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Two New Controllers for Boost, Flyback, SEPIC and Inverting DC/DC Converters Accept Inputs up to 100V

by Wei Gu

Introduction

Two new versatile DC/DC controller ICs, the LT®3757 and LT3758, are optimized for boost, flyback, SEPIC and inverting converter applications. The LT3757 operates over an input range of 2.9V to 40V, suitable for applications from single-cell lithium-ion battery portable electronics up to high voltage automotive and industrial power supplies. The LT3758 extends the input voltage to 100V, providing flexible, high performance operation in high voltage, high power telecommunications equipment. Both ICs exhibit low shutdown quiescent current of 1µA, making them an ideal fit for battery-operated systems.

Both integrate a high voltage, low dropout linear (LDO) regulator. Thanks to a novel FBX pin architecture, the LT3757 and LT3758 can be connected directly to a divider from either the positive output or the negative output to ground. They also pack many popular features such as soft-start, input undervoltage lockout, adjustable frequency and synchronization in a small 10-lead MSOP package or a 3mm × 3mm QFN package.

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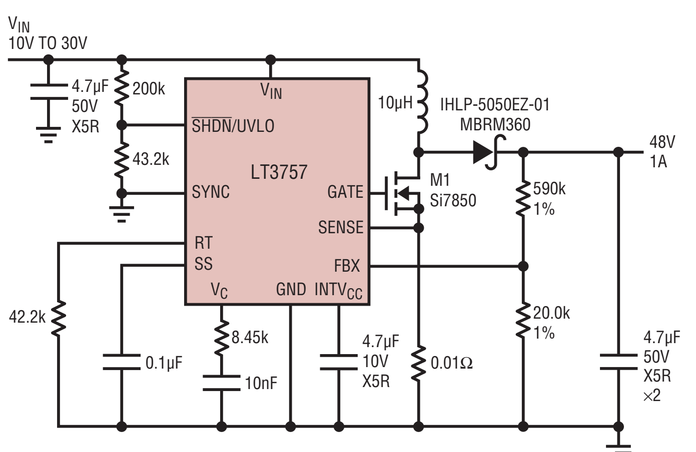


Figure 1. A 10V–30V input, 48V at 1A output boost converter

Linear in the News…

EDN Innovation Award Winners

EDN magazine on March 30 announced the winners of their annual Innovation Awards. Linear Technology's LTM®4606 Ultralow EMI, 6A DC/DC µModule® Regulator was selected as the winner in the Power ICs: Modules category. This innovative device significantly reduces switching regulator noise by attenuating conducted and radiated energy at the source. The µModule device is a complete DC/DC system-in-a-package, including the inductor, controller IC, MOSFETs, input and output capacitors and the compensation circuitry—all in a surface mount plastic package in an IC form factor.

The other Innovation Award winner, in the category Best Contributed Article, was Jim Williams for his article, "High Voltage, Low-Noise DC/DC Converters," which you can read at www.edn.com/jimwilliams.

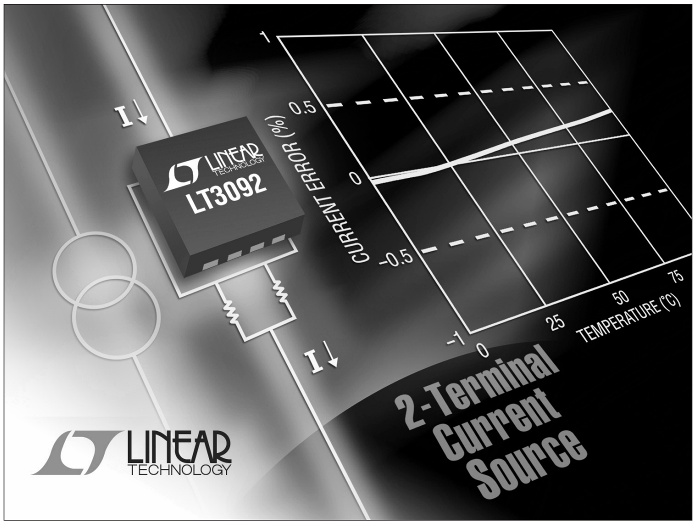
In addition to these winners, two other Linear Technology products were finalists for Innovation Awards:

- ❑ LTC®6802 Battery Stack Monitor in the Battery ICs Category
- ❑ LTC3642 50mA Synchronous Step-Down Converter in the Power ICs Category

Current Source Makes Worldwide Debut

Linear Technology has just introduced an elegant building-block component that promises to simplify many power designs—the LT3092 2-terminal current source. The LT3092 has recently been announced worldwide in a series of articles by Linear Technology CTO Bob Dobkin.

The LT3092 is a new solution to an old problem: how to create an easy-to-use current source that maintains regulation in a variety of conditions. In the past, a designer would have to choose between an imprecise IC solution, or build a current source from discrete components. The LT3092 200mA 2-terminal current source solves the problems of prior approaches, with its wide voltage range, high AC and DC impedance, good regulation, low temperature coefficient, and the fact that it requires no capacitors. The device's two floating terminals make it eminently easy to use.



On the surface, current source design appears relatively easy, but it is fraught with problems. Although high quality voltage sources are readily available, the current source as an IC has, until now, remained elusive.

The desirable *2-terminal* current source brings its own set of issues, especially if high accuracy and stability over temperature are required features. A current source must operate over a wide voltage range, have high DC and AC impedance when connected in series with unknown reactance, and exhibit good regulation and a low temperature coefficient. For optimal 2-terminal solutions, no power supply bypass capacitor should be used since it degrades AC impedance.

The LT3092 meets these expectations. It has better than 1% initial accuracy and a very low temperature coefficient. Output currents can be set from 0.5mA to 200mA, and current regulation is typically 10ppm per volt. The LT3092 operates down to 1.5V or up to 40V. This gives an impedance of 100MΩ at 1mA or 1 MΩ at 100mA. Unlike almost any other analog integrated circuit, special design techniques have been used for stable operation *without* a supply bypass capacitor, allowing the LT3092 to provide high AC impedance as well as high DC impedance. Transient and start-up times are about 20µs.

Linear Announces New Quad PSE Controller for PoE+

Last month, Linear Technology held press meetings in the US, Europe and Asia to introduce the LTC4266, a 4-port Power over Ethernet (PoE) controller for Power Sourcing Equipment (PSE), designed to meet the IEEE 802.3at requirements of 25.5W or proprietary higher power levels. Next-generation PoE applications call for more power to support demanding features, while increasing power efficiency in an effort to be more green and reduce costs.

The LTC4266 provides up to 100W over 4-pair Ethernet cabling and is fully compliant with the new IEEE 802.3at PoE+ standard and backward compatible with the prior IEEE 802.3af PoE standard. To help conserve power, the LTC4266 delivers the lowest-in-industry heat dissipation by using low $R_{DS(ON)}$ MOSFETs and 0.25Ω sense resistors, eliminating the need for expensive heat sinks and providing a more robust PSE solution.

The LTC4266 is suitable for a wide variety of PSE applications, including next-generation switches, routers, hubs and midspans. Users will appreciate the extremely low power dissipation, which simplifies thermal design when compared to designs that use PSEs with more fragile, normally higher $R_{DS(ON)}$, MOSFETs.

LT3757/58, continued from page 1

Internal High Voltage LDO

In high voltage applications, the LT3757 and LT3758 eliminate the need for an external regulator or a slow-charge hysteretic start scheme through the integration of an onboard linear regulator, allowing simple start-up and biasing. This regulator generates $INTV_{CC}$, the local supply that runs the IC from the converter input V_{IN}. The internal LDO can operate the IC continuously, provided the input voltage and/or MOSFET gate charge currents are low enough to avoid excessive power dissipation in the part.

When the $INTV_{CC}$ pin is driven externally above its regulated voltage during operation—from the input, the output or a third winding—the internal LDO is automatically turned off, reducing the power dissipation in the IC. The LDO also provides internal current limit function to protect IC from excessive on-chip power dissipation. The current limit decreases as V_{IN} increases. If the current limit is exceeded, the $INTV_{CC}$ voltage falls and triggers the soft-start.

Sensing Output Voltage Made Easier

Unlike traditional controllers, which can only sense positive outputs, the LT3757 and LT3758 have a novel FBX pin architecture that simplifies the design of inverting and non-inverting converters. The LT3757 and LT3758 each contain two internal error amplifiers; one senses positive outputs and the other negative. When the converter starts switching and the output voltage starts ramping up or down, depending on the topologies, one of the error amplifiers seamlessly takes over the feedback control, while the other becomes inactive.

The FBX pin can be connected directly to a divider from either a positive output or a negative output. This direct connection saves space and expense by eliminating the traditional glue circuitry normally required to level-shift the feedback signal above ground in negative converters. The power supply designer simply decides the output polarity he needs, the topology he wants to use and the LT3757 or LT3758 does the rest.

Precision UVLO Voltage and Soft-Start

Input supply UVLO for sequencing or start-up over-current protection is easily achieved by driving the UVLO with a resistor divider from the V_{IN} supply. The divider output produces 1.25V at the UVLO pin when V_{IN} is at the desired UVLO rising threshold voltage. The UVLO pin has an adjustable input hysteresis, which allows the IC to resist a settable input supply droop before disabling the converter. During a UVLO event, the IC is disabled and V_{IN} quiescent current drops to 1μA or lower.

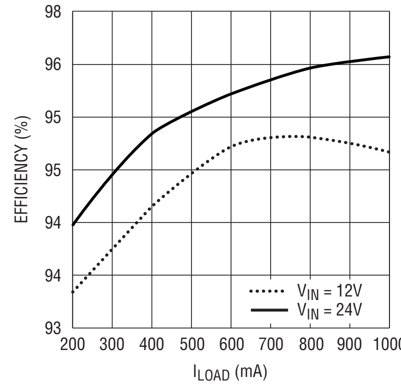


Figure 2. Efficiency of the converter in Figure 1

The SS pin provides access to the soft-start feature, which reduces the peak input current and prevents output voltage overshoot during start-up or recovery from a fault condition. The SS pin reduces the inrush current by not only lowering the current limit but also reducing the switching frequency. In this way soft-start allows the output capacitor to charge gradually towards its final value.

Adjustable/Synchronizable Switching Frequency

The operating frequency of the LT3757 and LT3758 can be programmed from 100kHz to 1MHz range with a single resistor from the R_T pin to ground, or synchronized to an external clock via the SYNC pin.

The adjustable operating frequency allows it to be set outside certain frequency bands to fit applications that are sensitive to spectral noise.

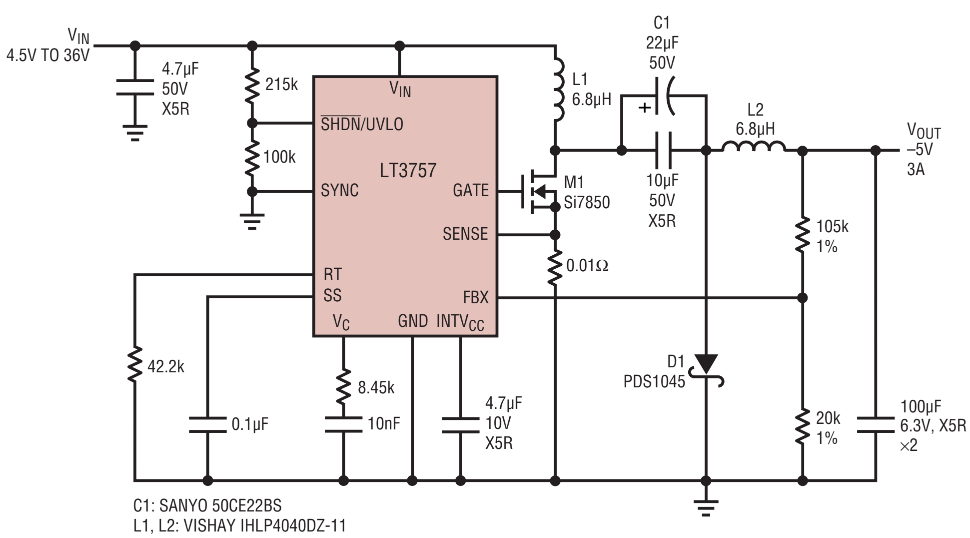


Figure 3. A 4.5V–36V to –5V at 3A inverting converter

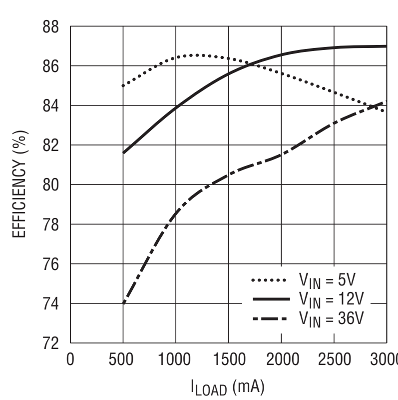


Figure 4. Efficiency of the converter in Figure 3

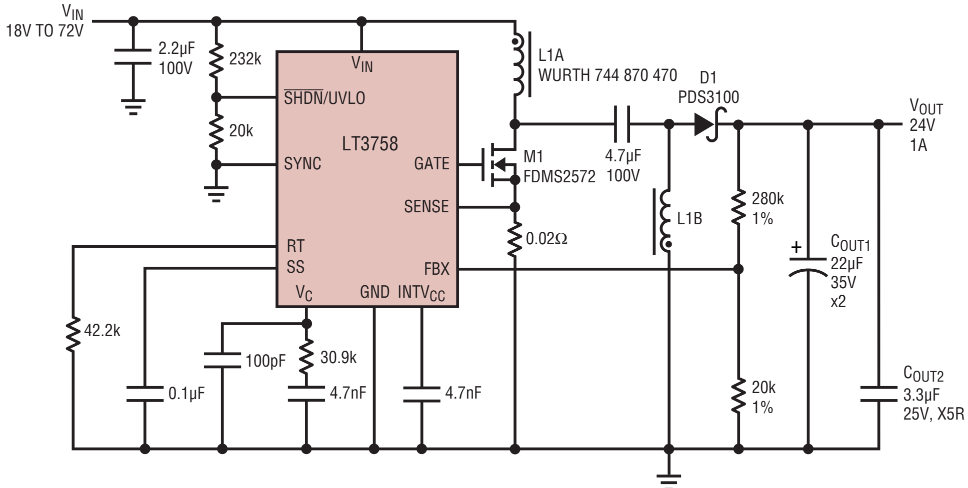


Figure 5. A 18V–72V input, 24V/1A output SEPIC converter

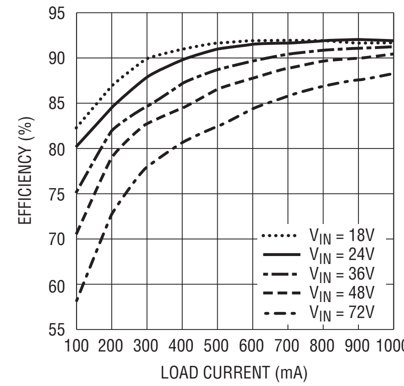


Figure 6. Efficiency of the converter in Figure 5

In space constrained applications, higher switching frequencies can be used to reduce the overall solution size and the output ripple. If power loss is a concern, switching at a lower frequency reduces switching losses, improving efficiency.

Current Mode Control

The LT3757 and LT3758 use a current mode control architecture to enable a higher supply bandwidth, thus improving response to line and load transients. Current mode control also requires fewer compensation components than voltage mode control architectures, making it much easier to compensate over all operating conditions.

A 10V–30V Input, 48V/1A Output Boost Converter

Figure 1 shows a 48V, 1A output converter that takes an input of 10V to 30V. The LT3757 is configured as a boost converter for this applications where the converter output voltage is higher than the input voltage. Figure 2 shows the efficiency for this converter.

A 4.5V–36V Input, –5V/3A Output Inverting Converter

Figure 3 shows the LT3757 in an inverting converter that operates from a 4.5V to 36V input and delivers 3A to a –5V load. The negative output can be either higher or lower in amplitude than the input. It has output short-circuit protection, which is further enhanced by the frequency foldback feature in the LT3757. The 300kHz operating frequency allows the use of small inductors. The ceramic capacitor used for the DC coupling capacitor provides low ESR and high RMS current capability. The output power can easily scaled by the choice of the components around the chip without modifying the basic design. Figure 4 shows the efficiency for this converter at different input voltages.

An 18V–72V Input, 24V/1A Output SEPIC Converter

A SEPIC converter is similar to the inverting converter in that it can step up or step down the input, but with a positive output. It also offers output disconnect and short-circuit protection. Figure 5 illustrates an 18V–72V input, 24/1A output SEPIC power supply using LT3758 as the controller. Figure 6 shows the efficiency for this converter at different input voltages.

An 18V–72V Input, –3.3V/2A Output Flyback Converter

Figure 7 shows the LT3758 in a non-isolated flyback converter with an 18V to 72V input voltage range and a –3.3V / 2A output. It provides robust output short-circuit protection thanks to the frequency foldback feature in the LT3758. The circuit can also be used for different negative voltages simply by changing the value of the resistor divider on the FBX pin.

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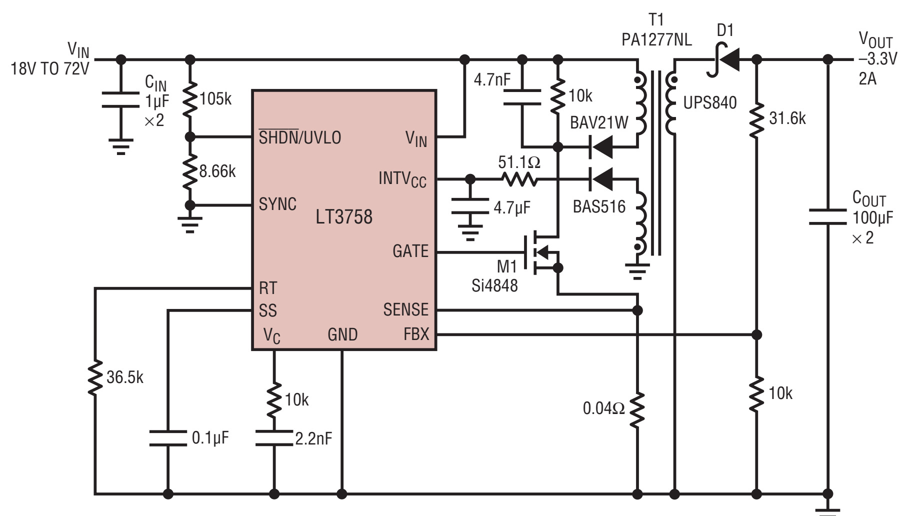

Figure 7. 18V–72V input, –3.3V/2A output flyback converter

Charge Li-Ion Batteries Directly from High Voltage Automotive and Industrial Supplies Using Standalone Charger in a 3mm × 3mm DFN

by Jay Celani

Introduction

Growth of the portable electronics market is in no small part due to the continued evolution of battery capacities. For many portable devices, rechargeable Li-Ion batteries are the power source of choice because of their high energy density, light weight, low internal resistance, and fast charge times. Charging these batteries safely and efficiently, however, requires a relatively sophisticated charging system.

One additional problem faced by battery charger designers is how to deal with relatively high voltage sources, such as those found in industrial and automotive applications. In these environments, system supply voltages exceed the input ranges of most charger ICs, so a DC/DC step-down converter is required to provide a local low voltage supply for the charger IC. The LT3650 standalone monolithic switching battery charger does not need this additional DC/DC converter. It directly accepts input voltages up to 40V and provides charge currents as high as 2A. It also includes a wealth of advanced features that assure safe battery charging and expand its applicability.

The LT3650 includes features that minimize the overall solution size, requiring only a few external components to complete a charger circuit. A fast 1MHz switching frequency allows the use of small inductors, and the IC is housed inside a tiny 3mm × 3mm DFN12-pin package. The IC has built-in reverse current protection, which blocks current flow from the battery back to the input supply if that supply is disabled or discharged to ground, so a single-cell LT3650 charger does not require an external blocking diode on the input supply.

A Charger Designed for Lithium-Ion Batteries

A Li-Ion battery requires constant-current/constant-voltage (CC/CV) charging system. A Li-Ion battery is initially charged with a constant current, generally between 0.5C and 1C, where C is the battery capacity in ampere-hours. As it is charged, the battery voltage increases until it approaches the full-charge float voltage. The charger then transitions into constant voltage operation as the charge current is slowly reduced. The LT3650-4.1 and LT3650-4.2 are designed to charge single-cell Li-Ion batteries to float voltages of 4.1V and 4.2V, respectively. The LT3650-8.2 and LT3650-8.4 are designed to charge 2-cell battery stacks to float voltages of 8.2V and 8.4V.

Once the charge current falls below one tenth of the maximum constant charge current, or 0.1C, the battery is considered charged and the charging cycle is terminated. The charger must be completely disabled after terminating charging, since indefinite trickle charging of Li-Ion cells, even at miniscule currents, can cause battery damage and compromise battery stability. A charger can top-off a battery by continuing to operate as the current falls lower than the 0.1C charge current threshold to make full use of battery capacity, but in such cases a backup timer is used to disable the charger after a controlled period of time. Most Li-Ion batteries charge fully in three hours.

The LT3650 addresses all of the charging requirements for a Li-Ion battery. The IC provides a CC/CV charging characteristic, transitioning automatically as the requirements of the battery change during a charging cycle. During constant-current operation, the maximum charge current

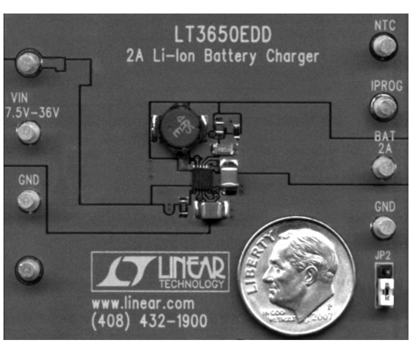

Figure 1. An LT3650 standalone battery charger is small and efficient.

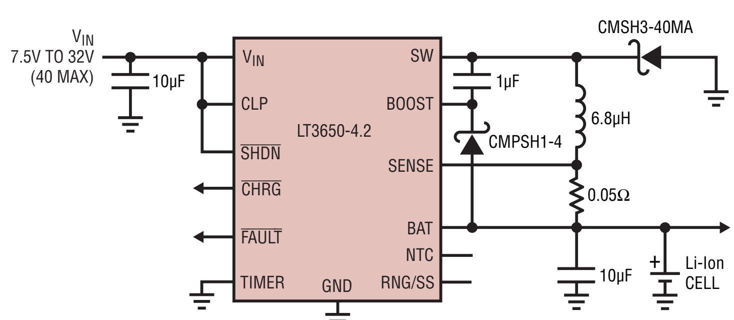

Figure 2. A single-cell 2A Li-Ion battery charger configured for C/10 charge termination

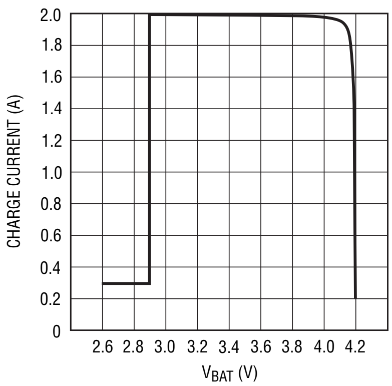

Figure 3. Battery charge current vs BAT pin voltage for the charger shown in Figure 2

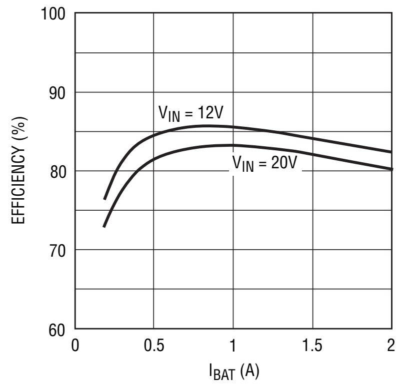

Figure 4. Power conversion efficiency vs charger output current (I_{BAT}) for the battery charger shown in Figure 2

A Basic Charger

Figure 2 shows a basic 2A single-cell Li-Ion battery charger that operates from a 7.5V to 32V input. Charging is suspended if the input supply voltage exceeds 32V, but the IC can withstand input voltages as high as 40V without damage. The 2A maximum charge current corresponds to 100mV across the 0.05Ω external sense resistor. This basic design does not take advantage of the status pins, battery temperature monitoring, or a safety timer features. The battery charging cycle terminates when the battery voltage approaches 4.2V and the charge current falls to 200mA. A new charge cycle is automatically initiated when the battery voltage falls to 4.1V.

provided to the battery is programmable via a sense resistor, up to a maximum of 2A. Maximum charge current can also be adjusted using the RNG/SS pin. The charger transitions to constant-voltage mode operation as the battery approaches the full-charge float voltage. Power is transferred through an internal NPN switch element, driven by a boosted drive to maximize efficiency. A precision $\overline{\text{SHDN}}$ pin threshold allows incorporation of accurate UVLO functions using a simple resistor divider.

