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Easy High Density Power: 48A Surface Mount DC/DC Power Supply Uses Four Parallel 12A µModule Regulators

by Alan Chern

Introduction

Linear Technology's µModule DC/DC regulators simplify power supply design by offering the black box convenience of traditional power modules in an IC form factor. For example, the LTM4601 µModule regulator is a complete step-down power module in a 15mm × 15mm × 2.8mm LGA package.

The LTM4601 accepts 4.5V to 20V inputs and can produce outputs anywhere from 0.6V to 5V at 12A. The wide input and output ranges and excellent thermal performance of the LTM4601 allow it to be easily dropped into a variety of applications with minimal design effort—just set the output voltage with a single resistor and determine the requisite bulk input and output capacitances.

Another significant advantage of the LTM4601 over power-module- or IC-based systems is its ability to easily scale up as loads increase. If load requirements are greater than one µModule regulator can produce, simply add more modules in parallel. The design of a parallel system involves little more than copying and pasting the layout of each 15mm × 15mm µModule regulator. Electrical layout issues are taken care of within the µModule package—there are no external inductors, switches or other components to worry about. Even heat distribution is improved with parallel regulators, thus enabling surface mount solutions for high power density applications.

The LTM4601 µModule DC/DC regulator is a high performance power module shrunk down to an IC form factor. The usual external components are integrated into the LGA package—including the PWM controller, inductor, input and output capacitors, ultralow $R_{DS(ON)}$ FETs, Schottky diodes and compensation circuitry. Only external bulk input and output capacitors and one resistor are needed to set the output from 0.6V to 5V.

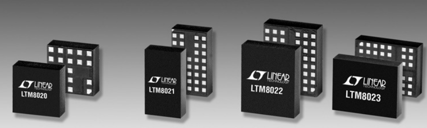
To demonstrate the simplicity and performance of a paralleled µModule regulator design, this article discusses electrical guidelines, layout considerations, and thermal specifics for designing a compact 48A, 0.6V–5V V_{OUT}, 4.5V–20V V_{IN} converter using four LTM4601 µModule DC/DC regulators.

continued on page 3

Linear in the News…

Big Power in Small Packages

Linear has just completed the launch of a new family of high voltage µModule™ DC/DC converters. These small, low profile devices are instant power supplies, packing a range of power system solutions into surface mount packages that can be automatically placed on either side of a PC board. With the introduction of the LTM802X high voltage µModule regulators, Linear has expanded its offering to solutions ideal for 24V industrial, 28V medical, automotive and avionics applications. (For more, see page 36.)



V_{IN}	4V-36V	3.6V-36V	3.6V-36V	3.6V-36V
V_{OUT}	1.25V-5V	0.8V-5V	0.8V-10V	0.8V-10V
I_{OUT}	200mA	500mA	1A	2A
SIZE	6.25 x 6.25 x 2.3mm	6.25 x 11.25 x 2.8mm	11.25 x 9 x 2.8mm Pin Compatible	

Power Electronics Technology Names LT3080 Product of the Year

Power Electronics Technology magazine selected Linear Technology's LT3080 3-terminal low dropout linear regulator as Product of the Year. The award was presented at the Power Electronics Technology Conference in Dallas to Linear Technology Vice President Engineering and Chief Technical Officer Robert Dobkin, who developed the product. As a historical note, the LT3080 is a significant refinement over the industry-standard 3-terminal linear regulators first developed by Robert Dobkin over 30 years ago.

David Morrison, Editor of *Power Electronics Technology*, stated, "Among the hundreds of power components introduced each year, there are numerous devices with exciting performance improvements and novel features. This continuing wave of innovation makes selecting a single product for special recognition a particularly daunting challenge. Linear Technology's LT3080 was selected as this year's Product of the Year because it offers an intriguing combination of novelty and usefulness. By redesigning the low-dropout linear regulator, Linear has given engineers an extremely flexible building block that should help solve current and future board-level power challenges."

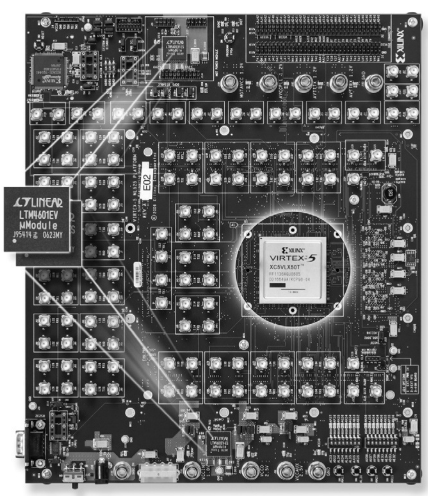
Robert Dobkin, CTO of Linear Technology, stated, "Manufactured in a bipolar transistor process, the LT3080 expands the easy-to-use linear regulator into modern high performance systems. With its low voltage operation and the ability to parallel devices for higher output, it can do circuit tricks that no other regulator can. This is a new general purpose and more useful architecture for regulators that will proliferate with time."

The LT3080 is a 1.1A 3-terminal linear regulator that can easily be paralleled for heat spreading and is adjustable to zero with a single resistor. This new architecture regulator uses a current reference and voltage follower to allow sharing between multiple regulators with a small length of PC trace as ballast, enabling multiamp linear regulation in all surface-mount systems without heat sinks.

The LT3080 achieves high performance with wide input voltage capability from 1.2V to 40V, a dropout voltage of only 300mV and millivolt regulation. The output voltage is adjustable, spanning a wide range from 0V to 40V, and the on-chip trimmed reference achieves high accuracy of ±1%. The LT3080 really shines in generating multirail systems.

Linear Highlights µModule Regulators in FPGA Net Seminar

Linear Technology power module Development Manager Eddie Beville recently co-presented a web seminar entitled, "Xilinx Virtex-5 Power Optimization and Power Design Guidelines." The online seminar is designed to teach designers how to leverage the dedicated blocks in Virtex-5, using the Xilinx Power Estimator (XPE) to reduce power consumption, increase system reliability and simplify thermal management and power supply design for FPGA-based systems. It also demonstrates how to implement Linear Technology power management solutions via real world design examples for Virtex-5 FPGAs. The seminar showed how to design the power distribution network using Linear Technology's µModule DC/DC converters, ultralow noise VLDOs and other devices for key system functions.



The seminar was conducted on *EE Times' TechOnline* engineering education website. It is currently available for viewing at www.techonline.com/learning/webinar/.

LTM4601, continued from page 1

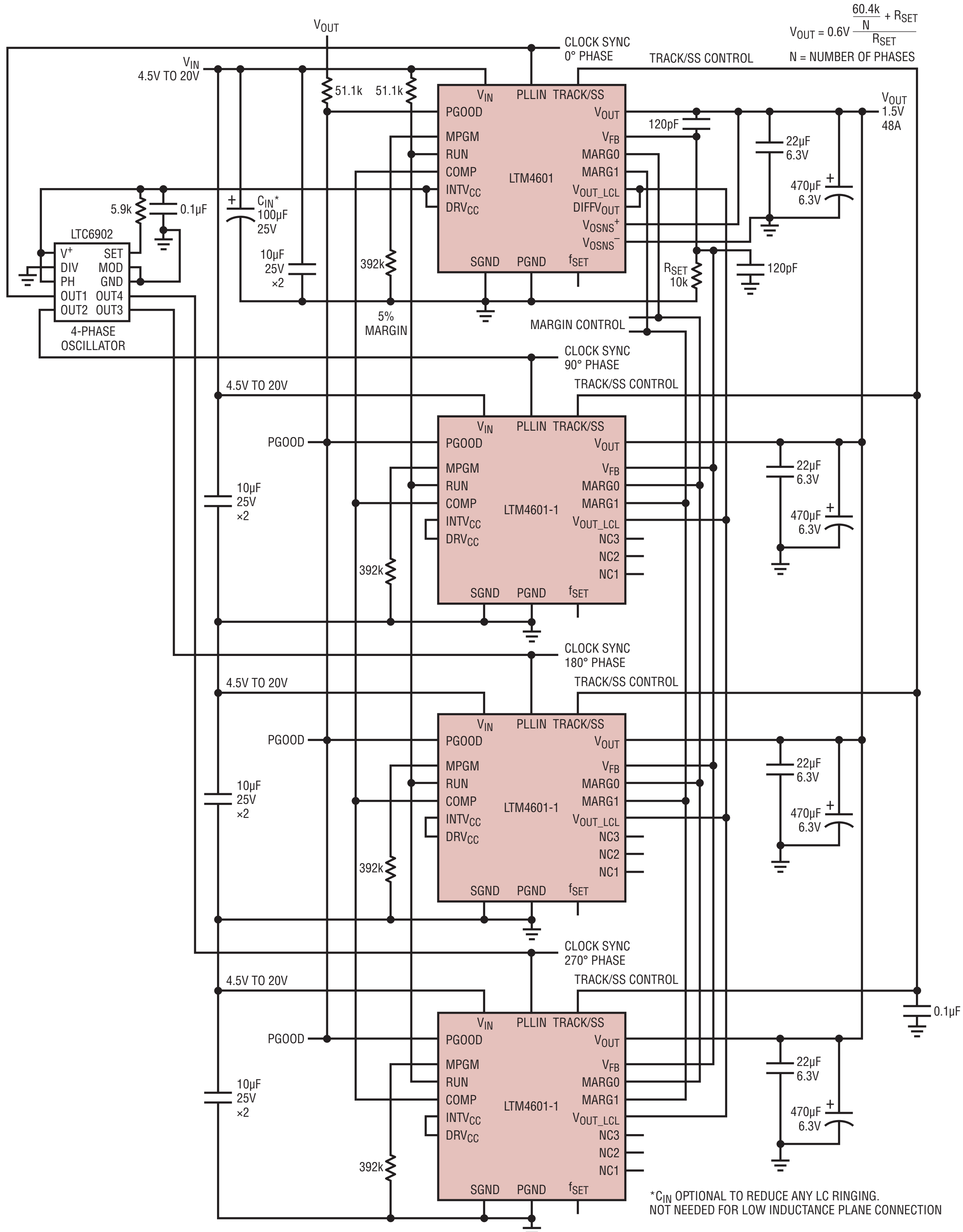


Figure 1. Designing a high density power supply for a limited space application could not be easier. Here, four LTM4601 µModule regulators are paralleled in a simple scheme. Board layout is just as easy, since there are so few external components.

DC/DC µModule Regulator: A Complete System in an LGA Package

The LTM4601 µModule DC/DC regulator is a high performance power module shrunk down to an IC form factor. It is a completely integrated solution—including the PWM controller, inductor, input and output capacitors, ultralow $R_{DS(ON)}$ FETs, Schottky diodes and compensation circuitry. Only external bulk input and output capacitors and one resistor are needed to set the output from 0.6V to 5V. The supply can produce 12A (more if paralleled) from a wide input range of 4.5V to 20V, making it extremely versatile. The pin compatible LTM4601HV extends the input range to 28V.

Output features include output voltage tracking and margining. The high switching frequency, typically 850kHz at full load, constant on time, zero latency controller delivers fast transient response to line and load changes while maintaining stability. Should frequency harmonics be a concern, an external clock can control synchronization via an on chip phase lock loop.

48A from Four Parallel µModule Regulators

Figure 1 shows a regulator comprising four parallel LTM4601s, which can produce a 48A (4 ×12A) output. The regulators are synchronized but operate 90° out of phase with respect to each other, thereby reducing the amplitude of input and output ripple currents through cancellation. The attenuated ripple in turn decreases the external capacitor RMS current rating and size requirements, further reducing solution cost and board space.

Synchronization and phase shifting is implemented via the LTC6902 oscillator, which provides four clock outputs, each 90° phase shifted (for 2- or 3-phase relationships, the LTC6902 can be adjusted via a resistor.). The clock signals serve as input to the PLLIN (phase lock loop in) pins of the four LTM4601s. The phase-lock loop of the LTM4601 comprises a phase detector and a voltage controlled os-

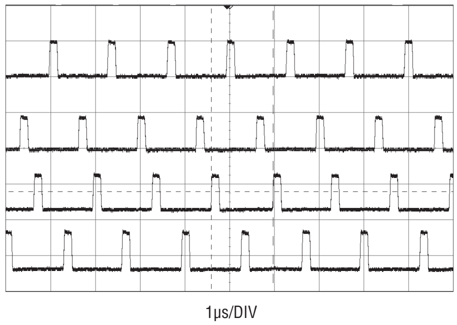


Figure 2. Individual LTM4601 switching waveforms for the circuit in Figure 1 shows the 90° out-of-phase relationship.

