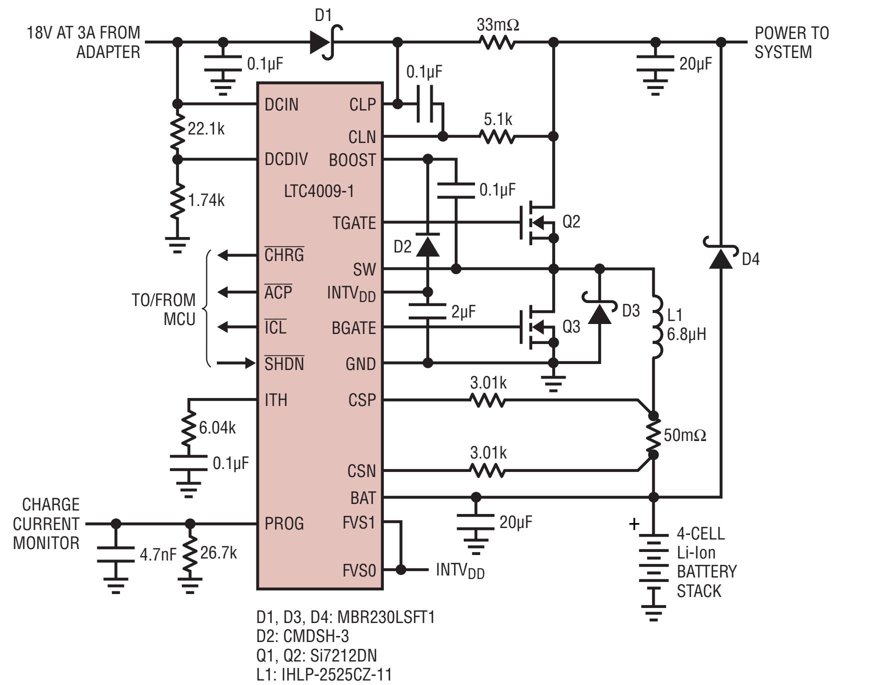


Figure 2. A 16.4V, 2A lithium-ion charger

Battery Charge Management

The LTC4009 family contains all of the features required for complete external charge control and state monitoring with a logic-level shutdown control input and three open-drain status outputs. All charging is unconditionally suspended and battery drain is reduced to its lowest levels if the $\overline{\text{SHDN}}$ input is asserted by driving the pin to ground. DC input supply voltage is sensed by feeding an external resistor voltage divider to the DCDIV sense input. The AC present status output indicates whether or not this input voltage is within a valid range for charging under all modes of operation, whether charging is in progress or suspended. There is a charge status output that indicates when the battery is being charged. The drive level of this pin changes from low impedance (about 2k) to a 25µA pull-down current source to indicate that the charge current has dropped to one-tenth of the programmed full-scale bulk value.

These control inputs and status outputs of the LTC4009, along with the analog current monitor output, can be used by the host system to perform necessary preconditioning, charge termination and safety timing functions.

Charge Fault Management: Safety First

The LTC4009 family has a built-in fault management system that suspends charging immediately for various internal and external fault conditions. First, battery overvoltage protection is provided with a comparator that looks for sudden loss of battery load during charge. This comparator instantly suspends PWM activity when the battery voltage rises above the programmed output voltage by 6%. This protects the charger, the battery, and downstream components in charger-fed topologies under the condition where the battery is suddenly removed or if internal battery pack electronics momentarily disconnect the load in order to perform functions such as calibration or pulse charging.

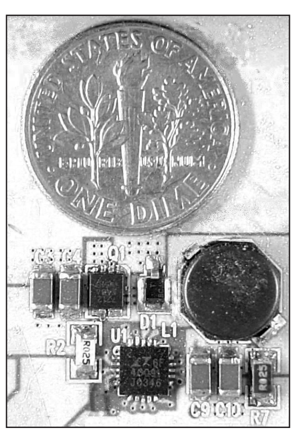


Figure 3. A typical LTC4009 application layout

Next, the DC sensing input has both under and overvoltage threshold limits to ensure the system is protected from starting or running during unsafe conditions, such as transient input overvoltage or an overloaded DC input adapter.

These parts have several means of detecting or avoiding reverse charge current. For instance, reverse current can occur in a synchronous system if a slightly overcharged battery is inserted, with the resulting reverse current discharging the battery and/or damaging other system components. To prevent reverse currents, the parts in this family first monitor the PROG pin for reverse current. PROG outputs a voltage analog of the average charge current flowing in the system. Next, the

continued on page 33

Dual Hot Swap Controller in 3mm × 2mm DFN is Perfect for Backplane or Card Resident 1V–6V Applications

by CY Lai

Introduction

High availability electronics, such as those used in telecom, real-time transaction processing, hospitals and air traffic control systems, cannot afford any down time. These systems must continue to operate even as components are added or removed (hot swapped) for expansion, upgrades or maintenance. The Hot Swap™ systems must be carefully designed to avoid burned PCB traces and power brownouts, which can result in system resets and data loss. The LTC4224 ensures dependable Hot Swap design while simplifying and shrinking total solution size. It does this by combining two feature-rich and independent Hot Swap controllers for 1V–6V applications in a 3mm × 2mm DFN package.

Figure 1 shows a functional block diagram of the LTC4224. The $\overline{ON}$ pin is used to turn an external N-channel MOSFET on or off via the GATE pin. When commanded on, an internal charge pump pulls the GATE above the supply rail to fully enhance the MOSFET, reducing its series resistance to several mΩ. The LTC4224's ability to derive power from the higher of its two supplies allows it to control load voltages as low as 1V. Active current limiting (ACL) acts on the GATE when the load current causes more than 25mV of voltage drop across the sense resistor. An electronic circuit breaker (ECB) performs the role of a timekeeper, latching off the MOSFET in the event of a prolonged current overload.

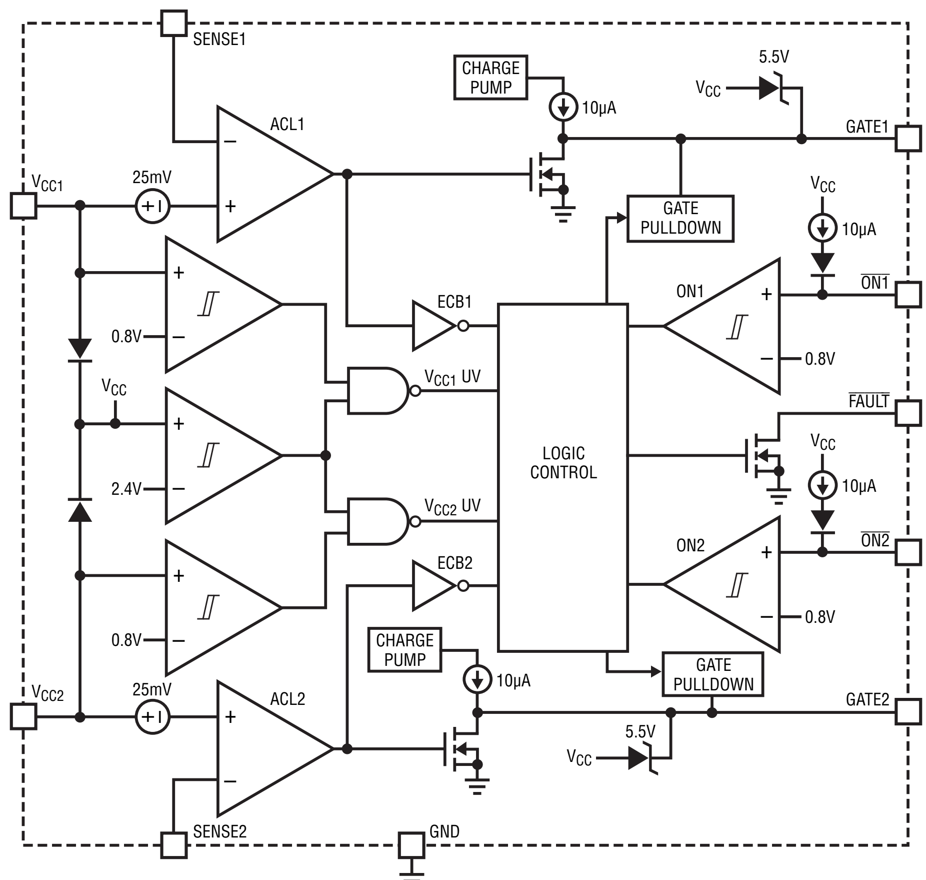


Figure 1. Functional block diagram of the LTC4224

Operation

Figure 2 shows the LTC4224 together with two N-channel MOSFETs and two sense resistors in a 5V backplane resident Hot Swap application. Initially, the $\overline{ON}$ pin is pulled high in the absence of an add-in card and the GATE is held low, shutting off the MOSFET. When an add-in card is fully inserted into the backplane connector, the $\overline{ON}$ pin is pulled low through the ground connections on the card connector. Spurious $\overline{ON}$ transitions can occur as the connectors mate. To prevent the MOSFET from turning on prematurely, the LTC4224 waits out these short term transitions with an internal 10ms debounce delay that restarts every time $\overline{ON}$ transitions high.

To turn on the MOSFET, an internal charge pump sources 10µA to soft-start the GATE with a slew rate of $10\mu A/C_{ISS}$, where C_{ISS} is the external MOSFET's gate capacitance. The start-up inrush current flowing into the load capacitor C_{OUT} is limited to $(C_{OUT}/C_{ISS}) \bullet 10\mu A$. However, if the sense resistor voltage drop becomes too large, the inrush current is limited at $25mV/R_{SENSE}$ by the ACL. The ECB monitors the ACL, and if it detects that the current limit is still active 5ms after the GATE began ramping, the MOSFET latches off and $\overline{FAULT}$ pulls low. If

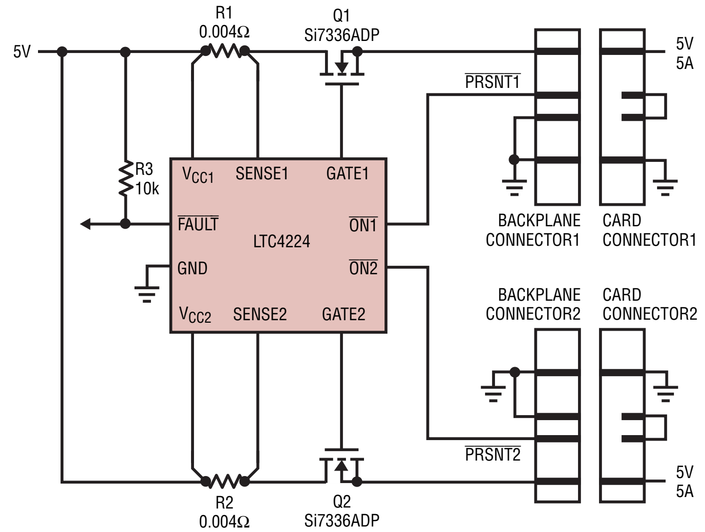


Figure 2. Hot Swap application for two add-in cards

C_{OUT} cannot be sufficiently charged within this period, connect a capacitor from GATE to ground to lower the inrush current, as shown in Figure 3. With C_{GATE}, the inrush current is reduced to $(C_{OUT}/(C_{GATE} + C_{ISS})) \cdot 10\mu A$. Adjusting C_{GATE} so that the inrush current stays below the ECB threshold prevents ECB faults with large load capacitors.

Overcurrent Protection

An important feature of the LTC4224 is its 25mV electronic circuit breaker (ECB) threshold with a 10% tolerance. This low ECB threshold allows the use of sense resistors with lower power ratings and hence smaller packages. In addition, the ECB threshold must not cut excessively into the supply voltage tolerance of downstream circuits. For instance, if the downstream circuits can tolerate at most a 5% variation on the 1V supply, the ECB threshold of an upstream Hot Swap controller must be significantly lower than 50mV.