Charge Cycle Termination and Automatic Restart

A LT3650 charger can be configured to terminate a battery charge cycle using one of two methods: it can use low charge current (C/10) detection, enabled by connecting the TIMER pin to ground, or terminate based on the onboard safety timer, enabled by connecting a capacitor to the TIMER pin. After termination, a new charge cycle automatically restarts should the battery voltage fall to 97.5% of the float voltage.

When C/10 termination mode is selected, the LT3650 terminates a charging cycle when the output current has dropped to 1/10 of the programmed maximum. In a 2A charger, for example, the charge cycle terminates when the battery charge current falls to 200mA.

Timer termination, or top-off charging, is enabled when a capacitor is connected to the TIMER pin. The value of the capacitor sets the safety timer duration—0.68µF corresponds to a 3-hour cycle time. When timer termination is implemented, the charger continues to operate in constant-voltage mode when charge currents fall below C/10, allowing additional low current charging to occur until the timer cycle has elapsed, thus maximizing use of the battery capacity. During top-off charging, the $\overline{\text{CHRG}}$ and $\overline{\text{FAULT}}$ status pins communicate "charge complete." At the end of the timer cycle, the LT3650 terminates the charging cycle.

After charge cycle termination, the LT3650 enters standby mode where the IC draws 85µA from the input supply and less than 1µA from the battery. Both the $\overline{\text{CHRG}}$ and $\overline{\text{FAULT}}$ pins are high impedance during standby mode. Should the battery voltage drop to 97.5% of the float voltage, the LT3650 automatically restarts and initializes a new charging cycle.

Safety Features: Preconditioning, Bad Battery Detection, and Temperature Monitor

Li-Ion batteries can sustain irreversible damage when deeply discharged, so care must be taken when charging such a battery. A gentle preconditioning charge current is recommended to activate any safety circuitry in a battery pack and to re-energize deeply discharged cells, followed by a full charge cycle. If a battery has sustained damage from excessive discharge, however, the battery should not be recharged. Deeply discharged cells can form copper shunts that create resistive shorts, and charging such a damaged battery could cause an unsafe condition due to excessive heat generation. Should a deeply discharged battery be encountered, a battery charger must be intelligent enough to determine whether or not the battery has sustained deep-discharge damage, and avoid initiating a full charge cycle on such a damaged battery.

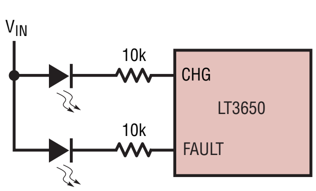

Figure 5. Visual charger status is easily implemented using LEDs

Table 1. Status pin state and corresponding operating states

$\overline{\text{CHRG}}$	$\overline{\text{FAULT}}$	Charger Status
High Impedance	High Impedance	Standby/Shutdown/Top-off
Low	High Impedance	CV/CC Charging (>C/10)
High Impedance	Low	Bad Battery Detected
Low	Low	Temperature Fault

The LT3650 employs an automatic precondition mode, which gracefully initiates a charging cycle into a deeply discharged battery. If the battery voltage is below the precondition threshold of 70% of the float voltage, the maximum charge current is reduced to 15% of the programmed maximum (0.15C) until the battery voltage rises past the precondition threshold.

If the battery does not respond to the precondition current and the battery voltage does not rise past the precondition threshold, a full-current charge cycle does not initiate.

If the safety timer is used for termination, the LT3650 also enables deep-discharge damage detection and incorporates a "bad battery" detection fault. Should the battery voltage remain below the precondition threshold for 1/8 of the charge cycle time (typically 22.5 minutes), the charger suspends the charging cycle and signals a "bad battery" fault on the status pins. The LT3650 maintains this fault state indefinitely, but automatically resets itself and starts a new charging cycle if the damaged battery is removed and another battery is connected.

Li-Ion batteries have a relatively narrow temperature range where they can be safely charged. The LT3650 has a provision for monitoring battery temperature, and suspends charging should the temperature fall outside of the safe charging range.

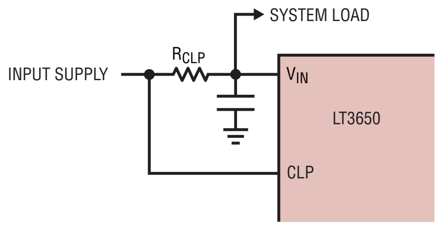

Figure 6. R_{CLP} sets the input supply current limit

Under/overtemperature protection is enabled by connecting a 10k (B = 3380) NTC thermistor from the IC's NTC pin to ground. This thermistor must be in close proximity to the battery, and is generally housed in the battery case. This function suspends a charging cycle if the temperature of the thermistor is greater than 40°C or less than 0°C. Hysteresis corresponding to 5°C on both thresholds prevents mode glitching. Both the $\overline{\text{CHRG}}$ and $\overline{\text{FAULT}}$ status output pins are pulled low during a temperature fault, signaling that the charging cycle is suspended. If the safety timer is used for termination, the timer is paused for the duration of a temperature fault, so a battery receives a full-duration charging cycle, even if that cycle is interrupted by the battery being out of the allowed temperature range.

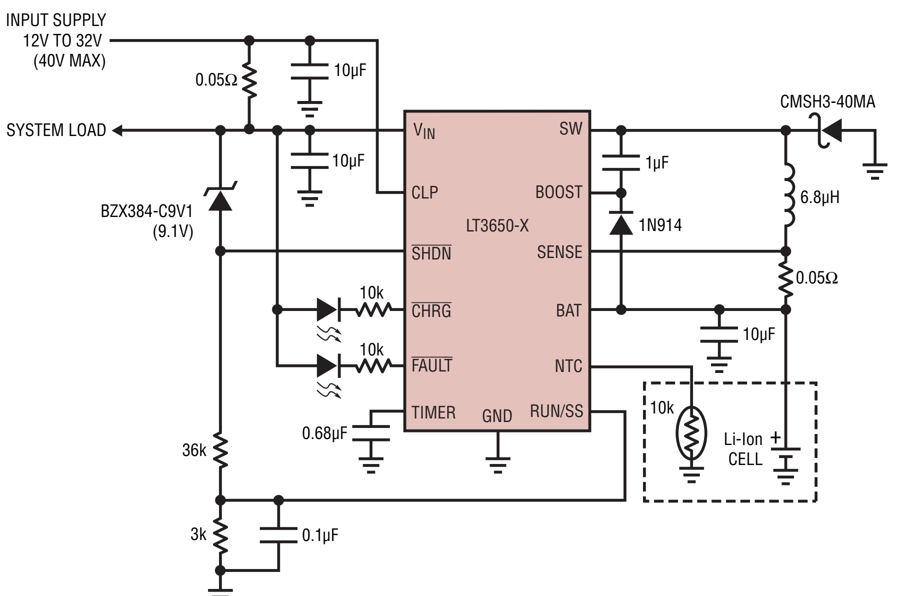

Figure 7. A single cell Li-Ion 2A battery charger with 3 hour safety timer termination, LED status indicators, temperature sensing, low input voltage charge current foldback, and input supply current limit

Status Indicator Pins

The status of a LT3650 charger is communicated via the state of two pins: $\overline{\text{CHRG}}$ and $\overline{\text{FAULT}}$. These status pins are open-collector pull-down, reporting the operational and fault status of the battery charger. CC/CV charging is indicated while charge currents are greater than 1/10 the programmed maximum charge current. The status pins also communicate bad battery and battery temperature fault states. Table 1 shows a fault-state matrix for these two pins.

The status outputs can be used as digital status signals in processor-controlled systems, and/or connected to pull current through an LED for visual status display. The status pins can sink currents up to 10mA and can handle voltages as high as 40V, so a visual display can be implemented by simply connecting an LED and series resistor to V_{IN}.

Maximum Charging Current Programming and Adjustment

Maximum charge current is set using an external sense resistor placed between the BAT and SENSE pins of the LT3650. Maximum charge current corresponds to 100mV across this resistor. The LT3650 supports maximum charge currents up to 2A, corresponding to a 0.05Ω sense resistor.

The LT3650 includes two control pins that allow reduction of the programmed maximum charge current. The RNG/SS pin voltage directly affects the maximum charge current such that the maximum voltage allowed across the sense resistor is 1/10 the voltage on RNG/SS for RNG/SS < 1V. This pin sources a constant 50μA, so the voltage on the pin can be programmed by simply connecting a resistor from the pin to ground. A capacitor tied to this pin generates a voltage ramp at start-up, creating a soft-start function. The pin voltage can be forced externally for direct control over charge current.

The IC includes a PowerPath™ control feature, activated via the CLP pin, which acts to reduce battery charge current should the load on a

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Power Management IC Combines USB On-The-Go and USB Charging in Compact Easy-to-Use Solution

by George H. Barbehenn and Sauparna Das

Introduction

The USB interface was originally designed so that the device providing power (an "A" device) would act as the host and the device receiving power (a "B" device) was the peripheral. The A plug of the USB cable would always connect to the host device and the B plug would connect to the peripheral. The USB On-The-Go (OTG) standard, however, removes that restriction, so that the B device can now become a host and the A device can act as a peripheral.

In the USB specification, standard hosts and hubs are limited to providing 500mA to each downstream device, but if a device is designated as a USB charger, it can supply up to 1.5A. USB chargers come in two flavors. A "dedicated charger" is a charger that is not capable of data communication with the attached B device. A "host/hub charger" is a charger that is capable of data communications with attached B devices.

When USB OTG functionality is combined with a USB battery charger in an end-user product, power can flow in both directions, with relatively complicated logic and handshaking steering the flow. To implement a robust solution, an integrated USB battery charger and power manager is a necessity. This article shows how to use the LTC3576 USB power management IC to easily combine USB On-The-Go functionality and battery charger capability into a single portable product.

Overview of the LTC3576

The LTC3576 provides the power resources needed to implement a portable device with USB OTG and USB battery charger detection capabilities (see block diagram in Figure 1). The USB input block contains a bidirec-

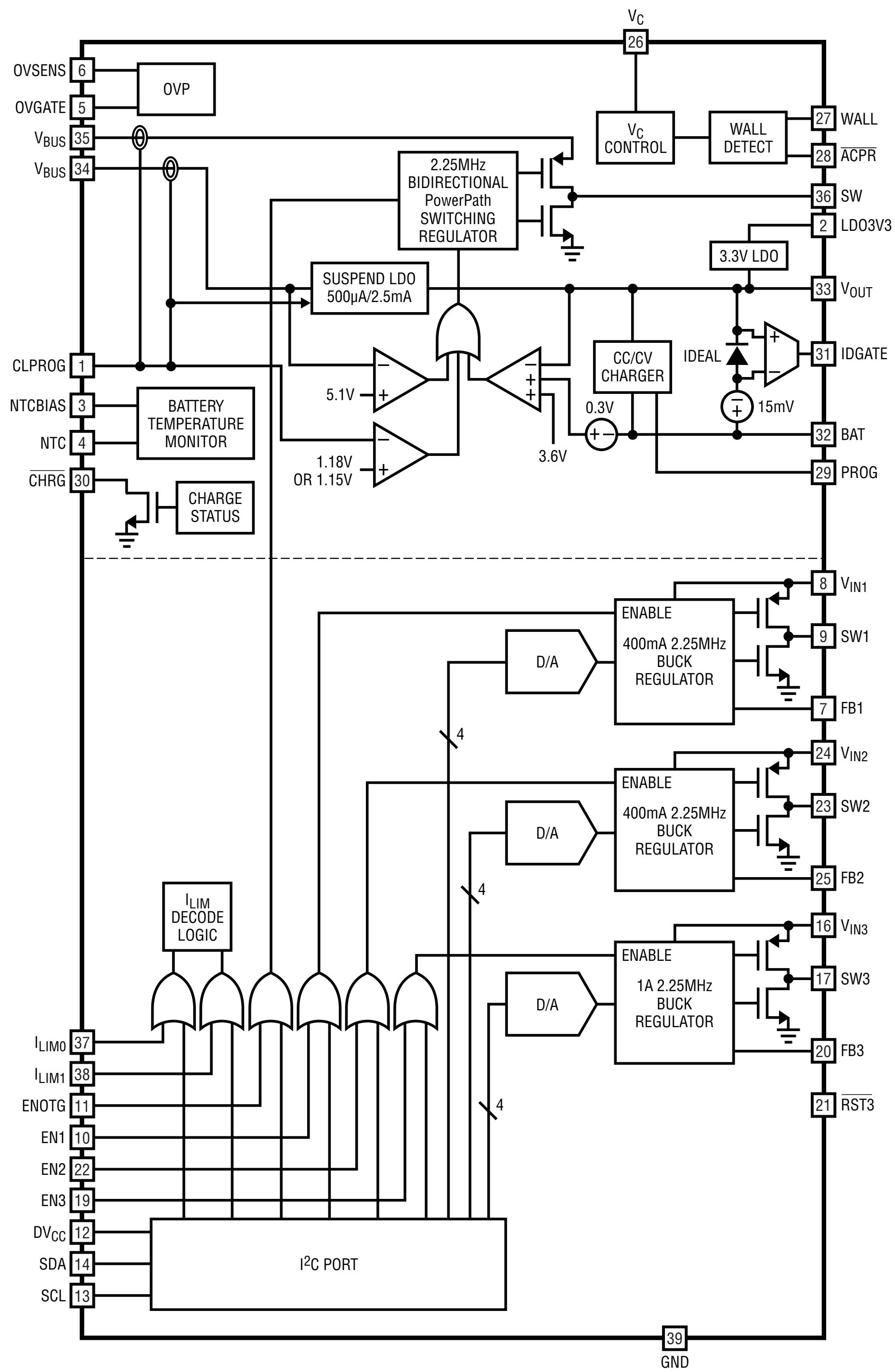


Figure 1. The LTC3576 combines USB charging and USB On-The-Go by using bidirectional DC/DC conversion from V_{BUS} to V_{OUT}

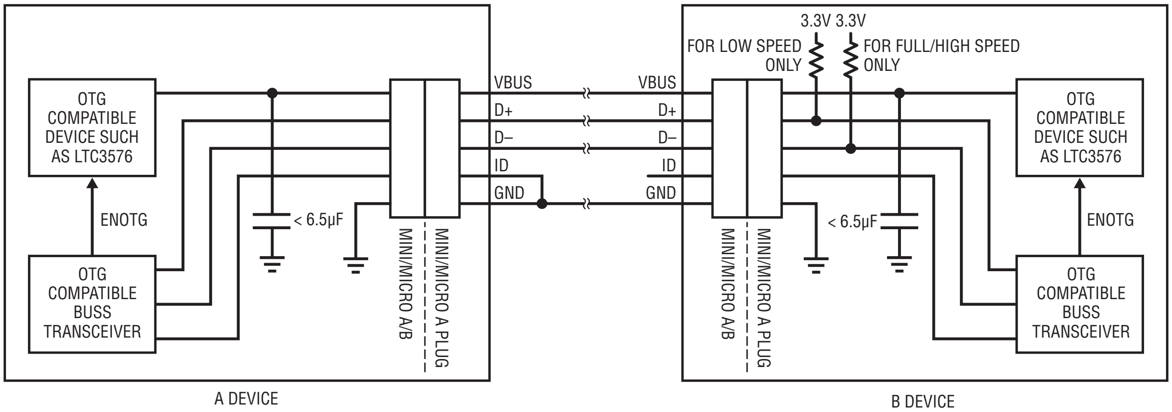


Figure 2. USB On-The-Go system diagram

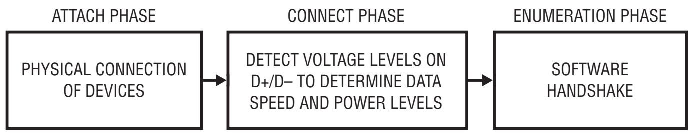


Figure 3. USB sequence of events at start-up

tional switching regulator between V_{BUS} and V_{OUT}. When power is coming from the USB input, this regulator operates as a step-down converter. Using the Bat-Track™ charging technique, the switching regulator sets the voltage at V_{OUT} to V_{BAT} + 0.3V, providing a very efficient charging solution. When operating as an OTG A device, the regulator acts as a step-up converter by taking power from V_{OUT} to produce 5V on V_{BUS}.

The LTC3576 also has overvoltage protection and can be used with an external HV Buck regulator to provide V_{OUT}. In OTG mode, the bidirectional switching regulator can take power from the HV buck regulator to supply power to the USB connection.

In addition, the LTC3576 provides two 400mA and one 1A step-down switching regulators for generating three independent voltage rails for the portable device. The LTC3576 allows all three step-down switching regulator output voltages to be enabled/disabled and adjusted over a 2:1 range via I^2C. All three step-down regulators feature pulse-skipping mode, Burst Mode® operation and LDO mode, which can also be adjusted on-the-fly via I^2C.

Mode Detection

The USB specification allows for a number of different modes of operation for products supporting both the USB OTG specification[1] and the battery charger specification[2]. Figure 2 shows a typical OTG system and Figure 3 shows the sequence of events that occur when the USB cable is plugged in. The product can be a B device and can draw up to 100mA, 500mA, 900mA or 1.5A, depending on the type of A device powering V_{BUS}, as shown in the Table 1.

When an OTG device has a micro/mini-A plug connected to its micro/mini-AB connector, the OTG device becomes the A device and starts off as the host. The OTG A device supplies power to V_{BUS}, as any other host A device would, when requested by an attached peripheral or OTG B Device. As an A device, the LTC3576 can supply up to 500mA

The USB OTG specification provides two means for a B device to signal to the A device that it wants power. The B device may drive the V_{BUS} line above 2.1V, momentarily, or it may signal by driving the D+ or D– signal lines. The D+/D– signaling method could be

Table 1. Load power signaling during Attach and Connect

	Host/Hub I_{BUS} < 500mA	Dedicated Charger I_{BUS} < 1.5A	Host/Hub Charger I_{BUS} < (LS,FS < 1.5A/HS < 0.9A)
Voltage on D– with VDAT_SRC on D+ during Attach	0V	0.5V–0.7V	0.5V–0.7V
1.5kΩ to 3.3V on D– during Connect for Low Speed, measure voltage on D+	—	> 2V	< 0.8V
1.5kΩ to 3.3V on D+ during Connect for Full/High Speed, measure voltage on D–	—	> 2V	< 0.8V

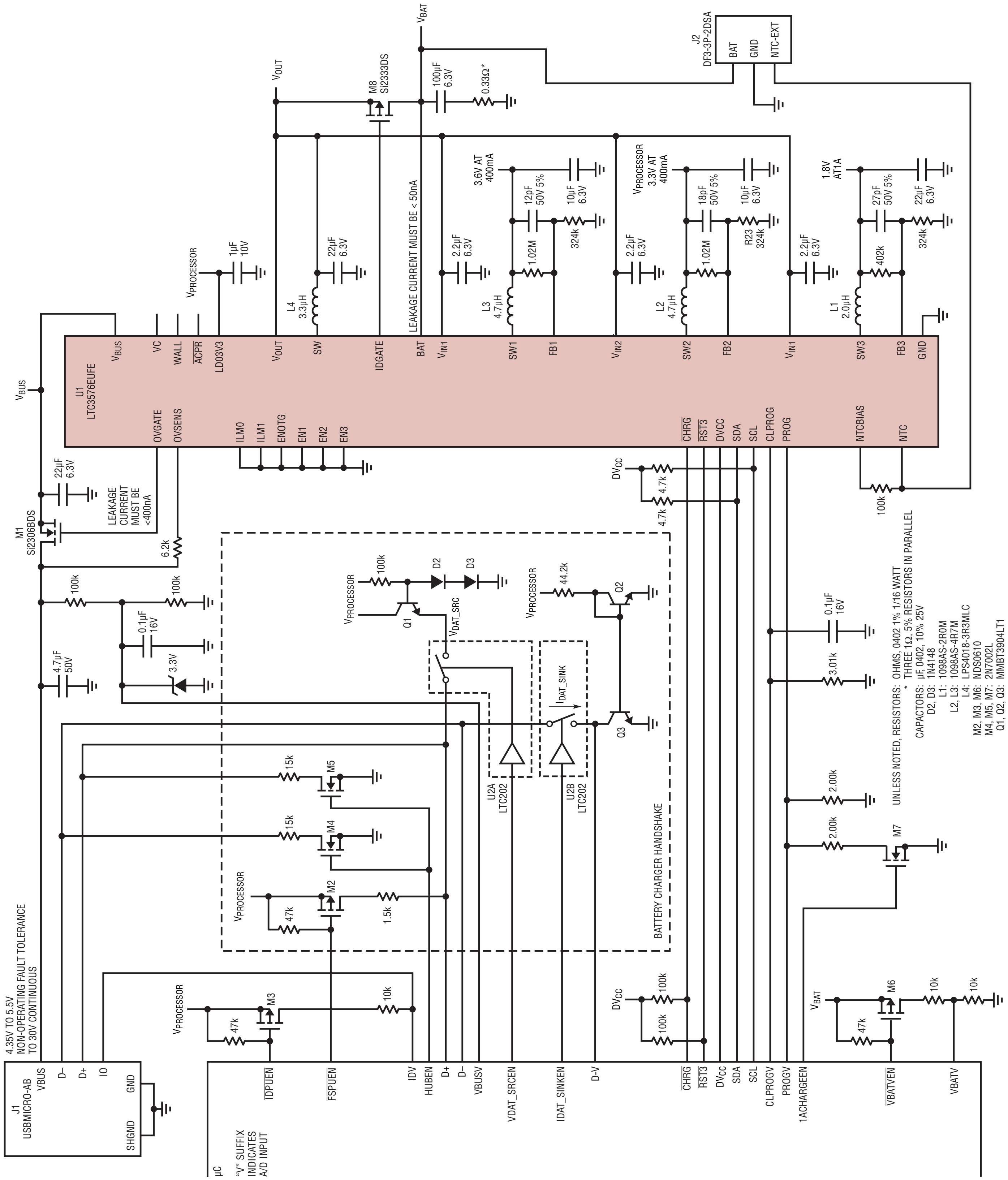


Figure 4. Portable system with OTG and battery charger support

detected by an OTG compatible USB module on the system microcontroller (µC). The V_{BUS} signaling method could be detected via an A/D on the µC. The LTC3576 bidirectional switching regulator is then enabled as a step-up converter (OTG mode) by setting the appropriate bit in the control registers via I^2C.

Implementing a System for USB OTG and Battery Charging

Figure 4 shows an application for a portable device that supports both USB battery charging and USB OTG.