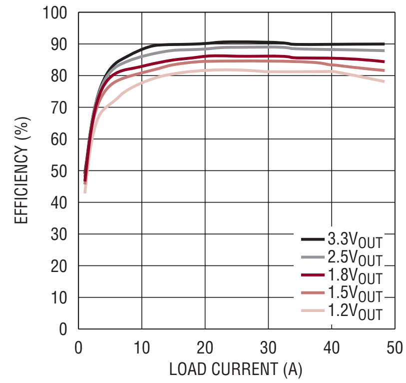


Figure 3. Efficiency of the four parallel LTM4601s remains high over a wide range of outputs

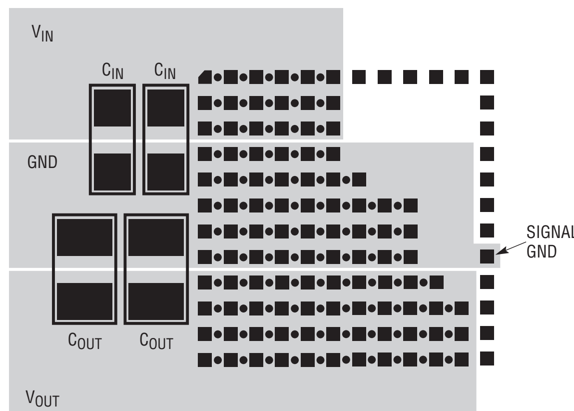


Figure 4. The LTM4601's pin layout promotes simple power plane placement and uncomplicated part paralleling

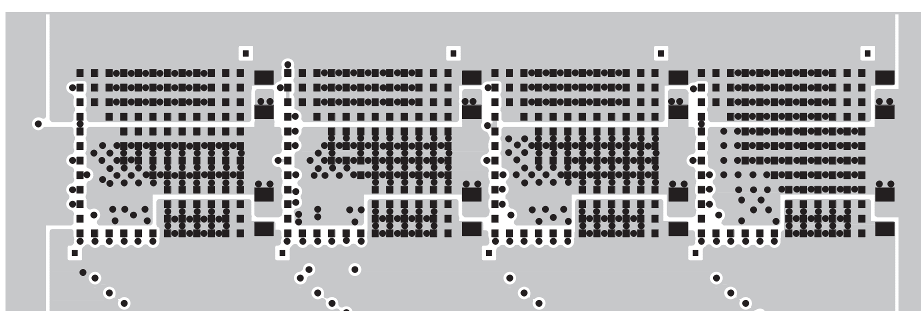


Figure 5. Top layer planes for 4-parallel µModule system

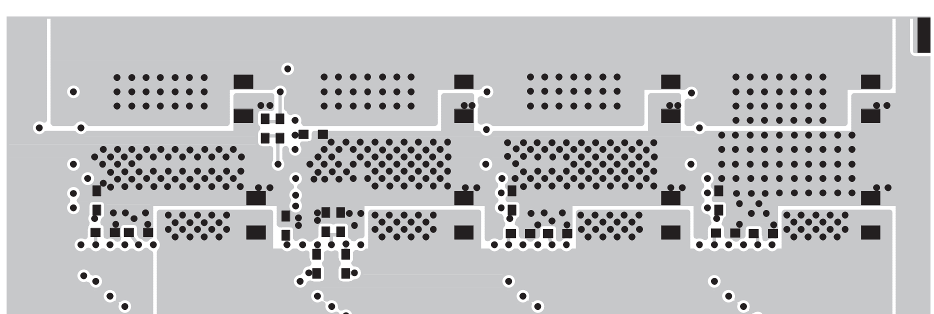


Figure 6. Bottom layer planes for 4-parallel µModule system

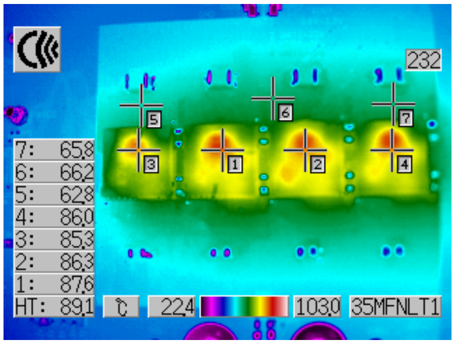


Figure 7. Thermograph of four parallel LTM4601s without airflow (20V input to 1.5V output at 40A)

cillator, which combine to lock onto the rising edge of an external clock with a frequency range of 850kHz ±30%. The phase lock loop is turned on when a pulse of at least 400ns and 2V amplitude at the PLLIN pin is detected, though it is disabled during start-up. Figure 2 shows the switching waveforms of four LTM4601 µModule regulators in parallel.

Only one resistor is required to set the output voltage in a parallel setup, but the value of the resistor depends on the number of LTM4601s used. This is because the *effective* value of the top (internal) feedback resistor changes as you parallel LTM4601s. The LTM4601's reference voltage is 0.6V and its internal top feedback resistor value is 60.4kΩ, so the relationship between V_{OUT}, the output voltage setting resistor (R_{FB}) and the number of modules (n) placed in parallel is:

$$V_{OUT} = 0.6V \frac{\frac{60.4k}{n} + R_{FB}}{R_{FB}}$$

Figure 3 illustrates the system's high efficiency over the vast output current range up to 48A. The system performs impressively with no dipping in the efficiency curve for a broad range of output voltages.

Layout

Layout of the parallel µModule regulators is relatively simple, in that there are few electrical design considerations. Nevertheless, if the intent of a design is to minimize the required PCB area, thermal considerations become paramount, so the important parameters are spacing, vias, airflow and planes.

The LTM4601 µModule regulator has a unique LGA package footprint, which allows solid attachment to the PCB while enhancing thermal heat sinking. The footprint itself simplifies layout of the power and ground planes, as shown in Figure 4. Laying out four parallel µModule regulators is just as easy, as shown in Figures 5 and 6.

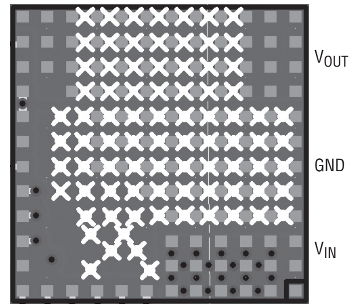


Figure 8. Via placement (cross marks) under a single µModule regulator

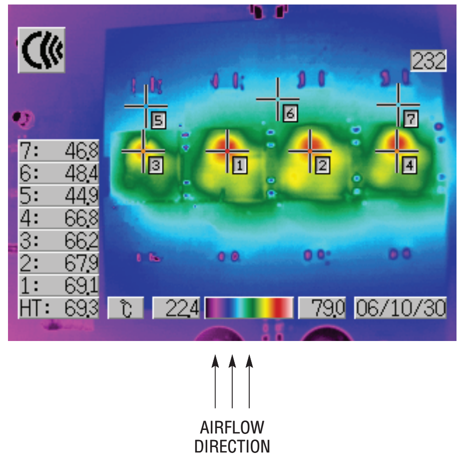


Figure 9. Thermograph of four parallel LTM4601s with 200LFM bottom-to-top airflow (20V input to 1.5V output at 40A)

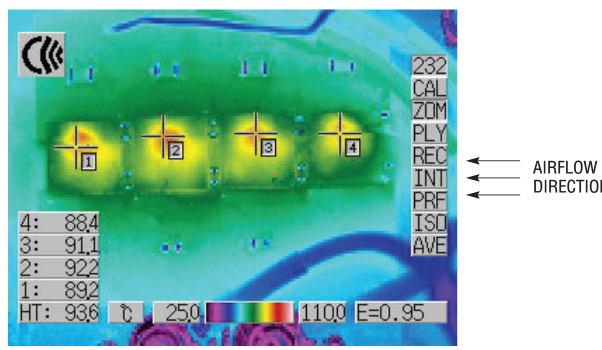


Figure 10. Thermograph of four parallel LTM4601s with 400LFM right-to-left airflow in 50°C ambient chamber (12V input to 1V output at 40A)

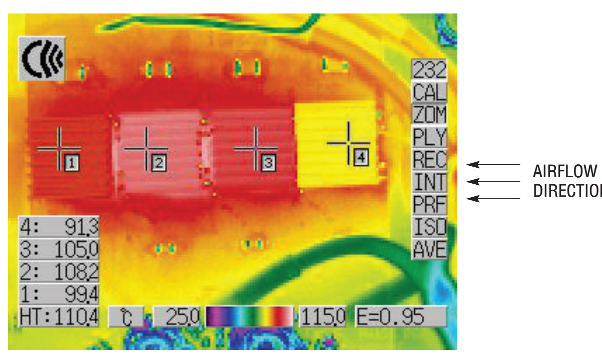


Figure 11. Thermograph of four parallel LTM4601s with BGA heat sinks and 400LFM right-to-left airflow in a 75°C ambient chamber (12V input to 1V output at 40A)

If laid out properly, the LGA packaging and the power planes alone can provide enough heat sinking to keep the LTM4601 cool.

Figure 7 is a thermal image of the DC1043A board with readings of the temperatures at specific locations. Cursors 1 to 4 give a rough estimation of the surface temperature on each module. Cursors 5 to 7 indicate the surface temperature of the PCB. Notice the difference in temperature between the inner two regulators, cursors 1 and 2, and the outside ones, cursors 3 and 4. The LTM4601 µModule regulators placed on the outside have large planes to the left and right promoting heat sinking to cool the part down a few degrees. The inner two only have small top and bottom planes to draw heat away, thus becoming slightly warmer than the outside two.

Further heat dissipation is possible by adding vias underneath the part. Vias provide a path to the power planes and into the PCB, which helps draw heat away. Vias should not be placed directly under the pads. Figure 8 shows the layout of the vias on the DC1043A demonstration circuit. The cross marks indicate the vias in between the LGA pads.

Airflow also has a substantial effect on the thermal balance of the system. Note the difference in temperature between Figure 7 and Figure 9. In Figure 9, a 200LFM airflow travels evenly from the bottom to the top of the demo board, causing a 20°C drop across the board compared to the no air flow case in Figure 7.

The direction of airflow is also important. In Figure 10 the airflow travels from right to left, pushing the heat from one µModule regulator to the next, creating a stacking effect. The µModule device on the right, the closest to the airflow source, is the coolest. The leftmost µModule regulator has a slightly higher temperature because of spillover heat from the other LTM4601 µModule regulators.

Heat transfer to the PCB also changes with airflow. In Figure 7, heat transfers evenly to both left and right sides of the PCB. In Figure 10, most of the heat moves to the left side.

Layout of the parallel µModule regulators is relatively simple, in that there are few electrical design considerations. Nevertheless, if the intent of a design is to minimize the required PCB area, thermal considerations become paramount. The important layout parameters are regulator spacing and usage of vias, airflow and planes.

Figure 11 shows an extreme case of heat stacking from one µModule device to the next. Each of the four µModule regulators is fitted with a BGA heat sink and entire board is operated in a chamber with an ambient temperature of 75°C.

Start-Up, Soft-Start and Current Sharing

The soft-start feature of the LTM4601 prevents large inrush currents at start-up by slowly ramping the output voltage to its nominal value. The relation of start-up time to V_{OUT} and the soft-start capacitor (C_{SS}) is:

$$V_{OUT(MARGIN)} = \frac{\%V_{OUT}}{100} \bullet V_{OUT}$$

$$t_{SOFTSTART} = 0.8 \bullet \left(0.6V - V_{OUT(MARGIN)}\right) \bullet \frac{C_{SS}}{1.5\mu A}$$

For example, a 0.1µF soft-start capacitor yields a nominal 8ms ramp (see Figure 12) with no margining.

Current sharing among parallel regulators is well balanced through start-up to full load. Figure 13 shows an evenly distributed output current curve for a 2-parallel LTM4601 system, as each rises to a nominal 10A each, 20A total.

Conclusion

The LTM4601 µModule regulator is a self-contained 12A step-down regulator in an IC form factor. It can be easily paralleled to increase load capability to 48A as shown here. Thermal performance is equally impressive at 48A of output current with balanced current sharing and smooth uniform start-up. The ease and simplicity of this design minimizes development time while saving board space.

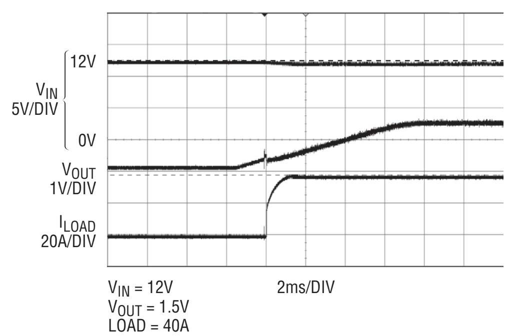


Figure 12. Soft-start ramp for four parallel LTM4601s

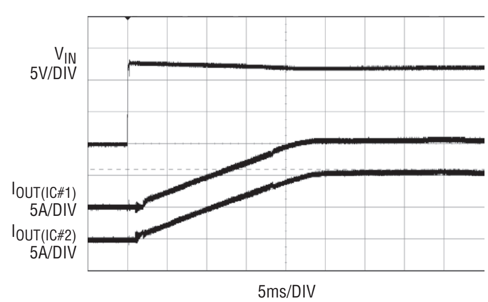


Figure 13. Current sharing among parallel regulators is well balanced through start-up to full load. Two parallel LTM4601s, as each rises to a nominal 10A each, 20A total.

Internal 2A, 42V Switch, Adjustable 2.5MHz Operating Frequency and 3mm × 3mm Package Allow Boost Regulator to Fit Numerous Applications

by Mathew Wich

Introduction

The world of switching DC/DC converters is awash with a dizzying array of product offerings. For a given application, much of the power supply design effort can be spent simply searching for the optimum combination of package size, switching frequency, input and output voltage range, and desirable features. In many cases, though, the LT3580 offers an optimal solution. It is the right choice for many diverse applications because of its smart combination of features, performance and ease of use.

The LT3580 is a current control switching regulator available in tiny 8-lead packages (MSOP and 3mm × 3mm DFN). Operating from 200kHz–2.5MHz, it supports numerous configurations including boost, inverting, flyback and SEPIC. Inputs can be from 2.5V–32V, and an integrated 2A, 42V NPN power switch allows the LT3580 to provide efficient power from a fraction of a watt up to more than several watts.

The LT3580 supports a variety of converter configurations including boost, inverting, flyback, and SEPIC. Inputs can be from 2.5V–32V, and an integrated 2A, 42V NPN power switch allows the LT3580 to provide efficient power from a fraction of a watt up to more than several watts.

Be Picky—Choose the Ideal Clock Frequency up to 2.5MHz

Choosing a converter switching frequency is often a compromise between several performance parameters such as physical size, output ripple, efficiency and spectral noise issues. While most converter ICs operate at a single fixed frequency, the LT3580 operates at any frequency from 200kHz–2.5MHz allowing you to choose the ideal frequency for any application.

The high frequency capability (up to 2.5MHz) of the LT3580 helps to reduce the overall size of the converter by permitting the use of smaller inductors and output capacitors. Small inductors, with correspondingly small inductances, work best at higher frequencies because they store and release less energy in each switching cycle. This can be seen by looking at the energy storage relationship for an inductor,

$$E = \frac{1}{2}LI^2,$$

which shows that for a given peak inductor current (I), the stored energy is proportional to the inductance (L). Thus smaller inductances, storing less *energy* per cycle, switch at

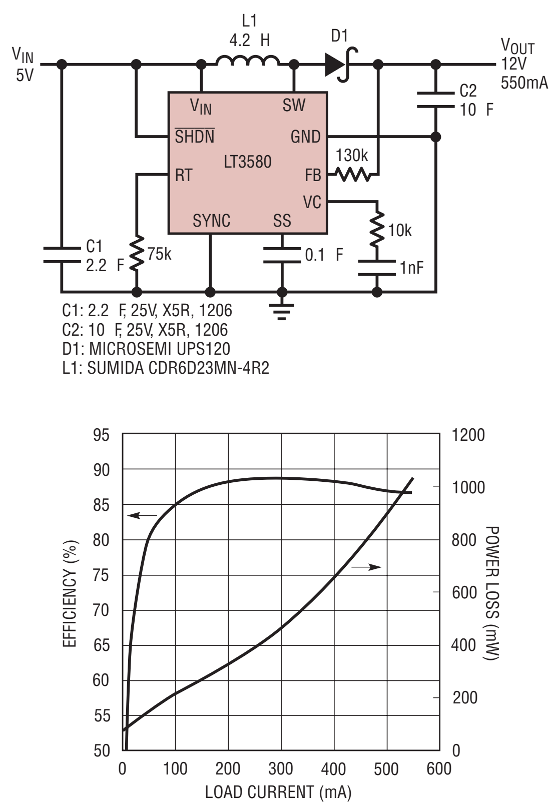


Figure 1. This 1.2MHz, 5V to 12V boost converter achieves over 88% efficiency.