To guard against damage to the external MOSFET from excessive power dissipation, active current limiting (ACL) regulates the gate to limit the sense resistor's voltage drop to about 25mV. To minimize external components, the current limit loop is compensated by the parasitic gate capacitance C_{ISS} of the MOSFET and remains stable for C_{ISS} values as low as 600pF. During ACL, the ECB activates and initiates an internal time-out period of 5ms. The waveform in Figure 4 shows the LTC4224 limiting the current and subsequently latching off the MOSFET due to a mild current overload at the output lasting longer than 5ms. $\overline{FAULT}$ is pulled low; this could either instruct the microprocessor to take actions or light an LED to attract operator's attention.

In the event of a severe short-circuit, the current typically overshoots the current limit level significantly as the gate overdrive of the external MOSFET is large initially. The LTC4224 responds in less than 0.1µs to swiftly discharge the gate with a 100mA current sink. Figure 5 shows the LTC4224 bringing the current under control in less than 0.5µs when a 3.3V rail is shorted into a 10mΩ load without any load capacitance. Also due to the fast ACL is the absence of gate undershoot, despite the speed at which the gate is discharged. The potential peak current is dictated by DC resistances along the power path (trace resistance + R_{DSON} of the MOSFET + R_{SENSE} + 10mΩ), while the path's parasitic inductance limits the current slew rate.

After the MOSFET latches off, the $\overline{ON}$ pin must be pulled above 0.8V to reset the internal fault latch. Alternatively, recycle the supply below its UV level. The LTC4224-1 latches off after a fault, while the LTC4224-2 automatically tries to apply power four seconds after latching off.

Optical Transceiver Hot Swap Application

Optical transceivers such as those specified for the popular XENPAK/X2

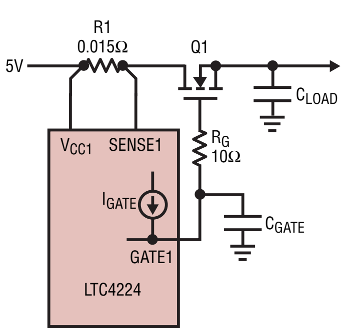


Figure 3. A method to adjust inrush current by gate capacitor. R_G prevents parasitic self-oscillation in Q1

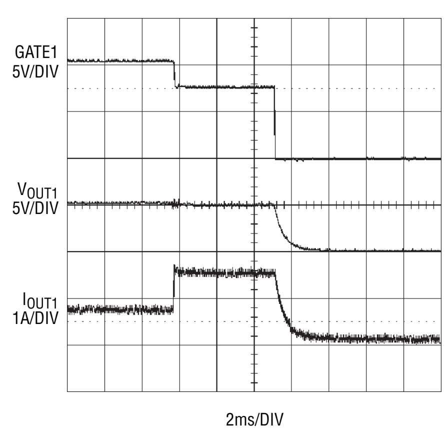


Figure 4. Active current limiting latches off the external MOSFET following a mild overcurrent

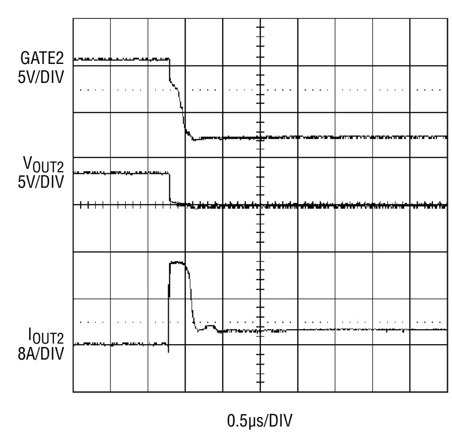


Figure 5. Fast current limit isolates severe short circuit fault in less than 0.5µs

Multi- Source Agreements (MSA) are employed in high speed networking routers as an interface between optical and electrical signals. The MSA mandates hot plug capability for transceiver modules, which are supplied with 5V, 3.3V and 1.xV.

A Hot Swap application based on the LTC4224 for the 5V and 3.3V rails is shown in Figure 6. Typically, a dedicated DC/DC converter controls the 1.xV rail and limits the inrush current for each module. As the optical module consumes relatively little power, a dual FET such as the FDS6911 is a good candidate for the power switches, saving cost and minimizing area. For the tiniest solution, sense resistors in a 0603 case size are selected. Figure 7 shows the full solution, which fits in the footprint of an SO8 package. In an application where all the three supply rails need to be hot swapped, three LTC4224s can be used to control the power to two modules, all in a solution no larger than the footprint of three SO8 packages.

5V/5A, 3.3V/5A Hot Swap Application

The LTC4224 can also reside on an add-in card as shown in Figure 8. There are no bulk capacitors on the inputs as these could draw large inrush current. In their place are the Transient Voltage Suppressors (Z1 and Z2) and RC Snubber networks. During current transients, inductive kickback can cause the input supply to swing beyond the absolute maximum (ABSMAX) rating of LTC4224's input pins without the TVS. By clamping the voltage, the TVS protects the LTC4224 from damage and an ABSMAX rating of 9V provides margin for the selection of the TVS. Snubbers damp the parasitic LC tanks to eliminate ringing on the input supplies. The Si7336ADP has been chosen for its SOA, 20V Gate-Source breakdown voltage and low R_{DSON}.

Conclusion

The LTC4224 simplifies the design of low voltage Hot Swap applications by integrating two Hot Swap controller and timing delay circuits in a tiny 3mm × 2mm DFN package. Fast current limiting ensures that system disturbances are minimized during a severe overload and that faults are quickly isolated. The LTC4224 offers a complete and robust Hot Swap solution for XENPAK/X2 optical modules that can be implemented in an SO8 footprint.

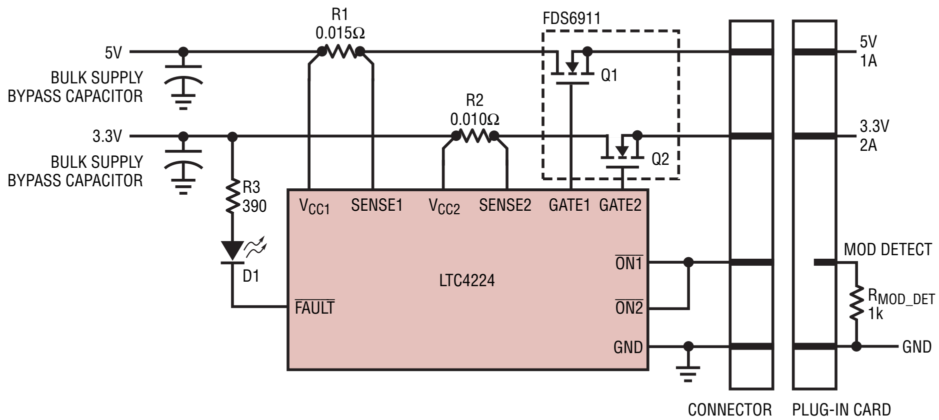


Figure 6. XENPAK/X2 optical module Hot Swap application

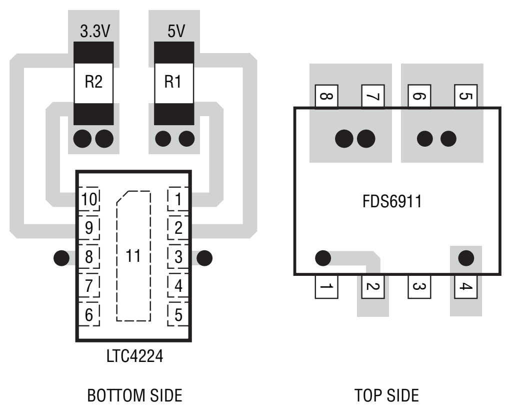


Figure 7. A compact PCB layout of the sense resistors, MOSFET and the LTC4224

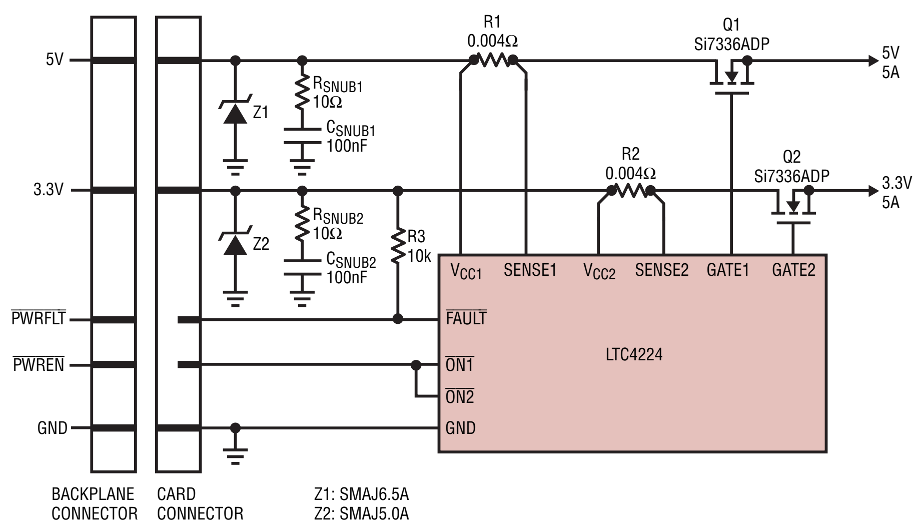


Figure 8. A 5V and 3.3V card resident Hot Swap application

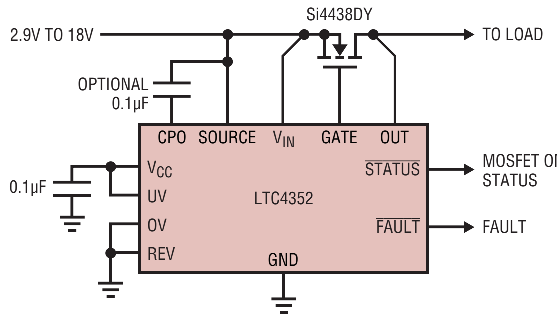
0V to 18V Ideal Diode Controller Saves Watts and Space over Schottky

by Pinkesh Sachdev

Introduction

Schottky diodes are used in a variety of ways to implement multisource power systems. For instance, high availability electronic systems, such as network and storage servers, use power Schottky diode-OR circuits to realize a redundant power system. Diode-ORing is also used in systems that have alternate power sources, such as an AC wall adapter and a backup battery feed. Power diodes can be combined with capacitors to hold up a load voltage during an input brownout. In this case, the power diodes are placed in series with the input voltage, with the capacitors on the load side of the diode. While the capacitors provide power, the reverse-biased diode isolates the load from the sagging input.

Schottky diodes suffice for these applications when currents are below a few amperes, but for higher currents, the excess power dissipated in the diode due to its forward voltage drop demands a better solution. For instance, 5A flowing through a diode with a 0.5V drop wastes 2.5W within the diode. This heat must be dissipated with dedicated copper area on the PCB or heat sinks bolted to the diode, both of which take significant space. The diode's forward drop also makes it impractical for low voltage applications. This problem calls out for an ideal diode with a zero forward voltage drop to save power and space.



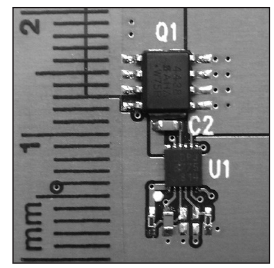


Figure 1. The LTC4352 controlling an N-Channel MOSFET replaces a power diode and associated heat sink to save power, PCB area, and voltage drop. Also shown: the small PCB footprint of the ideal diode circuit using a 3mm × 3mm DFN-12 packaged LTC4352 and SO-8 size MOSFET.