When $\overline{\text{IDPUEN}}$ is low, the ID pin is pulled up via R5, and if IDV is > 3V then it is configured to be a B device. If IDV is < 0.5V then it is configured to be an A device. The components enclosed in the box labeled "battery charger handshake" enable communication of the power capabilities depending on whether the portable device is configured as an A device or a B device. During the Attach phase, if the portable device is a B device, it can apply V_{DAT_SRC} (0.5V~0.7V) to the D+ line, load the D– line with I_{DAT_SINK} (50µA~150µA), and measure the resultant voltage on D– via D–V. If the voltage is 0, the A device is a Host/Hub, if the voltage is V_{DAT_SRC} then the A device is a USB Charger.

During the Connect phase, $\overline{\text{FSPUEN}}$ is pulled low to apply 3.3V to D+, indicating a full/high speed device. At the same time the voltage on the D– line is read again via D–V. If it is less than 0.8V, then the A device is a Host/Hub Charger. If the voltage on D–V is above 2V, then the A device is a Dedicated Charger.

For OTG functionality, if the portable device is configured as an A device, then it must drive V_{BUS} from V_{OUT}, which in this case is powered from the battery. Since the LTC3576 is capable of supplying 500mA as an A device, the µC asserts HUBEN to indicate it is a Host/Hub. The bidirectional switching regulator in the LTC3576 is enabled by setting the appropriate bit in the control registers via the I^2C port. If the B device drawing current from the V_{BUS} line goes idle, then the OTG A device may turn off the V_{BUS} voltage to conserve the battery. When the B device needs the V_{BUS} voltage to be present at some later time, it can request that the A device again drive V_{BUS} by turning the bidirectional switching regulator back on. It can do this by signaling on the D+ or D– lines or by driving the V_{BUS} line to > 2.1V (see Figure 5).

The Host A device only needs to respond to one of two SRP signaling methods. However, since not all USB engines respond to the D+/D– signaling, the V_{BUS} line is sensed to check if it is higher than 2.1V via the VBUSV A/D input.

When the portable device's µC detects that the B device is requesting power on V_{BUS}, either by sensing the D+/D– signaling or by sensing that V_{BUS} has been driven higher than 2.1V, it should again turn on the OTG step-up converter in the LTC3576.

The PROG (PROGV) and BAT (VBATV) pins allow a Coulomb counter to be implemented in the µC. Reading the BAT voltage requires that the sensing divider be enabled by setting $\overline{\text{VBATVEN}}$ low. This ensures that the sense divider network does not discharge the battery when the battery voltage isn't being measured.

The default battery charge current has been set to 500mA, but can be increased to 1A by asserting the 1AchargeEN signal. This turns on M7, halving the PROG resistance and increasing the charge current. The input current limit will need to be set to 10X mode (1A) using the I^2C port.

The optional network of C14 and R27/R28/R29 suppresses ripple on the BAT pin (and consequently on the V_{BUS} pin) if there is no battery present. This ripple can be in the tens of mV. While this will not damage anything, it may be desirable to suppress this signal.

The CLPROG (CLPROGV) and $\overline{\text{CHRG}}$ signals are often useful for housekeeping tasks in the µC.

The LTC3576 has an overvoltage protection function that controls M1, and protects the system from excessive voltages on the USB (J1) connector. Because the A/D is configured to monitor V_{BUS}, it must also be protected by D1 from excessive voltages.

The LDO3V3 regulator is configured to power the µC in low power mode (<20mA). When the µC needs to leave low power mode it first enables Buck Regulator 2, which will provide up to 400mA.

Conclusion

The LTC3576 is a versatile PMIC consisting of a bidirectional power manager, overvoltage protection, three step-down switching regulators and a controller for an external high voltage step-down switching regulator. In conjunction with a few support components, the LTC3576 allows the implementation of a complete power management system for portable devices that support both USB OTG and USB battery charging.

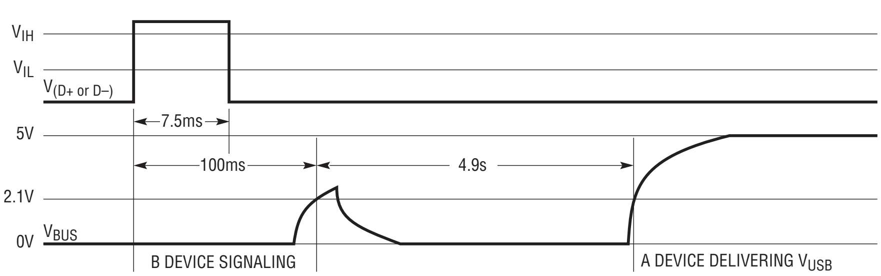


Figure 5. Session Request Protocol timing reference[1]

Bibliography

[1] "On-The-Go Supplement to the USB Specification", Revision 1.3

[2] "Battery Charging Specification", Revision 1.0

[3] www.usb,org/developers/docs

Power Management IC with Pushbutton Control Generates Six Voltage Rails from USB or 2 AA Cells Via Low Loss PowerPath Topology

by John Canfield

Introduction

As the complexity of portable electronic devices continues to increase, the demands placed on power supplies, and their designers, expand dramatically. Not only must typical power systems accommodate multiple input sources, with voltages as low as 1.8V for two AA cells, but they must also provide an increasing number of independent output rails to support a wide range of requirements—for memory, microprocessors, backlights, audio and RF components. To further complicate matters, expanding feature sets add up to increased power dissipation, making it important to optimize overall power system efficiency. This is particularly challenging given that the constant drive to minimize the required board area and profile height of the power system is at direct odds with improving efficiency.

The LTC3101 addresses all of these challenges with a single-IC power management solution that allows a designer to easily maximize overall power system efficiency while minimizing space requirements. The LTC3101 can generate six power rails by integrating three synchronous switching converters, two protected switched power outputs, and an LDO. Its integrated low loss PowerPath™ topology allows each switching converter to run directly from either of two input power sources.

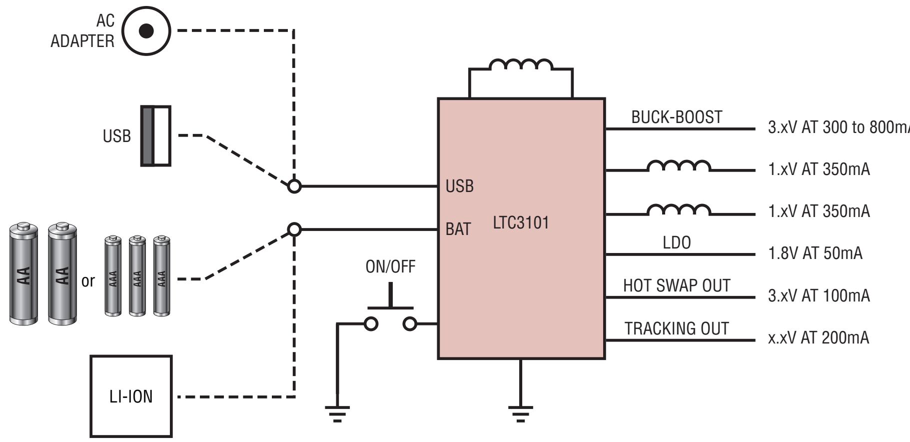


Figure 1. Six output rails, a low loss PowerPath and integrated pushbutton control

Two 350mA, high efficiency low voltage rails, typically used to power processors and memory, are generated by synchronous buck converters. Each converter is able to operate down to an input voltage of 1.8V thereby enabling single stage conversion from any input power source.

A single inductor buck-boost converter generates a high efficiency intermediate output rail, typically at 3V or 3.3V, and is able to operate from either input power source and with input voltages that are above, below, or even equal to the output regulation voltage. The buck-boost converter can supply a 300mA load at 3.3V for battery voltages down to 1.8V and an 800mA load for input voltages of 3.0V and greater.

Two always-alive outputs—MAX, which tracks the higher voltage input power source and LDO, a fixed 1.8V output—provide power to critical functions that must remain powered under all conditions. An integrated pushbutton controller with programmable µP reset generator provides complete ON/OFF control using only a minimal number of external components while independent enables allow total power-up sequencing flexibility. This complete portable power solution is packaged in a single low profile 24-lead 4mm × 4mm QFN package and the entire power supply, including all external components, occupies a PCB area of less than 3cm^2 as shown in Figure 2.

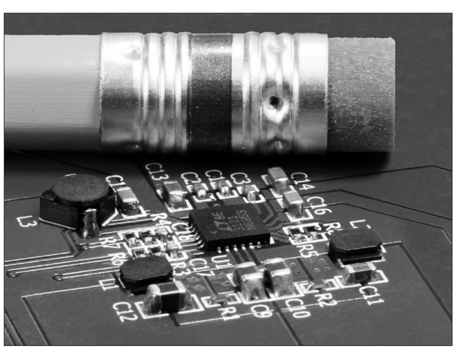


Figure 2. Complete portable power solution with a 16mm × 19mm footprint

Zero Loss PowerPath Topology Maximizes Efficiency

Although rechargeable Li-Ion and Li-Polymer batteries are the leading chemistries for powering portable devices due to their high energy density and long cycle life, many portable devices continue to be powered by alkaline and NiMH cells. This allows indefinite periods of use away from a charging socket—which is particularly important for devices intended for use in remote locales such as handheld personal navigation devices or portable medical devices. Voice recorders, digital still cameras and ultra-small video recorders are additional examples of devices that benefit from the ability to operate from a pair of commonly available batteries, rather than requiring the lengthy recharging cycle needed for an internal Li-Ion battery.

Even in portable devices where the primary power source is restricted to AA or AAA form factor cells, there still exist a wide variety of compatible chemistries including alkaline, rechargeable alkaline, NiMH and single-use lithium. As a result, the AA/AAA powered device must accommodate a wide range of input voltages, from 1.8V for two series alkaline cells near end of life, to approximately 3.7V for a pair of fresh non-rechargeable lithium cells. With its wide 1.8V to 5.5V input voltage range, the LTC3101 can easily support all of these battery chemistries. In addition, the LTC3101 is able to operate from a single standard Li-Ion/Polymer cell in cases where recharging is performed independently.

Although rechargeable cells are usually charged outside these types of devices, the power supply must accommodate a secondary tethered power source such as USB or a regulated wall adapter. Consequently, the power supply must include a means to generate every power rail from either of two input sources, and the ubiquitous 3.3V rail must be generated from input power sources that can be higher or lower voltage.

In many devices, the capability to handle dual power sources is provided by using discrete power MOSFETs to switch regulator inputs between the two input power sources or by utilizing two regulators for generation of each rail (for example, a buck converter that generates a 3.3V rail from the USB input in conjunction with a boost converter that generates the 3.3V rail from the battery input).

Both of these approaches suffer from significant drawbacks. The parallel converter approach increases system cost and size given that only one converter is ever active at any given time and often suffers from glitches and disruptions to the output rails during the transition between the two input power sources. Similarly, the discrete power switch technique reduces efficiency due to the addition of extra series elements in the power path, increases component count, and can also lead to disruptions in the output rails unless the supply crossover is carefully controlled.

The LTC3101 avoids these problems by using a low loss PowerPath topology as shown in Figure 4, where each converter is able to operate directly from either input power source. In this architecture, each switching converter utilizes an additional power switch, which is connected to the alternate power input. As a result, each converter is able to run with maximum efficiency from either input power source so no efficiency penalty is incurred in supporting dual input power sources.

The total solution area is minimized by the fact that the same inductor is used in either case. In addition, the automatic transition between the two input power sources is seamless—there is no interruption to any of the output rails. Figure 5 shows the transient response of the buck-boost converter as the input power source transitions from battery power to USB power in response to a live cable plug into a USB port.

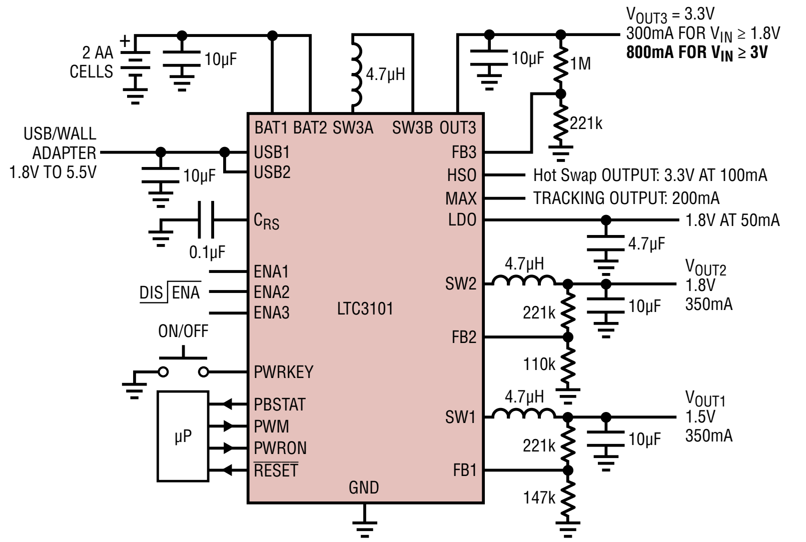


Figure 3. Typical application

Integrated Buck-Boost Provides High Efficiency 3V/3.3V Rail from Any Power Source

In many portable devices an intermediate supply rail, typically regulated to 3.3V, is required to power an RF stage or audio amplifiers. Often this rail is generated from the two series AA cells using a boost converter. However, the higher cell voltage of single-use lithium

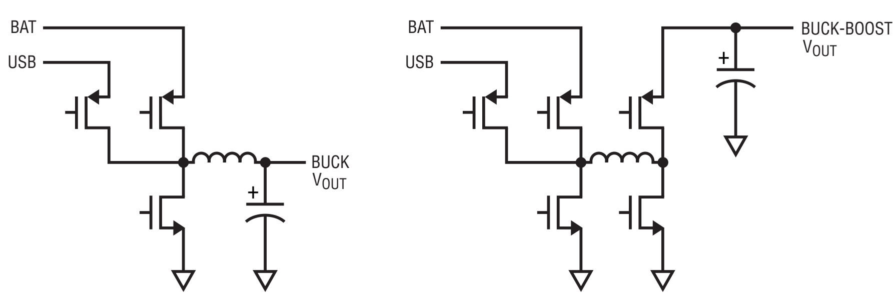


Figure 4. The low loss PowerPath architecture

batteries such as the Energizer e[2] brand can cause problems when the battery voltage is significantly higher than the output voltage. Depending on the boost converter utilized, this can result in low efficiency operation or even loss of regulation on the 3.3V rail.

To avoid this problem, the LTC3101 generates the 3.3V rail utilizing a buck-boost converter, which accepts any input voltage in the range 1.8V to 5.5V without sacrificing efficiency. In fact, when operating with a fresh pair of single-use lithium batteries at 3.7V, the LTC3101 buck-boost efficiency is greater than 94% at 150mA load current. In addition, the same buck-boost converter is able to operate directly from the USB input, so generation of the 3.3V rail requires only a single inductor.

Reverse Blocking LDO Enables Data Retention During Battery Swaps

Many portable electronic devices contain critical circuitry such as real time clocks, which must remain powered under all conditions. The MAX and LDO outputs of the LTC3101 are alive as long as either input power source is present, regardless of the state of the pushbutton interface or enable inputs. It is also possible to connect a large capacitor directly to the LDO output to serve as a charge reservoir for powering critical functions during times, such as battery swaps, when both input power sources are temporarily removed. In its reverse blocking state, the maximum reverse current through the LDO is limited to under 1µA in order to preserve charge in the reservoir capacitor.

MAX and Hot Swap Outputs Power Additional Regulators and Flash Memory Cards

Portable electronic devices often require additional miscellaneous power supplies, such as current regulated drivers for LED backlighting and LDOs for low power rails. Typically these secondary supplies must be functional whenever either input power source is present, so they also require power path control to switch between the two input power sources.

External supplies can take advantage of the LTC3101's PowerPath control circuit via the MAX output, which continuously tracks the higher voltage input power source. Additional regulators can be directly connected to this output, thus freeing the designer from the need to implement an additional switched power path. The MAX output is able to support a 200mA load and is current limited to protect against overload conditions and short circuits.

Many portable electronic devices provide flash memory card interfaces for use as bulk storage memory. Typical flash memory cards such as Compact Flash (CF) and Secure Digital (SD) formats require a regulated 3.3V supply that is typically capable of providing tens of milliamps. However, many flash memory cards have a significant amount of supply bypass capacitance installed on the card and when hot plugged into a live 3.3V rail, the inrush current required to charge these supply bypass capacitors on the memory card can momentarily drag down the host's supply, causing disruption to other ICs powered by that rail.

The LTC3101's dedicated 100mA hot swap output (powered from the buck-boost converter rail) does not have this problem. The independent current limit of the hot swap switch allows flash memory cards to be hot plugged without disruption to the primary 3.3V rail. In addition, the hot swap output is fully short circuit protected to safeguard against accidental shorts at the memory card interface port.

Low Quiescent Current Minimizes Battery Drain

Most portable electronic devices spend significant, if not the majority, of their time in sleep or standby modes. In fact, even when an appliance is off, there is often circuitry that must remain powered, including real time clocks and volatile memory storing configuration settings. The always-alive 1.8V LDO and tracking MAX outputs remain powered whenever either input power source is present allowing them to be utilized for supplying such critical functions. In order to minimize battery discharge during this time, the total quiescent current draw of the LTC3101 with both the MAX and LDO outputs active is reduced to 15µA.

Many portable electronic devices also support a standby mode in which several of the system's voltage rails must be kept in regulation. Typically, in standby the microprocessor and memory remain powered and the processor is placed in a low current sleep mode enabling the device to return to an active operating state with minimal delay.

In order to minimize battery drain in such modes of operation, all three switching converters in the LTC3101 feature Burst Mode operation, which can be enabled via a dedicated pin. With Burst Mode operation enabled, the buck converters automatically transition from PWM to Burst Mode operation at sufficiently light load (typically 10mA) while the buck-boost converter uses Burst Mode operation at all load currents. In Burst Mode operation with all six output rails maintained in regulation the total quiescent current draw of the LTC3101

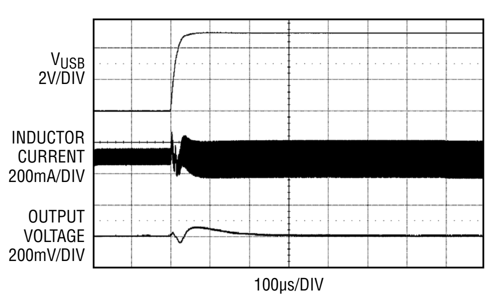


Figure 5. Buck-boost output voltage transient on USB hot plug

is reduced to only 38µA. In addition, to ensure low supply rail noise, the Burst Mode operation output voltage ripple is typically less than 1% of the regulation voltage of each output rail. All three switching converters can be forced into fixed frequency PWM mode operation to ensure low noise operation while critical system functions are underway.

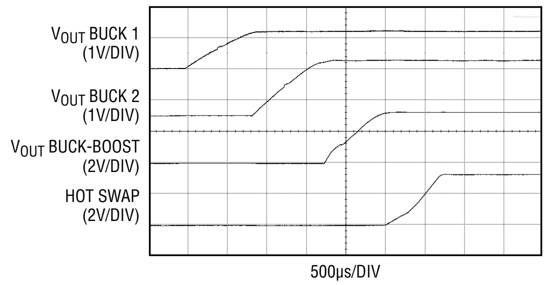


Figure 6. Default power-up sequencing

Flexible Power-Up Sequencing Options

The LTC3101 provides a variety of sequencing options. Most systems that incorporate multiple power supply rails require that they come into regulation in a certain sequence with specific timing. This is because individual ICs and modules that are powered from multiple rails need particular sequencing to minimize start-up current and ensure predictable power-up behavior.

Common examples include microprocessors and FPGAs, which often require that the peripheral supply powering the I/O buffers is made available only after the lower voltage core is in regulation. In addition, at the board level, many systems bring up the supplies for peripheral devices only after the processor is powered up to avoid erratic behavior from peripherals lacking processor oversight.

Each switching converter in the LTC3101 has an internal power-good comparator, which is used internally to sense when that rail is in regulation. The default power-up sequence enables the individual outputs in the following order: buck converter 1, buck converter 2, buck-boost converter, and finally the hot swap output. Each converter is enabled once the preceding converter in the sequence reaches regulation (typically 94% of the target output voltage). The default power-up sequence using all converter channels is shown in Figure 6.

If the dedicated enable pin for any switching converter is held low during the pushbutton triggered initiation, that converter is simply skipped in the default power-up sequence, but that channel can still be enabled at a later time. This functionality allows the LTC3101 to implement any arbitrary power-up sequence using few if any external components.

For example, in some systems the 3.3V buck-boost rail must come up first, followed by both buck rails in unison. This can be accomplished by driving the buck enables from the hot swap output, HSO, as shown in Figure 7. The bucks do not power up in the normal sequence since their enables are low to start. Once the buck-boost reaches regulation, the hot swap output is enabled, which in turn enables the two buck converters. Since the hot swap output is not powered until the buck-boost is in regulation, this configuration ensures that the buck converters do not become active until after the buck-boost is in regulation, as shown by the waveforms in Figure 8.

If an additional delay is required before the bucks are enabled, this can be accomplished by adding a simple RC filter with the desired time constant between the hot swap output and the buck enables. Notice however, that if the hot swap output is forced to ground, the buck converters will be disabled. If there is a potential for the hot swap output to fall below the enable threshold (typically 0.7V) during normal operation, then the buck enables can instead be driven through an RC delay from the buck-boost voltage directly rather than from the hot swap output.

Conclusion

The LTC3101 is perfectly suited for the needs of the next generation of extended functionality compact portable electronic devices.

The job of the power system designer is simplified by its compact solution footprint and ability to generate six commonly required output voltage rails automatically from two independent wide input voltage range power sources. The LTC3101's low quiescent current and a high efficiency, low loss PowerPath architecture maximize battery life. A wide range of output voltages, programmable duration µP reset generator, and independent enables offer flexibility and easy customization.

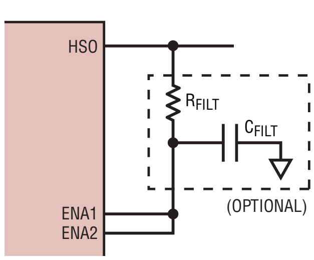


Figure 7. Sequencing the buck enables using the hot swap output rail

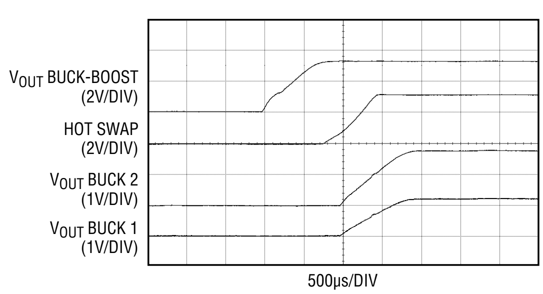


Figure 8. Power-up sequencing, buck-boost followed by the buck outputs

Improve Hot Swap Performance and Save Design Time with Hot Swap Controller that Integrates 2A MOSFET and Sense Resistor

by David Soo

Introduction

The LTC4217 Hot Swap controller turns a board's supply voltage on and off in a controlled manner allowing the board to be safely inserted and removed from a live backplane. No surprise there, this is generally what Hot Swap controllers do, but the LTC4217 has a feature that gives it an advantage over other Hot Swap controllers. It simplifies the design of Hot Swap systems by integrating the controller, MOSFET and sense resistor in a single IC. This saves significant design time that would otherwise be spent choosing an optimum controller/MOSFET combination, setting current limits, and carefully designing a layout that protects the MOSFET from excessive power dissipation.