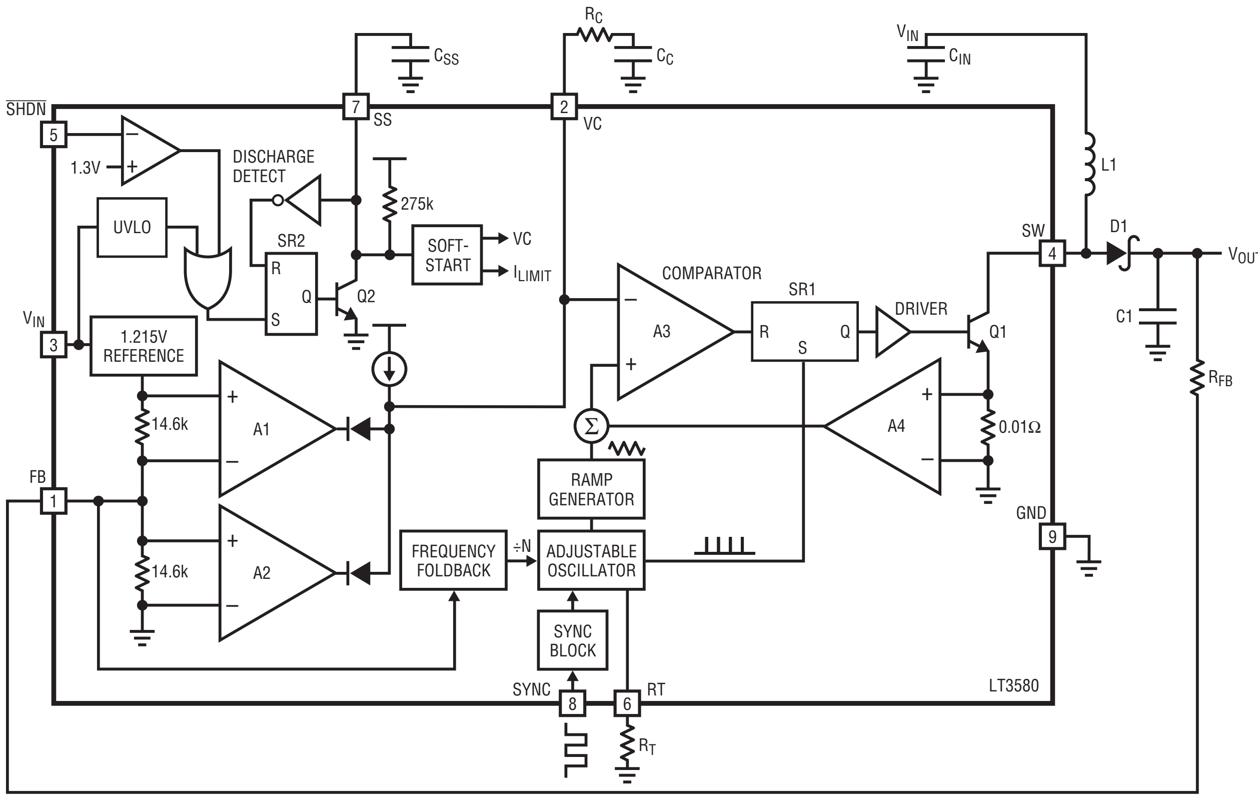


Figure 2. Block diagram of the LT3580 in a boost converter configuration

higher frequencies to deliver the same *power* as larger inductances. Also, smaller inductances reach their peak current (or energy) faster than large inductances as seen by rearranging the relationship

$$V = L\frac{di}{dt} \Rightarrow L\frac{\Delta I}{\Delta T}$$

and solving for ΔT.

$$\Delta T = \frac{L \bullet \Delta I}{V}$$

This shows that, for a given inductor voltage (V), a smaller inductor (L) will ramp to its peak current (I) in less time (T) than a larger inductance, again leading to higher frequency operation to make best use of the inductor.

Depending on the load requirements, high frequency operation also facilitates smaller output capacitors. Since charge is delivered to the output in smaller but more frequent packets, the voltage ripple is reduced for a given capacitance.

Figure 3 shows an example of reduced solution size at a higher switching frequency. The 5V to 12V boost converter operates at 2.5MHz and uses a smaller inductor and less output capacitance than the 1.2MHz solution in Figure 1. The tradeoff is slightly reduced efficiency due to the increased switching losses incurred at the higher switching frequency.

For large voltage gains, the LT3580's low frequency capability (down to 200kHz) is very useful. Figure 5 shows a direct conversion from 5V to 40V running at 750kHz. Figure 6 shows a 5V to 350V flyback converter running at 200kHz.

Finally, the LT3580's wide frequency range makes it easy to avoid

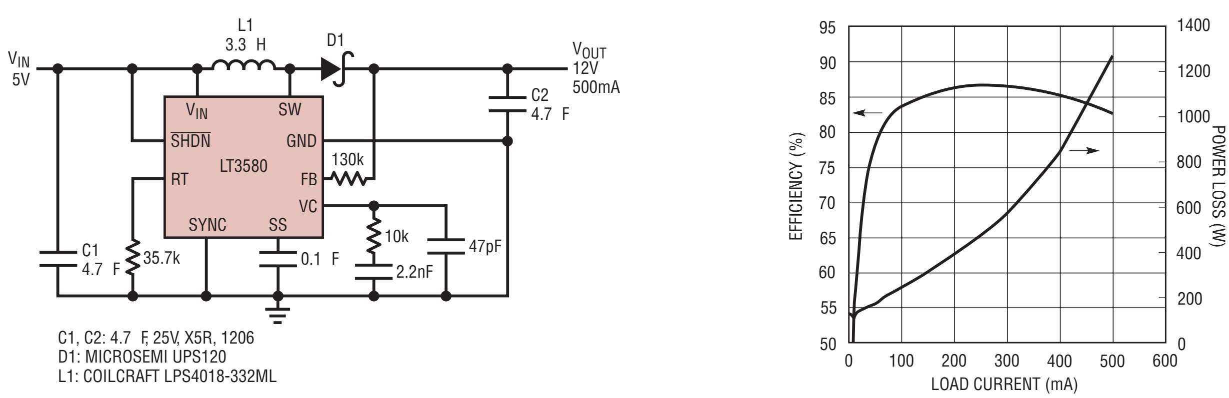


Figure 3. The high 2.5MHz switching frequency of this 5V to 12V boost converter allows the use of a tiny 4mm × 4mm × 1.7mm inductor.

sensitive frequency bands that can't tolerate spectral noise. For example radio power supplies may operate at 2MHz or above to avoid the AM broadcast band. Also, some RF communications products are sensitive to noise at 455kHz, therefore switching above 600kHz is desired.

Accurate Clocking Options

The LT3580 provides two options for generating the clock. First, the integrated oscillator can be accurately set between 200kHz–2.5MHz by connecting a single resistor from the R_T pin to ground, where

$$R_T(k\Omega) = \frac{91.9}{f_{OSC}(MHz)} - 1$$

The boost converter in Figure 3, for example, uses a 35.7k R_T resistor to set the switching frequency to 2.5MHz. The internal oscillator's frequency is accurate to ±10% with little temperature variation as shown in Figure 4. The excellent frequency tolerance maximizes system performance by reducing necessary design margin.

The switching frequency can also be synchronized to an external clock source. The SYNC pin overrides the internal oscillator when toggled at frequencies greater than 75% of the internal oscillator's set frequency. Simply connect a digital clock signal to the SYNC pin using V_{IH} levels from 1.3V to 5.5V, V_{IL} levels below 0.4V and any frequency between 200kHz and 2.5MHz. Using an external clock source is often helpful for several reasons, including...

- ❑ Synchronization of several switching regulators, often out of phase, to reduce switching current spikes
- ❑ Additional frequency precision yielding higher performance
- ❑ Precisely targeting the frequency out of sensitive bands for EMI benefits.

The LTC6908 resistor set oscillator is a nice choice for generating the SYNC clock due to its high precision, dual phase outputs, spread spectrum capabilities, small size and simple operation.

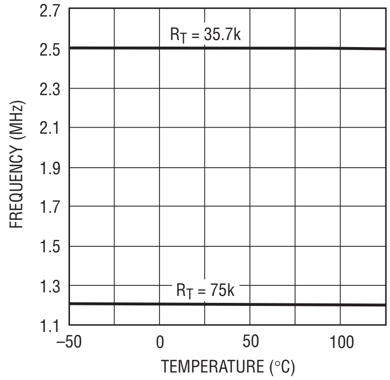


Figure 4. Typical internal oscillator frequency at V_{IN} = 5V

Single-Pin Feedback and Support for Multiple Configurations

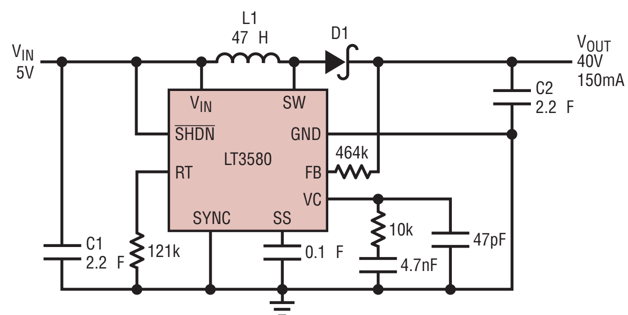
The novel single-pin feedback of the LT3580 reduces external component count and allows it to be used in many different converter topologies. The output voltage is set by simply connecting a single external resistor from V_{OUT} to the FB pin. The FB pin automatically servos to the correct reference voltage for a given topology (1.215V for positive V_{OUT} and 5mV for negative V_{OUT}).

Supported configurations include boost, SEPIC (Figure 10), and other topologies such as the flyback (Figure 6) and inverting (Figure 7).

Finally, to improve V_{OUT} accuracy, the FB pin is factory trimmed to an accurate *current*, instead of trimming the *resistance*, which is typical of other parts. This eliminates multiplication of reference voltage errors to V_{OUT}.

Soft-Start Feature Limits Start-Up Current

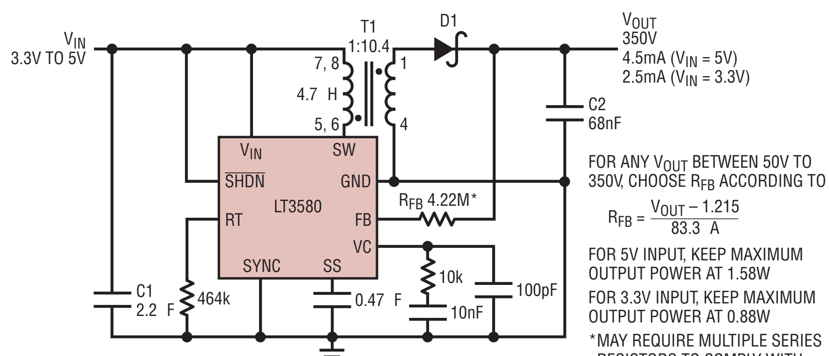
The LT3580 contains a soft-start circuit to limit peak switch currents during start-up. High start-up current is inherent in switching regulators since the feedback loop is saturated



C1, C2: 2.2 F, 25V, X5R, 1206
D1: MICROSEMI UPS140
L1: SUMIDA CDRH105R-470

Figure 5. A 750kHz, 5V to 40V, 150mA boost converter

Danger High Voltage! Operation by High Voltage Trained Personnel Only



C1: 2.2 F, 25V, X5R, 1206
C2: TDK C3225X7R2J683M
D1: VISHAY GSD2004S DUAL DIODE CONNECTED IN SERIES
T1: TDK LDT565630T-041

Figure 6. This 350V power supply features a tiny 5.8mm × 5.8mm × 3mm transformer switching at 200kHz.

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 start-up current can be limited by connecting an external capacitor (typically 100nF to 1µF) to the SS pin. This capacitor is slowly charged to ~2.2V by an internal 275k resistor once the part is activated. SS voltages below ~1.1V reduce the internal current limit. Thus, the gradual ramping of SS also gradually increases the current limit as the capacitor charges. This, in turn, allows the V_{OUT} capacitor to charge gradually toward its final value while limiting the start-up current (see Figure 9).

Innovative $\overline{\text{SHDN}}$ Pin Resets Soft-Start and Serves as Undervoltage Lockout (UVLO)

The $\overline{\text{SHDN}}$ pin has threshold hysteresis to resist noise and tolerate slowly varying input voltages. Driving the $\overline{\text{SHDN}}$ pin to ground shuts down the LT3580 and reduces input current to less than 1µA. Driving $\overline{\text{SHDN}}$ above 1.38V enables the part and begins the soft-start sequence. A built in safety feature ensures that the SS capacitor is actively discharged before start-up begins. This allows for proper soft-start even in the event of short $\overline{\text{SHDN}}$ pulses or thermal lockout.

The LT3580 also features an integrated UVLO that shuts down the chip when the input voltage falls below ~2.3V. However, the $\overline{\text{SHDN}}$ pin can also be configured to disable the chip below even higher voltages as shown in Figure 8.