The LTC4352 ideal diode controller in tandem with an N-channel MOSFET creates a near-ideal diode for use with 0V to 18V input supplies. Figure 1 illustrates the simplicity of this solution. This ideal diode circuit can replace a power Schottky diode to create a highly efficient power ORing or supply holdup application. Figure 2 shows the power savings of the ideal diode circuit over a Schottky diode. 3.5W is saved at 10A, and the saving increases with load current. With its fast dynamic response, the controller excels in low voltage diode-OR applications which are more sensitive to voltage droop.

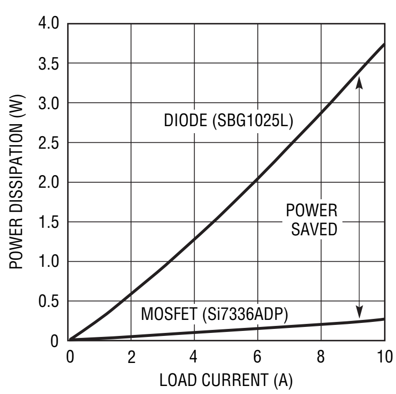


Figure 2. As load current increases, so do the power savings gained from using an ideal diode (LTC4352 + Si7336ADP) instead of a power Schottky diode (SBG1025L).

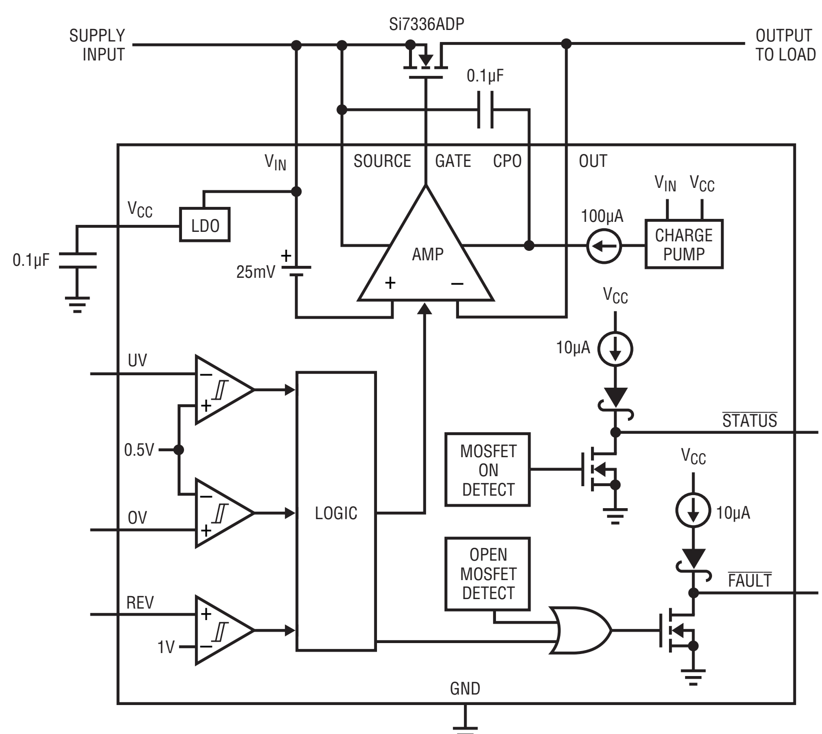


Figure 3. Simplified internals of the LTC4352

What Makes It Ideal?

The LTC4352 monitors the differential voltage across the MOSFET source (the "anode") and drain (the "cathode") terminals. The MOSFET has an intrinsic source-to-drain body diode which conducts the load current at initial power-up. When the input voltage is higher than the output, the MOSFET is turned on, resulting in a forward voltage drop of $I_{LOAD} \bullet R_{DS(ON)}$. The $R_{DS(ON)}$ can be suitably chosen to provide an easy 10x reduction over a Schottky diode's voltage drop. When the input drops below the output, the MOSFET is turned off, thus emulating the behavior of a reverse biased diode.

An inferior ideal diode control technique monitors the voltage across the MOSFET with a hysteretic comparator. For example, the MOSFET could be turned on whenever the input to output voltage exceeds 25mV. However, choosing the lower turn-off threshold can be tricky. Setting it to a positive forward voltage drop, say 5mV, causes the MOSFET to be turned off and on repeatedly at light load currents. Setting it to a negative value, such as –5mV, allows DC reverse current.

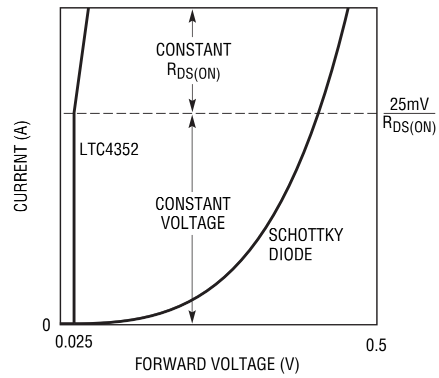


Figure 4. The forward I-V characteristic of the LTC4352 ideal diode vs a Schottky diode.

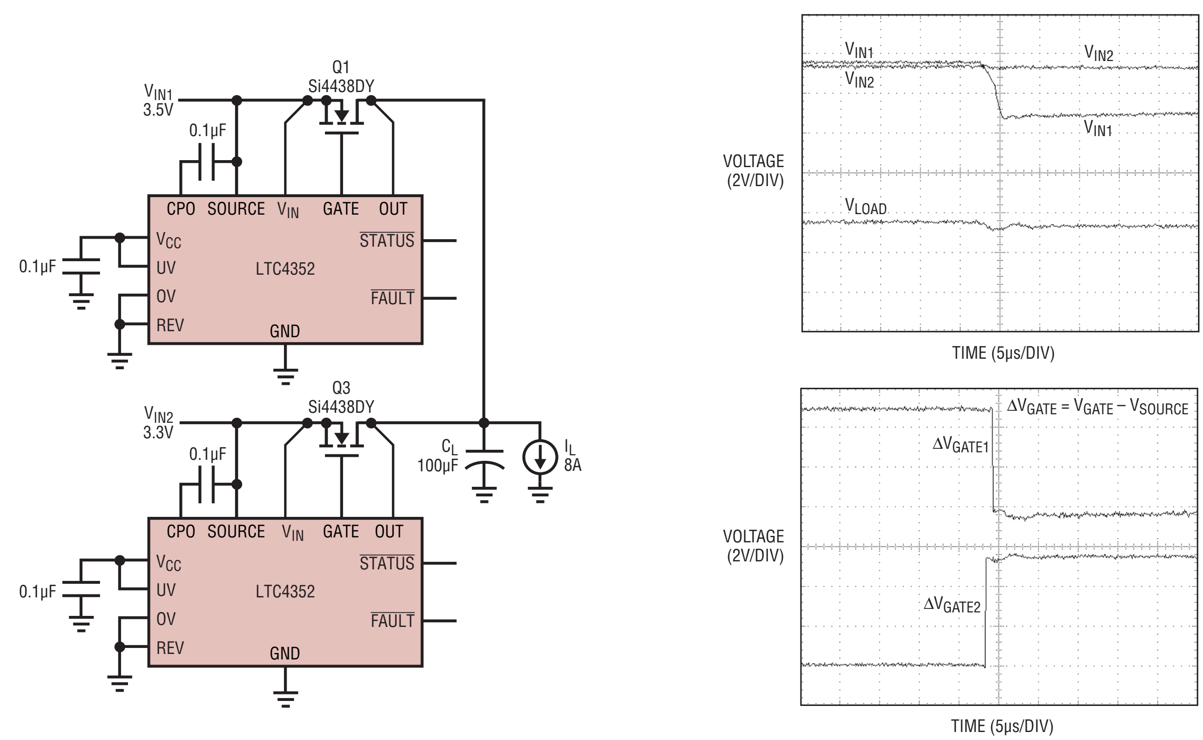
The LTC4352 implements a linear control method to avoid the problems of the comparator-based technique. It servos the gate of the MOSFET to maintain the forward voltage drop across the MOSFET at 25mV (AMP of Figure 3). At light load currents, the gate of the MOSFET is slightly above its threshold voltage to create a resistance of $25mV/I_{LOAD}$. As the load current increases, the gate voltage rises to reduce the MOSFET resistance. Ultimately, at large load currents, the MOSFET gate is driven fully on, and the forward voltage drop rises linearly with load current as $I_{LOAD} \bullet R_{DS(ON)}$. Figure 4 shows the resulting ideal diode I-V characteristic.

In a reverse voltage condition, the gate is servoed low to completely turn off the MOSFET, thus avoiding DC reverse current. The linear method also provides a smooth switchover of currents for slowly crossing input supplies in diode-OR applications. In fact, depending on MOSFET and trace impedances, the input supplies share the load current when their voltages are nearly equal.

Fast Switch Control

Most ideal diode circuits suffer slower transient response compared to conventional diodes. The LTC4352, on the other hand, responds quickly to changes in the input to output voltage. A powerful driver turns off the MOSFET to protect the input supply and board traces from large reverse currents. Similarly, the driver turns on the switch rapidly to limit voltage droop during supply switchover in diode-OR applications.

Figure 5 shows a fast switchover event occurring in a 3.3V ideal diode-



a. Ideal diode-OR of 3.5V and 3.3V input supply.

b. Supply switchover from V_{IN1} to V_{IN2} due to short-circuit on V_{IN1} shows minimal disturbance on load voltage.

Figure 5. Ideal diode-OR fast switchover

OR circuit. Initially V_{IN1} supplies the entire load current since it is higher than V_{IN2}. In this state, MOSFET Q1 is on and Q3 is off. A short circuit causes V_{IN1} to collapse below V_{IN2}. The LTC4352's fast response shuts off Q1 and turns on Q3 so that the load current can now be supplied by V_{IN2}. This fast switchover minimizes disturbance on the load voltage so that downstream circuits can continue to operate smoothly.

To achieve fast switch turn-on, the LTC4352 uses an internal charge pump with an external reservoir capacitor. This capacitor is connected between the CPO and SOURCE pins. CPO is the output of a charge pump that can deliver up to 100µA of pull-up current. The reservoir capacitor accumulates and stores charge, which can be called upon to produce 1.5A of transient GATE pull-up current during a fast turn-on event. The reservoir capacitor voltage drops after the fast turn-on since it charge-shares with the input gate capacitance (C_{ISS}) of the MOSFET. For an acceptable drop, the reservoir capacitor value should be around 10 times the C_{ISS} of the MOSFET.

It is easy to disable fast turn-on. Omitting the reservoir capacitor slows down the gate rise time as determined by the CPO pull-up current charging C_{ISS}. Slow gate turn-on may cause the load to droop roughly a volt below the input as current flows through the MOSFET body diode until the channel is enhanced. This may be acceptable at higher input voltage applications, such as 12V.

Table 1. Operating state of the LTC4352 ideal diode as indicated by the $\overline{\text{STATUS}}$ and $\overline{\text{FAULT}}$ lights

LED State		Ideal Diode Operating State	
$\overline{\text{STATUS}}$ Green LED	$\overline{\text{FAULT}}$ Red LED	MOSFET	UV/OV
○	○	OFF	NO
●	○	ON	NO
○	●	OFF	YES
●	●	OPEN	NO

Do What No Diode Has Done Before

The LTC4352 goes above and beyond the functionality of a diode by incorporating input undervoltage and overvoltage protection, outputs to report status and fault information, open MOSFET detection, and the ability to allow reverse current.