One significant advantage of an integrated solution over discrete solutions is that the current limit accuracy is well known. In discrete solutions, the overall precision of the current limit is a function of adding the tolerances of contributing components, while in the LTC4217, it appears as a single 2A specification.

The integrated solution also simplifies layout issues by optimizing MOSFET and sense resistor connections. The inrush current, current limit threshold and timeout can be set to default values with no external components or easily adjusted using resistors and capacitors to better suit a large range of applications. The part is able to cover a wide 2.9V to 26.5V voltage range and includes a temperature and current monitor. The MOSFET is kept in the safe-operating–area (SOA) by using a time-limited foldback current limit and overtemperature protection.

The LTC4217 can be easily applied in its basic configuration, or, with a few additional external components, set up for applications with special requirements.

Monitoring the MOSFET

The LTC4217 features MOSFET current and temperature monitoring. The current monitor outputs a current proportional to the MOSFET current, while a voltage proportional to the MOSFET temperature is available. This allows external circuits to predict possible failure and shutdown the system.

The current in the MOSFET passes through a sense resistor, and the voltage on the sense resistor is converted to a current that is sourced out the I_{MON} pin. The gain is 50µA from I_{MON} for 1A of MOSFET current. The output current can be converted to a voltage using an external resistor to drive a comparator or ADC. The voltage compliance for the I_{MON} pin is from 0V to ($INTV_{CC}$ – 0.7V).

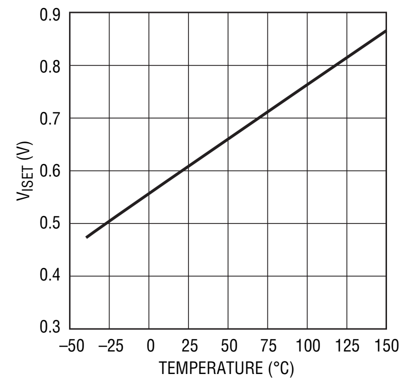


Figure 1. V_{ISET} vs temperature

The MOSFET temperature corresponds linearly to the voltage on the I_{SET} pin, with the temperature profile shown in Figure 1. The open circuit voltage on this pin at room temperature is 0.63V. In addition, the overtemperature shutdown circuit turns off the MOSFET when the controller die temperature exceeds 145°C, and turns it on again when the temperature drops to 125°C.

12V Application

Figure 2 shows the LTC4217-12 in a 12V Hot Swap application with default settings. The only external component required is the capacitor on the $INTV_{CC}$ pin. The current limit, inrush current control, and protection timer are internally set at levels that protect the integrated MOSFET. The input voltage monitors are preset for a 12V supply using internal resistive dividers from the V_{DD} supply to drive the UV and OV pins. The UV condition occurs when V_{DD} falls below 9.23V; OV when V_{DD} exceeds 15.05V.

The LTC4217 turns a board's supply voltage on and off in a controlled

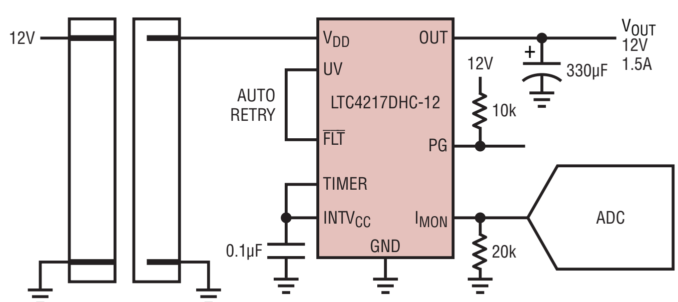


Figure 2. 12V, 1.5A card resident application

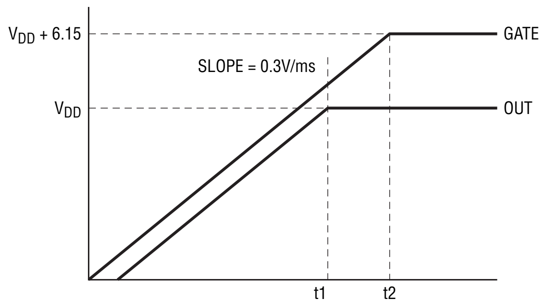


Figure 3. Supply turn-on

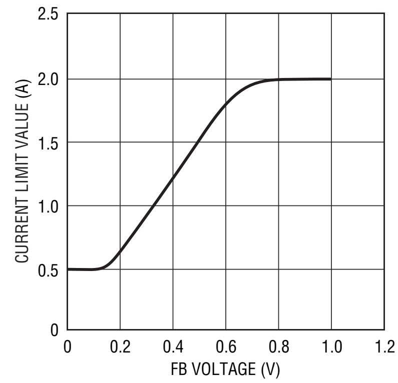


Figure 4. Current limit threshold foldback

manner, allowing the board to be safely inserted and removed from a live backplane. Several conditions must be present before the internal MOSFET can be turned on. First the V_{DD} supply exceeds its 2.73V undervoltage lockout level and the internally generated $INTV_{CC}$ crosses 2.65V. Next the UV and OV pins must indicate that the input power is within the acceptable range. These conditions must be satisfied for the duration of 100ms to ensure that any contact bounce during the insertion has ended.

The MOSFET is then turned on by a controlled 0.3V/ms gate ramp as shown in Figure 3. The voltage ramp of the output capacitor follows the slope of the gate ramp thereby setting the supply inrush current at:

$$I_{INRUSH} = C_L \bullet (0.3V/ms)$$

To reduce inrush current further, use a shallower voltage ramp than the default 0.3V/ms by adding a ramp capacitor (with a 1k series resistor) from gate to ground.

As OUT approaches the V_{DD} supply, the powergood indicator (PG) becomes active. The definition of power good is the voltage on the FB pin exceeds 1.235V while the GATE pin is high. The FB pin monitors the output voltage via an internal resistive divider from the OUT pin. Once the OUT voltage crosses the 10.5V threshold and the GATE to OUT voltage exceeds 4.2V, the PG pin ceases to pull low and indicates that the power is good. Once OUT reaches the V_{DD} supply, the GATE ramps until clamped at 6.15V above OUT.

The LTC4217 features an adjustable current limit with foldback that protects against short circuits or excessive load current. The default current limit is 2A and can be adjusted lower by placing a resistor between the I_{SET} pin and ground. To prevent excessive power dissipation in the switch during active current limit, the available current is reduced as a function of the output voltage sensed by the FB pin as shown in Figure 4.

An overcurrent fault occurs when the current limit circuitry has been engaged for longer than the delay set by the timer. Tying the TIMER pin to $INTV_{CC}$ configures the part to use a preset 2ms overcurrent time-out and a 100ms cool-down time. After the 100ms cool-down, the switch is allowed to turn on again if the overcurrent fault has been cleared. Bringing the UV pin below 0.6V and then high clears the fault. Tying the $\overline{FLT}$ pin to the UV pin allows the part to self-clear the fault and turn on again after the 100ms cool-down.

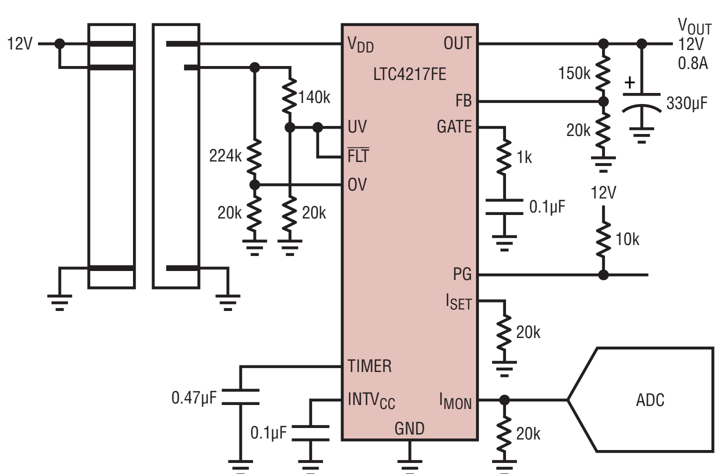


Figure 5. 0.8A, 12V card resident applicaiton

Programmable Features

The LTC4217 application shown in Figure 5 demonstrates the adjustable features.

The UV and OV resistive dividers set undervoltage and overvoltage turn-off thresholds while the FB divider determines the power good trip point. The R-C network on the GATE pin decreases the gate ramp to 0.24V/ms from the default 0.3V/ms to reduce the inrush current.

The 20k I_{SET} resistor forms a resistive divider with an internal 20k resistor to reduce the current limit threshold (before foldback) to one-half of the original threshold for a 1A current limit. The graph in Figure 6 shows the current limit threshold as the I_{SET} resistor varies.

As in the previous application, the UV and $\overline{FLT}$ signals are tied together so that the part auto-retries turn-on following shutdown for an overcurrent fault.

continued on page 25

Compact No R_{SENSE} Controllers Feature Fast Transient Response and Regulate to Low V_{OUT} from Wide Ranging V_{IN}

by Terry J. Groom

Introduction

The trend in digital electronics is to lower voltages and increasing load currents. This puts pressure on DC/DC converters to produce low voltages from increasingly voltage-variable supplies, such as stacked batteries and unregulated intermediate power buses, so power converters must be optimized for low output voltages, low duty factors, and wide control bandwidths. To meet these requirements, the DC/DC controller IC must offer high voltage accuracy, good line and load regulation, and fast transient response. The constant on-time valley current mode architecture used in the LTC3878 and LTC3879 is ideally suited to low duty factor operation, offering a compact solution with excellent system performance.

The LTC3878 and LTC3879 are a new generation of No R_{SENSE}™ controllers that meet the demanding requirements of low voltage supplies for digital electronics. The LTC3878 is a pin compatible replacement for the LTC1778 in designs where $EXTV_{CC}$ is not required. The LTC3879 adds separate RUN and TRACK/SS pins for applications requiring voltage tracking. Both devices offer continuously programmable current limit, using the bottom MOSFET V_{DS} voltage to sense current.

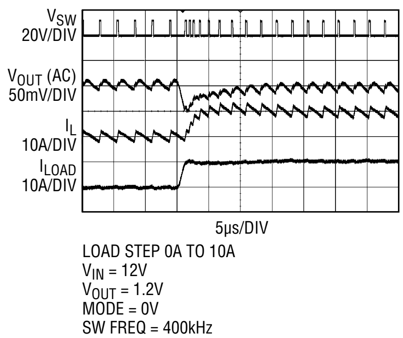


Figure 1. Transient response, positive load step

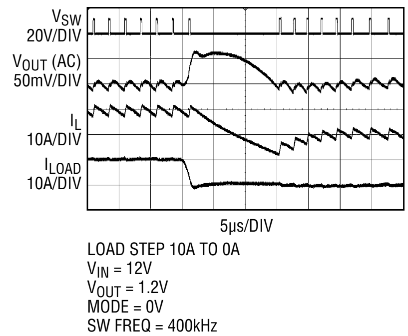


Figure 2. Transient response, load release

Valley Current Mode Control Simplifies Loop Compensation...

There are two common implementations of current mode control. Peak current mode control regulates the high side MOSFET on-time, while valley current mode regulates the bottom side MOSFET off-time. The current mode loop bandwidth is inversely proportional to the on-time for a peak current controller and inversely proportional to the off-time for a valley mode controller. A peak current mode controller with an on-time of 50ns must have a closed current loop bandwidth exceeding 20MHz. For a valley current mode controller, the current loop bandwidth is determined by the typical off-time of 220ns, resulting in a closed current loop bandwidth requirement of only 4.5MHz. Consequently, valley current mode control has less stringent bandwidth requirements for the same system performance when compared to a peak current mode control in a similar application. This allows the LTC3878 and LTC3879 to offer high performance, low duty factor operation at reasonable current loop bandwidths.

The constant on-time valley current mode control of the LTC3878 and LTC3879 simplifies compensation design by eliminating the need for slope compensation. A fixed frequency valley mode controller requires slope compensation when operating at less than 50% duty factor to prevent subcycle oscillation. Subcycle oscillation occurs because the PWM pulse width is not uniquely determined by inductor current alone. This oscillation cannot exist in constant-on-time control because the PWM pulse width is uniquely determined by the internal open loop pulse generator. True current mode control and constant on-time combine to give the LTC3878 and LTC3879 performance advantages over other constant on-time regulators or fixed frequency valley current mode control architectures.

...and Improves Transient Response Time

In a buck controller, transient response is largely determined by how quickly the inductor current responds to loop disturbances. The most demanding loop disturbances are load steps and load releases.

The inherent speed advantage of a constant on-time architecture lies in the fact that the regulator is pulse frequency modulated (PFM) insead of pulse width modulated (PWM). Although the switching frequency is fixed in steady state operation, it can increase or decrease as required in response to an output load step or load release.

The maximum frequency in response to a load step is determined by the on-time plus the off-time:

$$f_{MAX} = \frac{1}{\left(t_{ON} + t_{OFF(MIN)}\right)} (Hz)$$

In low duty factor applications the maximum frequency is typically much greater than the nominal operating frequency, producing excellent transient characteristics.

Figure 1 shows the load step response of a 12V-to-1.2V converter operating at 400kHz. In this case the on-time is equal to 250ns and the minimum off-time is 220ns. The maximum frequency available to respond to a load step is 2.12MHz, which is over five times the nominal switching frequency. Note the increase in switching frequency of the V_{SW} waveform in response to the 10A load step. The increase in switching frequency causes the inductor current to ramp faster in constant on-time PFM controllers than is possible in a true fixed frequency PWM.

In response to a load release (Figure 2), the minimum frequency is effectively zero, since the bottom gate is held high as long as needed to ramp the inductor current down to the internal regulation set point. In this example, the inductor current ramps from 11A to –8A in 13μs as the output recovers from the load step. For both load transient cases, variable frequency has an inherent speed advantage over fixed frequency in transient recovery.

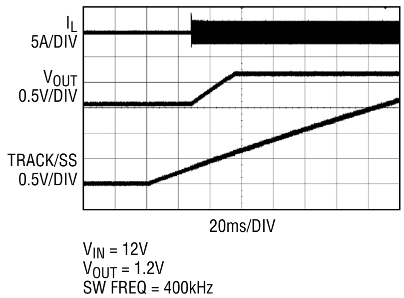


Figure 3. Start-up into a prebiased output

Transient settling requires both the large signal ramping of inductor current and the stable settling of the output to the desired regulation point. Excessive output overshoot or ringing indicates marginal system stability likely caused by inadequate compensation. A rough compensation check can be made by calculating the gain crossover frequency, given by the following equation (where V_{REF} = 0.8V for the LTC3878 and V_{REF} = 0.6V for the LTC3879):

$$f_{CGO} = g_m(EA)R_C \frac{I_{LIMIT}}{1.6} \bullet \frac{1}{C_{OUT}} \bullet \frac{V_{REF}}{V_{OUT}}$$

As a rule of thumb, the gain crossover frequency should be less than 20% of the switching frequency. With any analog system, transient response is determined by closed loop bandwidth. In order to optimize for transient performance, it is desirable to have a small inductor and a wide closed loop bandwidth. A small inductor is desired for quick output current response, while the closed loop bandwidth and phase margin determines how quickly the output settles after a load step.

Start-Up Options

The LTC3878 offers the simplicity of current limited start-up through the combined RUN/SS pin. When RUN/SS is greater than 0.7V all internal bias is activated. Once RUN/SS exceeds 1.5V, switching begins. The current limit is gradually increased as the RUN/SS pin voltage ramps until reaching full output at approximately 3V.

The LTC3879 adds the flexibility of separate RUN and TRACK/SS pins. All internal bias is activated when RUN exceeds 0.7V. Switching begins when RUN exceeds 1.5V. The TRACK/SS pin can also be used for input voltage tracking, where the LTC3879's output tracks the voltage on the TRACK/SS pin until it exceeds 0.6V. Once TRACK/SS exceeds 0.6V the output regulates to the internal 0.6V reference. An internal 1μA pull-up current is available to create a soft-start voltage ramp when a small capacitor is connected to TRACK/SS. Together, RUN and TRACK/SS enable a number

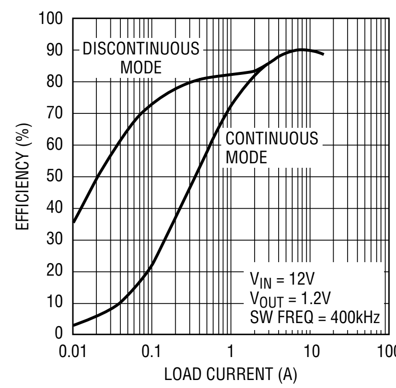


Figure 4. Efficiency for application in Figure 5

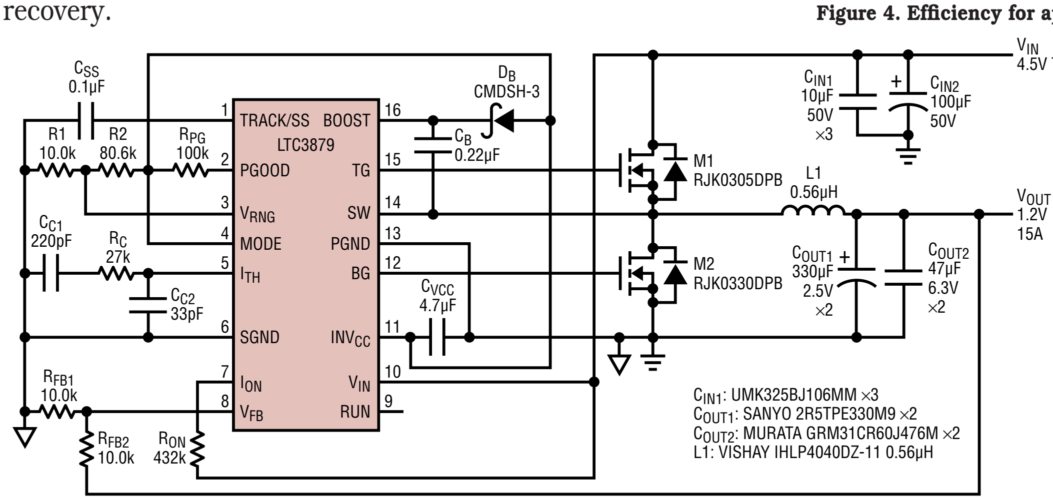


Figure 5. Wide input range to 1.2V at 15A, operating at 400kHz

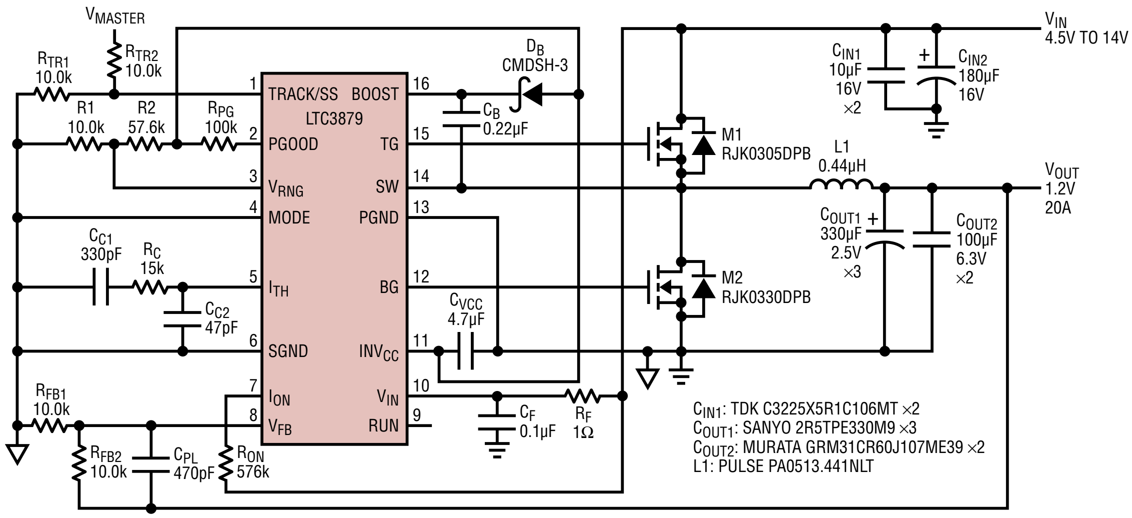


Figure 6. Coincident tracking example produces 1.2V at 20A, operating at 300kHz

of start-up supply sequencing and tracking options.

Both the LTC3878 and LTC3879 have the ability to start up onto prebiased outputs. Because current limit is ramped in the LTC3878, prebiased output voltages are not an issue. The LTC3879 output tracks the input on the TRACK/SS pin. To accommodate prebiased outputs, the LTC3879 will not switch until the TRACK/SS pin exceeds the V_{FB} voltage. Once TRACK/SS exceeds V_{FB} the output follows the TRACK/SS pin in continuous conduction mode until the output regulates to the internal reference.

In Figure 3 the LTC3879 output is prebiased to 0.5V. The TRACK/SS pin ramps from zero and crosses the prebiased output feedback point at approximately 28ms, when switching begins. Once switching begins the output enjoys a smooth soft-start ramp. The LTC3879 operates in continuous conduction mode during start-up, regardless of the mode setting, allowing regulation of the output voltage to the TRACK/SS input pin voltage during soft-start.

High Efficiency

The LTC3879 and LTC3879 offer excellent efficiency through the combination of strong gate drivers and short dead time. The top gate driver offers a 2.5Ω pull up resistance and a 1.2Ω pull down, while the bottom gate driver offers a 2.5Ω pull up and a 0.7Ω pull down. Dead time has been measured as low as 12ns, minimizing switching loss. Efficiency has been measured at 91.8% in a 1.2V/20A application.

The LTC3878 and LTC3879 offer both discontinuous conduction mode (DCM) and continuous conduction mode (CCM) operation. Figure 4 shows peak efficiency over 90% for 12V and 15A in CCM. In CCM, either the top MOSFET or the bottom MOSFET is active and the output inductor is continuously conducting. In DCM, the top and bottom MOSFET can be off simultaneously in order to improve low current efficiency. In Figure 4, at 100mA, the efficiency is greater than 70% in DCM, compared to only 20% in CCM. Improvements in efficiency in DCM are seen when the load is less than the DC average of the steady state ripple current, causing the regulator to enter discontinuous conduction.

Application Example: 4.5V-to-28V In to 1.2V Out with 90% Peak Efficiency

Figure 5 shows an application that converts a wide 4.5V-to-28V input voltage to a 1.2V ±5% output at 15A. The nominal ripple current is chosen to be 35% resulting in a 0.55µH inductor and ripple current of 5.1A. Because the top MOSFET is on for a short time, an RJF0305DPB ($R_{DS(ON)}$ = 10mΩ (nominal), C_{MILLER} = 150pF, V_{MILLER} = 3V) is sufficient. The stronger RJK0330DPB is chosen for the bottom MOSFET, with a typical $R_{DS(ON)}$ of 3.8mΩ. This results in 90% peak efficiency. Note that the efficiency, transient and start-up waveforms in Figures 1–4 were taken from this design example.

Tracking

Figure 6 shows a LTC3879 in a 1.2V/20A output, 300kHz application design with coincident rail tracking. In coincident tracking, two supplies ramp up in unison until the lower voltage supply reaches regulation, at which point the higher voltage supply continues to ramp to its regulated value. Coincident tracking is implemented by making the resistor divider from the master voltage to the TRACK/SS pin equal to the feedback divider from V_{OUT} to V_{FB}. In Figure 6, the output is 1.2V, so the divider is equal to 0.6V/1.2V, or 0.5. This design tracks any master supply that is equal to or greater than 1.2V. The TRACK/SS pin should be greater than 0.65V in regulation to ensure that the LTC3879 has sufficient

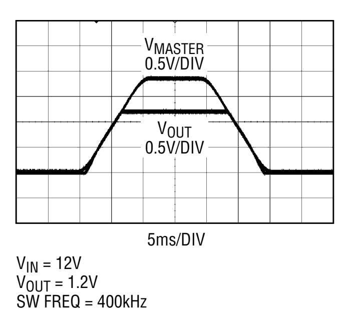


Figure 7. Coincident tracking waveforms for application in Figure 6

margin to switch from tracking the TRACK/SS input voltage to regulating to the internal reference.