Typically, UVLO is needed in situations where the input supply is current-limited, has a relatively high source resistance, or ramps up/down slowly. A switching regulator draws constant power from the source, so source current increases as source voltage drops. This looks like a negative resistance load to the source and can cause the source to current-limit or latch low under low voltage conditions. The configurable UVLO prevents the regulator from operating at source

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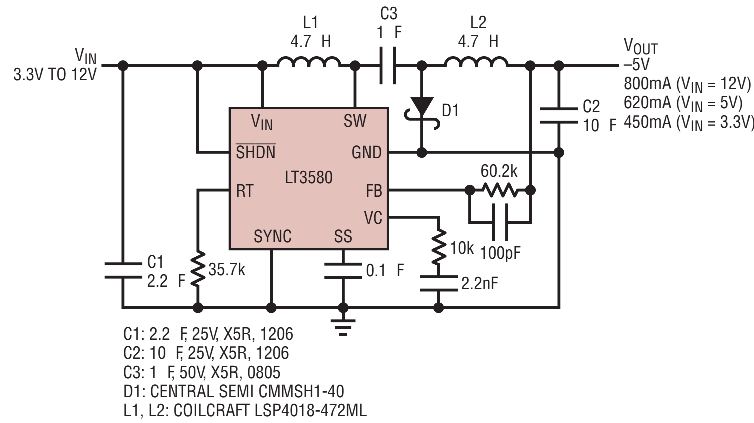


Figure 7. This –5V output inverting converter switches at 2.5MHz and accepts inputs between 3.3V and 12V

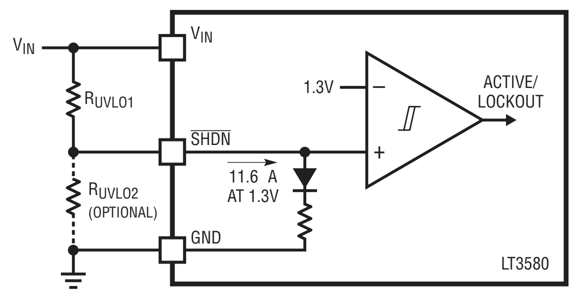


Figure 8. Configurable undervoltage lockout

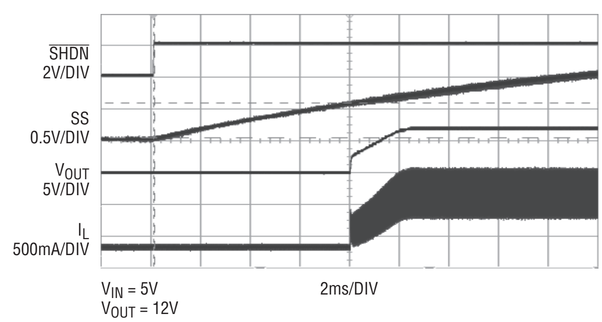


Figure 9. Soft-start of a 5V to 12V boost topology

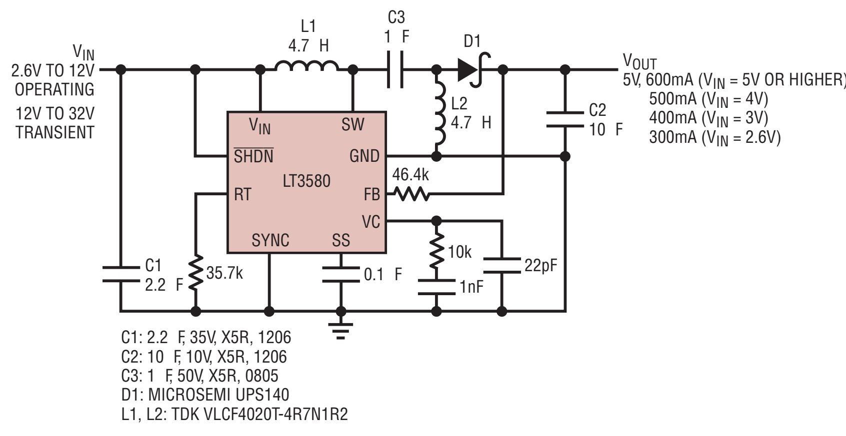


Figure 10. Wide input range SEPIC converter with 5V output switches at 2.5MHz

36V, 3.5A DC/DC Buck Regulators for Automotive, Industrial and Wall Adapter Applications Offer High Efficiency in a Small Package

by Kevin Huang

Introduction

Automotive batteries, industrial power supplies, distributed supplies and wall transformers are all sources of wide-ranging, high voltage inputs. The easiest way to step down the voltage from these sources is with a high voltage monolithic step-down switching regulator that can directly accept a wide input range and produce a well-regulated output. The LT3680 and LT3693 are new step-down switching regulators that accept inputs up to 36V and provide excellent line and load regulations and dynamic response. Both regulators offer high efficiency solutions over wide load range. The LT3680 adds low ripple Burst Mode® operation to maximize efficiency at light load currents.

LT3680 and LT3693 Features

Available in either a 10-pin MSOP or a 3mm × 3mm DFN package, the LT3680 and LT3693 offer an integrated 5A power switch and external compensation for design flexibility. Both regulators employ a constant frequency, current mode architecture. The switching frequency can be set between 200kHz and 2.4MHz by using a resistor tied from the RT pin to ground. This allows a trade off between component size and efficiency. The switching frequency can also be synchronized to an external clock for noise sensitive applications. An external resistor divider programs the output voltage to any value above the part's 0.79V reference.

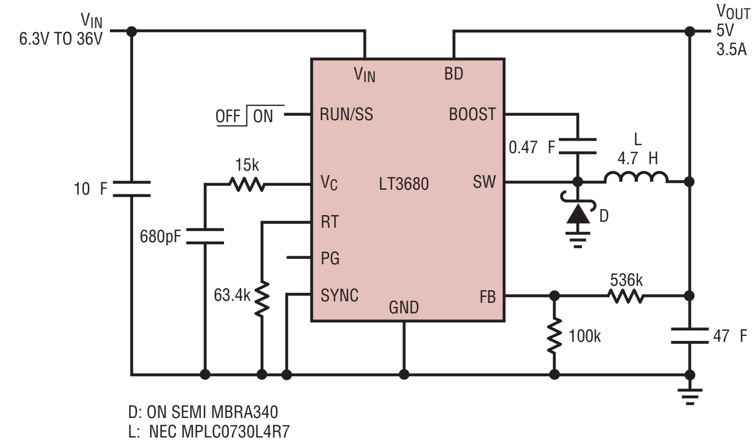


Figure 1. This 600kHz 6.3V–36V input DC/DC converter delivers 3.5A at 5V output.

The easiest way to step down the voltage from a wide ranging, high voltage source is with a monolithic step-down switching regulator that can directly convert the input to a well-regulated output.

The LT3680 and LT3693 offer soft-start via a resistor and capacitor on the RUN/SS pin, thus reducing maximum inrush currents during start-up. Both regulators can withstand a shorted output. A cycle-by-cycle internal current limit protects the circuit in overload and limits output power; when the output voltage is pulled to ground by a hard short, the LT3680 and LT3693 reduce the operating frequency to limit dissipation and peak switch current. This lower frequency allows the inductor current to safely discharge, thus preventing current runaway. The high side bootstrapping boost diode is integrated into the IC to minimize solution size and cost. When

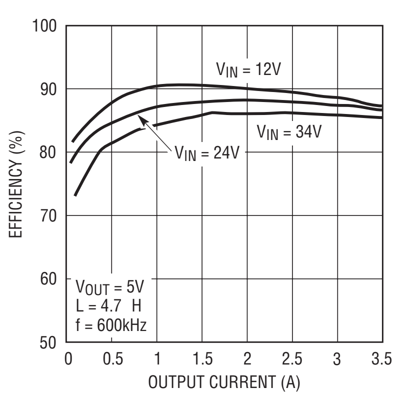


Figure 2. Efficiency vs load current for circuit in Figure 1

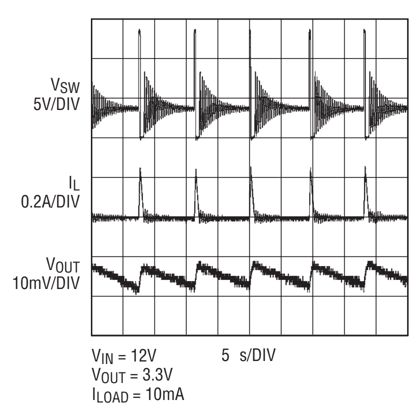


Figure 3. LT3680 Burst Mode operation at 10mA load

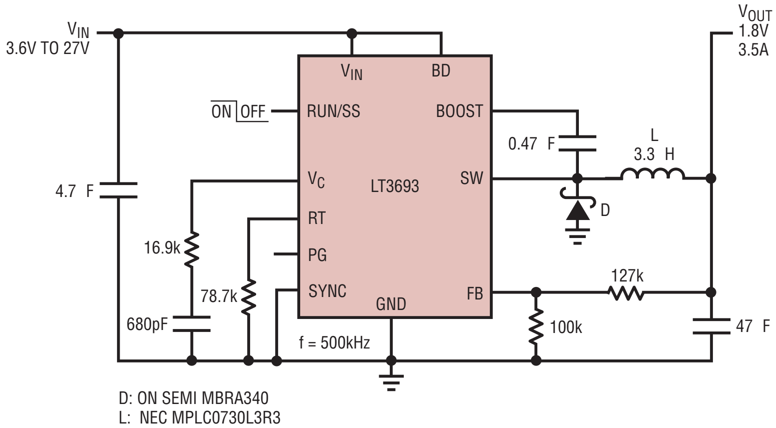


Figure 4. This 500kHz 3.6V–27V input DC/DC converter delivers 3.5A at 1.8V output.

the output voltage is above 2.5V, the anode of the boost diode can be connected to output. For output voltages lower than 2.5V, the boost diode can be tied to a separate rail or to the input. For systems that rely on a well-regulated power source, the LT3680 and LT3693 provide a power good flag that signals when V_{OUT} reaches 90% of the programmed output voltage.

Low Ripple Burst Mode Operation of LT3680

The only difference between LT3680 and LT3693 is that the LT3680 offers low ripple Burst Mode operation, which can be selected by applying a logic low to the SYNC pin. Low ripple Burst Mode operation maintains high efficiency at light load while keeping the output voltage ripple low. During Burst Mode operation, the LT3680 delivers single cycle bursts of current to the output capacitor followed by sleep periods when the output power is delivered to the load only by the output capacitor. Between bursts, all circuitry associated with controlling the output switch is shut down, reducing the input supply current and BD quiescent current to 30µA and 80µA, respectively. As the load current decreases to a no load condition, the percentage of time that LT3680 operates in sleep mode increases and the average input current is greatly reduced, resulting in high efficiency. Both LT3680 and LT3693 have a very low (less than 1µA) shutdown current which significantly extends battery life in applications that spend long periods of shutdown mode. For applications that require constant frequency operation at no load or light load, the LT3693 can be used.

6.3V–36V to 5V, 3.5A DC/DC Converter with All Ceramic Capacitors

Figure 1 shows the LT3680 producing 5V at 3.5A from an input of 6.3V to 38V with 65V transient. The circuit is programmed for a 600kHz switching frequency and requires 100mm^2 of PCB. Figure 2 shows the circuit efficiency at 12V and 24V inputs. At 12V input, the efficiency peaks above 90% and remains high across the entire load range.

The SYNC pin is tied to the ground to enable Burst Mode operation and achieve high efficiency at light load. Figure 3 shows the inductor current and output voltage ripple under single pulse Burst Mode operation at 10mA load. The output voltage ripple $V_{P–P}$ is less than 20mV as a result of low ripple Burst Mode operation.

An external signal can drive the RUN/SS pin through a resistor and capacitor to program the LT3680's soft-start, reducing maximum inrush current during start-up.

3.5V–27V V_{IN} to 1.8V V_{OUT}, 3.5A DC/DC Converter with All Ceramic Capacitors

For output voltages lower than 2.5V, the integrated boost diode can be tied to the input or a separate rail greater than 2.8V. Figure 4 shows a 1.8V output converter using the LT3680 with the integrated boost diode tie to input. In this application, the maximum input voltage is 27V so that the maximum voltage rating of Boost pin and BD pin are not exceeded.

Negative Output from Buck Regulators

Negative output supplies are required for many applications. The circuit in Figure 5 can generate a negative voltage of –5V from buck regulators such as LT3680 or LT3693. The circuit sets the input ground reference and the LT3680 ground reference to –5V to generate negative 5V supply.

Conclusion

The wide input range, small size and robustness of the LT3680 and LT3693 make them easy fit in automotive, industrial and distributed power applications. They are highly efficient over the entire load range. The unique low ripple Burst Mode operation of LT3680 helps to save battery power life while maintaining low output ripple.

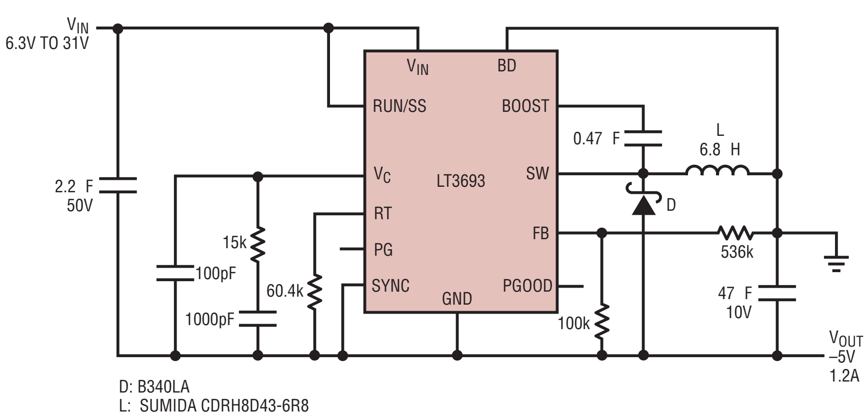


Figure 5. This negative output DC/DC converter delivers 1.2A at –5V output.

Monolithic 2A Buck Regulator Plus Linear Regulator Simplifies Wide Input Voltage Applications

by Rich Philpott

Introduction

Wide ranging voltage sources—such as automotive batteries, unregulated wall transformers, and industrial power supplies—require regulation to provide stable output voltages during harsh input transient conditions. Simple, robust and relatively inexpensive linear regulators offer one solution. They produce low output ripple and offer excellent power supply ripple rejection, but low efficiency, high power dissipation and thermal constraints are problems at high input-to-output ratios.

The typical alternative to the linear solution is a high voltage monolithic step-down switching regulator. Switching regulators offer high efficiency, excellent line and load regulation, and good dynamic response, but systems with multiple outputs require multiple switchers. This can quickly drive up the power supply cost, space requirements, design effort and noise.

A better solution combines the advantages of switchers and linear regulators in a single package. The LT3500 does just this by integrating a high frequency switcher and a linear regulator in a 3mm × 3mm 12-pin DFN package, thus eliminating the need for a second switching regulator in a dual output system.