Figure 6 shows the LTC4352 in a 5V ideal diode circuit with undervoltage and overvoltage protection. The UV and OV pins have comparators with a 0.5V trip threshold and 5mV hysteresis (Figure 3). The resistive dividers from the input supply to these pins set up an input voltage window, typically 4.36V to 5.78V, where the ideal diode function operates. The $\overline{\text{STATUS}}$ pin pulls low to light up a green LED whenever the gate is high and power is flowing through the external MOSFET. For V_{IN} outside the input voltage window, the gate is held off and the $\overline{\text{FAULT}}$ pin pulls low to signal a fault condition. A red LED, D2, provides visual indication. Back-to-back MOSFETs are needed to block conduction through their intrinsic source-to-drain body diodes in the gate low condition. A single MOSFET, Q1, could be used in the case where only a V_{IN} out-of-range indication is sufficient. But care should be taken that the load current flowing through Q1's body diode, when its gate is low, does not cause excessive heat dissipation in the MOSFET.

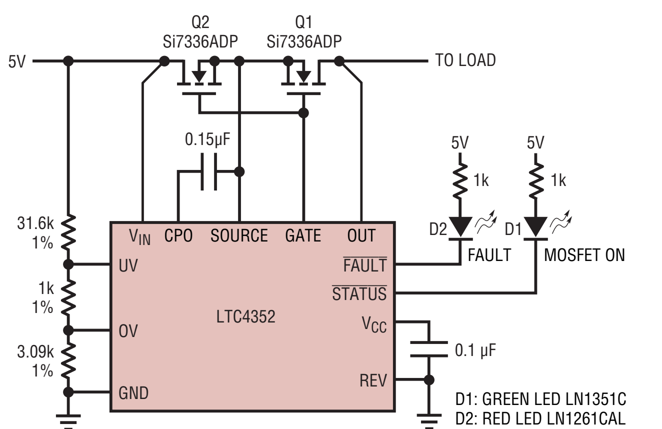
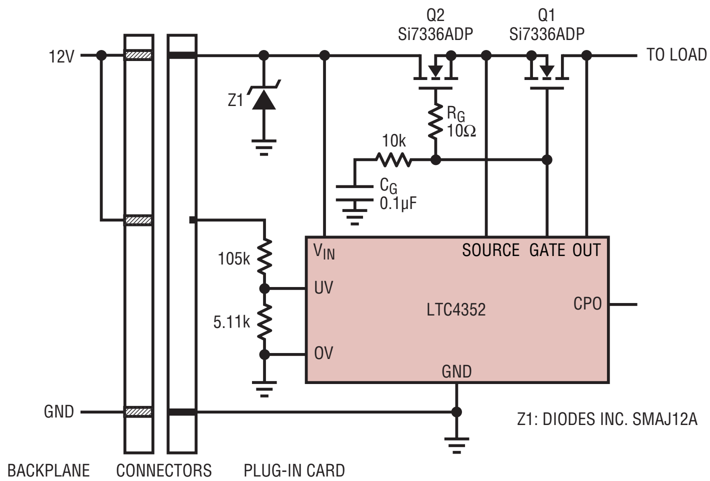


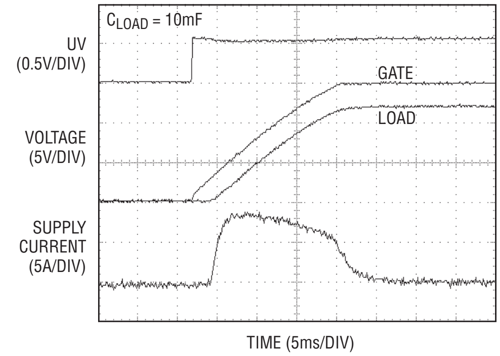
Figure 6. A 5V ideal diode circuit with input undervoltage and overvoltage protection. Ideal diode function operates for 4.36V < V_{IN} < 5.78V, else GATE is low.

The MOSFET switch could fail open circuit or its $R_{DS(ON)}$ may degrade over years of operation, increasing the voltage drop across the switch. A large drop also results when excessive current flows through the MOSFET, possibly due to an output short circuit. The LTC4352 detects such failures and flags it through its $\overline{\text{FAULT}}$ pin. The open MOSFET detection circuit trips whenever it senses more than 250mV of forward voltage drop across the MOSFET—even with the gate turned on. Note that this condition only causes the $\overline{\text{FAULT}}$ pin to pull low, but no action is taken to turn off the switch. Table 1 translates $\overline{\text{STATUS}}$ and $\overline{\text{FAULT}}$ LED status to the operating state of the LTC4352.

The input at the REV pin configures the LTC4352's behavior for reverse current. It is tied low for normal diode operation, which blocks reverse current from flowing through the external MOSFET. Driving REV above 1V turns the gate completely on to its limit, even during reverse current conditions.



a. Omitting the CPO capacitor and adding an RC network on the gate allows inrush current control on a Hot Swap board.



b. After short pin makes contact and UV is above 0.5V, GATE starts ramping up. Once it crosses the MOSFET threshold voltage, LOAD follows with the same dV/dt. Here, inrush is limited to 8.3A peak for a 10mF C_{LOAD}.

Figure 7. Controlling inrush current

Only undervoltage, overvoltage, and V_{CC} undervoltage lockout can override this to turn-off the gate. This feature is handy either in power path control applications which allow reverse current flow to occur, or for testing purposes.

Inrush Control on a Hot Swap Board

When the diode power input flows across a connector on a hot swap board, the LTC4352 can do double-duty to control the inrush current. Again, back-to-back MOSFETs are required for this application to block conduction through the MOSFET body diodes. The inrush current is limited by slowing the rise rate of the load voltage. This is done by limiting dV/dt on the MOSFET gate and operating it in a source-follower configuration.

Figure 7 illustrates an application where the LTC4352 is used for inrush control. Since the goal is to limit dV/dt on the gate, the fast turn-on characteristic of the ideal diode is disabled by omitting the CPO reservoir capacitor. The gate current is now limited to the CPO pull-up current of 100µA. To further reduce dV/dt, an RC network is added on the gate. The resistor decouples the capacitor during fast turn-off due to reverse current or overvoltage faults. Resistor R_G prevents high frequency oscillations in Q2.

When the board is hot-plugged, the long power pins make contact first. The LTC4352 powers up, but holds the gate off since UV is low. After a few milliseconds of board insertion delay, the short UV pin makes contact. If V_{IN} is above 10.8V, the MOSFET gate starts ramping up. The MOSFET turns on as the gate reaches the threshold voltage, and current starts charging the output. Q2 operates in the source follower mode and suffers the most power dissipation. Its V_{DS} starts off at V_{IN} and decreases to 25mV/2. Care should be taken that the power dissipated during inrush falls within the safe operating area (SOA) of the MOSFET.

Down to Earth Operation

The V_{IN} operating range extends all the way down to 0V. However, when operating with inputs below 2.9V, an external supply is needed on the V_{CC} pin. This supply should be in the range 2.9V to 6V. For a 2.9V to 4.7V subset of this range, V_{IN} should always be lower than V_{CC}. A 0.1µF bypass capacitor is also needed between the V_{CC} and GND pins. Figure 8 shows an ideal diode circuit, where a 5V supply powers up the V_{CC} pin. In this case, V_{IN} can operate all the way down to 0V and up to 18V.

For input supplies from 2.9V to 18V, the external supply at the V_{CC} pin is not needed. Instead, an internal low dropout regulator (LDO in Figure 3)

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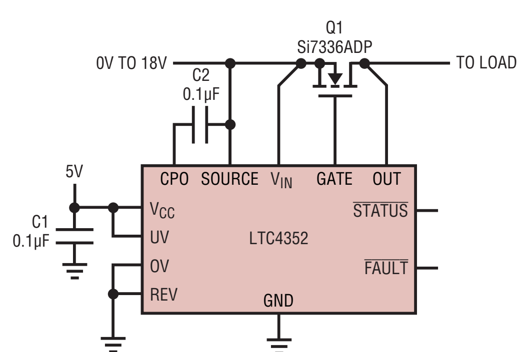

Figure 8. A 0V to 18V ideal diode circuit. By powering the V_{CC} pin with an external supply in the 4.7V to 6V range (here 5V), V_{IN} can operate down to 0V and up to 18V.

Low Voltage, High Current Step-Down µModule Regulators Put a (Nearly) Complete Power Supply in a 15mm × 9mm × 2.8mm Package

by Judy Sun, Sam Young and Henry Zhang

Introduction

Endlessly increasing power density requirements are a major driving force behind the continuous need to find new power supply solutions. Switching regulators are the top choice for high current applications because of their high efficiency and high performance, but high power density doesn't come for free with a switcher. Components must be carefully chosen and laid out to maximize efficiency, transient response and thermal performance. Making a high density switching power supply requires significant design and test time, or does it?

The LTM4604 and LTM4608 LTC µModule switching regulators make it possible to create high density designs with minimal effort. Both are high density power supplies for ≤5.5V input voltage, high output current, step-down applications. Each µModule regulator comes in a 15mm × 9mm LGA surface mount package and is nearly self-contained—only a few passive components are required to complete a power supply design. The switching controller, MOSFETs, inductor and all support components are already carefully chosen and laid out in the package. Low profile packages (2.3mm and 2.8mm, respectively) allow them to be easily mounted in unused space on the bottom of PC boards and simplify thermal management.

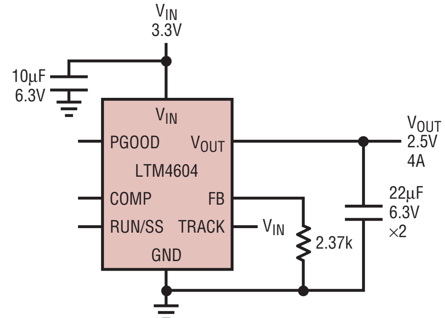

Figure 1. Only a few components are required for a 2.5V/4A design with LTM4604.

The LTM4604 features a 2.375V to 5.5V input range and a 0.8V to 5V output range, while the LTM4608 takes a 2.7V to 5.5V input to a 0.6V to 5V output. The LTM4604 can deliver up to 4A continuous current with up to 95% efficiency. The slightly higher profile of the LTM4608 allows it to deliver up to 8A continuous current thanks to its high efficiency design and low thermal impedance package.

Easy Design with Few Components

Figure 1 shows a typical 2.5V/4A design with LTM4604 and Figure 2 shows the resulting efficiency. Ceramic input capacitors are integrated into the µModule package—additional input capacitors are only required if a load step is expected up to the full 4A level. Additional required output capacitance is typically in the range of 22µF to 100µF. A single resistor on the FB pin sets the output voltage.

For applications needing more output current, the LTM4608 fits the bill. Figure 3 shows a 1.8V/8A design with LTM4608 and Figure 4 shows its efficiency. As with the LTM4604, the number of necessary external components has been reduced to a minimum, significantly simplifying the design effort. Nevertheless, a very fast transient response to the line and load changes is guaranteed by the optimized design of the µModule's high switching frequency and current mode control architecture. Furthermore, a number of features can be enabled on the LTM4604 and LTM460408 to suit the needs of various applications.