Figure 7 shows typical tracking waveforms of the application in Figure 6. V_{OUT} and the reference supply voltage, V_{MASTER}, are equal and track together during start-up until they reach 1.2V, at which point V_{OUT} regulates to 1.2V while V_{MASTER} continues ramping to 1.8V.

Conclusion

The LTC3878 and the LTC3879 support a V_{IN} range from 4V to 38V (40V abs max). The regulated output voltage is programmable from 90% V_{IN} down to 0.8V (for the LTC 3878) and 0.6V (for the LTC3879). The output regulation accuracy is ±1% over the full –40°C to 85°C temperature range. The operating frequency is resistor programmable and is compensated for variations in V_{IN}. Current limit is continuously programmable and is measured without a sense resistor by using the voltage drop across the external synchronous bottom MOSFET.

The valley current mode architecture is ideal for low duty factor operation and allows very low output voltages at reasonable current loop bandwidths. Compensation is easy to design and offers robust and stable operation even with low ESR ceramic output capacitors. The LTC3878 offers current limited start-up, while the LTC3879 has separate run and output voltage tracking pins. The LTC3878 is available in the GN16 package, and the LTC3879 is available in thermally enhanced MSE16 and QFN (3mm × 3mm) packages. Excellent performance and compact size make the LTC3878 and LTC3879 well suited to small, tightly constrained applications such as distributed power supplies, embedded computing and point of load applications.

LT3757/58, continued from page 4

An 18V–72V Input, 5V/2A Output Isolated Flyback Converter

The basic design shown in Figure 7 can be modified to provide DC isolation between the input and output with the addition of a reference, such as the LT4430, on the secondary side of the transformer and an optocoupler to provide feedback from the isolated secondary to the LT3758. Figure 8 shows an 18V–72V input, 5V/2A output isolated flyback converter.

Conclusion

The LT3757 and LT3758 are versatile control ICs optimized for a wide variety of single-ended DC/DC converter topologies. Both offer a particularly wide input voltage range. These ICs produce space saving, cost efficient and high performance solutions in any of these topologies. The range of applications extends from single-cell, lithium-ion powered systems to automotive, industrial and telecommunications power supplies.

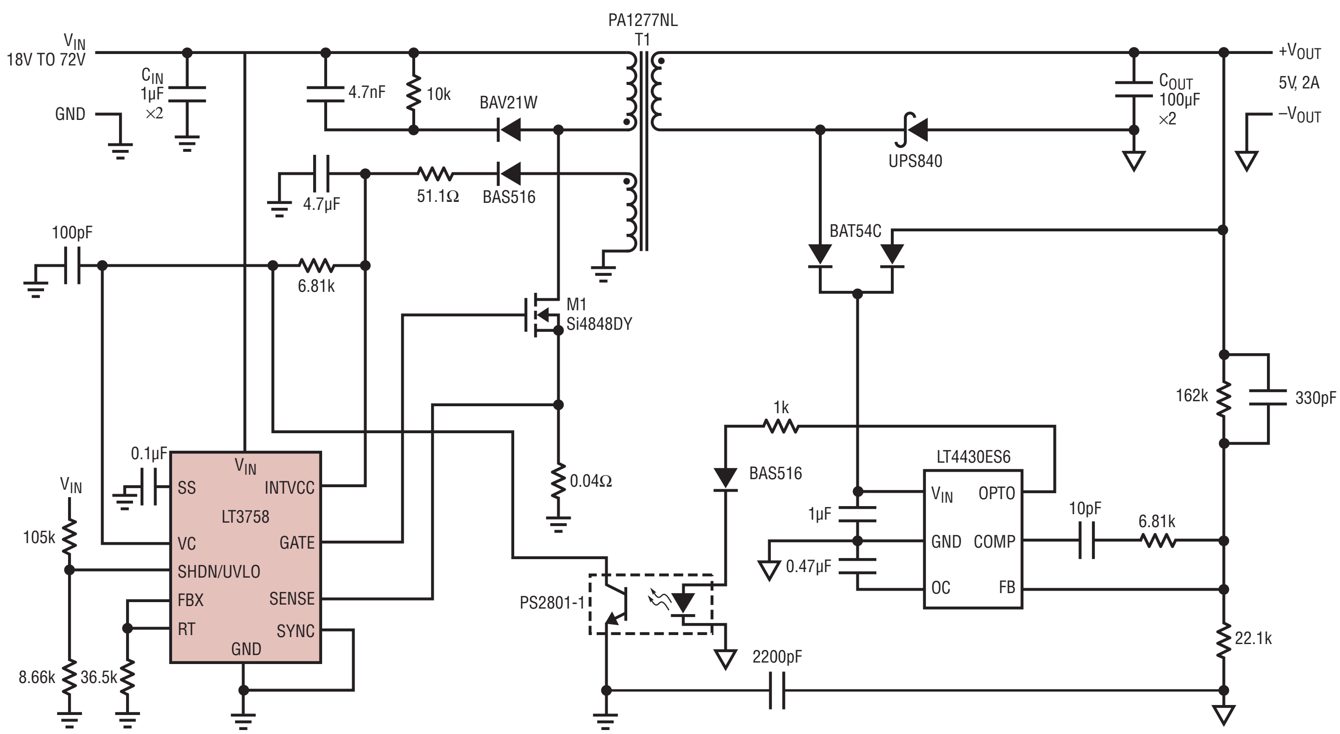


Figure 8. 18V–72V input, 5V/2A isolated flyback converter

Space-Saving, Dual Output DC/DC Converter Yields Plus/Minus Voltage Outputs with (Optional) I^2C Programming

by Mathew Wich

Introduction

There are many applications that require both positive and negative DC voltages generated from a single input supply. The LT3582 is a highly integrated dual switching regulator that produces positive and negative voltages for AMOLEDs, CCDs, op amps, and general ±5V and ±12V supplies. The LT3582 uses a novel control scheme resulting in low output voltage ripple and high conversion efficiency over a wide load current range. The total solution size is very small due to the tiny 3mm × 3mm 16-pin QFN package, integrated feedback resistors, integrated loop compensation networks and the single-inductor negative output topology (see Figure 1).

The LT3582-5 and LT3582-12 are factory configured for accurate ±5V and ±12V outputs respectively, making it easy to squeeze a high performance solution into a small space. For other voltage combinations, the LT3582 offers I^2C digitally programmable outputs of 3.2V to 12.775V and –1.2V to –13.95V that can be made permanent with on-chip OTP (One-Time-Programming) memory. The input supply range is 2.55V to 5.5V and switch current limits are 350mA and 600mA for the boost and inverting switches, respectively. In addition, the LT3582 features power up sequencing with ramping from ground to regulation, power down discharging, positive output disconnect and soft-start.

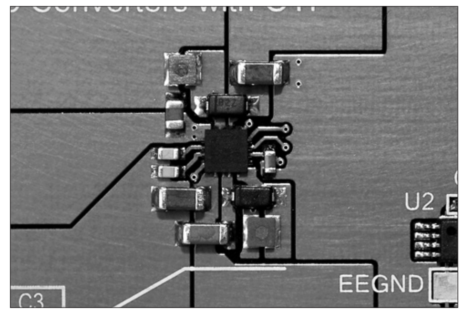


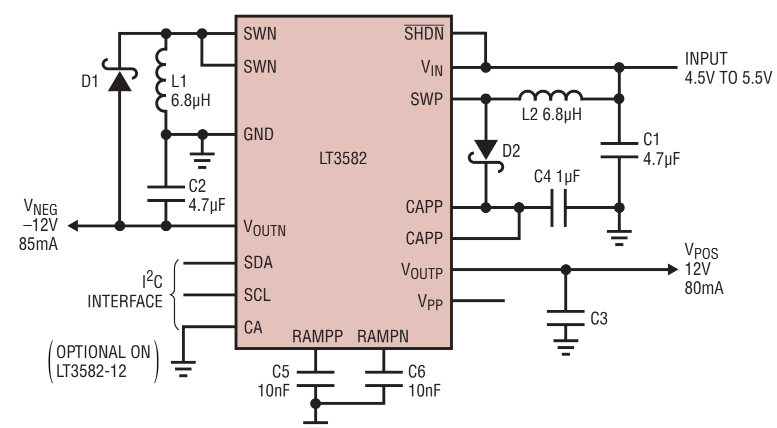
Figure 1. Dual output supplies in a small board footprint

Accurate Output Voltages without External Feedback Resistors

The LT3582 series uses integrated feedback resistors to select the output voltages. The LT3582-5 and LT3582-12 are pre-configured at the factory for ±5V and ±12V outputs with ±1.5% accuracy or better. The LT3582 allows other output voltages to be configured using the I^2C interface. There are nine bits to configure the positive output voltage from 3.2V to 12.775V in 25mV steps and another eight bits to configure the negative output voltage from –1.2V to –13.95V in 50mV steps. Default settings can be stored in One-Time-Programmable memory and, if left unlocked, the voltages can be subsequently changed on the fly using the I^2C interface.

Great Performance Includes Low Ripple and High Efficiency Across the Load Range

The LT3582 is among several novel parts from Linear Technology that modulate peak switch current and switch off time to reduce ripple and improve light load efficiency (also see the LT3494, LT3495, LT8410 and



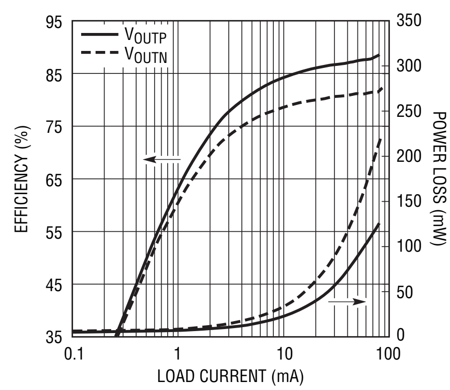
REG0/OTP0 = B0h
REG1/OTP1 = D8h
REG2/OTP2 = 03h

D1-D2: DIODES INC. B0540WS-7
L1-L2: COILCRAFT XPL2010-682
C1: 4.7µF, 6.3V, X5R, 0805

C2: 4.7µF, 16V, X5R, 0805
C3: 1× 4.7µF OR 2× 4.7µF OR 10µF 16V, X5R, 0805

C4: 1µF, 16V, X5R, 0603
C5-C6: 10nF, 0603

Figure 2. ±12V supplies from a single 5V input



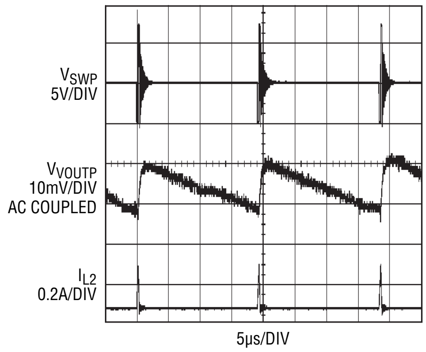


Figure 3. Switching waveforms at 1mA load for the boost application shown in Figure 2

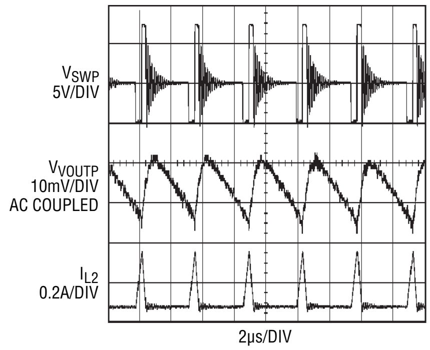


Figure 4. Switching waveforms at 10mA load for the boost application shown in Figure 2

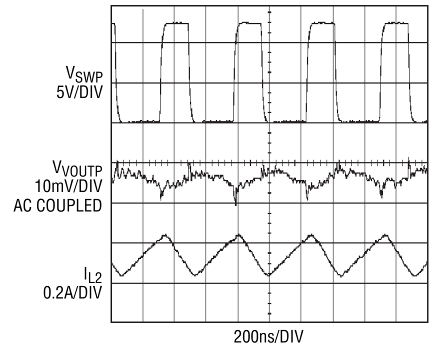


Figure 5. Switching waveforms at 100mA load for the boost application shown in Figure 2

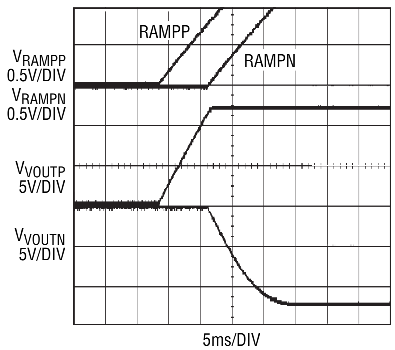


Figure 6. Power-Up Sequencing (V_{OUTP} followed by V_{OUTN})

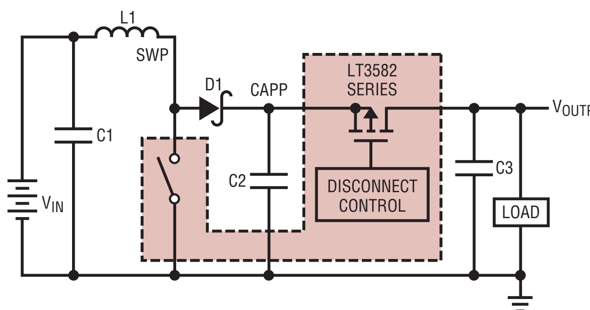


Figure 7. Output disconnect PMOS

LT8415). Under light load conditions, the LT3582 chooses an optimum combination of frequency and peak switch current to improve efficiency while moderating the output ripple. Figures 3–5 show how the frequency and peak inductor current vary from light to heavy loads. At very light loads (typically < 1mA), peak switching currents are dramatically reduced to further reduce ripple when frequencies are in the audio band.

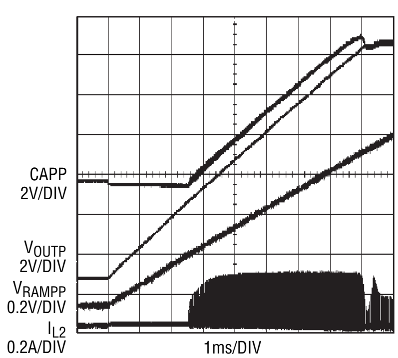


Figure 8. V_{OUTP} soft-start ramping from ground

Adjustable Power-Up Sequencing and Soft-Start Options

The LT3582 has digitally configurable power-up sequencing that forces the outputs to power up in one of four ways:

- ❑ V_{OUTP} ramps up first, followed by V_{OUTN} (shown in figure 6)
- ❑ V_{OUTN} ramps up first, followed by V_{OUTP}
- ❑ both outputs ramp up simultaneously
- ❑ both outputs are disabled

The LT3582-5 and LT3582-12 are factory configured for both outputs to ramp up simultaneously.

The power-up ramp rates of the output voltages are also adjustable. Slowly ramping the outputs (also known as soft-start) reduces what would otherwise be high peak switching currents during start-up. Without soft-start, high start-up current is inherent in switching regulators due to V_{OUT} being far from its final value. The regulator tries to charge the output capacitors as quickly as possible, which results in large peak currents.

The output voltage ramp rates are proportional to the ramp rates of the RAMPP and RAMPN pin voltages. Upon chip enable, a programmable current (1µA, 2µA, 4µA or 8µA) linearly charges capacitors (typically about 10nF) connected to the RAMPP and RAMPN pins. By varying the capacitor sizes or charging currents, a wide range of output voltage ramp rates can be accommodated.

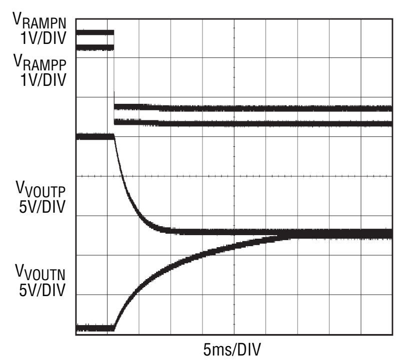


Figure 9. Power-down discharge waveforms

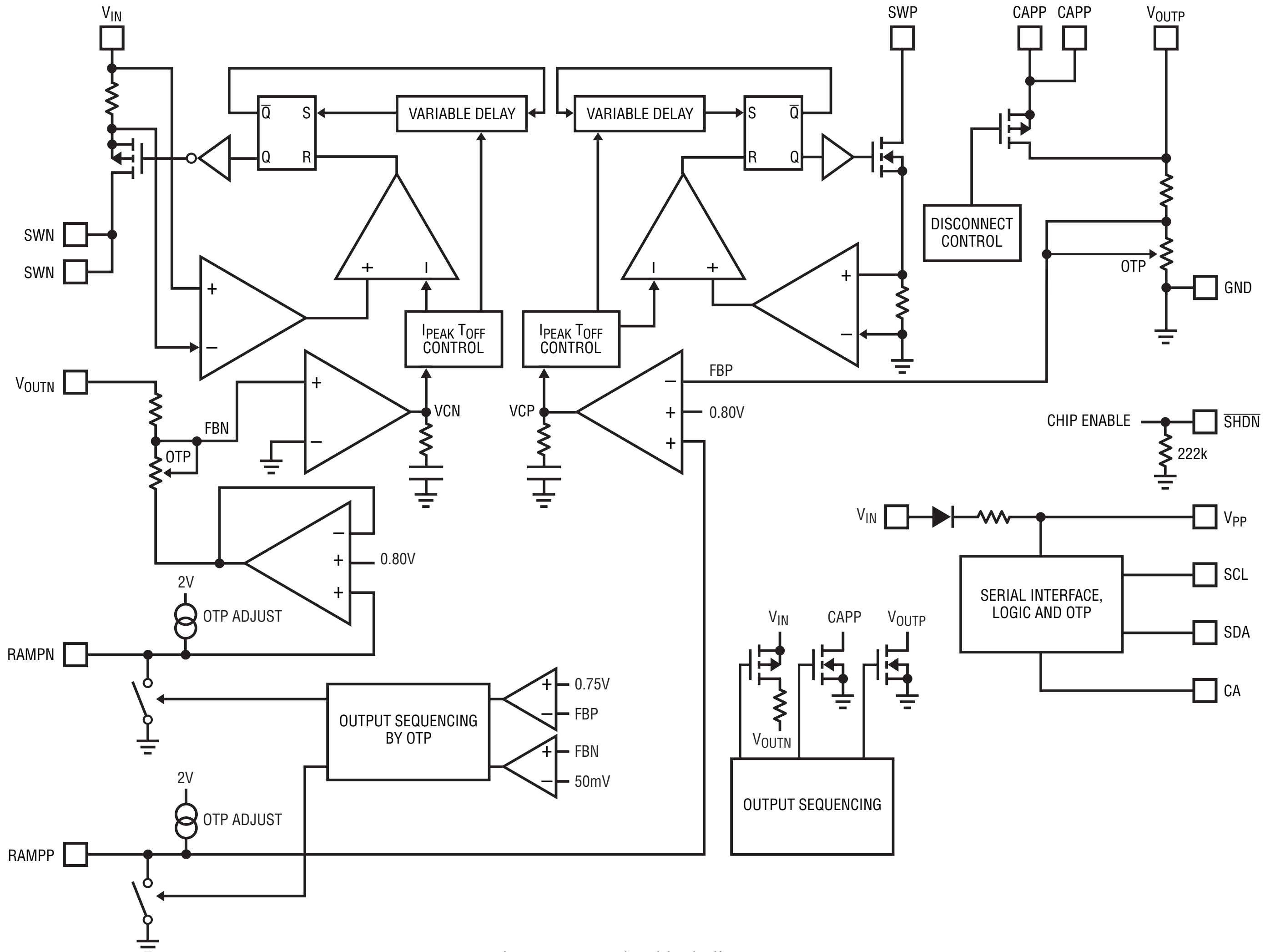


Figure 10. LT3582 block diagram

Output Disconnect and Improved Efficiency

The LT3582 series has a PMOS output disconnect switch connected between CAPP and V_{OUTP} (see Figure 7). During normal operation the switch is closed and current is limited to about 155mA to help protect against output shorts. During shutdown, the PMOS switch is open providing up to 5V–5.5V of isolation between CAPP and V_{OUTP}. In most cases this allows V_{OUTP} to discharge to ground.

In normal operation, the output disconnect switch represents ~1.4Ω of resistance in series with the output leading to a 1%–2% efficiency loss under heavy load conditions. The CAPP pin can be externally shorted to the V_{OUTP} pin to eliminate the power loss in the switch and improve efficiency.

Unique Ability to Ramp Output Up From Ground

Smart control of the output disconnect PMOS also gives the LT3582 the unique ability to generate a smooth V_{OUTP} voltage ramp starting from ground and continuing all the way up to regulation (see Figures 6 and 8). This ability is not possible with typical boost converters because the current path from V_{IN} through the inductor (L1) and Schottky diode (D1) to the output prevents it from starting at 0V (see Figure 7).

The disconnect control circuitry in the LT3582 allows V_{OUTP} to discharge to ground when disabled. Once enabled, the gate of the output disconnect PMOS is precisely controlled such that V_{OUTP} rises smoothly from ground up to regulation where the PMOS is fully turned on to reduce power losses.

Power Down Discharge Assist

The power down discharge feature assists in discharging the outputs after shutdown (see Figure 9). This option is factory enabled on the LT3582-5 and LT3582-12 and can be enabled through the I^2C interface in conjunction with the "both together" power-up setting on the LT3582.

Upon $\overline{SHDN}$ falling and when power-down discharge is enabled, internal transistors activate to assist in discharging the outputs toward ground. After both outputs are within ~0.5V to ~1.5V of ground, the chip powers down.

Digital Control and One-Time Programming

The LT3582 series supports the Standard Mode I^2C interface. Although using this interface is not required for the LT3582-5 or LT3582-12, it does permit reading of the chip's configuration and the ability to disable the power switches through the interface.

Additional I²C functionality is available with the LT3582 including re-programmability of the output voltages, and setting the power up sequencing and power down discharge.

A default power-up configuration can be made permanent in the LT3582 through the One-Time-Programmable memory. The chip will always use the default configuration from OTP memory upon power-up. Unless locked by programming a specific OTP memory bit, the chip configuration can be changed after power-up by writing new settings through the I²C interface.

Conclusion

The LT3582 is an easy-to-use compact solution for DC/DC converter applications where positive and negative outputs are required. It is accurate, efficient and includes an outsized number of features for its diminutive 3mm × 3mm 16-pin QFN package. It is offered in ±5V (LT3582-5), ±12V (LT3582-12) and I²C-programmable (LT3582) output versions.