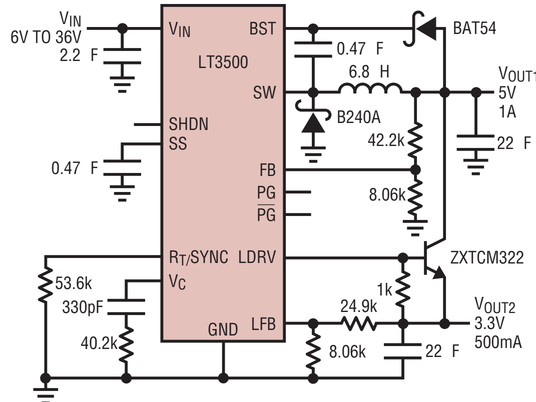


Figure 1. Dual step-down converter for 5V at 1A and 3.3V at 1A

Get Two-for-One and Change…

A common power supply problem is producing 3.3V and 2.5V power rails from a high voltage supply. To solve this problem, the LT3500's switcher efficiently converts the high voltage input to 3.3V, while the linear regulator—plus an external NPN transistor—generates 2.5V from the switcher's 3.3V output. You get two outputs for the cost of one small package.

…Or, Just Beat the Heat

In high voltage input, single-output systems where linear regulation is preferred because of low output ripple and power supply rejection, but heat dissipation is an issue, the LT3500 also offers an elegant solution. For example, if a linear regulated 3.3V output is needed, the LT3500's switcher can efficiently step-down the input voltage to 3.6V. The integrated linear regulator (plus an external NPN) can generate a clean 3.3V from 3.6V with minimal heat dissipation.

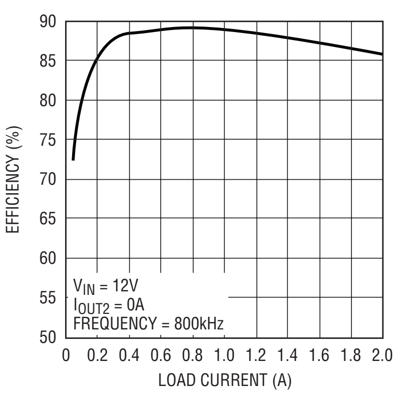


Figure 2. LT3500 switching regulator efficiency

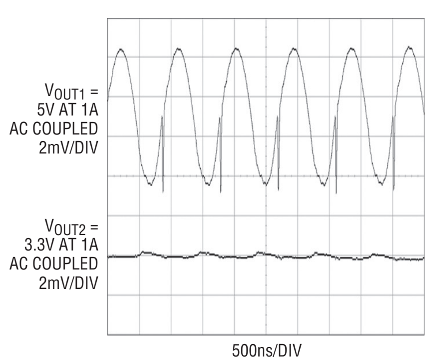


Figure 3. 5V and 3.3V output ripple waveforms

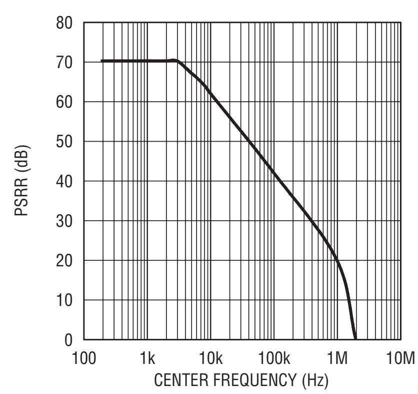


Figure 4. PSRR vs Frequency for V_{OUT2} for the application shown in Figure 1

Features of the LT3500

The LT3500's switching regulator is a constant frequency, current mode PWM step-down DC/DC converter with an internal 2.3A switch. The wide 3V–36V input range makes the LT3500 ideal for regulating power from a wide variety of sources, including automotive batteries, 24V industrial supplies and unregulated wall adapters.

The switching frequency can be set from 250kHz to 2.2MHz via a single resistor from the RT/Sync pin to ground, or synchronized over the same range by driving the pin with a square wave. Programmable frequency range and synchronization capability enable optimization between efficiency and external component size. Cycle-by-cycle current limit, frequency foldback and thermal shutdown protect the LT3500 from harmful fault conditions.

In addition to the switching regulator, the LT3500 contains an internal NPN transistor capable of delivering 13mA with feedback control, which can be configured as a linear regulator or a linear regulator controller. The LT3500's soft-start feature controls the ramp rate of the output voltages, eliminating input current surge during start-up, while providing output tracking between the switcher and linear outputs. The SHDN pin has an accurate threshold with current hysterisis, which enables the user to program an undervoltage lockout. The LT3500 provides open collector power good flags that signal when the output voltages on both outputs rise above 90% of their programmed values. The PG pin is high impedance when the outputs are in regulation and is typically used for a system reset function. The PG pin is active when the outputs are in regulation and is used as a drive signal for an output disconnect device. In shutdown mode the LT3500 draws less than 12µA of quiescent current.

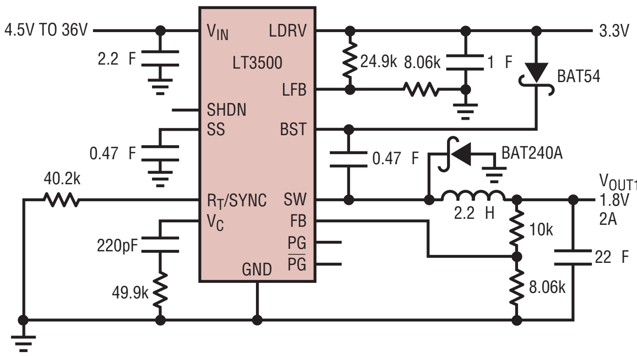


Figure 5. 1.8V/2A step-down regulator

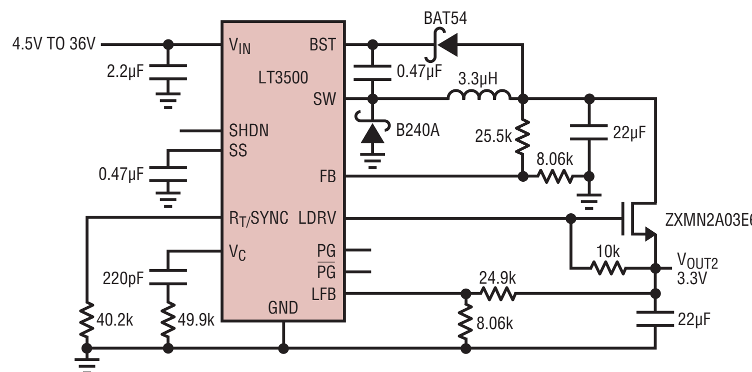


Figure 6. High efficiency linear regulator

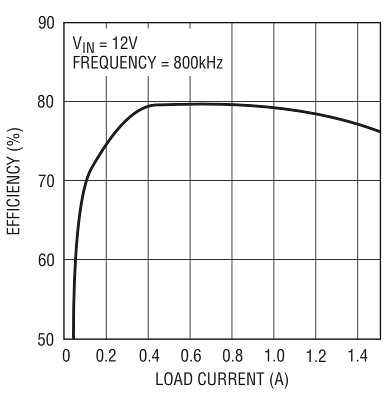


Figure 7. Efficiency vs load current for Figure 6 application

High Voltage Step-Down Regulator Plus Low Ripple Linear Regulator

One of the most common applications for a high voltage step-down regulator is as a pre-regulator to other power supplies. The pre-regulator must be immune to harsh input transients as it produces a stable output voltage for other downstream regulators. In systems where noise and ripple are of concern, a linear regulator is often used to step down the output of the switcher to the desired voltage.

The LT3500 plus an external NPN transistor as shown in Figure 1 is a perfect fit in these types of applications. The circuit takes an input from 6V to 36V and generates an intermediate 5V output. The LT3500's linear regulator is configured as a controller for the external NPN with its output set to 3.3V. Note that although the load current rating for each individual output is 2A, here the sum of both outputs must be less than 2A. Also, care must be taken not to violate the maximum power dissipation of the external NPN.

The comparison of output ripple at 1A load current shown in Figure 3 illustrates the benefit of using linear regulation to reduce switching ripple and noise. The excellent PSRR versus frequency of the LT3500's linear regulator is shown in Figure 4.

High V_{IN}, Low V_{OUT}, and Boost Pin Problems Solved

Operating the LT3500 at high frequencies allows the use of small low cost inductors and ceramic capacitors while maintaining low output ripple. However, due to minimum on time restrictions ($T_{ON(MIN)}$ < 140ns) high V_{IN}-to-V_{OUT} ratios may cause increased output ripple. The LT3500's adjustable frequency allows the user to optimize

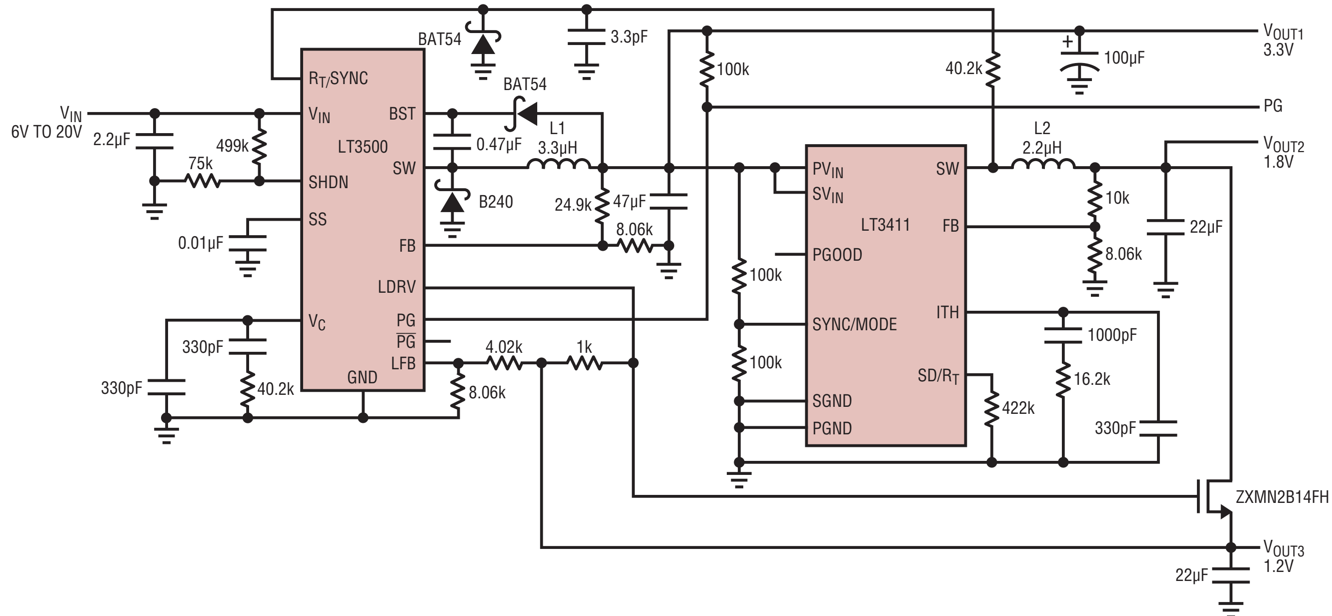


Figure 8. Triple output application

external component size regardless of V_{IN}-to-V_{OUT} ratio.

High V_{IN}-to-V_{OUT} ratios also pose a boost pin problem for most monolithic step-down regulators. When the desired output voltage is not high enough to fully turn on the output switch, the boost voltage must be derived from the input voltage or another available voltage. Taking the boost voltage from the input poses a couple of problems. First, the switcher efficiency suffers due to the large drop from the boost pin to the switch pin. Second, the boost pin is exposed to high input transients, which may violate its ratings. The LT3500 alleviates boost voltage problems by generating the boost voltage with the on chip linear regulator as shown in Figure 5. This circuit generates its own 3.3V boost rail to regulate 1.8V from 4.5V to 36V.

High Efficiency Linear Regulator

In many step-down applications linear regulators are preferred because of their excellent PSRR and output ripple, but are not used due to low efficiency or thermal constraints. Figure 6 shows another way to optimally combine the benefits of a switcher and a linear regulator, resulting in a high efficiency, low noise regulator. The switcher output is set to step down the 4.5V to 36V input voltage range to 3.5V and the linear controller is set to generate 3.3V from the 3.5V output of the switching regulator. With only 200mV across the NMOS pass device, the efficiency of the linear regulator is only 6% less than a switcher only solution with the added reduction in output ripple. The efficiency versus load current for the application is shown in Figure 7.

NPN or NMOS Pass Transistor

NPN or NMOS pass transistors both work well when configured as a linear controller, but each has its advantages and disadvantages.

During a shorted linear output fault, the current through the NPN is limited to $\beta_{NPN} \bullet I_{LDRV(MAX)}$, while the current through an NMOS is essentially unlimited. Since the maximum NPN current is typically less than the maximum switcher current, a shorted output will flag as an error but it will not affect the switcher output (assuming the switcher load plus shorted linear load is less than 2A). A shorted output on the NMOS will likely cause both outputs to crash to zero.

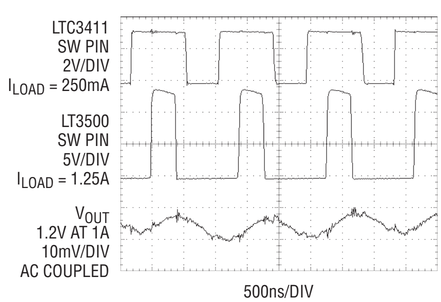


Figure 9. Synchronized switch waveforms for Figure 8 application

The minimum input voltage for the linear controller to regulate is V_{OUT2} + (V_{be} or V_{gs} at max load) + 1.2V. The V_{be} for a NPN is typically 0.7V where as the NMOS can range from 1.8V to 4.5V depending on the transistor size. For example, the minimum input voltage for a 1.8V output is typically 3.8V for a NPN pass transistor and 5V for a low threshold NMOS transistor.

The power loss of the linear regulator is simply the voltage drop across the device multiplied by the current through the device. NMOS transistors can be sized such that the device can be operated with V_{ds} less than the saturation voltage of most NPN transistors resulting in lower power loss (greater efficiency).

Multiple Output Application

The trend in many of today's systems is to provide multiple regulated voltages from a single high voltage source to optimize performance. When multiple switching regulators are used, beat frequencies along with output ripple can cause problems with some systems. The application circuit in Figure 8 tackles these issues by synchroniz-

continued on page 18

Efficient 48V Buck Mode LED Driver Delivers 50mA

by Mohammad J. Navabi

Introduction

LEDs are efficient, compact and durable, and thus they are replacing other more traditional light sources in a variety of applications. One such application is signage. LEDs save energy, take less space and need less maintenance than other sign solutions, such as neon, incandescent or fluorescent lighting.