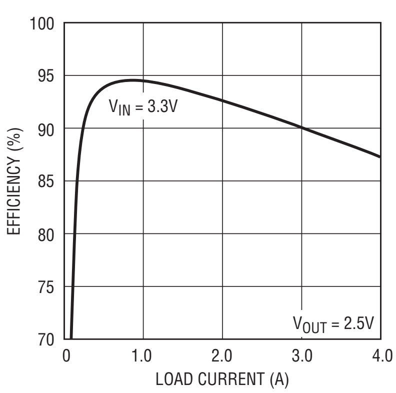

Figure 2. High efficiency is achieved with the LTM4604 in the application of Figure 1

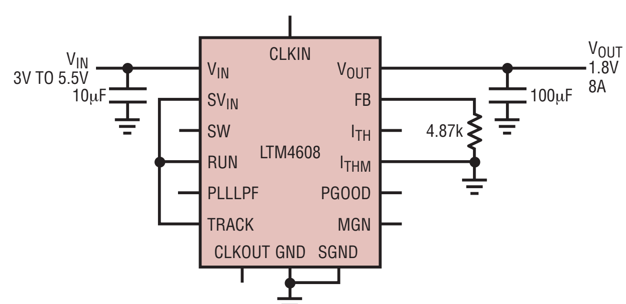

Figure 3. Only a few components are required for a 1.8V/8A design with the LTM4608.

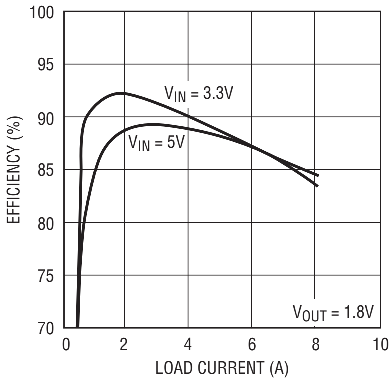

Figure 4. High efficiency is achieved with the LTM4608 in the application of Figure 3.

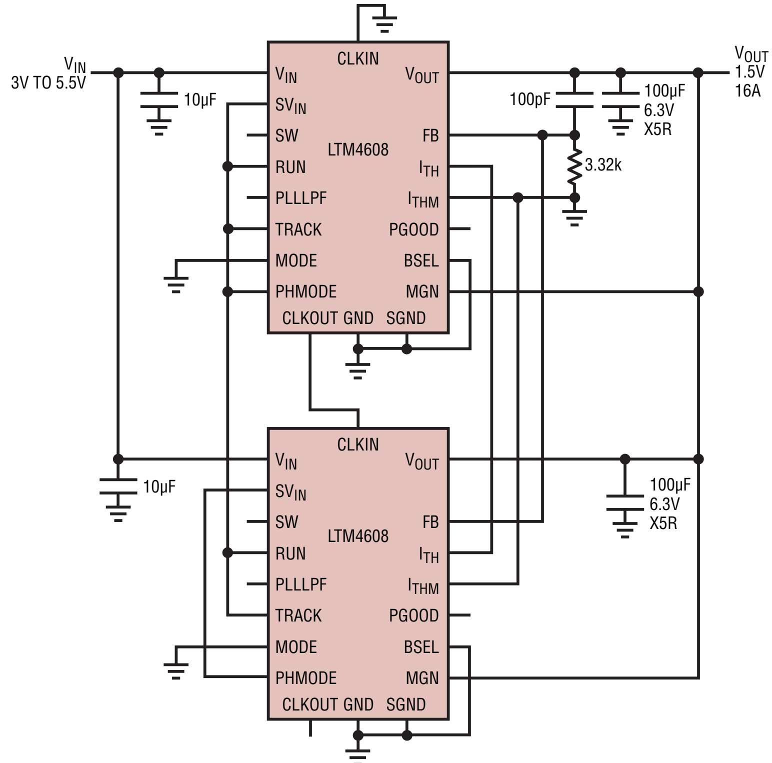

Figure 5. Two LTM4608s are easily paralleled to provide 1.5V/16A output with interleaved switching operation.

Wealth of Features

Both LTM4604 and LTM4608 feature RUN pin control, output voltage tracking selections and power good indicators. For systems requiring voltage sequencing between different power supplies, the sequencing function can be implemented by controlling the RUN pins and the PGOOD signals with a few additional components. Fault protection features include overvoltage protection, over current protection and thermal shutdown.

The LTM4608 offers some additional features. Burst Mode® operation, pulse-skipping mode or continuous current mode can be selected to improve light load efficiency. Burst Mode operation provides the highest efficiency at very light load, while forced continuous current mode leads to the lowest output ripple. Pulse-skipping mode offers a compromise between Burst Mode operation and continuous mode, offering good light load efficiency while keeping output voltage ripple down. Programmable output voltage margining is supported for ±5%, ±10% and ±15% levels. The LTM4608 also allows frequency synchronization and spread spectrum operation to further reduce switching noise harmonics.

Parallel for More Power

With cycle-by-cycle current mode control, the LTM4604 and LTM4608 can be easily paralleled to provide more output power with excellent current sharing. The LTM4608 includes CLKIN and CLKOUT pins to make it possible to operate paralleled devices out of phase of one another to reduce input and output ripple. A total of 12 phases can be cascaded to run simultaneously with respect to each other by programming the PHMODE pin of each LTM4608 to different levels.

Figure 5 shows an example of two LTM4608s in parallel to provide 16A output current. Figure 6 shows the measured current sharing performance of the circuit, illustrating that the DC current sharing error is less

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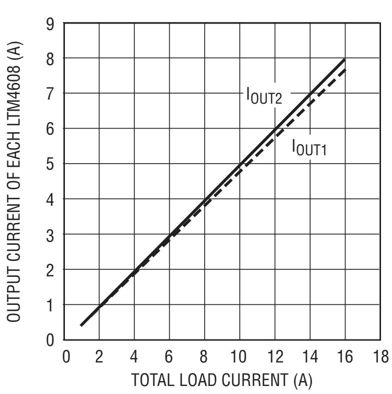

Figure 6. Bench test shows excellent current sharing between two paralleled LTM4608s over the entire load range.

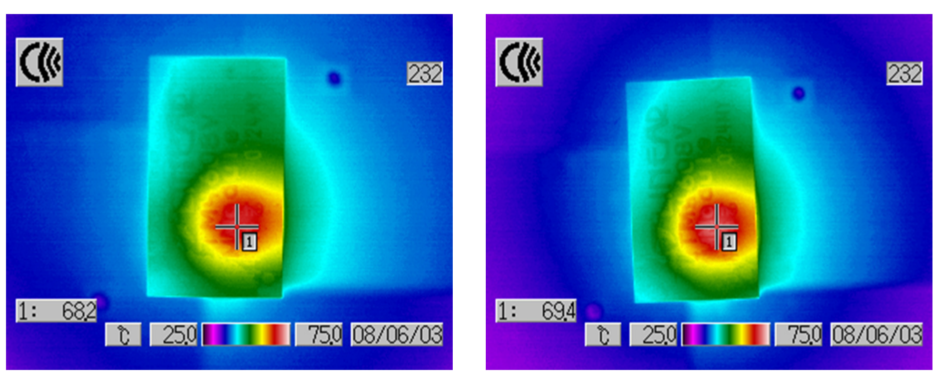

Figure 7. Good thermal balance is maintained between two paralleled LTM4608 boards supplying 16A output current.

5-Output High Current Power Supply for TFT-LCDs in a Low Profile QFN Features Space-Saving 2MHz Switching Regulators

by Kevin Huang

Introduction

The LT3513 is a highly integrated, 5-output regulator designed to provide all the supply voltages typically required by large TFT liquid crystal displays (LCDs) with a single IC. The part features a step-down switching regulator to produce a 3.3V or 5V logic voltage from a wide voltage range input, such as automotive battery. A lower voltage logic supply can be generated from the first supply by adding an external NPN driven by an internal linear regulator. The other three on-chip regulators provide the three bias voltages required by LCDs: a high power boost regulator to generate AV_{DD}, a low power boost regulator to generate V_{ON} and an inverting regulator to provide V_{OFF}.

Switching regulators are chosen over linear regulators to accommodate a wide input voltage range (providing both step up and step down functions) and to minimize power dissipation. The LT3513's wide input range, 4.5V to 30V, allows it to accept a variety of power sources, including automotive batteries, distributed supplies and wall transformers. The low profile 38-pin QFN package has an exposed metal pad on the backside to maximize thermal performance.

All of the regulators are synchronized to a 2MHz internal clock, allowing the use of small, low cost inductors and ceramic capacitors. Since different types of panels may require different bias voltages, all output voltages are adjustable for maximum flexibility. Programmable soft-start capability is included in each of the regulators to limit inrush current.

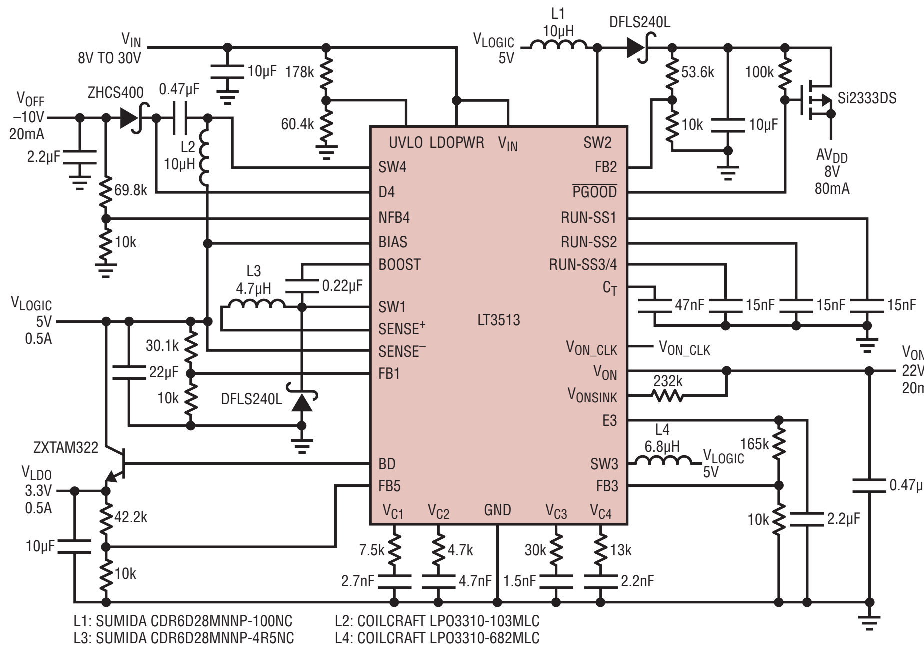

Figure 1. A complete 5-output 2MHz TFT-LCD power supply

Operation

Figure 1 shows a 5-output TFT LCD power supply that can accommodate an 8V to 30V input voltage. The first switching converter produces a 5V logic supply using a buck regulator. The internal linear regulator with an external NPN produces a 3.3V logic supply using the 5V supply as input. The second switcher is used to boost the 5V supply to an 8V, 80mA AV_{DD}

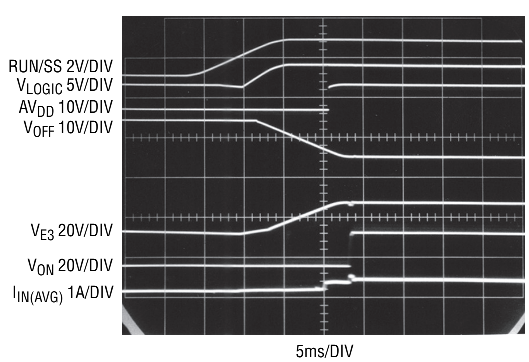

Figure 2. Startup waveforms of the power supply in Figure 1

bias supply. Another boost converter and an inverter generate V_{ON} and V_{OFF}, which also use the 5V supply as input.