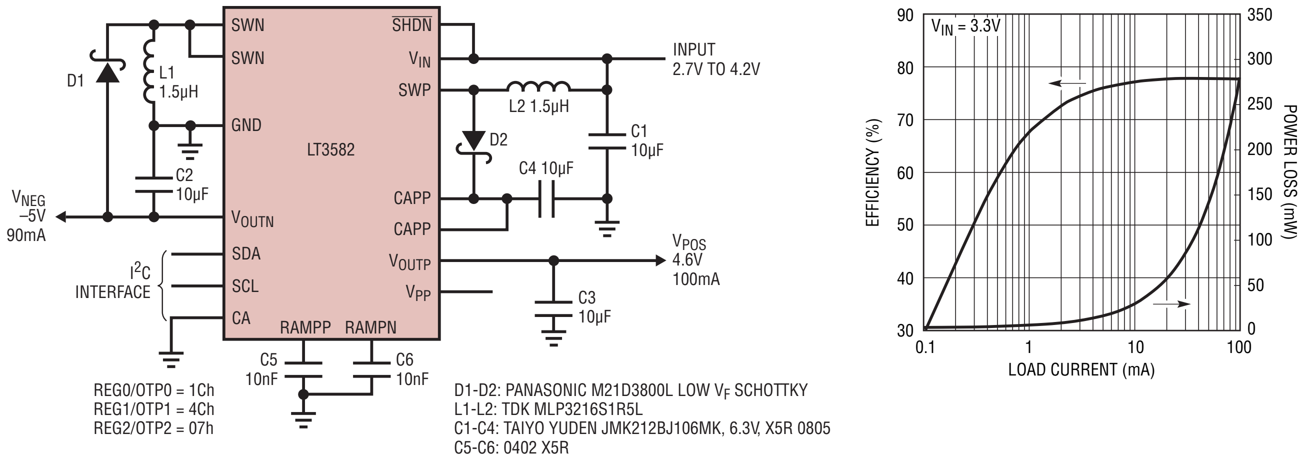


Figure 11. Tiny AMOLED power supply is 0.8mm (max) thin

LTC4217, continued from page 17

This example places a 20k resistor on the I_{MON} pin to set the gain of the current monitor output to 1V per amp of MOSFET current.

Instead of tying the TIMER pin to the $INTV_{CC}$ pin for a default 2ms overcurrent timeout, an external 0.47µF capacitor is used to set a 5.7ms timeout. During an overcurrent event the external timing capacitor is charged with a 100µA pull-up current. If the voltage on the capacitor reaches the 1.2V threshold, the MOSFET turns off. The equation for setting timing capacitor's value is as follows:

$$C_T = T_{CB} \cdot 0.083(\mu F/ms)$$

While the MOSFET is cooling off, the LTC4217 discharges the timing capacitor. When the capacitor voltage reaches 0.2V an internal 100ms timer is started. Following this cool down period the fault is cleared (when using auto-retry) and the MOSFET is allowed to turn on again.

It is important to consider the safe operating area of the MOSFET when extending the circuit breaker timeout beyond 2ms. The SOA graph for the MOSFET used in LTC4217 is shown in Figure 7. The worse case power dissipation occurs when the voltage versus current profile of the foldback current limit is at maximum. This occurs when the current is 1A and the voltage is one half of the 12V or 6V (see Figure 4, FB pin at 0.7V). In this case the power is 6W, which dictates a maximum time of 100ms (Figure 7, at 6V and 1A).

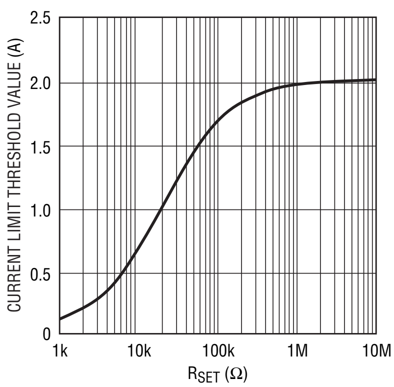


Figure 6. Current limit adjustment

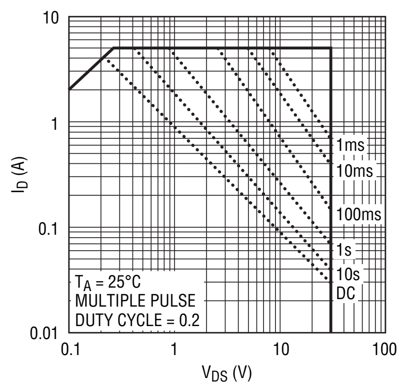


Figure 7. MOSFET SOA curve

Conclusion

The primary role of the LTC4217 is to control hot insertion and provide the electronic circuit breaker function. Additionally the part includes protection of the MOSFET with focus on SOA compliance, thermal protection and precise 2A current limit. It is also adaptable over a large range of applications due to adjustable inrush current, overcurrent fault timer and current limit threshold. A high level of integration makes the LTC4217 easy to use yet versatile.

Triple Output LED Driver Works with Inputs to 60V and Delivers 3000:1 PWM Dimming

by Hua (Walker) Bai

Introduction

The LT3492 is a 60V triple output LED driver for high input and/or high output voltage backlighting or direct lighting applications. A single 4mm × 5mm IC can drive a large number of LEDs, reducing overall solution cost when compared to less capable drivers. A built-in gate driver for a disconnect PMOS in series with the LED string, along with other techniques, enables a 3000:1 PWM dimming ratio. When coupled with the part's analog dimming functions, the overall dimming ratio can be as high as 30,000:1. The LT3492 can be configured into buck-mode, boost-mode or buck-boost mode, depending on the available input voltage source and the number and configuration of LEDs to be driven.

High Input Voltage Triple Buck Mode LED Driver

Many "regulated" supplies actually have fairly loose tolerances. For ex-

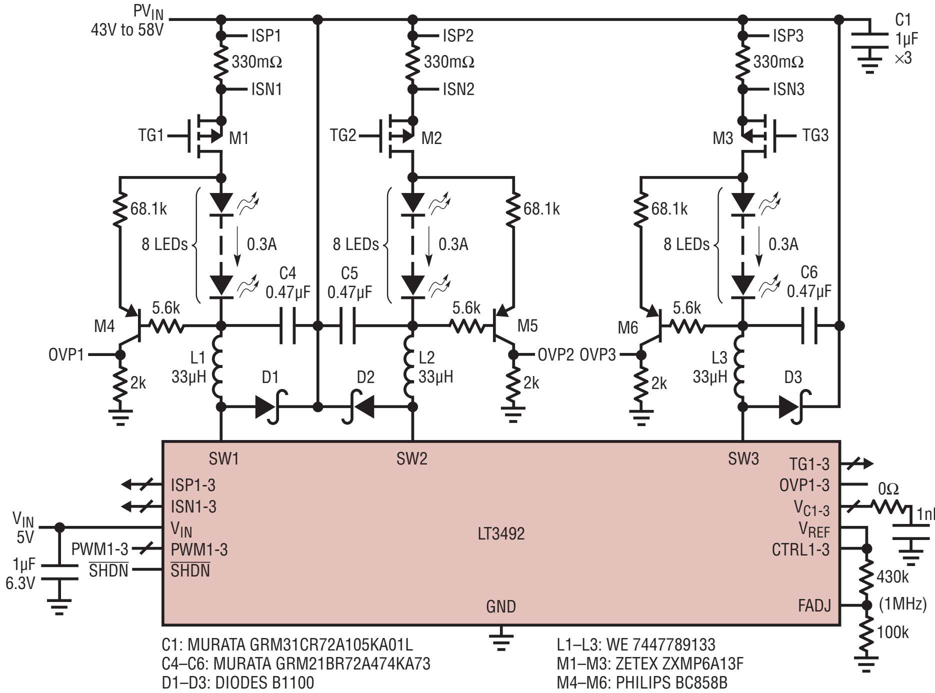


Figure 1. Triple buck mode LED driver with open LED protection

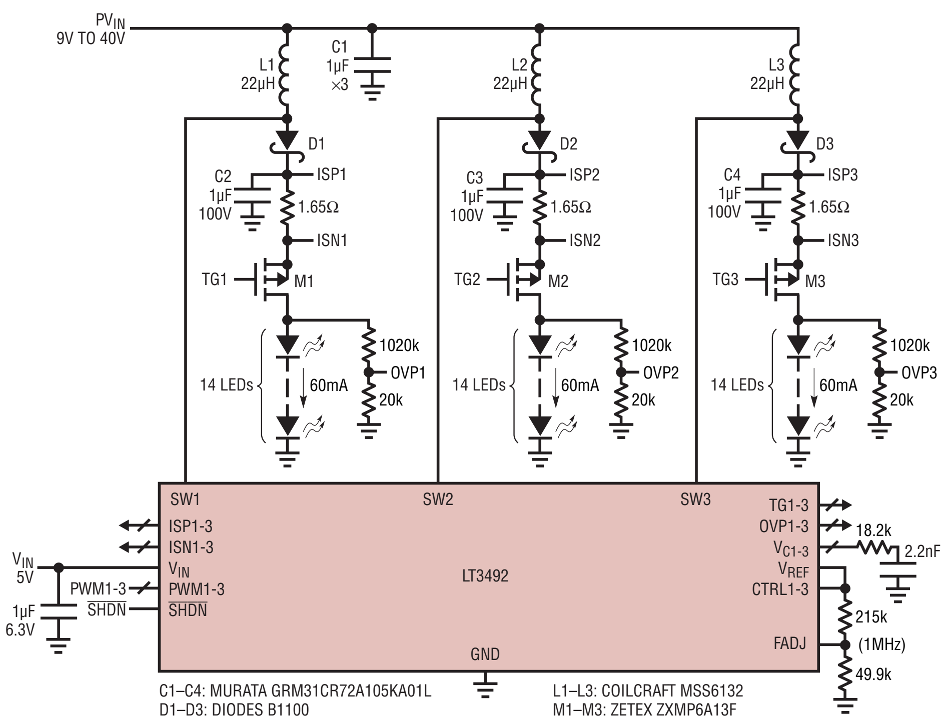


Figure 2. Triple boost mode 60mA × 14 LED driver

DESIGN IDEAS

ample, a 48V supply can range between 43V and 58V, well above most LED drivers' safe operating voltage ratings. The LT3492's 60V input voltage rating makes it an easy fit in such volatile voltage environments.

Figure 1 shows a triple buck-mode LED driver for high voltage inputs. Each channel can drive up to eight 300mA white LEDs in series, a limit set by assuming 4V maximum forward voltage and a 43V minimum input voltage. Red LEDs or infrared LEDs have much lower forward voltage, therefore each output can drive as many as 20 infrared LEDs. The V_{IN} pin in Figure 1 is tied to a 5V supply, as opposed to PV_{IN}, to improve circuit efficiency.

Triple Boost Mode Driver Supports 14 LEDs per Output from a 9V–40V Input

Figure 2 shows a triple boost mode LED driver that delivers 60mA to each LED string. Due to the LT3492's 60V switch rating, each output can support up to 14 LEDs. The 9V-to-40V input range covers a diverse range of applications, including regulated 12V, 24V, 32V to 36V, etc. Unlike in a buck mode regulator, where the output current capability is determined by the switch current limit, the current driving capability of a boost regulator is a function of the ratio of output voltage to minimum input voltage. Figure 3 shows the maximum output current vs output voltage for a 9V minimum input (assuming 85% efficiency at 1MHz). For applications that require less than 40V output, the LT3496 should be considered instead.

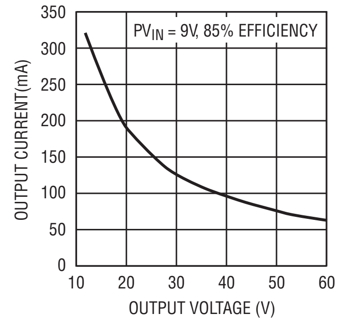


Figure 3. Maximum output current capability of an LT3492 boost circuit

Triple Buck-Boost Mode LED Driver Regulates During Load Dump Events

Buck-boost mode is used when the LED string voltage falls within the input voltage range. Figure 4 shows a buck-boost application that uses one inductor per driver. The LED string is returned to the input—returning all LED strings to the same potential allows easy heat sinking. To prevent body diode conduction, the drain of the disconnect PMOS is tied to the anode of the LED string. The high input voltage of the circuits in Figure 2 and Figure 4 is a real benefit in automotive applications, where the ability to ride through 40V load dump events while maintaining LED current regulation is required. Figure 5 shows the greater than 3000:1 PWM dimming ratio achievable with the LT3492. This high PWM dimming ratio helps improve the picture quality of an LCD display under various dynamic conditions.

Conclusion

The LT3492 is a high voltage triple output LED driver with 60V rated switches, allowing high input voltage and/or high output voltage operations with accurate LED current. It can run in buck mode, boost mode or buck-boost mode with 3000:1 PWM dimming capability.

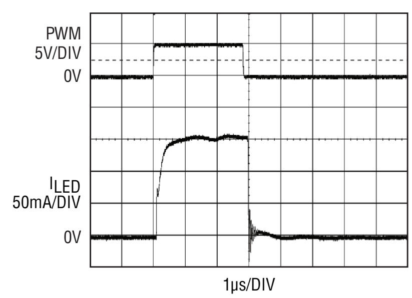


Figure 5. High dimming ratio (>3000:1) improves quality of an LCD display

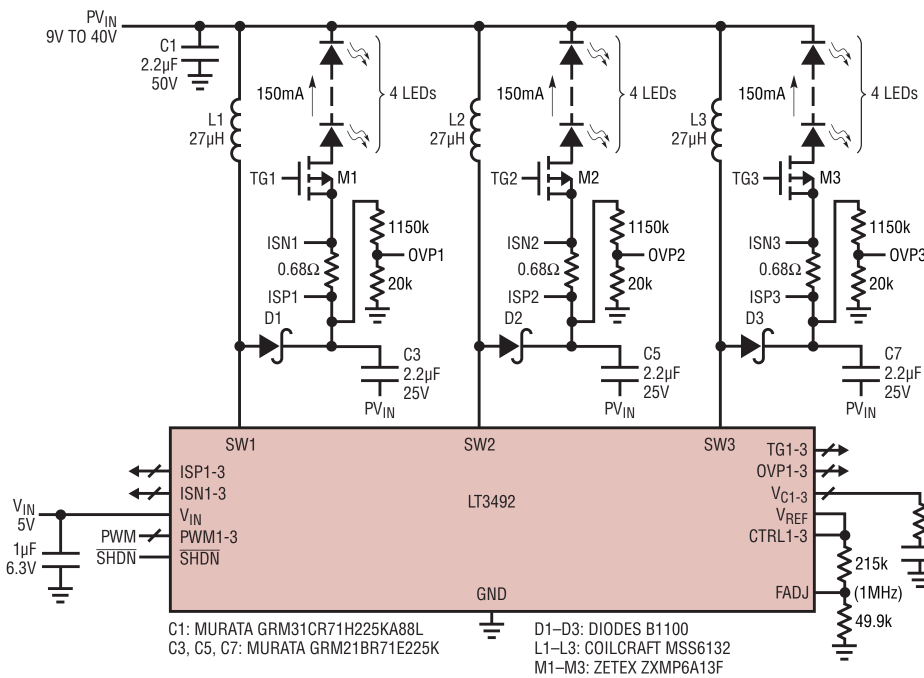


Figure 4. Triple buck-boost mode 150mA × 4 LED driver

Bidirectional Power Manager Provides Efficient Charging and Automatic USB On-The-Go with a Single Inductor

by Sauparna Das

Introduction

Imagine that your car won't start—the battery is dead, the kids are getting fussy, you're stranded in the middle of nowhere, and your cell phone won't turn on because you forgot to charge it. What do you do now? Fortunately, you remember that your new camera is in the car, and it has a fully charged battery. Even better, this camera supports USB On-The-Go using a bidirectional power manager. You connect a USB micro-AB cable between the cell phone and camera and instantly start charging your phone. The phone powers up and you're able to call for help.

The LTC4160 is a versatile, high efficiency power manager and battery charger that incorporates a bidirectional switching regulator, full featured battery charger, an ideal diode (with a controller for an optional external ideal diode), and an optional overvoltage protection circuit. The bidirectional switching regulator is able to power a portable system and charge its battery or provide a 5V output for USB On-The-Go using a single inductor (Figure 1). This reduces component count and board space, key attributes for a power management IC in today's feature rich portable devices. In shutdown, the part only draws 8µA of current, thus maximizing battery life.

Bidirectional Switching Power Path for USB On-The-Go

The LTC4160 contains a bidirectional switching regulator between V_{BUS} and V_{OUT}. When power is applied to V_{BUS},the switching regulator acts as a step down converter and provides power to the application and battery charger (Figure 1). The switching regulator includes a precision average input current limit with multiple settings. Two of the settings correspond to the USB 100mA and 500mA limits.

The bidirectional switching regulator is able to power a portable system and charge its battery or provide a 5V output for USB On-The-Go using a single inductor.

The voltage on V_{OUT} is approximately 300mV above the battery when the switcher is not in input current limit and the battery voltage is above 3.3V. This technique, known as Bat-Track output control, provides very efficient charging, which minimizes loss and heat and eases thermal constraints. For battery voltages below 3.3V, V_{OUT} regulates to 3.6V when the switcher is not in input current limit. This instant-on feature provides power to the system even when the battery is completely discharged.

Power to the application is always prioritized over charging the battery. If the combined system load and charge current exceed the current available at the input, the battery charger reduces its charge current to maintain power to the application. If the load alone exceeds the input current limit, then additional current is supplied by the battery via the ideal diode(s).

For USB On-The-Go applications, the bidirectional switching regulator steps up the voltage on V_{OUT} to produce 5V on V_{BUS}. In this mode the switching regulator is capable of delivering at least 500mA. Power to V_{OUT} comes from the battery via the ideal diode(s). A precision output current limit circuit, similar to the one in step-down mode, prevents a load on V_{BUS} from drawing more than 680 mA (Figure 1). The switching regulator also features true output disconnect which prevents body diode conduction of the PMOS switch. This allows V_{BUS} to go to zero volts during a short circuit condition or while shut down, drawing zero current from the battery. When V_{OUT} is ≥ 3.2V, the LTC4160 allows a portable

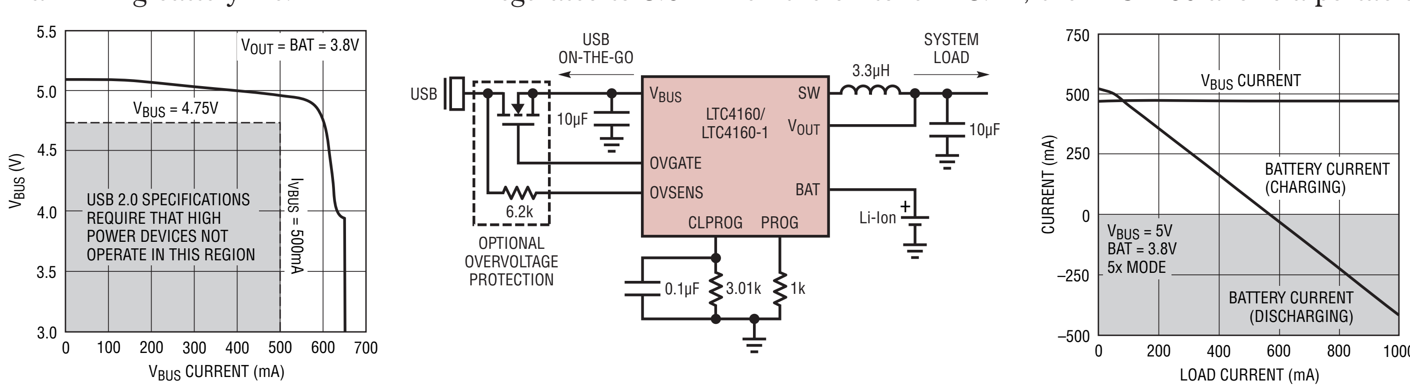


Figure 1. The LTC4160 provides bidirectional power transfer. Left plot: V_{BUS} voltage vs V_{BUS} current in On-The-Go mode. Right plot: battery and V_{BUS} currents vs load current when input power is available.

product to meet the specification for a high power USB device by maintaining V_{BUS} above 4.75V for currents up to 500mA.

Automatic USB On-The-Go

When two On-The-Go devices are connected, one is the A-device and the other is the B-device, depending on the orientation of the cable, which has a micro-A and a micro-B plug. The A-device provides power to the B-device and starts as the host. Micro-A/micro-B cables include an ID pin in addition to the four standard pins (V_{BUS}, D–, D+, and GND)—the micro-A plug has its ID pin shorted to GND while on the micro-B plug the ID pin is floating. The impedance on the ID pin allows the USB power manager to determine whether it receives power from an external device or whether it should power up V_{BUS} to provide power to an external device.

Step-up mode can be enabled by either the ENOTG pin or the ID pin. The ENOTG pin can be connected to a microcontroller. The ID pin, on the other hand, is designed to be connected directly to the ID pin of a micro-AB receptacle. The pin is active low and contains an internal 2.5µA pull up current source. When the ID pin is floating or a micro-B plug is connected to the AB receptacle, the internal current source pulls ID up to the max of V_{BUS}, V_{OUT} and BAT. When a micro-A plug is connected to the receptacle, the short between ID and ground in the micro-A plug overrides the pull-up current source and pulls the ID pin on the LTC4160 down to ground. This activates the bidirectional switching regulator in step-up mode and powers up V_{BUS}. A complete application schematic is shown in Figure 2.

Other Features

The LTC4160 also includes a battery charger featuring programmable charge current (1.2A max), cell preconditioning with bad cell detection and termination, CC-CV charging, C/10 end of charge detection, safety timer termination, automatic recharge and a thermistor signal conditioner for temperature qualified charging. For the LTC4160, the nominal float voltage is 4.2V. The LTC4160-1 provides a nominal float voltage of 4.1V.

The overvoltage protection circuit can be used to protect the low voltage USB/Wall adapter input from the inadvertent application of high voltage or a failed wall adapter. This circuit controls the gate of an external high voltage N-channel MOSFET, and in conjunction with an external 6.2k resistor, can provide protection up to 68V.

The LTC4160 includes an integrated ideal diode and a controller for an optional external ideal diode. This provides a low loss power path from the battery to V_{OUT} when input power is limited or unavailable. When input power is removed, the ideal diode(s) prevent V_{OUT} from collapsing, with only the output capacitor required for the switching regulator.

Conclusion

The LTC4160 is a feature rich power manager that is especially suited for USB On-The-Go applications, enabling bidirectional USB power transfer between portable devices. The part can directly detect the impedance on the ID pin of a micro-AB receptacle to automatically tell the internal bidirectional switching regulator to provide a 5V output on V_{BUS} for USB On-The-Go. The switching regulator can supply at least 500mA and comes with a current limit of 680mA. In addition, the LTC4160 can efficiently take power from 5V inputs (USB, Wall adapter, etc.) to power a portable application and charge its battery using a single inductor. Its unique switching architecture and Bat-Track output control provides fast and efficient charging. Furthermore, an optional overvoltage protection circuit can provide protection against voltages of up to 68V on the V_{BUS} pin. The combination of bidirectional power transfer, automatic USB On-The-Go functionality and high voltage protection make the LTC4160 a must have for today's high end portable devices.