LEDs require proper drivers to perform at their peak. A simple DC/DC converter is not quite enough. It must convert an input voltage to the LED string voltage, but it must do it at constant output current. It must also be able to dim the LEDs by adjusting the current applied to the LED string.

Buck Mode Constant Current LED Driver

The LT3590 is a high voltage current mode buck mode LED driver capable of providing a constant current to an LED string of up to 40V total voltage. It features internal compensation, an internal 55V power switch and an internal 55V Schottky diode (see Figure 1). The part can deliver up to 50mA of DC current with efficiencies as high as 91%. Figure 2 shows a typical application for the LT3590, driving a string of ten white LEDs at 50mA current.

The LT3590 uses a constant frequency, current mode architecture resulting in stable operation over a wide range of input voltage and output voltage. The high switching frequency permits the use of tiny, low profile inductors and capacitors. The LT3590 is available in 2mm × 2mm DFN and 8-lead SC70 packages

The control scheme is detailed in the block diagram of Figure 1. At power-up, the bandgap reference, start-up bias, and linear regulator are turned on. If CTRL is pulled higher than 150mV, the switching converter—including the oscillator, PWM comparator and error amplifier—is also turned on. The LT3590 uses a buck mode converter to regulate the output voltage to the level needed for the LEDs to run at the programmed current. It operates similarly to conventional current mode buck converters, but uses LED current rather than output voltage as the main source of feedback for the control loop.

The CTRL pin directly controls the regulated current sense voltage across the sense resistor (R1 in Figure 1). As shown in Figure 3, when V_{CTRL} is less than 100mV, the switcher is in shutdown mode and the current sense voltage and LED current are zero. When V_{CTRL} is greater than 150mV and less than 1.25V, the current sense voltage is proportional to V_{CTRL}, reaching a full scale value of 200mV ±5% when V_{CTRL} is 1.25V. Further increases in the CTRL input voltage do

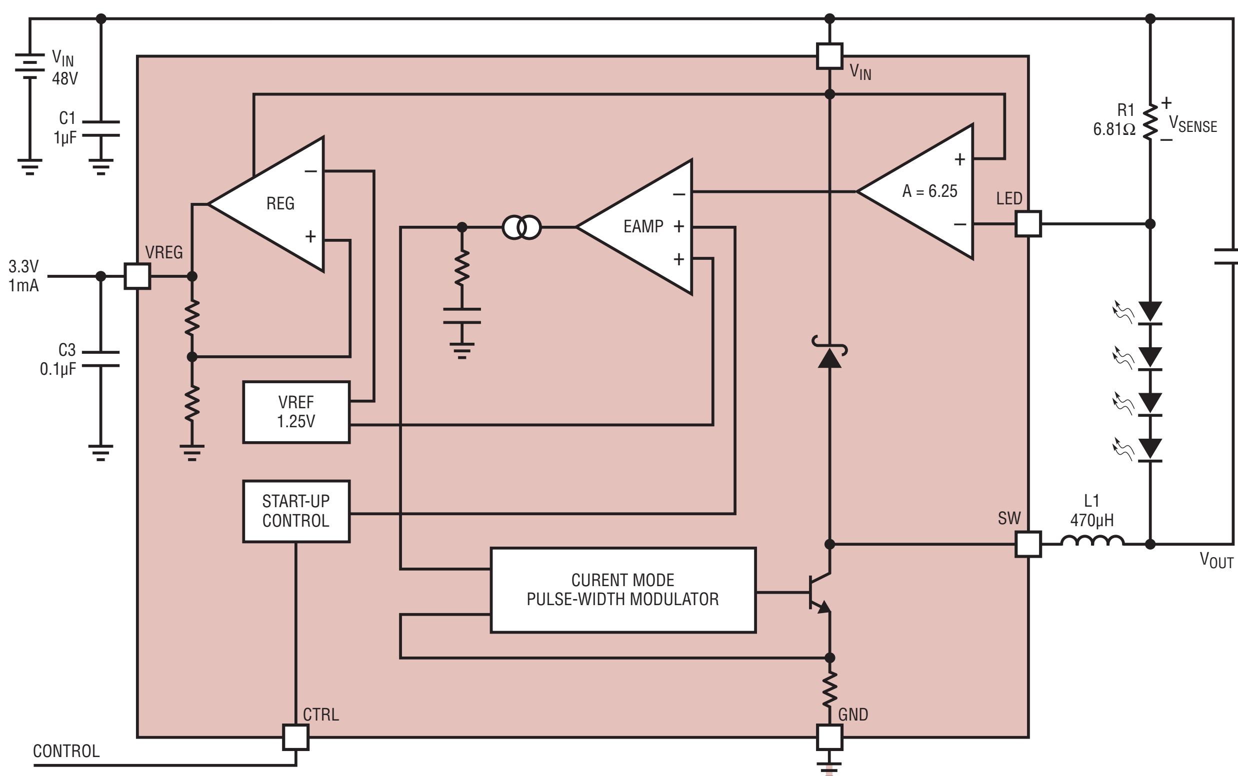


Figure 1. Block diagram of the LT3590

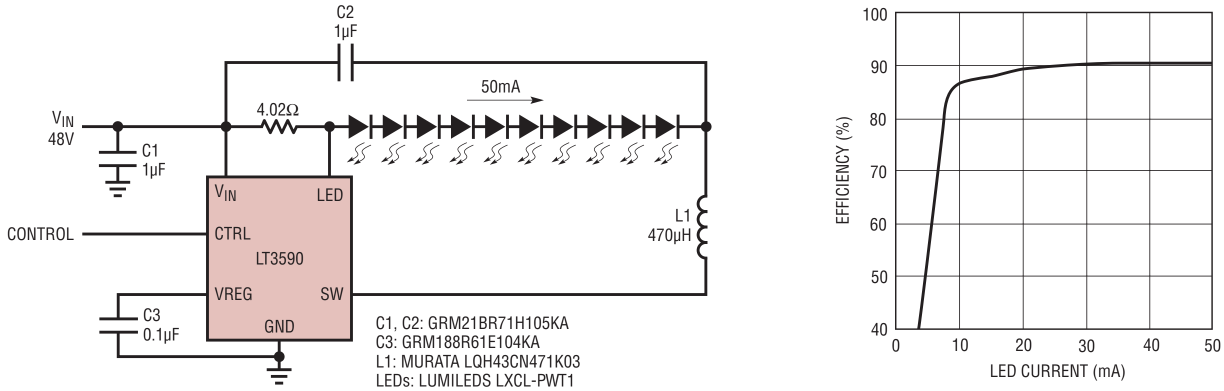


Figure 2. A buck mode converter for ten white LEDs requires very few components

not increase the current sense voltage beyond 200mV. In order to achieve accurate LED current, 1% precision resistors should be used.

Dimming Control

The LT3590 supports three types of dimming control. As previously explained, the LED current can be set by modulating the CTRL pin with a DC voltage. This method is referred to as analog dimming. Alternatively, a variable duty cycle PWM signal can be applied to the CTRL pin through an RC low-pass filter. The corner frequency of the RC network should be much lower than the frequency of the PWM signal. The DC value of the filtered PWM signal seen at the CTRL pin corresponds to the duty cycle of the PWM signal and controls the LED current just as in the analog dimming scheme.

Direct PWM dimming is also possible and preferred in applications where the chromaticity of the LEDs must be maintained over the dimming range. Dimming the LEDs via a PWM signal essentially involves turning the LEDs on and off at the PWM frequency. With the LT3590, a 200:1 dimming range is achievable for a 100Hz PWM frequency.

Onboard 3.3V Regulator

The LT3590 has a 3.3V onboard linear regulator capable of sourcing up to 1mA of current for use by an external device. The 3.3V regulator is available even during shutdown. This feature could be used to power-up an external controller from the LT3590 which in turn can control the LED current by applying a PWM signal directly or through a lowpass RC filter to the CTRL pin. Alternatively, the regulator output pin (V_{REG}) may be directly connected to the CTRL pin. This way, at power-up the LED driver is enabled and will drive the full scale current programmed by the feedback resistor through the LED string.

High LED Count

In most signage and backlighting applications, it is best to place as many LEDs as possible in the same series string. This guarantees that all the LEDs have the same current flow and therefore have uniform brightness and color. The limiting factor on the number of LEDs is the forward voltage drop across the LED string.

The high voltage rating of the LT3590 allows safe operation with

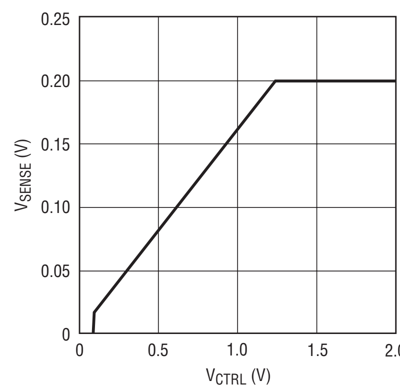


Figure 3. Dimming and shutdown using the CTRL pin

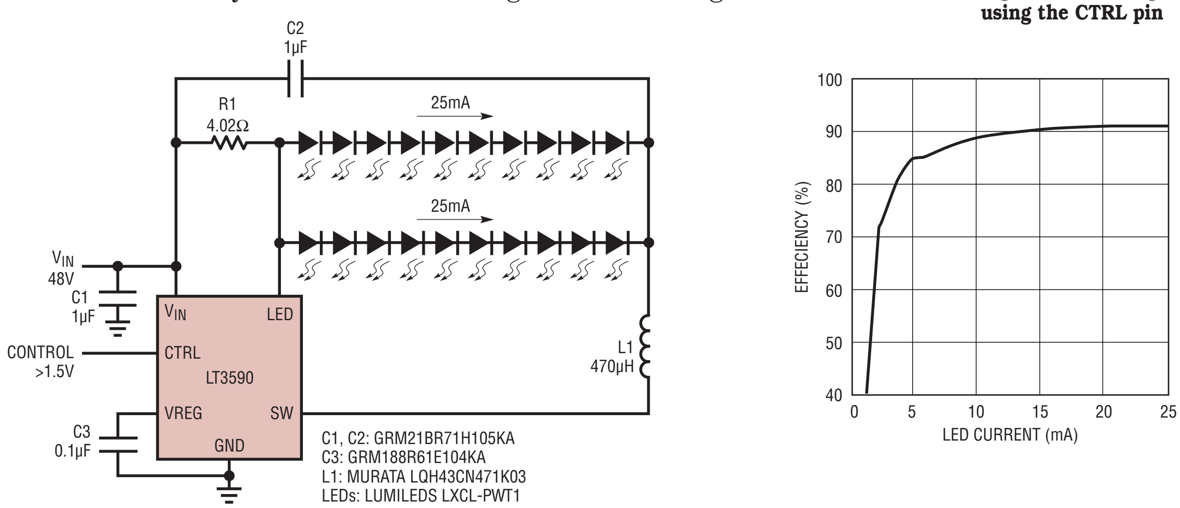


Figure 4. A 48V supply for two strings of ten LEDs, 25mA current

a 48V input power supply. Figure 2 shows the LT3590 driving ten white LEDs from 48V input supply. Figure 4 shows another high voltage application for the LT3590. Here, two strings of ten white LEDs are driven at 25mA. In this example we rely on the fact that the voltage drop across each LED string is a sum of ten average LEDs. Differences in individual LEDs are averaged across the string. Reasonable current matching is expected in this scheme with better than 90% efficiency for a wide range of LED currents.

In larger applications, where multiple LED strings are used, it is important to match the string currents accurately to produce uniform brightness. The LT3590's accurate current control makes this possible.

Indicator Light

Single-LED Indicator lights are popular in a wide range of applications from consumer electronics to automotive. In applications where a low voltage supply is available, it is easy to bias the LED using a simple series resistor. If the input supply voltage is much higher than the LED's forward drop, using a resistor is inefficient and could generate excessive heat. Also, in order to handle the power, bulky power resistors are needed. Another drawback of biasing with a resistor is that the LED current, and therefore its brightness, depends on the input supply voltage.

The LT3590 is the ideal solution for driving low LED counts from high voltage supplies. Figure 5 shows the application circuit with one LED and a 12V or 24V input supply. The resulting efficiencies for both input supply voltages are also shown in Figure 5. At 50mA LED current, this solution provides 67% and 61% efficiencies for the 12V and the 24V input supplies respectively. In comparison, the resistor-biasing approach would yield dismal 25% and 12.5% efficiencies.

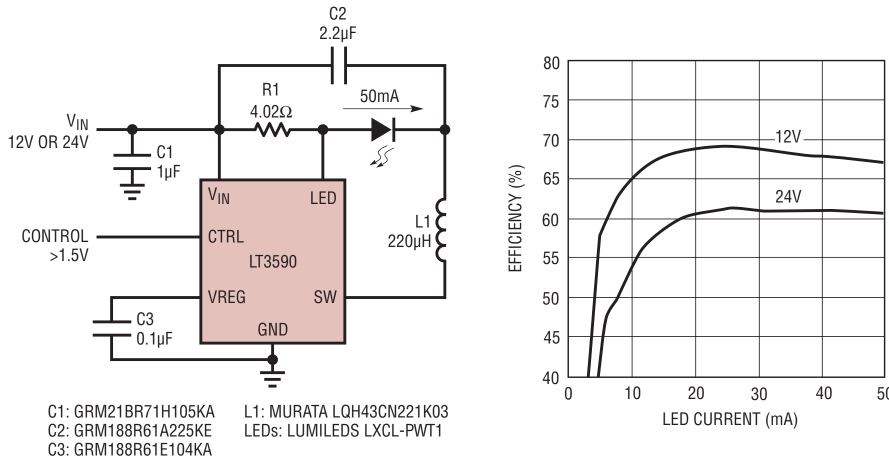


Figure 5. A 12V or 24V supply for a single LED, 50mA current

Conclusion

The LT3590 offers easy-to-use accurate current drive for LED strings. Overall solution size is very small due to its small package size and an architecture that requires few additional components. Its high efficiency and wide input voltage range makes it suitable for a variety of applications, including driving LED strings with up to 40V of total LED voltage.

LT3500, continued from page 15

ing the switching regulators and also providing a low ripple linear output.

The LT3500 in Figure 8 steps down voltages between 6V and 20V to 3.3V. The 3.3V output is fed to the LTC3411, which generates 1.8V and also provides the drain voltage for the NMOS pass transistor. The output of the NMOS provides a low ripple 1.2V output controlled by the LT3500. Operating the LTC3411 in forced continuous mode generates a 3.3V square wave at its SW pin, which is used to synchronize the LT3500 to the LTC3411, thus removing any system beat frequencies. The application switching waveforms are shown in Figure 9. The LT3500 controls start-up, and provides power good information via the SHDN, SS and PG pins as shown in Figure 10.