When power is first applied to the input, the RUN-SS1 capacitor starts charging. When its voltage reaches 0.8V, Switcher 1 is enabled. The capacitor at the RUN-SS1 pin controls the ramp rate for the Switcher 1 output, V_{LOGIC} and inrush current in L1. Switchers 2, 3 and 4 are controlled by the BIAS pin, which is usually connected to V_{LOGIC}. When the BIAS pin is higher than 2.8V, the capacitors at the RUNSS-2 and RUN-SS3/4 pin begin charging to enable Switchers 2, 3 and 4. When AV_{DD} reaches 90% of its programmed voltage, the PGOOD pin is pulled low. When AV_{DD}, V_{OFF} and E3 all reach 90% or their programmed voltages, the C_T timer is enabled and a 20μA current source begins to charge C_T. When the C_T pin reaches 1.1V, the output PNP turns on, connecting E3 to V_{ON}. Figure 2 shows the start up sequence of the circuit in Figure 1.

If one of the regulated voltages, V_{LOGIC}, AV_{DD}, V_{OFF} or E3 dips more than 10%, the internal PNP turns off to shut down V_{ON}. This action protects the panels, as V_{ON} must be present to turn on the TFT display. The PGOOD pin can drive an optional PMOS device at the output of the boost regulator to disconnect the load at AV_{DD} from the input during shutdown. The converter uses all ceramic capacitors. X5R and X7R types are recommended, as these materials maintain capacitance over a wide temperature range.

All four switchers employ a constant frequency, current mode control scheme. Switching regulator 1 uses a feedback scheme that senses inductor current, while the other switching regulators monitor switch current. The inductor current sensing method avoids minimum on-time issues and maintains the switch current limit at any input-to-output voltage ratio. The other three regulators have frequency foldback scheme, which reduces the switching frequency when its FB pin is below 0.75V. This feature reduces the average inductor current during start up and overload conditions, minimizing the power dissipation in the power switches and external components.

Layout Considerations

Proper PC board layout is important to achieve the best operating performance. Paths that carry high switching current should be short and wide to minimize parasitic inductance. In a buck regulator, this loop includes the input capacitor, internal power switch and Schottky diode. In a boost regulator, this loop includes the output capacitor, internal power switch and Schottky diode. Keep all the loop compensation components and feedback resistors away from the high switching current paths. The LT3513 pin out was designed to facilitate PCB layout. Keep the traces from the center of the feedback resistors to the corresponding FB pins as short as possible. LT3513 has an exposed ground pad on the backside of the IC to reduce thermal resistance. A ground plane with multiple vias into ground layers should be placed underneath the part to conduct heat away from the IC.

Conclusion

The LT3513 is a comprehensive, but compact, power supply solution for TFT-LCD panels. Its wide input range and low power dissipation allow it to be used in a wide variety of applications. All four of the integrated switching regulators have a 2MHz switching frequency and allow the exclusive use of the ceramic capacitors to minimize circuit size, cost and output ripple.

LTM4604, LTM4608, continued from page 29

than 5% at full load. Excellent current sharing results in well balanced thermal stresses on the paralleled LTM4608s, which in turn makes for a more reliable system. Figure 7 demonstrates the small temperature difference between these two paralleled LTM4608 boards supplying 16A output current.

Conclusion

The LTM4604 and LTM4608 15mm × 9mm μModule regulators are complete power supply solutions for low input voltage and high output current applications. They significantly simplify circuit and layout designs by effortlessly fitting into the tightest spaces, including the bottom of the PCB. Despite their compact form, these μModules are rich in features, and they can be easily paralleled when more output current is needed.

LTC4352, continued from page 27

generates a 4.1V supply at the V_{CC} pin. For V_{IN} below 4.1V, V_{CC} follows approximately 50mV below V_{IN}. The 0.1μF V_{CC} capacitor is still needed for bypassing and LDO stability.

Conclusion

An ever-present theme in electronic system design has been to pack more computation in smaller form factors and tighter power budgets. Another trend has been to lower the voltage of distributed power, which increases the current to maintain power levels. Given these constraints, board designers must scrutinize each diode in a high current power path for its power and area consumption.

The LTC4352 MOSFET controller provides the same functionality as a diode but at higher efficiencies and cooler temperatures, especially as currents increase. It also incorporates useful features such as fast switch control, 0V operation, undervoltage and overvoltage protection, open MOSFET detection, ability to allow reverse current, Hot Swap capability, and fault and status outputs. All of this functionality comes wrapped in space-saving 12-pin DFN (3mm × 3mm) and MSOP packages, making it possible to produce an ideal diode solution in a smaller footprint than conventional diodes.

32V$_{IN}$ Synchronous Buck Regulators with Integrated FETs Deliver up to 12A from Sub-1mm Height Packages

by Stephanie Dai and Theo Phillips

Introduction

Monolithic buck regulators are easy to hook up and they make it possible to squeeze an entire DC/DC converter into very tight spaces. Although monolithics are an easy fit, they aren't the perfect fit for every application. For instance, they typically lack the capability to efficiently convert high input voltages (>12V) to low voltages at high output currents (>4A), thus leaving the job to a traditional controller IC and external MOSFETs.

A new family of devices, though, offers the advantages of monolithics with the low duty cycle and high efficiency of discrete components. The LTC3608, LTC3609, LTC3610 and LTC3611 are synchronous buck converters that bring high power density and simplified design to point-of-load applications. With a maximum input of 32V they utilize current-mode control up to a 2MHz switching frequency, deliver up to 12A of load current, and are packaged in thermally enhanced packages less than 1mm in height. A typical application of the LTC3608 is shown in Figure 1.

A new family of devices offers the advantages of monolithic DC/DC converters with the low duty cycle and high efficiency of discrete components. The LTC3608, LTC3609, LTC3610 and LTC3611 are synchronous buck converters that bring high power density and simplified design to point-of-load applications.

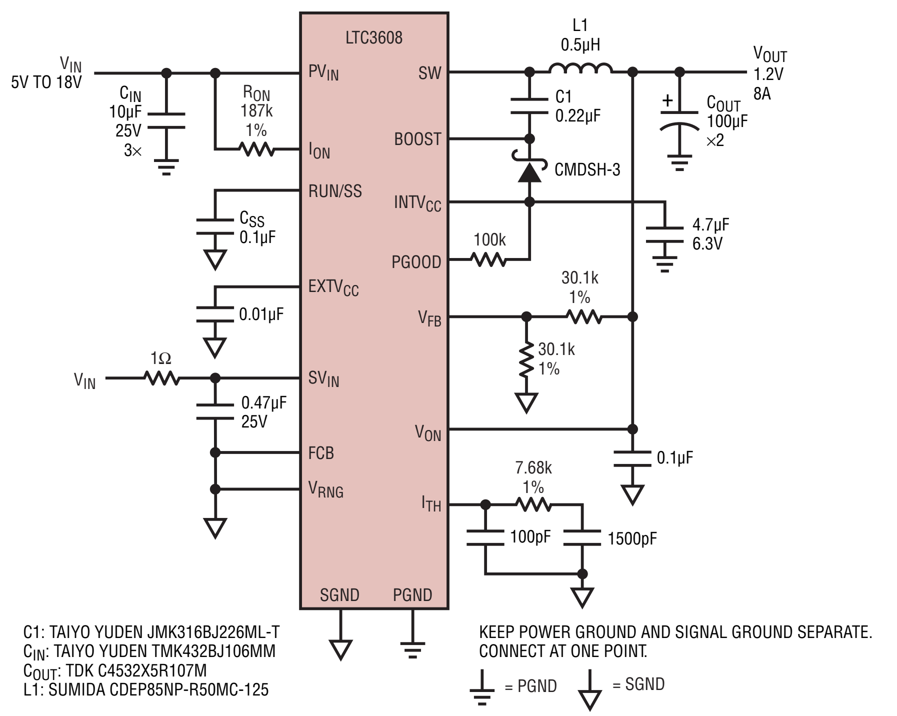

Figure 1. Typical application of the LTC3608

Features

The LTC3608, LTC3609, LTC3610 and LTC3611 integrate high performance synchronous buck controllers with super-low $R_{DS(ON)}$ DMOS MOSFETs to produce compact high efficiency converters (Figure 2). Two package sizes are available, each having a high voltage or high current option (Table 1). Each device features a sub-100ns on-time, allowing very low duty cycle operation and high switching frequency. The current-mode control architecture of these parts simplifies tuning of loop stability and allows excellent transient response with a variety of output capacitor types, including all-ceramic output capacitor applications.

The LTC3610 can operate in forced continuous mode, which provides the lowest possible output ripple and EMI, or discontinuous mode, which has better light load efficiency because inductor current is not allowed to reverse.

Current into the I_{ON} pin sets the on-time—a resistor R_{ON} from V_{IN} to the I_{ON} pin reduces on-time as V_{IN} rises, thus limiting changes in switching frequency. Furthermore, response to a load step can be very fast since the loop does not have to wait for an oscillator pulse before the top switch is turned on and current begins increasing.

The current limit, which is inferred from the maximum allowable sense voltage across the on-resistance of the bottom FET, can be adjusted by applying a voltage to the V_{RNG} pin. Maximum load current limits for each part are shown in Table 1. Soft-start and latch off functions are controlled by the RUN/SS pin, preventing inrush current and current overshoot during startup, and providing the option of latch-off if an under voltage or short circuit is presented. An open drain power-good pin monitors the output and pulls low if the output voltage is ±10% from the regulation point.

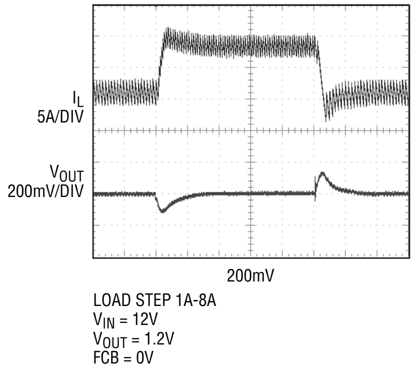

Figure 3. Transient response for the typical LTC3608 application represented in Figure 1 with a load step of 1A to 8A

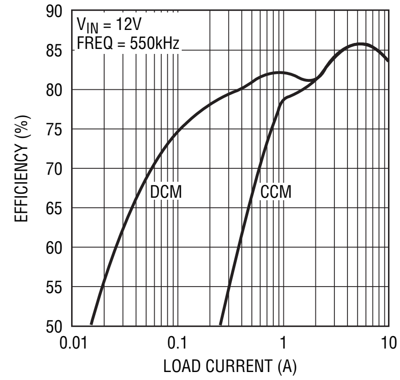

Figure 2. Efficiencies for a typical LTC3608 application in discontinuous conduction mode (DCM) and continuous conduction mode (CCM)

Conclusion

The LTC3608, LTC3609, LTC3610 and LTC3611 buck regulators offer the efficiency and power output capability of separate (controller + discrete) MOSFET solutions with the ease-of-use and space-saving advantages of traditional MOSFET-on-the-die monolithics. These parts also yield higher efficiencies than traditional monolithic solutions. They conserve power, save space, and simplify power designs. They reduce discrete components over controller-based solutions, making them a good fit in everything from low power portable device applications such as notebook and palmtop computers to high-power industrial distributed power systems.

Table 1. Integrated MOSFET buck regulators

	LTC3610	LTC3611	LTC3608	LTC3609
PV_{IN} Max	24V	32V	18V	32V
I_{LOAD} Max	12A	10A	8A	6A
Package	9mm × 9mm × 0.9mm 64-pin	9mm × 9mm × 0.9mm 64-pin	7mm × 8mm × 0.9mm 52-pin	7mm × 8mm × 0.9mm 52-pin
$R_{DS(ON)}$ Top FET	12mΩ	15mΩ	14mΩ	19mΩ
$R_{DS(ON)}$ Bottom FET	6.5mΩ	9mΩ	8mΩ	12mΩ

LTC4009, continued from page 20

LTC4009 family monitors the voltage across the input blocking diode for unexpected voltage reversal. Initial startup, restarts from fault conditions, and charge current reduction during input current limit are also carefully controlled to avoid producing reverse current.