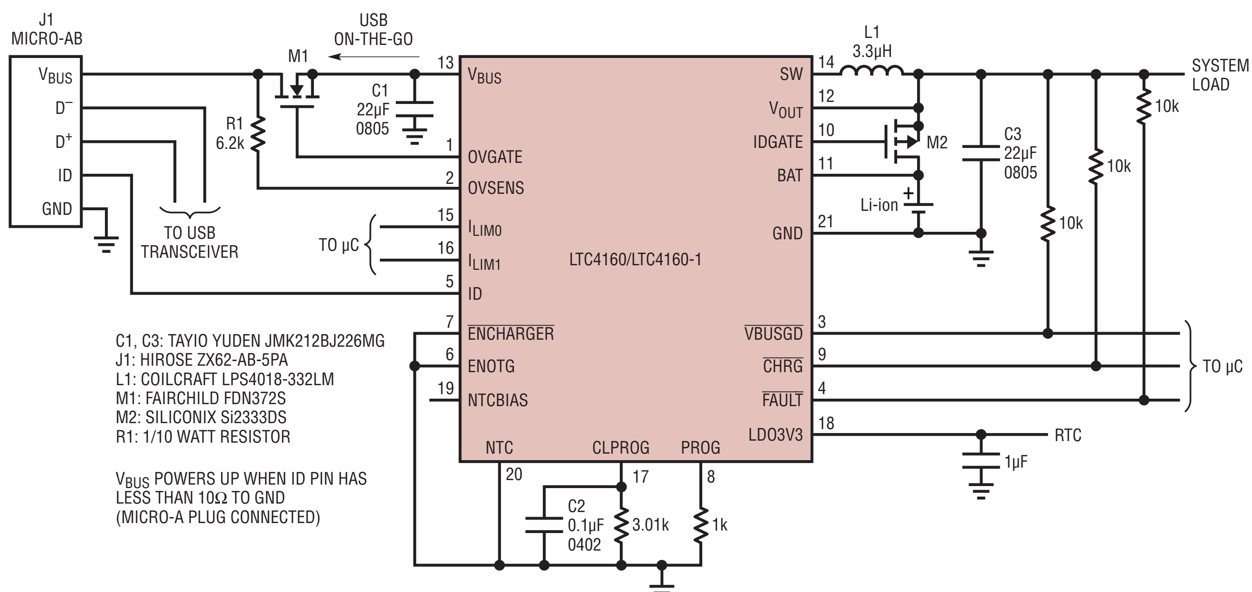


Figure 2. LTC4160 with automatic USB On-The-Go

Supercapacitor Charger with Adjustable Output Voltage and Adjustable Charging Current Limit

by Jim Drew

Introduction

For applications using larger value supercapacitors (tens to hundreds of farads), a charger circuit with a relatively high charging current is needed to minimize the recharge time of the system. Supercapacitors are used as energy hold up devices in applications such as solid state RAID disks, where information stored in high speed volatile memory must be transferred to non-volatile flash memory when power is lost. This transfer time may take minutes, requiring hundreds of farads to hold up the power supply until the transfer is complete. The requirement for the recharge time of these banks of supercapacitors is typically less than one hour. To accomplish this, a high charging current is required. This article describes a supercapacitor charging circuit using the LT3663 that meets these difficult requirements.

The LT3663 is a 1.2A, 1.5MHz step-down switching regulator with output current limit ideal for supercapacitor applications. The part has an input voltage range of 7.5V to 36V,has adjustable output voltage and adjustable output current limit. The output voltage is set with a resistor divider network in the feedback loop while the output current limit is set by a single resistor connected from the I_{LIM} pin to ground. With its internal compensation network and internal boost diode, the LT3663 requires a minimal number of external components.

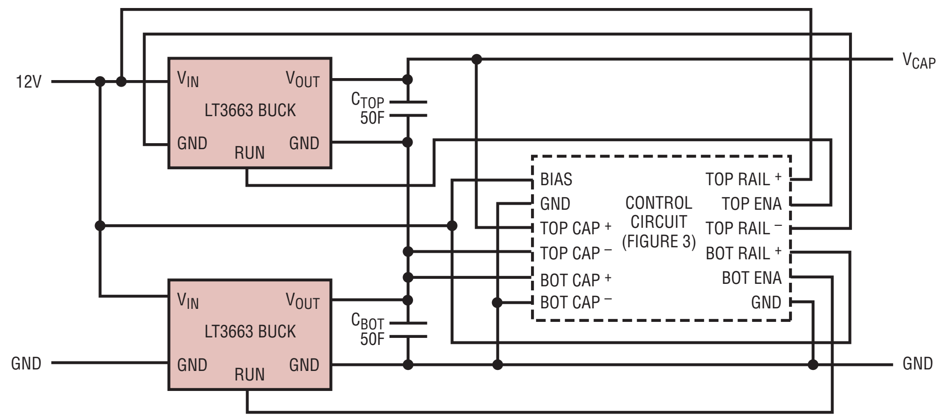


Figure 1. Block diagram for charging two supercapacitors in series

Power Ride-Through Application

A procedure for selecting the size of the supercapacitor is outlined in the September 2008 edition of *Linear Technology*, in an article titled "Replace Batteries in Power Ride-Through Applications with Supercaps and 3mm × 3mm Capacitor Charger." The procedure determines the effective supercapacitor (C_{EFF}) capacitance at 0.3Hz, based on the power level to be held up, the minimum operating voltage of the DC/DC converter supporting the load, the distributed circuit resistances including the ESR of the supercapacitors, and the required hold up time.

Once the size of the supercapacitor is known, the charging current can be determined to meet the recharge time requirements. The recharge time ($T_{RECHARGE}$) is the time required to recharge the supercapacitors from the minimum operating voltage (V_{UV}) of the DC/DC converter to the full charge voltage (V_{FC}) of the supercapacitors. The voltage on the individual supercapacitors at the start of the recharge cycle is the minimum operating voltage divided by the number (N) of supercapacitors in series. From here on, this article describes an application with two supercapacitors in series. The recharge current (I_{CHARGE}) is determined by the capacitor charge control law:

$$I_{CHARGE} = \frac{C_{EFF}\left(N \bullet V_{FC} - V_{UV}\right)}{N \bullet T_{RECHARGE}}$$

This assumes that the voltage across the supercapacitor doesn't discharge below the V_{UV}/N value. This assumption is valid if the time period

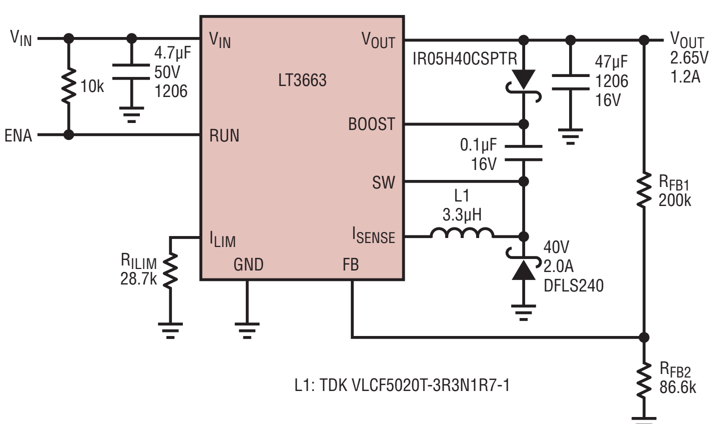


Figure 2. Capacitor charger circuit using the LT3663

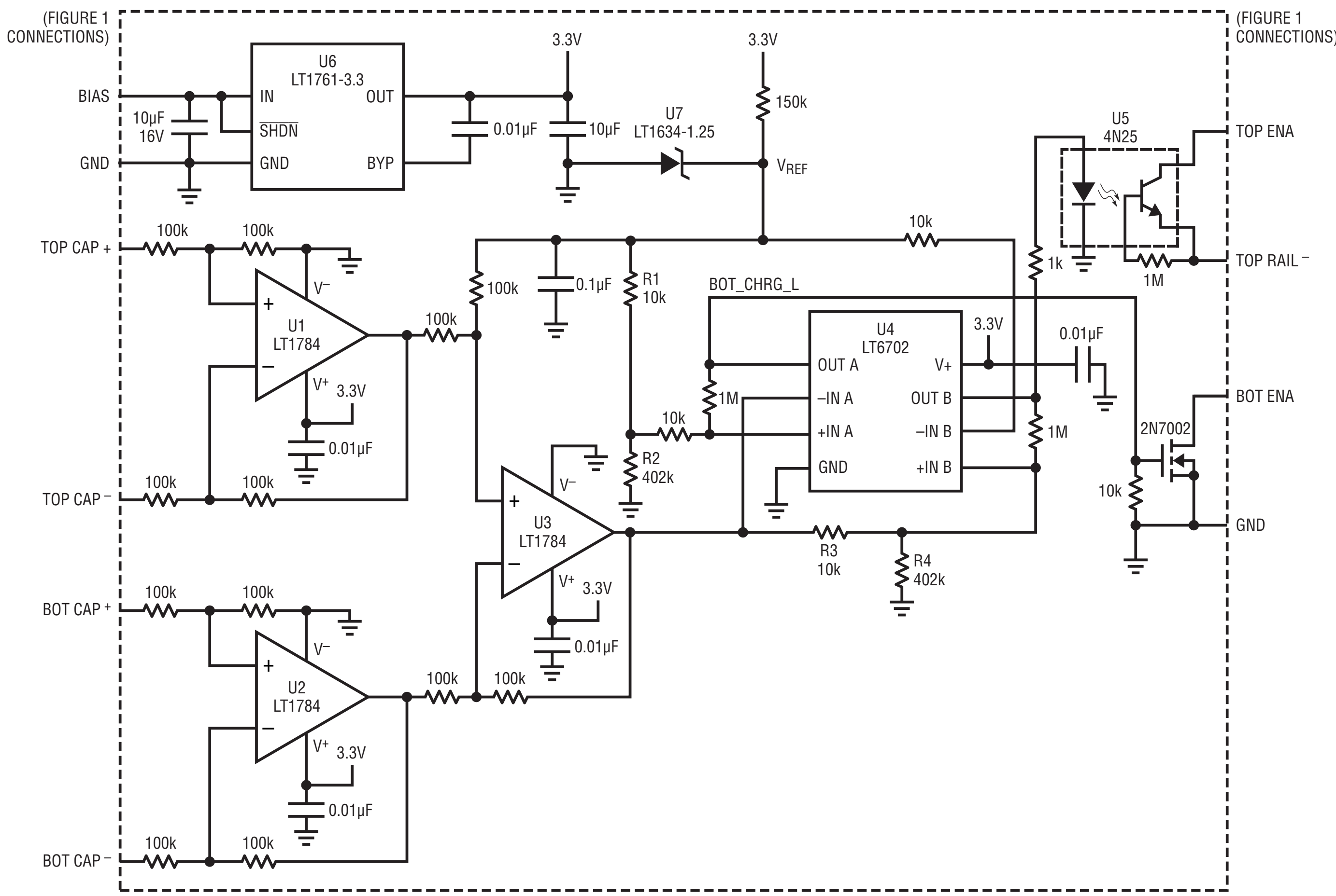


Figure 3. Charger control circuit

while input power isn't available is such that the supercapacitor's leakage current hasn't significantly reduced the voltage across the capacitor. The voltage across the supercapacitor may actually rise slightly after the DC/DC converter shuts down due to the dielectric absorption effect. The initial charge time T_{CHARGE} for a fully discharged bank of supercapacitors is:

$$T_{CHARGE} = \frac{C_{EFF} \cdot V_{FC}}{I_{CHARGE}}$$

Figure 1 shows a block diagram of the components for this supercapacitor charger application.

Charging Circuit Using the LT3663

To set the charging current, a resistor R_{ILIM} is connected from the I_{LIM} pin of the LT3663 to ground. Table 1 shows the nominal charging currents for various values of R_{ILIM}.

The full charge voltage is set by the resistor divider network in the feedback loop. Table 2 shows various full charge voltages versus the value of R_{FB2} (resistor from the FB pin to ground) when resistor R_{FB1} (resistor tied between the V_{OUT} pin and the FB pin) is 200k. Figure 2 shows the charging circuit for each supercapacitor.

Control Circuit for Charging Supercapacitors

The control circuit in Figure 3 is used to balance the voltages of the supercapacitors while they are charging. This is accomplished by prioritizing charge current to the lower voltage supercapacitor—specifically by enabling the charging circuit for the supercapacitor with the lower voltage while disabling the circuit for the other supercapacitor.

If the top charging circuit is enabled while the bottom charging circuit is disabled, the bottom supercapacitor is charged by the input return current from the top charger. This return current is a fraction of the charging current so the top supercapacitor charges faster. The control circuit

continued on page 33

Table 1. Charging current vs R_{ILIM}

Charging Current (A)	R_{ILIM} Value (kΩ)
0.4	140
0.6	75
0.8	48.7
1.0	36.5
1.2	28.7

Table 2. Full charge voltage vs R_{FB2}

Full Charge Voltage (V)	R_{FB2} (kΩ)
2.65	86.6
2.5	93.1
2.4	100
2.2	115
2.0	133

Monolithic Triple Output Converter for Li-Ion Powered Handheld Devices

by Chuen Ming Tan

Introduction

Handheld devices often require several voltage rails to power microprocessors, communication I/O and other peripherals with a range of voltages from as low as 1V to as high as 3.3V. Producing these voltage rails from a single-cell Li-Ion battery requires multiple converters that are efficient, can operate in a combination of buck and boost modes, and fit into the already crowded board space of the handheld device. To meet these challenges, the LTC3521 triple-output converter combines a buck-boost converter and two synchronous buck converters in a 4mm × 4mm QFN package (Figure 1).

The LTC3521 is a monolithic device internally compensated and with built-in soft-start capacitors. External components are limited to feedback resistors, output inductors and capacitors (Figure 2). The internal switching frequency of 1MHz makes it possible to select a wide range of tiny, low profile capacitors and inductors. A complete 3-output converter occupies less than $0.5in^2$ (Figure 1), delivering up to 5W of total output power with less than a 15°C temperature rise.

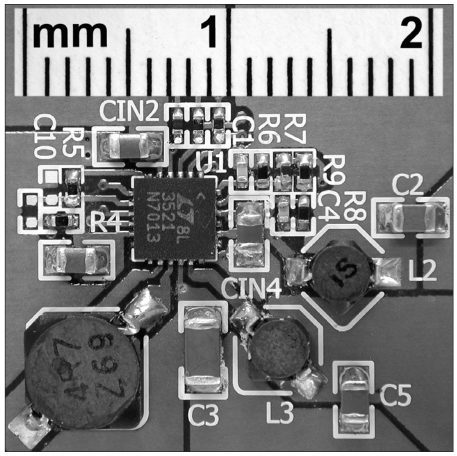


Figure 1. Buck-boost and buck converters occupy less than $0.5in^2$ of board space.

The LTC3521's wide input voltage range allows its buck-boost converter to operate from 1.8V to 5.5V. Its proprietary buck-boost switching algorithm makes it possible to produce seamless transitions between buck and boost modes, using only a single inductor in a fixed frequency operation. Smooth buck-boost transitions are especially useful in 3.3V applications where battery run time depends on using the entire 2.4V–4.2V operating range of a single cell Li-Ion battery. The buck-boost converter can support up to 1A loads.

The LTC3521 buck converters feature internally compensated current mode control that ensures a rapid transient response over a wide range of output capacitor values. The buck converters can supply a load current of up to 600mA each over the entire input voltage range and its output can be set as low as 0.6V. The buck converter transitions smoothly to 100% duty cycle operation to extend battery life in low dropout operation. Other useful features of LTC3521 include short circuit protection, individual open-drain power good indicator, which allows for undervoltage fault detection, and sequenced start-up. Each converter can be independently enabled. With all converters disabled, the total supply current is reduced to under 1μA.

High Efficiency

Due to its high efficiency, the LTC3521 is able to operate in a tiny package, delivering 1A of output current on the buck-boost converter and 600mA each on the buck converters. As shown in Figure 3, all the converters can easily operate at efficiencies above 90% in PWM mode. Peak efficiency

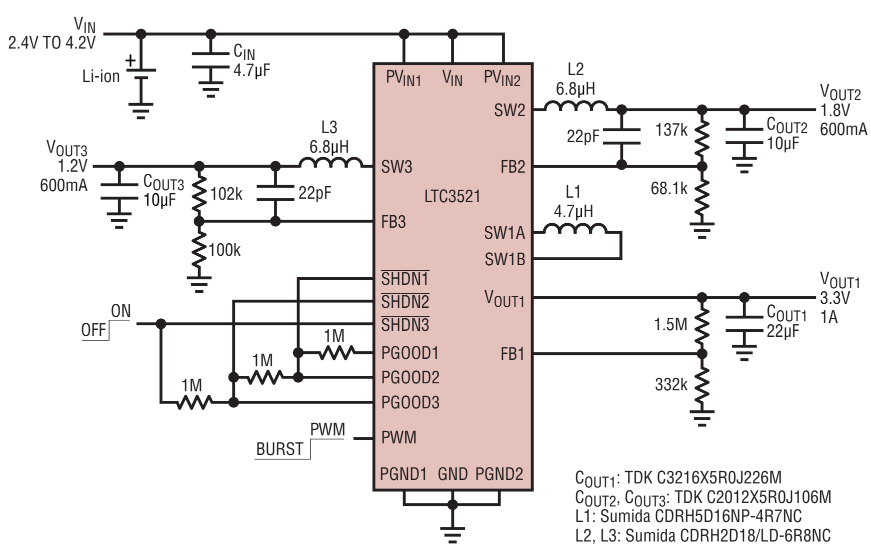


Figure 2. A 3-output converter takes a single Li-Ion battery to 3.3V at 1A (buck-boost mode), 1.8V at 600mA and 1.2V at 600mA.

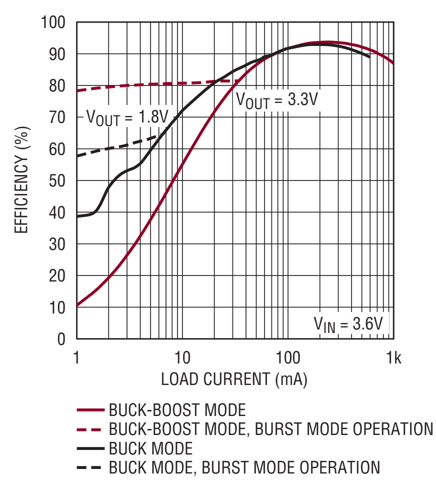


Figure 3. Efficiency vs load current for the circuit in Figure 2

occurs at the midpoint of the available output current range—ensuring high efficiency under most operating conditions. When the application enters low power mode, the converters can be independently set to Burst Mode operation to further improve efficiency at light loads. In Burst Mode operation, the total quiescent current of the converters is reduced to 35µA. During noise critical phases, Burst Mode operation can be temporarily forced to low noise by dynamically driving the PWM pin high.

Supply Sequencing

Digital applications with multiple supplies typically specify sequenced start-up and shut-down of the supplies. Supply sequencing is important to prevent powering up I/O pins that are driven by unpowered core logic. Without defined logic states, erratic fluctuations may occur at the I/O pins. LTC3521 provides individual control of shutdown and PGOOD indicator pins, which can be used for supply sequencing. The three outputs of LTC3521 can be powered sequentially by tying the $\overline{SHDN}$ and PGOOD pins as shown in Figure 2. A low-to-high transition on $\overline{SHDN3}$ pin powers up channel 3. When channel 3 is powered up, PGOOD3 pulls $\overline{SHDN2}$ high to turn on channel 2. When channel 2 is powered up and PGOOD2 is high, $\overline{SHDN1}$ is pulled high, finally turning on all three outputs (Figure 4).

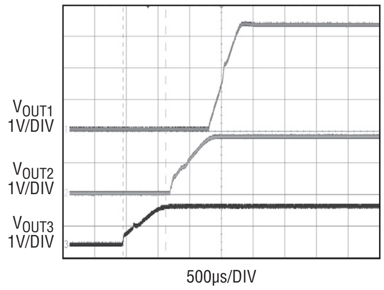


Figure 4. Sequenced power-up waveforms

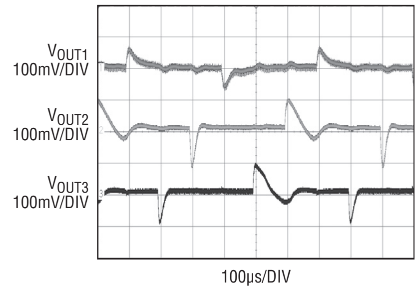


Figure 5. Alternating light to full load step responses show little crosstalk between channels.

Inter-Channel Performance

While in PWM mode, all three converters operate synchronously from a common 1MHz oscillator. This minimizes the interaction between the converters so that load steps on the output of one converter have minimum impact on the others. For example, Figure 5 shows the output voltages as two separate 20mA to 600mA load steps are applied to the buck channels and a 0A to 1A load step is applied to the buck-boost channel. In this case, even with small 10µF output capacitors on the buck converters and 22µF on the buck-boost converter, the interaction among channels is minimal.

Conclusion

The LTC3521 provides a highly integrated monolithic solution for applications requiring multiple voltage rails in a compact footprint. Its high efficiency and exceptional performance make the LTC3521 well suited for even the most demanding handheld applications.

LT3663, continued from page 31

consists of a 3.3V LDO (U6) and a precision 1.25V reference (U7). U1 and U2 are configured as difference amplifiers with a gain of one to measure the voltage across each supercapacitor while U3 is a level shifted difference amplifier used to determine the voltage difference between the two supercapacitors. By level shifting the output of U3 to the reference voltage, the two comparators in U4 determine which supercapacitor needs charging.

An additional pair of level shifting resistors (R14 and R15, R16 and R17) are used to allow both supercapacitors to charge when they are within a 50mV window. When both supercapacitors are being charged, the bottom supercapacitor charges faster because it is being charged by its charging current plus the input return current of the top charger. This effect can be seen in Figure 4. The enable signal of the bottom charger is toggling as the bottom supercapacitor is being charged faster than the top supercapacitor to maintain the 50mV difference between the two supercapacitors. Figure 5 shows the effect of a 2-to-1 mismatch in capacitance value where the top is a 50F supercapacitor and the bottom is a 100F. Here the voltage on the bottom supercapacitor rises more slowly and the top supercapacitor charger enable signal toggles to allow it to maintain voltage balance.

Conclusion

The LT3663 allows for a low component count supercapacitor charging circuit with adjustable full charge voltage and adjustable current limit ideal for larger value supercapacitors. A control circuit can monitor and balance the voltage across each supercapacitor, even if the supercapacitors are grossly mismatched in capacitance or initial voltage.

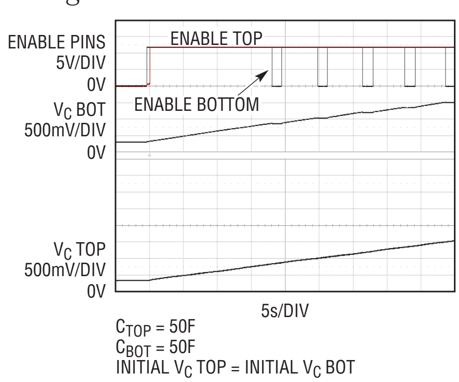


Figure 4. Charging with equal value capacitors

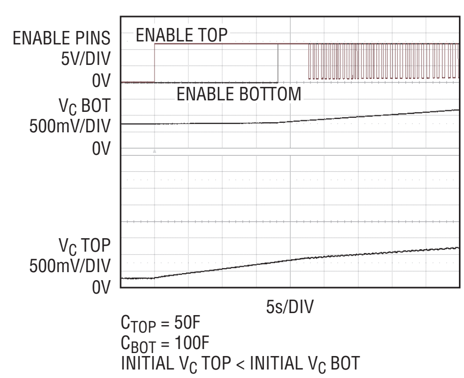


Figure 5. Charging with mismatched capacitors

Ultralow Power Boost Converters Require Only 8.5µA of Standby Quiescent Current

by Xiaohua Su

Introduction

Industrial remote monitoring systems and keep-alive circuits spend most of their time in standby mode. Many of these systems also depend on battery power, so power supply efficiency in standby state is very important to maximize battery life. The LT8410/-1 high efficiency boost converter is ideal for these systems, requiring only 8.5µA of quiescent current in standby mode. The device integrates high value (12.4M/0.4M) output feedback resistors, significantly reducing input current when the output is in regulation with no load. Other features include an integrated 40V switch and Schottky diode, output disconnect with current limit, built in soft-start, overvoltage protection and a wide input range, all in a tiny 8-pin 2mm × 2mm DFN package.