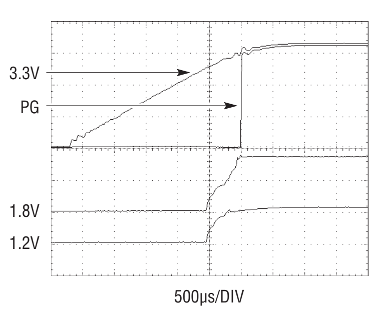


Figure 10. Start-Up waveforms for Figure 8 application

The current capability for each output must be determined with the entire system in mind. The maximum output current for the LTC3411 is 1.25A, which must be shared between the 1.8V and 1.2V outputs. The LT3500 powers the LTC3411 so the available current to the 3.3V rail depends on whatever power is left. For example, assuming the 1.2V output maximum current is 1A, the maximum current available for the 1.8V output is 250mA. The maximum output power for the 1.8V output is 2.25W (1.8V • 1.25A). The load seen by the 3.3V rail due to the LTC3411 is defined as

$$I_{LOAD(3.3V)} = \frac{P_{OUT(1.8V)}}{\varepsilon_{LTC3411(1.8V)} \bullet V_{IN(LTC3411)}} = \frac{2.25W}{0.9 \bullet 3.3V} = 0.75A$$

The current capability of the 3.3V rail is 1.25A (2A maximum minus 0.75A).

Conclusion

The combination of a wide input range switcher and a linear regulator makes the LT3500 a perfect solution to a wide variety of automotive, industrial and distributed power problems.

Synchronous Boost Converters Provide High Voltage without the Heat

by Greg Dittmer

Introduction

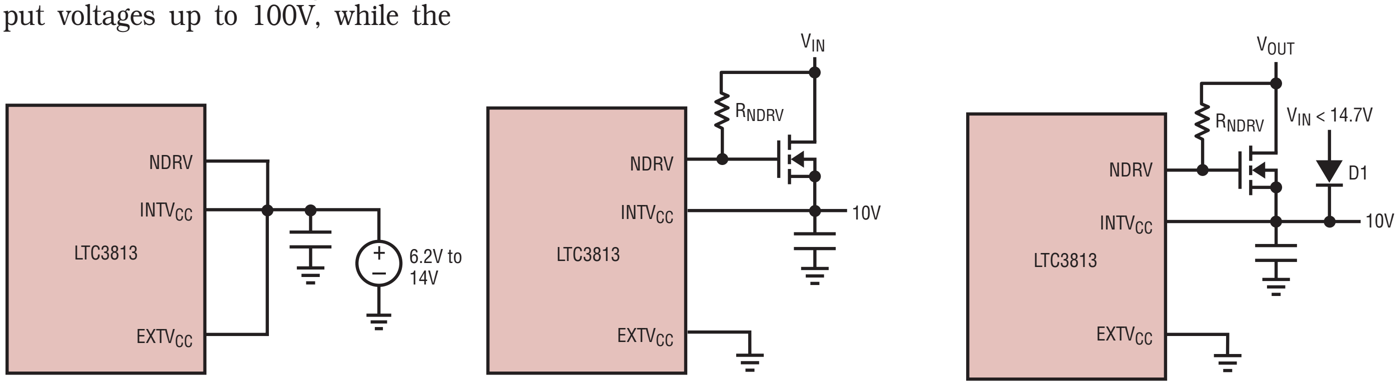
The LTC3813 and LTC3814-5 reduce the size of high voltage, high power boost converters by incorporating heat-saving features that eliminate the need for large components and heat sinks. In particular, two features significantly reduce heat losses over other high power boost solutions:

- ❑ Synchronous control eliminates the high power loss in the diode at high output currents
- ❑ Strong internal gate drivers reduce switching losses at high output voltages.

The LTC3813 can regulate output voltages up to 100V, while the LTC3814-5 is suitable for applications up to 60V. They both use a constant off-time peak current mode control architecture. Current mode control provides tight cycle-by-cycle monitoring of inductor current and constant off-time allows high conversion ratios such as 7V input to 100V output at 250kHz.

Advantage of Synchronous Control in High Power Boost Converters

As load current increases, synchronous boost converters have a significant advantage over non-synchronous boost converters due to the low power dissipation of the synchronous MOSFET compared to that of the boost diode in a non-synchronous converter. For example, an output load of 5A dissipates 5A • 0.5V = 2.5W in the diode in a non-synchronous converter. This high power dissipation requires a large package (e.g. D^2PAK) and a heat sink, which adds complexity, cost and area to the power supply. In contrast, a synchronous converter using a typical 10mΩ MOSFET would dissipate only $(5A)^2 \bullet 0.01\Omega = 0.25W$. Thus the



a. 6.2V to 14V supply available

b. $INTV_{CC}$ from V_{IN}, V_{IN} > 14V

c. $INTV_{CC}$ from V_{OUT}

Figure 1. Three ways to generate IC/driver supply

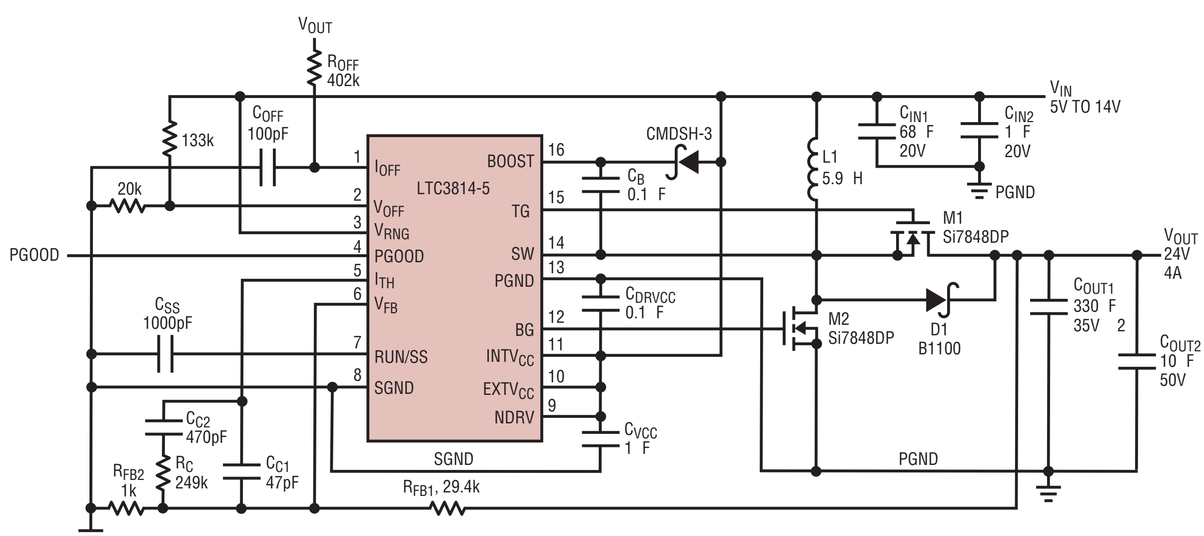


Figure 2. 5V–14V to 24V, 100W DC/DC converter

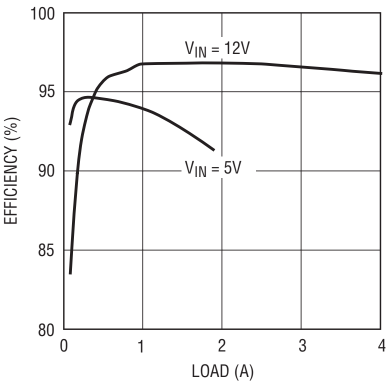


Figure 3. Efficiency of the circuit in Figure 2

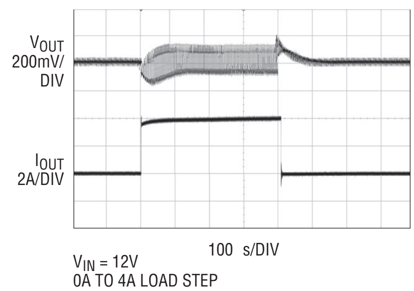


Figure 4. Load transient performance of the circuit in Figure 2

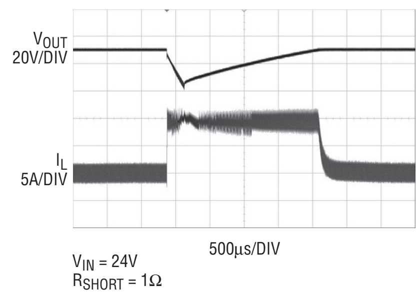


Figure 5. Overcurrent performance of the circuit in Figure 2

synchronous MOSFET requires only a small SO8-size package and no heat sink to carry the same current.

Without heat sinking, the maximum load current of a non-synchronous boost converter is limited by the power dissipation of the boost diode. Assuming a thermal resistance of 50°C/W on the PC board where the boost diode is mounted, the DC forward current derating curves of a typical 5A Schottky diode show that at a 50°C ambient temperature, the maximum current the diode can carry is about 3A.

Feature-Rich Controllers

Besides synchronous conversion, the LTC3813 and LTC3814-5 provide many additional features for a high performance boost converter. No R_{SENSE}™ current sensing utilizes the voltage drop across the bottom MOSFET to eliminate the need for a sense resistor—saving cost and simplifying board layout. For applications that require more accurate current limit, the LTC3813 can accommodate a sense resistor to achieve higher accuracy.

The off-time is programmable with an external resistor and, with an additional resistive divider from V_{IN} to the V_{OFF}, can be compensated for changes in input voltage to keep the frequency relatively constant over a wide supply range. Off-times as low as 100ns can be chosen to provide high V_{OUT}/V_{IN} step-up ratios. At low duty cycles, the step up ratio is limited by the 350ns minimum on time of the bottom MOSFET.

A high bandwidth error amplifier provides fast line and load transient response and a precise 0.8V, ±0.5% reference (0°C to 85°C) provides a very accurate output voltage. An internal undervoltage lockout comparator monitors the driver supply voltage and shuts down the drivers if the supply voltage is below a threshold that is safe for the power MOSFETs (6.2V for the LTC3813 and 4.2V for the LTC3814-5). The LTC3813 also provides a pin for undervoltage lockout on the input supply that is programmable with a resistive divider. Finally, the LTC3813 also has a phase-locked loop for external clock synchronization in noise sensitive applications.

A power good pin, accurate cycle-by-cycle inductor current limit, and overvoltage protection are additional fault protection features. Programmable soft-start ensures that the output capacitor ramps up in a controlled manner at start-up with no overshoot.

The LTC3814-5 provides a simplified feature set in a smaller more convenient package (thermally enhanced 16-lead TSSOP). The LTC3814-5 has a maximum output voltage of 60V and offers all the features of the LTC3813 except for input supply UVLO and external clock synchronization.

Strong Gate Drivers for High Efficiency

Because switching losses are proportional to the square of the output voltage, these losses can dominate in high output voltage applications with inadequate gate drive. The LTC3813 and 3814-5 have strong 1Ω gate drivers that minimize transition losses, even when multiple MOSFETs are used for high current applications. Dual N-channel synchronous drives combined with strong drivers result in very high power conversion efficiencies (see Figures 3 and 7). The LTC3813 uses a high voltage floating driver to drive the synchronous MOSFET at output voltages up to 100V (60V for the LTC3814-5).

The LTC3813 is optimized for driving 100V MOSFETs, which are typically rated at a V_{GS} of 6V or higher. As a result, the LTC3813 has an internal under-voltage lockout that keeps the drivers off until the driver supply is greater than 6.2V, with 500mV of hysterisis. The LTC3814-5 is optimized for driving logic level MOSFETs, which are rated at a V_{GS} of 4.5V and this version has an internal undervoltage lockout threshold of 4.2V with 500mV of hysterisis.

IC/Driver Supply Regulator

The LTC3813's internal control circuitry and top and bottom MOSFET drivers operate from a supply voltage in the range of 6.2V to 14V (4.2V to 14V for the LTC3814-5). If the input supply voltage or another available supply falls within this voltage range it can be used to supply IC/driver power (see Figure 1a). If a supply in this range is not available, a single low current external MOSFET and resistor can be added to easily generate a regulated 10V (5.5V for the LTC3814-5) IC/driver supply using the internal linear regulator circuitry (Figure 1b). Using an external pass element has the advantage of reducing power dissipation on the IC and it also allows the transistor to be chosen with the

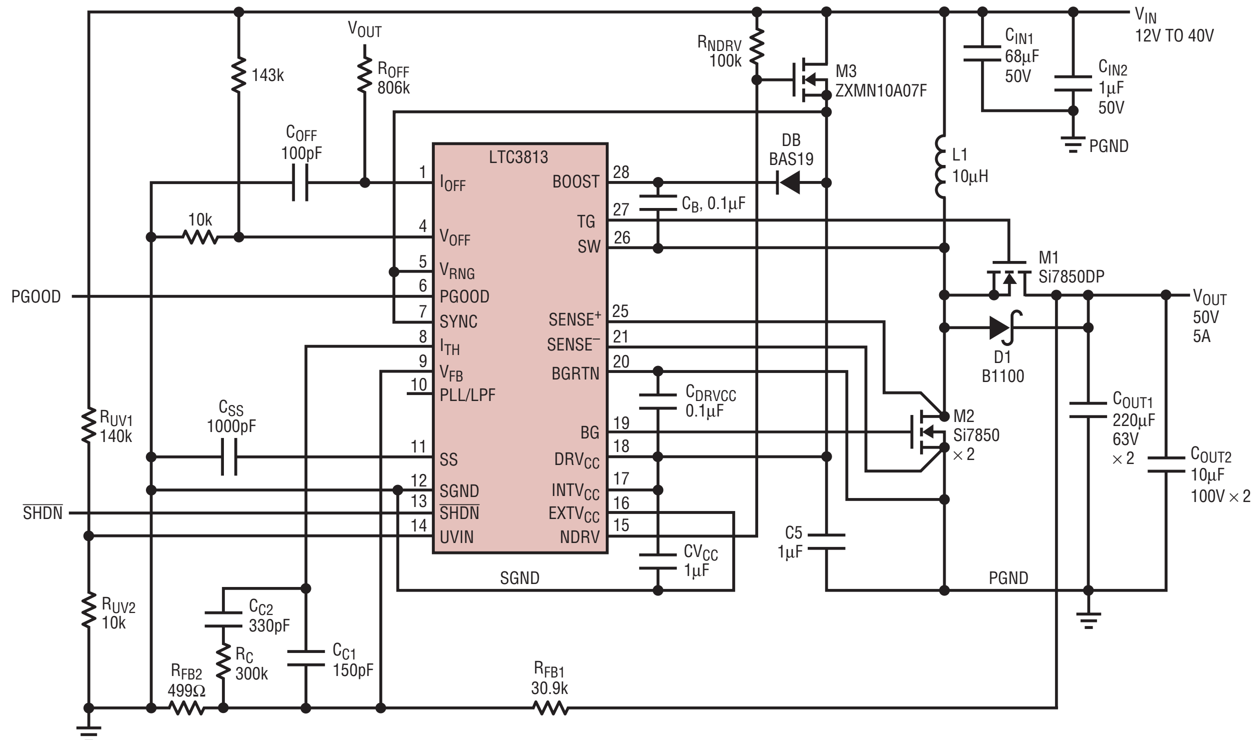


Figure 6. 12V–40V to 50V, 250W DC/DC converter

appropriate BV_{DSS} and power rating for the application—a small SOT23 package will often suffice.