All members of the family provide an input current limit flag to tell the system when the adapter is running at over 95% of its current capacity. Finally, each IC features internal over-temperature protection to prevent silicon damage during elevated thermal operation.

Recovery from all fault conditions is under full control of the analog feedback loops, which guarantees charging remains suspended until the internal feedback loops respond coherently and report the need to supply current to the load to maintain proper voltage or current regulation.

Conclusion

The LTC4009 family integrates a full set of charger building blocks in a small PCB footprint. The result is a high power battery charger IC with high precision and a full set of monitoring and fault handling features.

The LTC4009 provides adjustable output voltage control with a simple, external, user-programmed resistive voltage divider. As such, it is suitable as a general purpose charger that works with multiple battery chemistries and supercaps. It offers direct control over the entire charge process, facilitating implementation of a wide range of charge termination algorithms with an external microprocessor.

The LTC4009-1 and LTC4009-2 feature pin-programmable output voltage for common lithium-ion or lithium-polymer battery pack configurations with one to four series cells. For these chemistries, the number of precision external application components is reduced without sacrificing accuracy. Both 4.1V/cell (LTC4009-1) and 4.2V/cell (LTC4009-2) options are available, allowing the user to balance capacity and safety per the demands of the application.

Complete Power Solution for Digital Cameras and Other Complex Compact Portable Applications

by Brian Shaffer

Introduction

Digital cameras, portable GPS systems, MP3 players and other feature-rich mobile devices have complicated power requirements. In these complex devices, the flow of power must be carefully managed between a number of specialized sources and loads, including charging/discharging the battery, current-limited USB power and a set of multivoltage power supply rails, including negative rails for CCDs or LCDs. The supply rails must be sequenced and tracked and faults must be handled cleanly and communicated to a microcontroller.

When these requirements are added together, the task of squeezing an efficient and robust power system into a handheld device can seem near impossible. Linear Technology solves this problem with a family of devices called PMICs (Power Management Integrated Circuits) that greatly simplify the design of complex rechargeable battery power systems.

Some Linear Technology PMICs use a switching PowerPath controller topology with the unique Bat-Track feature, which allows charge currents above the USB limit (see Figure 1) for faster battery charging. The power solution for digital cameras presented here takes advantage of this and other powerful PMIC features.

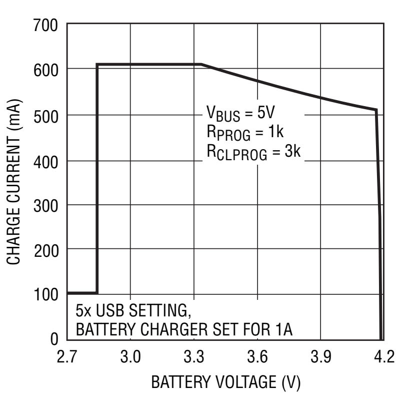

Figure 1. Battery charge current vs battery voltage

The LTC3586 implements Linear Technology's unique Bat-Track™ technology, which can use more power from a USB source than traditional linear chargers, resulting in faster charging.

Complete Digital Camera Power System

Figure 2 shows a complete digital camera power solution using the LTC3586 PMIC as the power traffic control center. Its 4mm × 6mm QFN package includes a USB PowerPath manager, a battery charger, plus a boost DC/DC converter, a buck-boost and two buck converters. The LT3587 in a 3mm × 3mm package is used to drive a CCD and an LED backlight for an LCD screen with a high voltage monolithic inverter and dual boost converter.

Switching PowerPath Controller Maximizes Available Power

The LTC3586 implements Linear Technology's unique Bat-Track™ technology, which maximizes the use of available power from a USB source for either providing current to the load or charging the battery at rates greater than achievable from linear chargers.

The switching PowerPath controller maintains accurate control of the average input current for USB applications. The average level of input current is controlled by the state of two digital inputs and can be set to 100mA, 500mA, 1A or suspend (500µA). The switching PowerPath controller is highly efficient, which results in battery charge currents of well over 600mA from a 500mA USB source (Figure 1).

The battery charging efficiency is between 85% and 90% for the entire battery voltage range. In contrast, the efficiency of a traditional linear charger falls as low as 57%, generating the losses as heat. See Figure 3 for a graph of the battery charger efficiency as a function of battery voltage.

Instant-On Operation

The LTC3586 also features instant-on operation, which allows the camera to function immediately when external power is applied even if the battery voltage is below the system cutoff voltage. This is achieved by generating a separate voltage rail, V_{OUT}, which is decoupled from the battery voltage when the battery is below 3.3V. When external power is applied, the PowerPath controller prioritizes load current over battery charge current and regulates V_{OUT} to 3.6V, enabling the system to operate immediately upon the application of external power. The instant-on feature is important in camera applications because important moments do not wait for batteries to charge.

Fault Handling

The $\overline{\text{FAULT}}$ signals on both of these devices are designed to work together for seamless fault handling. By making the fault signals both an input and an output, the two chips can communicate fault events to each other. If either of the devices has a fault then all the outputs turn off, protecting the system and battery from damage. The enable lines and the fault signal

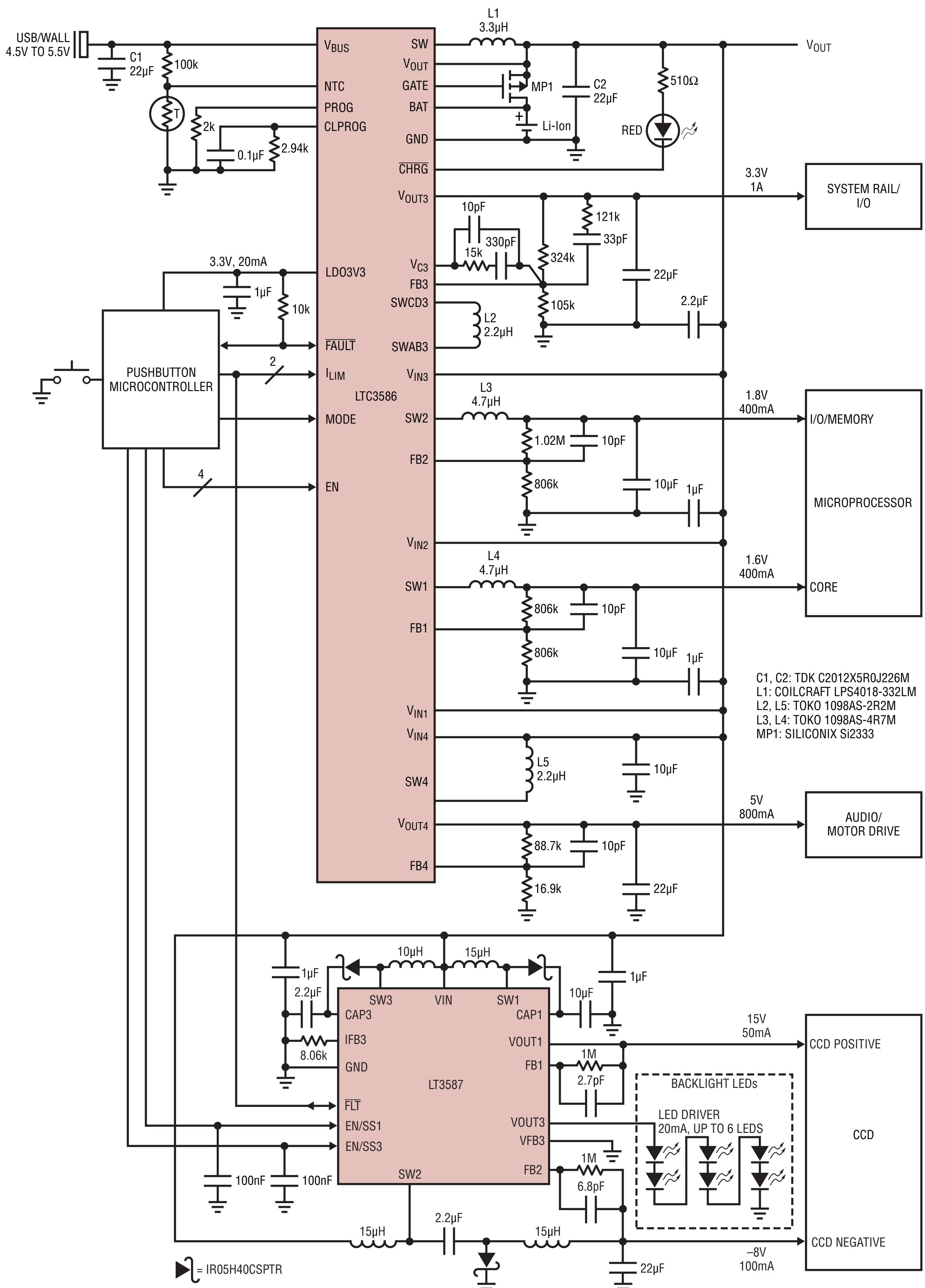

Figure 2. Complete power solution for portable cameras

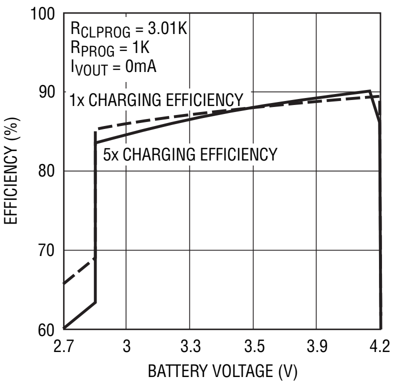

Figure 3. Battery charging efficiency vs battery voltage with no external load (P_{BAT}/P_{BUS})

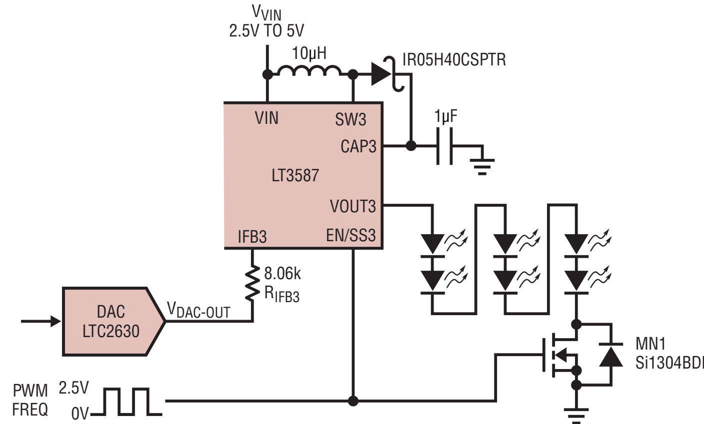

Figure 4. Six white LED driver with PWM and analog dimming

should be pulled-up to the same voltage. In Figure 2 the LDO3V3 regulator is used as the pull-up voltage for the $\overline{\text{FAULT}}$ signal and the power supply for the low power microcontroller used to process pushbutton events and sequence the power supplies. The $\overline{\text{FAULT}}$ pin also acts as an input and hence, must be high before any outputs are enabled.

Compact LED Driver

The LT3587 LED driver is designed to drive up to six LEDs with average LED currents between 20mA and 1µA. When the LT3587's V_{OUT3} is used as a current regulated LED driver, the V_{FB3} pin can be used as an overvoltage protection function. By connecting a resistor between V_{OUT} and V_{FB3} the device limits the maximum allowable output voltage on V_{OUT3}. This feature is extremely important in LED applications because without it the client device may be damaged if one of the LEDs were to open; in such a case, the output would continue to rise as the current regulation loop increases voltage in an attempt to regulate the current.

The integrated LED driver in the LT3587 is capable of accepting a direct PWM dimming signal into its enable input (EN/SS3) and/or accommodates analog dimming via an external DAC. See Figure 4 for a partial application circuit showing the LED driver with direct PWM and analog dimming.