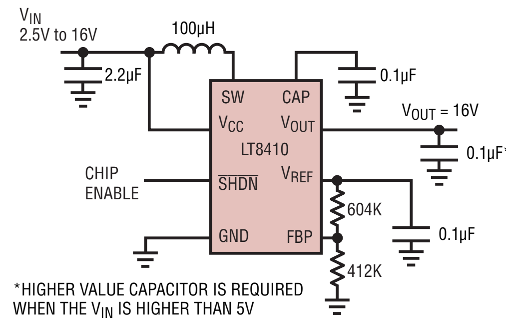


Figure 1. 2.5V–16V To 16V boost converter

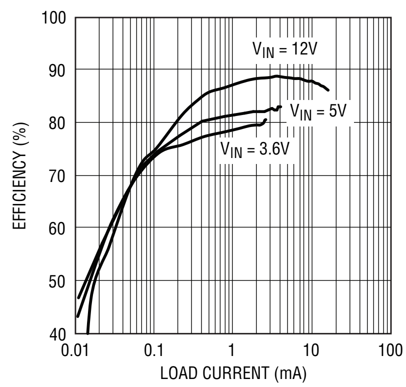


Figure 2. Efficiency vs load current for Figure 1 converter

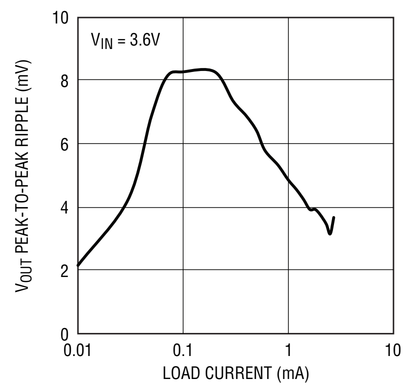


Figure 3. Output peak-to-peak ripple vs load current for Figure 1 converter at 3.6V

Application Example

Figure 1 details the LT8410 boost converter generating a 16V output from a 2.5V-to-16V input source. The LT8410/-1 controls power delivery by varying both the peak inductor current and switch off time. This control scheme results in low output voltage ripple as well as high efficiency over a wide load range. Figures 2 and 3 show efficiency and output peak-to-peak ripple for Figure 1's circuit. Output ripple voltage is less than 10mV despite the circuit's small (0.1µF) output capacitor.

The soft-start feature is implemented by connecting an external capacitor to the V_{REF} pin. If soft-start is not needed, the capacitor can be removed. Output voltage is set by a resistor divider from the V_{REF} pin to ground with the center tap connected to the FBP pin, as shown in Figure 1. The FBP pin can also be biased directly by an external reference.

The $\overline{SHDN}$ pin of the LT8410/-1 can serve as an on/off switch or as an undervoltage lockout via a simple resistor divider from V_{CC} to ground.

Ultralow Quiescent Current Boost Converter with Output Disconnect

Low quiescent current in standby mode and high value integrated feedback resistors allow the LT8410/-1 to regulate a 16V output at no load from a 3.6V input with about 30µA of average input current. Figures 4, 5 and 6 show typical quiescent and input currents in regulation with no load.

The device also integrates an output disconnect PMOS, which blocks the output load from the input during shutdown. The maximum current through the PMOS is limited by circuitry inside the chip, allowing it to survive output shorts.

Compatible with High Impedance Batteries

A power source with high internal impedance, such as a coin cell battery, may show normal output on a voltmeter, but its voltage can collapse under heavy current demands. This makes it incompatible with high current DC/DC converters. With very low switch current limits (25mA for the LT8410 and 8mA for the LT8410-1), the LT8410/-1 can operate very efficiently from high impedance sources without causing inrush current problems. This feature also helps preserve battery life.

continued on page 36

$15V_{IN}$, 4MHz Monolithic Synchronous Buck Regulator Delivers 5A in 4mm × 4mm QFN

Tom Gross

Introduction

The LTC3605 is a high efficiency, monolithic synchronous step-down switching regulator that is capable of delivering 5A of continuous output current from input voltages of 4V to 15V. Its compact 4mm × 4mm QFN package has very low thermal impedance from the IC junction to the PCB, such that the regulator can deliver maximum power without the need of a heat sink. A single LTC3605 circuit can power a 1.2V microprocessor directly from a 12V rail—no need for an intermediate voltage rail.

The LTC3605 employs a unique controlled on-time/constant frequency current mode architecture, making it ideal for low duty cycle applications and high frequency operation. There are two phase-lock loops inside the LTC3605: one servos the regulator on-time to track the internal oscillator frequency, which is determined by an external timing resistor, and the other servos the internal oscillator to an external clock signal if the part is synchronized. Due to the controlled on-time design, the LTC3605 can achieve very fast load transient response while minimizing the number and value of external output capacitors.

The LTC3605's switching frequency is programmable from 800kHz to 4MHz, or the regulator can be synchronized to an external clock for noise-sensitive applications.

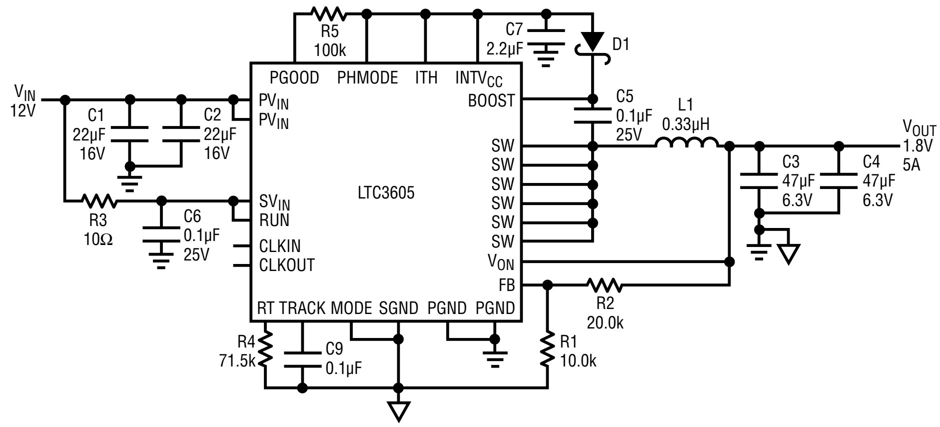


Figure 1. 12V to 1.8V at 5A buck converter operating at 2.25MHz

Furthermore, multiple LTC3605s can be used in parallel to increase the available output current. The LTC3605 produces an out-of-phase clock signal so that parallel devices can be interleaved to reduce input and output current ripple. A multiphase, or PolyPhase®, design also generates lower high frequency EMI noise than a single-phase design, due to the lower switching currents of each phase. This configuration also helps with the thermal design issues normally associated with a single high output current device.

$1.8V_{OUT}$, 2.25MHz Buck Regulator

The LTC3605 is specifically designed for high efficiency at low duty cycles such as 12VIN-to-1.8VOUT at 5A, as shown in Figure 1. High efficiency is achieved with a low $R_{DS(ON)}$ bottom synchronous MOSFET switch (35mΩ) and a 70mΩ $R_{DS(ON)}$ top synchronous MOSFET switch.

This circuit runs at 2.25MHz, which reduces the value and size of the output capacitors and inductor. Even with the high switching frequency, the efficiency of this circuit is about 80% at full load.

Figure 2 shows the fast load transient response of the application circuit shown in Figure 1. It takes only 10µs to recover from a 4A load step with less than 100mV of output voltage deviation and only two 47µF ceramic output capacitors. Note that compensation is internal, set up by tying the compensation pin (ITH) to the internal 3.3V regulator rail ($INTV_{CC}$).

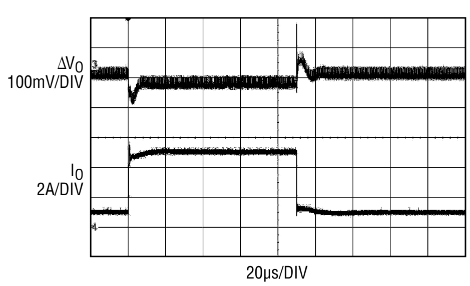


Figure 2. Load step response of the circuit in Figure 1

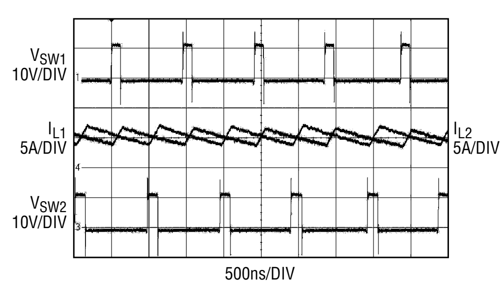


Figure 3. Multiphase operation waveforms of the circuit in Figure 4. The switch voltage and inductor ripple currents operate 180° out of phase with respect to each other.

This connects an internal series RC to the compensation point of the loop, while introducing active voltage positioning to the output voltage: 1.5% at no load and –1.5% at full load. The hassle of using external components for compensation is eliminated. If one wants to further optimize the loop, and remove voltage positioning, an external RC filter can be applied to the ITH pin.

1.2V$_{OUT}$, 10A, 2-Phase Supply

Several LTC3605 circuits can run in parallel and out of phase to deliver high total output current with a minimal amount of input and output capacitance—useful for distributed power systems.

The 1.2V$_{OUT}$ 2-phase LTC3605 regulator shown in Figure 4 can support 10A of output current. Figure 3 shows the 180° out-of-phase operation of the two LTC3605s. The LTC3605 requires no external clock device to operate up to 12 devices synchronized out of phase—the CLKOUT and CLKIN pins of the devices are simply cascaded, where each slave's CLKIN pin takes the CLKOUT signal of its respective master. To produce the required phase offsets, simply set the voltage level on the PHMODE pin of each device to INTV$_{CC}$, SGND or INTV$_{CC}$/2 for 180°, 120° or 90° out-of-phase signals, respectively, at the CLKOUT pin.

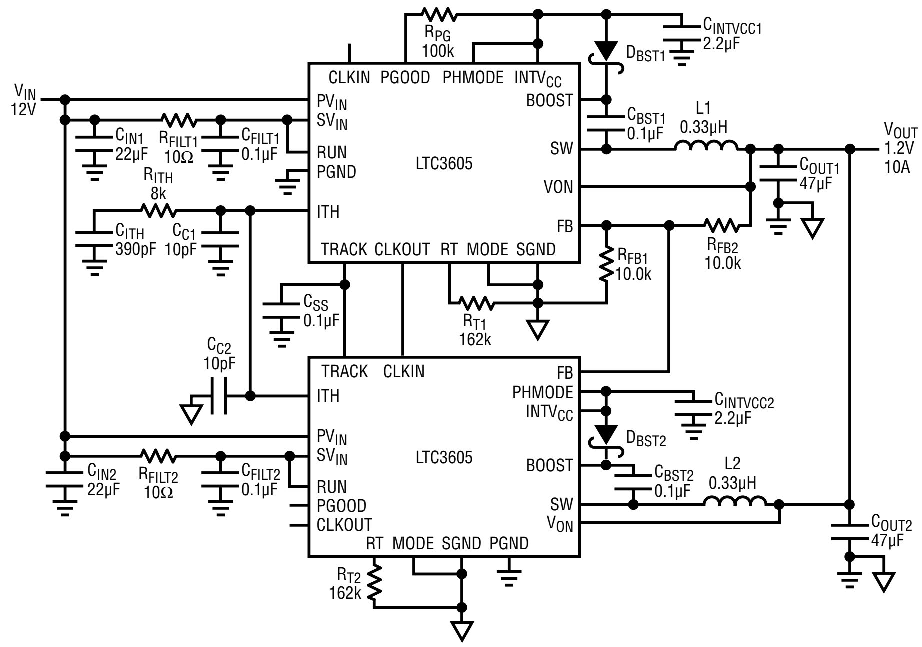


Figure 4. 12V to 1.2V at 10A 2-phase buck converter

Conclusion

The LTC3605 offers a compact, monolithic, regulator solution for high current applications. Due to its PolyPhase capability, up to 12 LTC3605s can run in parallel to produce 60A of output current. PolyPhase operation can also be used in multiple output applications to lower the amount of input ripple current, reducing the necessary input capacitance. This feature, plus its ability to operate at input voltages as high as 15V, make the LTC3605 an ideal part for distributed power systems.

LT8410, continued from page 34

Conclusion

The LT8410/-1 is a smart choice for applications which require low standby quiescent current and/or require low input current, and is especially suited for power supplies with high impedance sources. The ultralow quiescent current and high value integrated feedback resistors keep average input current very low, significantly extending battery operating time. The LT8410/-1 is packed with features without compromising performance or ease of use and is available in a tiny 8-pin 2mm × 2mm package.

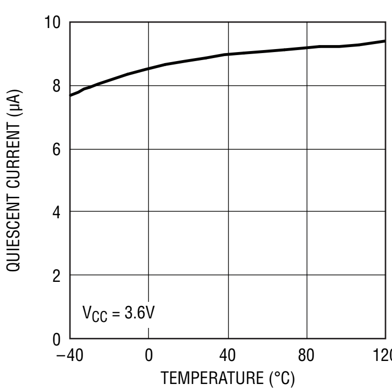


Figure 4. Quiescent current vs temperature (not switching)

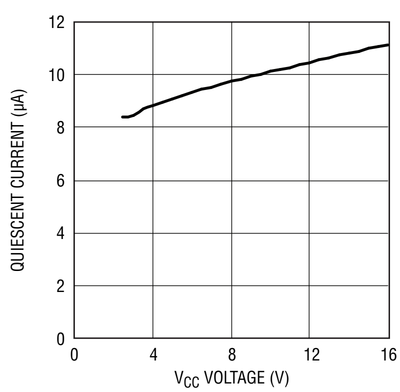


Figure 5. Quiescent current vs V_{CC} voltage (not switching)

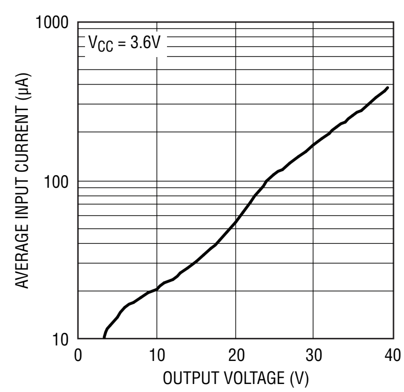


Figure 6. Average input current in regulation with no load

New Device Cameos

Ultralow Power, 14-Bit 150Msps ADC Reduces Digital Feedback in Data Conversion Systems

The LTC2262 is a low power 14-bit, 150Msps Analog-to-Digital Converter (ADC) that dissipates only 149mW, less than one-third the power of competitive solutions. This new benchmark enables portable applications limited by stringent power budgets to extend their performance capabilities, as well as providing higher operating efficiency and reduced recurring operating costs for 3G/4G LTE and WiMAX basestation equipment. In addition to offering considerably lower power, the LTC2262 integrates two unique features for reducing digital feedback in situations where even good layout practice may fail. These features in combination with low power ease the task of designing with high speed ADCs in a wide variety of applications, including portable medical imaging and ultrasound, portable test and instrumentation, non-destructive test equipment, software defined radios and cellular basestations.

Digital feedback occurs when energy from ADC outputs couples back into the analog section, causing interaction that appears as odd shaping in the noise floor and spurs in the ADC output spectrum. The worst situation is at midscale, where all outputs are changing from ones to zeroes, or vice versa, generating large ground currents that couple back into the input.

To combat this effect, the LTC2262's proprietary alternate bit polarity (ABP) mode inverts all of the odd bits before the output buffers to equalize the number of ones and zeroes switching. This method effectively cancels the large ground plane currents that contribute to digital feedback. In addition to the alternate bit polarity mode, an optional data output randomizer is also available for reducing interference from the digital outputs. The randomizer decorrelates the digital output to reduce the likelihood of repetitive code patterns that couple back into the ADC input, causing unwanted tones in the output spectrum. Both digital feedback reduction techniques have proven to improve spurious free dynamic range (SFDR) performance by 10dB –15dB.

Operating from a low 1.8V analog supply, the LTC2262 achieves significant power savings without sacrificing AC performance. This ADC offers signal to noise ratio (SNR) performance of 72.8dB and spurious free dynamic range (SFDR) of 88dB at baseband. Ultralow jitter of 0.17ps_{RMS} allows undersampling of IF frequencies with excellent noise performance.

The LTC2262's innovative digital outputs can be set to full rate CMOS, double data rate CMOS, or double data rate LVDS. Double data rate digital outputs allow data to be transmitted on both the rising edge and the falling edge of the clock, reducing the number of data lines needed by half. A separate output power supply allows the CMOS output swing to range from 1.2V to 1.8V.

Offered in a 6mm × 6mm QFN package, the LTC2262 includes a clock duty cycle stabilizer circuit to facilitate non-50% clock duty cycles, programmable digital output timing, programmable LVDS output current and optional LVDS output termination. These features combine to make the data transmission between the ADC and the digital receiver more flexible.

Quad 12-Bit/10-Bit/8-Bit DACs Include 10ppm/°C Reference

The LTC2634 quad 12-bit, 10-bit and 8-bit rail-to-rail digital-to-analog converters (DACs) integrate a precision reference in tiny 3mm × 3mm QFN and MSOP packages. The LTC2634 is the latest offering in Linear's family of tiny 12-bit, 10-bit and 8-bit DACs with internal references. The LTC2634 joins the previously released LTC2636 octal and LTC2630/LTC2640 single channel DACs, offering a versatile selection of the smallest DACs for numerous applications.

The LTC2634's small size and internal reference is important for a variety of industrial, automotive and ATE applications. By integrating a 10ppm/°C reference, the LTC2636 offers further space reduction for compact circuit boards. The LTC2634 offers 12-bit performance of ±2.5LSB (max) INL error and less than 2.4nV•s crosstalk, ensuring that a voltage change on one DAC has minimal effect on the other DACs. Operating from a single 2.7V to 5.5V supply, supply current is a low 125µA per DAC.

The LTC2634 DACs are available in a number of ordering options to meet a wide range of applications. In addition to selecting one of three resolution options, designers can also choose between a 2.5V or 4.096V full-scale range. Ordering options provide the choice between powering up the DACs at zero-scale or mid-scale, offering flexibility for designs that cannot be forced to ground when power is first applied. Designers can choose between an MSOP-10 package or a 16-pin 3mm × 3mm QFN package that includes a hardware load-DAC (LDAC) pin, a clear pin that asynchronously forces the DAC outputs to their respective reset state, and a serial data output pin.

10MHz to 6GHz Low Power RMS Detector with 40dB Dynamic Range for Accurate RF Power Measurement

The LT5581 is a broadband 6GHz RMS detector, featuring 40dB dynamic range and a low operating supply current of 1.4mA. The device is well suited for a wide range of power monitor and control applications in portable and battery-powered wireless systems, cellular basestations, picocells and femtocells, fiber optic transmitters and instrumentation. The LT5581 outputs a DC voltage that is linearly proportional to the log input power, providing an easy-to-use, mV/dB scaling with exceptional linearity of better than ±1dB across 40dB range.

The LT5581's RMS measurement capability provides accurate RF power readings to within ±0.2dB regardless of waveforms that have high crest-factor modulated content, multicarrier or multitone. Moreover, the LT5581 offers exceptional accuracy of ±1dB over its operating temperature range of –40°C to 85°C.

Operating over a wide supply voltage range of 2.7V to 5.25V, the LT5581's low power consumption makes it ideal for battery-powered communication and multimedia devices. Yet, it has the accuracy performance to meet the performance required by basestations, picocells and femtocells, cable infrastructure and optical communication systems. Additionally, the LT5581's wide frequency range extends to applications including WiMAX and wireless systems in the 5GHz ISM bands. The LT5581's single-ended RF input does not require an external RF transformer, thus simplifying the application design while reducing costs. The LT5581 has a fast response time of 1µs rise time to a full power swing, suitable for time-division duplexing systems.

The LT5581 also incorporates a shutdown feature. When the LT5581's Enable input pin is pulled low, the chip draws a typical shutdown current of 0.2µA, and a maximum of 6µA. The device is offered in a tiny 8-lead, 3mm × 2mm DFN surface mount package.

LT3650, continued from page 7

monitored input supply become excessive. The CLP pin can be configured to implement an input current limit function for systems having multiple loads that share the LT3650 V_{IN} supply. The LT3650 reduces maximum battery charge current if the voltage on the CLP pin exceeds the voltage on V_{IN} by 50mV. Total load current on the input power supply can be monitored by connecting a sense resistor from the CLP pin to V_{IN}, and connecting any external loads to the V_{IN} pin. The LT3650 servos the charger maximum output current such that 50mV is maintained across the CLP sense resistor.

A Full Complement of Battery Charger Features

Figure 7 shows a battery charger that incorporates many of the LT3650's unique features. This charger incorporates top off charging with a 3-hour backup safety timer, and directly accepts input voltages from 12V to 40V (32V operating maximum). This charger uses a 9.1V Zener diode to level-shift the input supply, incorporating an undervoltage lockout function for V_{IN} < 10V.

Battery pack temperature-sensing is enabled by connecting an NTC thermistor to the NTC pin. Charging is suspended if the battery temperature does not remain within a 0°C to 40°C range. The charger uses a resistor divider to modulate the voltage on RNG/SS, which reduces the maximum battery charge current if V_{IN} is below 20V, useful for current-limited input sources such as wall adapters. A capacitor on the RNG/SS pin enables a soft-start function. A secondary system load is supported, with the input supply protected by an input current limit feature, incorporated by connecting the input supply to the CLP pin via a 0.05Ω sense resistor. The maximum charge current is automatically reduced to keep the total input supply current from exceeding the 1A limit set by the sense resistor.

Conclusion

The LT3650 provides a versatile and easy-to-use platform for a wide variety of efficient Li-Ion battery charger solutions. Low power dissipation makes continuous charging up to 2A practical, deriving power directly from input supplies up to 32V without the need for an intermediate DC/DC converter. The compact size of the IC coupled with modest external component requirements allows construction of space saving, cost-effective, and feature-rich Li-Ion battery chargers.

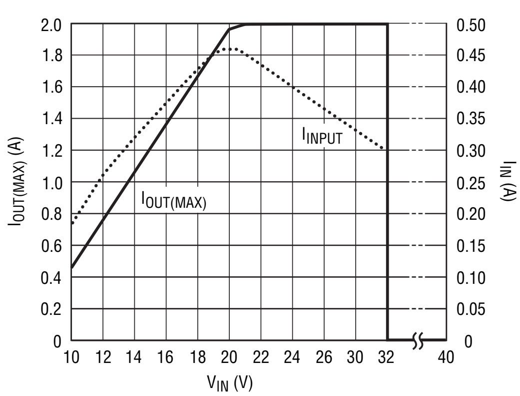


Figure 8. Charger maximum input current (I_{IN}) and maximum output current ($I_{OUT(MAX)}$) vs V_{IN} for the battery charger shown in Figure 7. Charge current reduction for V_{IN} < 20V keeps the charger input supply current below 0.5A

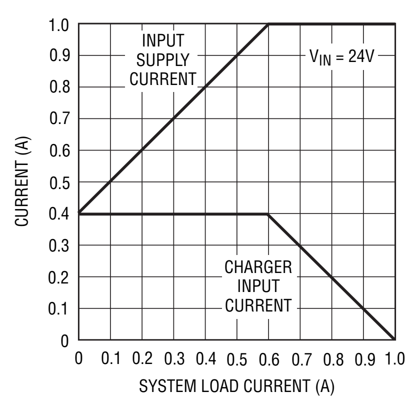


Figure 9. Charger maximum input current, system load current, and total input supply current for the battery charger shown in Figure 7 for V_{IN} = 24V. Battery charger output current is reduced to maintain a maximum input supply current of 1A, which corresponds to 50mV across the 0.05Ω resistor that is connected between the CLP and V_{IN} pins of the LT3650.

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