LEDs can change color when the current through them changes, but PWM dimming maintains color consistency over the dimming range, as the ON part of the PWM cycle is always the same current. In PWM dimming, the brightness of the LEDs is a function of average current, adjusted by changing the duty cycle of the PWM signal. In analog dimming, the constant current through the LEDs is adjusted, which causes variations in color.

The LT3587 accepts PWM signals with frequencies over 60Hz to assure flicker-free operation. High PWM frequencies are achievable because of the internal disconnect FET between CAP3 and V_{OUT3}. This FET ensures that CAP3 maintains its steady-state value while the PWM signal is low, resulting in minimal startup delays. For a 100Hz PWM dimming signal and allowing for 10% deviation from linearity at the lowest duty cycle, the LT3587 allows for a dimming ratio of 30:1. If the maximum amount of adjustment range is desired, an external DAC, such as the LTC2630, can be used to feed an adjustment voltage onto the IFB3 resistor, creating an LED current range of 20,000:1.

Conclusion

Two highly integrated devices, the LTC3586 and LT3587 can be combined to create a complete USB compatible power solution for portable cameras and other feature-rich portable devices. The solution is robust, high performance and compact, with efficient battery charging, instant-on capability and LED protection.

LTC3851, continued from page 17

protects against insufficient turn-on voltage for the top MOSFET.

3.3V/15A Regulator with DCR Sensing

Figure 2 shows a 400kHz, 3.3V output regulator using DCR current sensing. The DC resistance of the inductor is used as the current sense element, eliminating the need for a discrete sense resistor and thus maximizing efficiency. Figure 3 shows a plot of the efficiency vs load for all three modes of operation with an input voltage of 12V.

1.5V/15A Regulator Synchronized at 350kHz

Figure 4 illustrates a 1.5V output regulator that is synchronized to an external clock. The loop filter components connected to the FREQ/PLLFLTR pin are optimized to achieve a jitter free oscillator frequency and reduced lock time.

Conclusion

The LTC3851 combines high performance, ease of use and a comprehensive feature set in a 3mm × 3mm 16-pin package. DCR current sensing and Burst Mode® operation keep efficiency high. With a broad 4V to 38V input range, strong MOSFET drivers, low minimum on-time and tracking, the LTC3851 is ideal for automotive electronics, server farms, datacom and telecom power supply systems and industrial equipment.

New Device Cameos

I²C Buffer Level Shifts 2.3V–5.5V Busses to Low Voltage Busses as Low as 1V

The LTC4308 is a low voltage, level shifting hot swappable 2-wire bus buffer device with output rise time acceleration and stuck bus recovery. The LTC4308's negative offset from output to input allows communication between output bus devices with high V_{OL} and devices on the low voltage input side, where bus supplies can be as low as 0.9V. The transparent level shifting provides reliable communications between new low voltage supply devices, such as EEPROMs and microcontrollers, with legacy devices operating at supply voltages ranging from 2.3V to 5.5V. Bus buffering provides capacitive isolation between the upstream and downstream busses, allowing a single large bus to be broken up into two manageable smaller busses.

The LTC4308 also provides rise time acceleration on the output side and stuck bus recovery. The strong rise time accelerator pull up currents reduce long rise times associated with high bus capacitances, allowing weaker pull-up resistors to be used, thereby reducing DC power consumption. Stuck bus recovery automatically disconnects the input and output busses when the connected busses remain low for greater than 30ms. The LTC4308 attempts to free the stuck bus by generating up to 16 clock pulses and a Stop Bit on the output bus. If the stuck bus recovers to a logic high the busses are automatically reconnected.

The LTC4308 is also ideal for output side data and clock hot-swapping. During insertion the LTC4308 precharges the SDAOUT and SCLOUT pins to 1V, minimizing the voltage differential between its pins and the live bus. Once inserted, the LTC4308 waits for a Stop Bit or Bus Idle to occur on both sides, to ensure data transfers are complete and coherent, before a connection is made. High 6kV HBM ESD performance provides added protection from stresses during assembly, handling, and insertion. The combination of low voltage level shifting and Hot Swap features allows low voltage supply I/O cards to interface with legacy backplanes.

Available in a small 8-pin DFN (3mm × 3mm) and MS8 package, the LTC4308 is the ideal solution for low voltage level shifting in 2-wire bus systems.

Low Voltage Hot Swap Controller with Adjustable Current Limit

Linear Technology Corporation introduces the LTC4218 Hot Swap Controller for protecting boards with load supply voltages ranging from 2.9V to 26.5V. When a board is plugged into a backplane, large inrush currents can create a glitch on the load supply causing other boards on the bus to malfunction. The LTC4218 enables safe board insertion and removal from a live backplane, using an external N-channel pass MOSFET in the power path to limit the inrush current during power up. An adjustable current limit allows users to vary the current limit threshold under various loading conditions, such as disk drive spin-up to normal operation. The wide operating voltage and adjustable current limit differentiate the LTC4218 from other low voltage Hot Swap controllers on the market today.

The LTC4218 features are tailored for use in RAID, server, telecom (i.e., ATCA, AMC, µTCA) and industrial applications. The load current is monitored using the voltage sensed across a current sense resister and adjusting the MOSFET's gate-to-source voltage accordingly. A separate I_{SET} pin allows users to adjust the 5% accurate (15mV) current limit threshold during startup and normal operation as needed. Meanwhile, current foldback and power-good circuitry ensure that the switch is protected from excessive load current and indicate whether a power-good condition is maintained. The LTC4218 also features current monitor and fault outputs, 2% accurate overvoltage and undervoltage protection, and an adjustable current limit timer. A dedicated 12V version (LTC4218-12) is also available, which contains preset 12V specific thresholds.

The LTC4218 is available in a 16-lead SSOP, while the LTC4218-12 is available in a 16-lead 5mm × 3mm DFN, both of which are RoHS compliant.

The small size, high integration, low quiescent curent draw, and low external component requirements of the LTC3670 make it ideal for driving the myriad low voltage rails in Li-ion powered handheld devices.

Micropower 50mA Linear Regulator Withstands 80V Input and Offers Power-Good Status Signaling with Programmable Delay

Linear Technology Corporation announces the LT3011, a high voltage micropower, low dropout regulator that delivers up to 50mA of continuous output current with a low dropout voltage of only 300mV at full load. The LT3011 features an input voltage range of 3V to 80V, delivering output voltages as low as 1.24V and up to 60V. The device's power-good flag indicates output regulation. However, a single capacitor may be used to program the delay between this regulated output level and the flag indication. The 80V input voltage capability makes it ideal for automotive applications, 48V telecom backup supplies and industrial control applications. Low quiescent current of 46µA (operating) and 1µA (in shutdown) make it an excellent choice for battery-powered "keep alive" systems that require optimum run time.

Output noise is minimized at only $100\mu V_{RMS}$ over a 10Hz to 100kHz bandwidth, making the LT3011 ideal for noise-sensitive applications. For high voltage applications that require large input-to-output voltage differentials, the LT3011 provides a very compact solution. Its thermally enhanced MSOP and DFN packages offer thermal resistance equivalent to much larger conventional packages.

The LT3011 is able to operate with very small, low cost, ceramic output capacitors and is stable with a 1µF output capacitor—far better than the 10µF to 100µF required by most other linear regulators. These tiny external capacitors can be used without the necessary addition of series resistance (ESR) as is common with many other regulators. Internal protection circuitry includes reverse-battery protection, current limiting, thermal limiting, and no reverse current flow from output to input.

Ideal Diode Controller with Integrated 5A MOSFET Replaces Lossy Schottky Diodes

The LTC4358 is a high voltage ideal diode controller with an internal 5A MOSFET. The controller and 20mΩ internal N-channel MOSFET perform the function of a low forward voltage diode, making it a simple, low loss replacement to Schottky diodes in high current applications. This provides a lower loss path compared to the Schottky diode that in high current applications provides higher efficiency and preserves precious board area by eliminating the need for heat sinking.

The LTC4358 regulates the forward voltage drop across the internal MOSFET to ensure smooth switchover from one path to another without oscillation. A fast pull-down circuit minimizes reverse current transients in the event a power supply fails or is shorted. The LTC4358 can be viewed as a 3-terminal diode for general purpose applications such as reverse battery protection in automotive applications, or ORing power supplies together in applications that demand high system reliability.

The LTC4358 single ideal diode controller is useful in applications where multiple, redundant power supplies are paralleled to provide load sharing. In N+1 redundant systems, the LTC4358 provides a convenient method to OR together an additional supply to safeguard the system in the event one of the N supplies fail. This ORing technique provides necessary isolation for live insertion and removal of converters onto the power bus and to provide isolation from the bus during a hard short. If the power source fails or is shorted, the LTC4358 ensures a fast 500ns turn-off to minimize reverse current transients.

The LTC4358 joins a growing family of ideal diode-OR controllers, including the LTC4355 positive voltage ideal diode-OR, LTC4354 negative voltage ideal diode-OR, and the LTC4357 and LT4352 single ideal diode controllers.

The LTC4358 is offered in 4mm × 3mm 14-pin DFN and 16-lead TSSOP packages.

70µA I_Q Triple Power Supply in 3mm × 2mm DFN

The LTC3670 is a triple power supply in a single IC, integrating a 400mA synchronous buck regulator with two 150mA low dropout linear regulators (LDOs) in a 0.75mm profile, 3mm × 2mm DFN. The input supply range of 2.5V to 5.5V is especially well-suited for single-cell lithium-ion and lithium-ion/polymer applications, and for powering low voltage ASICs and SoCs from 3V, 3.3V or 5V rails. To extend battery life, total quiescent current with all three regulators running is only 70µA.

Regulated output voltages are programmed via external resistors, and can be set as low as 0.8V. Each output has its own enable pin for maximum flexibility. An onboard supply monitor indicates when all enabled outputs are in regulation.

The 400mA buck regulator features constant-frequency 2.25MHz operation, allowing the use of small surface mount inductors and capacitors. Burst Mode operation maintains high efficiency in light-load and no-load conditions. Internal control-loop compensation simplifies application design. The 150mA LDOs are stable with as little as 1µF of external output capacitance, minimizing application size, and feature short-circuit protection.

Dual 8A or Single 16A Step Down DC/DC µModule Regulator in a 15mm × 15mm Surface Mount Package

The LTM4616 is a complete dual DC/DC µModule™ power supply in a tiny surface mount package. The LTM4616 can regulate two outputs ranging from 0.6V to 5V at 8A each, or it can regulate one output at 16A by sharing current from the two outputs in a multiphase configuration. The LTM4616 is just as versatile on the input. It can operate from two different input supply rails ranging from 2.375V to 5.5V (6V max) or from one input supply by tying the input pins together.

All of the support components needed for a dual point-of-load regulator—inductors, capacitors, DC/DC controller, compensation circuitry and power switches—are encapsulated and protected in the 15mm × 15mm × 2.8mm plastic surface mount LGA (land grid array) package. The package's low profile allows smooth airflow for cooling in densely populated circuit boards. It is a perfect solution for powering both core and I/O supplies for FPGAs and ASICs.

The LTM4616 is guaranteed to better than ±1.75% total DC output error over the full operating temperature range, including the line and load regulation. As a current mode device with high switching frequency, the LTM4616 has a fast transient response to line and load changes while operating with excellent stability with a variety of output capacitors, including schemes that use all ceramic capacitors.

Efficiency is as high as 94%. Frequency synchronization, multiphase operation, spread spectrum phase modulation, output voltage tracking and margining are just a few of the other features of this versatile part. Safety features include overvoltage and overcurrent protection as well as thermal shutdown.

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