Figure 1c shows a solution for applications that require the boost converter to continue operating when the input voltage has fallen below the undervoltage threshold of the IC. The cost is slightly lower efficiency. In this circuit, the regulator is connected to the output instead of the input. Diode D1 supplies power to the IC until the output voltage is high enough to generate the chip supply from the output. When the output is in regulation, the minimum input supply voltage is only limited by the maximum inductor current:

$$V_{IN(MIN)} = I_{OUT(MAX)} \bullet \frac{V_{OUT}}{I_{L(MAX)}}$$

Since IC/Driver power loss is proportional to the output voltage in this circuit, it is only practical for output voltages of ~30V or less.

5V–14V to 24V, 100W DC/DC Converter

The circuit shown in Figure 2 generates a 24V output voltage at 4A from a 5V–14V input voltage using the LTC3814-5. Synchronous conversion allows the use of two small Si7848DP power MOSFETs and results in the high conversion efficiency shown in Figure 3. Since the input supply is within the LTC3814-5's 4.2V–14V operating range, it can be connected directly to the IC supply pin. NDRV and EXTVCC are shorted to INTVCC to disable the INTVCC regulator.

A 403kΩ resistor is connected from V_{OUT} to the I_{OFF} pin to set the frequency to 250kHz. Connecting the resistor to the output (as opposed to a constant supply voltage) has the advantage of keeping the frequency constant during output start-up. Connecting the resistive divider from V_{IN} to the V_{OFF} pin sets input supply range for constant frequency operation from 5V to 12V. The V_{RNG} pin is connected to V_{IN} to set the max sense voltage to 200mV. This sets the nominal peak inductor current limit to 200mV/0.01Ω = 20A using the Si7848DP MOSFET and, after accounting for parameter variations and inductor ripple amplitude, provides a maximum load of 2A at V_{IN} = 5V and 4A at V_{IN} = 12V. Figures 4 and 5 illustrate the outstanding load transient and overcurrent performance of the power supply.

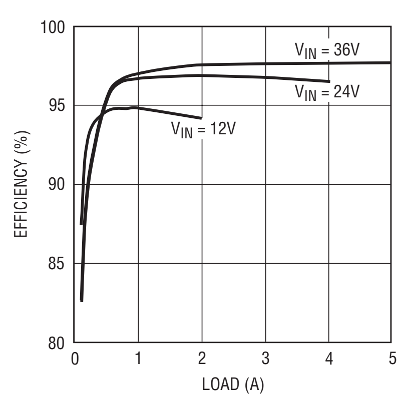


Figure 7. Efficiency of the circuit in Figure 6

12V–40V to 50V, 250W DC/DC Converter

The circuit shown in Figure 6 generates a 50V output voltage from a 12V–40V input using the LTC3813. Since the maximum input voltage is greater than 14V, the LTC3813 produces a regulated 10V from the input supply using a ZXMN10A07F MOSFET in a SOT23. A resistive divider is connected from V_{IN} to the UVIN pin to set the undervoltage lockout threshold to 10V on the input supply. This ensures that the boost converter doesn't hang at start-up when the powered by a current limited source supply when

continued on page 37

Wide Input Voltage Range, Dual Step-Down Controller Reduces Power Supply Size and Cost

by Wei Gu

Introduction

The LT3742 is an easy-to-use dual non-synchronous DC/DC controller for medium power step-down applications. It offers high efficiency over a wide input voltage range (4V–30V) and a wide output voltage range (0.8V–30V). A 500kHz fixed frequency current mode architecture provides fast transient response with simple loop compensation components and cycle-by-cycle current limiting. An internal step-up regulator is used to generate the gate drive voltage, allowing the gate of the external high side N-channel MOSFET to be driven to full enhancement for high efficiency operation. The two channels operate 180° out of phase to reduce the input ripple current, minimizing the noise induced on the input supply and reducing the input capacitance requirement. The device also includes individual shutdown controls and power-good outputs for each channel. The LT3742 is available in a small 4mm × 4mm QFN package.

Figure 1 shows the LT3742 in a compact, dual-output power supply. Figure 2 shows the resulting efficiency.

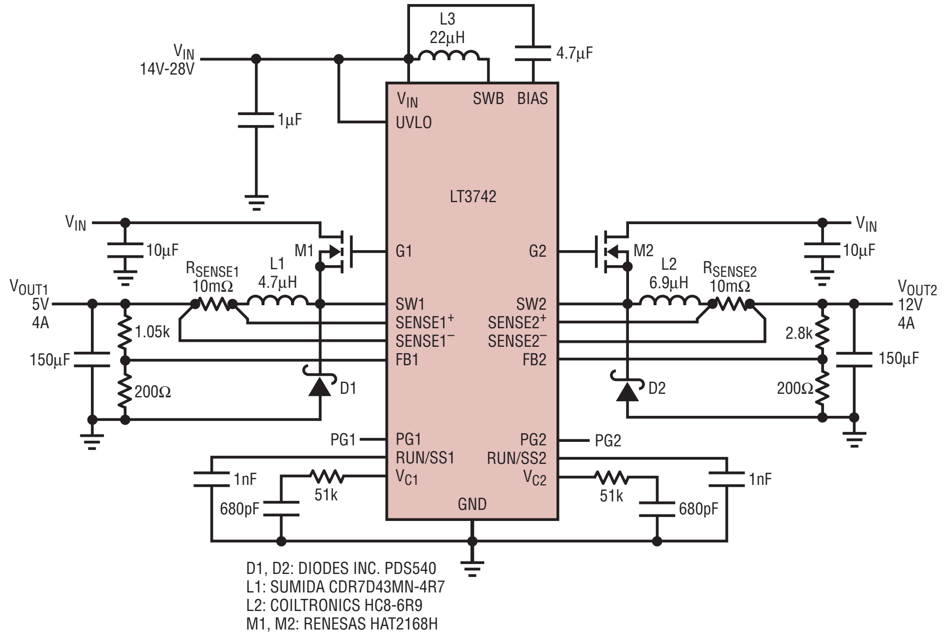


Figure 1. Compact, dual-output DC/DC converter: 14V–28V input to 12V at 4A and 5V at 4A

Internal Step-Up Bias Converter

The LT3742 integrates a DC/DC step-up converter to generate the gate drive voltage for the N-channel MOSFETs. The gate drive voltage is regulated to (V_{IN} + 7V), which permits the use of inexpensive off-the-shelf 5V gate-drive N-channel MOSFETs, offering higher efficiency than sub-logic-level gate-drive MOSFETs. The gate driver is capable of driving large, low $R_{DS(ON)}$, standard level, N-channel MOSFETS without the need for a gate drive buffer.

Integrating the step-up converter also allows low dropout and 100% duty cycle operation. This is in contrast to the commonly used bootstrap scheme, which does not allow 100% duty cycle since a minimum off-time is required to charge the bootstrap capacitor.

Continuous Inductor Current Sensing

The LT3742 offers robust short-circuit protection thanks to continuous inductor current sensing. A wide common-mode input range current sense amplifier that operates from 0V to 30V provides continuous inductor current sensing via an external sense resistor. A continuous inductor current sensing scheme does not require blanking intervals or a minimum on-time to monitor current, limitations that are common to schemes that sense the switch current.

The sense amplifier monitors the inductor current independent of the switch state, so the gate is held low until the inductor current is below the programmed current limit. This turn-on decision is performed at the start of each cycle, and individual switch cycles are skipped should an over-current condition occur. This eliminates many of the potential over-current dangers caused by minimum on-time requirements, such as those that can occur during start-up, short-circuit, or abrupt input transients. Figures 3 and 4 show the switching node voltage waveforms and inductor current waveforms in normal operation and in short circuit, respectively.

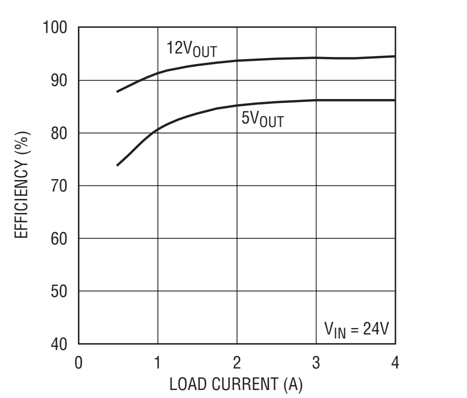


Figure 2. Efficiency of the converter in Figure 1

Precision UVLO Voltage

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 resistor divider is set such that the divider output puts 1.25V onto 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 user-defined input supply droop before disabling the converter. During a UVLO event, both controllers and the gate drive boost regulator are disabled.

2-Phase Operation

When two outputs are derived from the same input source, any slight difference in the switching frequencies generates a beat frequency that is difficult to filter. To avoid this, the two output channels must be synchronized. The problem is that if the output channels are switched in unison, the input RMS current is maximized as each channel concurrently calls for current. This, of course, is counter to a designers desire to minimize input current. Minimizing RMS input current serves to minimize the input capacitance requirement, reduce power loss along the input supply path (batteries, switches, connectors and protection circuits) and reduce radiated and conducted electromagnetic interference (EMI).

The LT3742 eliminates the beat frequency and minimizes the input RMS current by interleaving the output channels. The two channels switch at the same frequency with 180° phase difference between the rising edges of G1 and G2. This 2-phase operation minimizes input RMS current, thus reducing the solution size, increasing the overall efficiency and attenuating EMI.

Soft-Start

The SS pins are used to enable each controller independently and to provide a user-programmable soft-start function that reduces the peak input current and prevents output voltage overshoot during start-up. The LT3742 employs a soft-start scheme that directly controls the DC/DC converter output voltage during start-up. The rising rate of this voltage is programmed with a capacitor connected to the SS pin. The capacitor value is chosen such that the desired $\Delta V/\Delta t$ of the output results in a 1µA charge current through the capacitor. Figure 5 shows the output voltage waveforms during start-up.

If both outputs are always enabled together, one soft-start capacitor can be used with the RUN/SS pins tied together.

Current Mode Control

The LT3742 uses a current mode control architecture, enabling a higher supply bandwidth and thereby improving line and load transient response. Current mode control also requires fewer compensation components than voltage mode control architectures, making it much easier to compensate over all operating conditions.

Conclusion

The LT3742 provides a space-saving and cost-saving solution over a wide input voltage range. The LT3742 is a versatile platform on which to build high voltage DC/DC converter solutions that use few external components and maintain high efficiencies over wide load ranges. The integrated start-up regulator facilitates true single-supply operation.

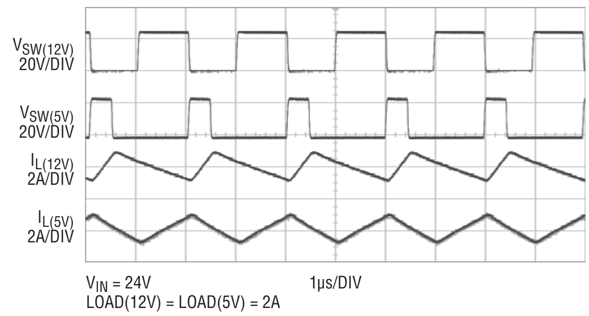


Figure 3. Switching node and inductor current waveforms (normal operation)

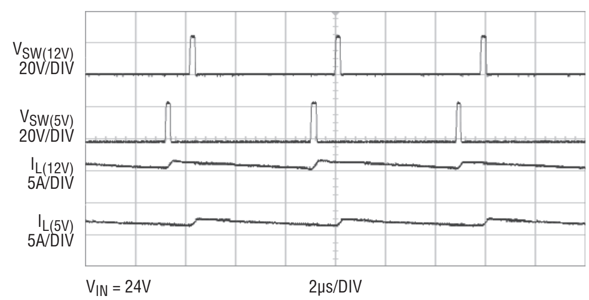


Figure 4. Switching node and inductor current waveforms (both outputs shorted)

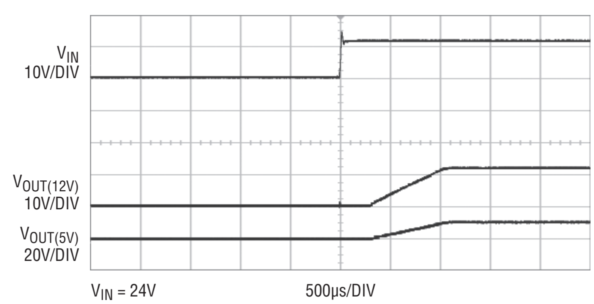


Figure 5. Start-up waveforms

Surge Stopper Protects Sensitive Electronics from High Voltage Transients

by James Herr

Introduction

In automotive and industrial applications, electronics are subjected to high voltage power supply spikes that can last from a few microseconds to hundreds of milliseconds. For instance, microsecond supply spikes result from load steps transmitted via parasitic wiring inductance. Longer surges, such as an automotive load dump, caused by a break in battery connections, is a voltage surge that stays at an elevated level for hundreds of milliseconds. All electronics in these systems must be protected from high voltage transients or risk degraded performance or failure and costly replacement.

The most common way of protecting electronics from voltage spikes combines a series iron core inductor and high value electrolytic bypass capacitor, augmented by a high power transient voltage suppressor (TVS) and fuse. The bulky inductor and capacitor take up valuable board space and are often the tallest components in the system. Even with all this protection, supply voltage excursions are still high enough to warrant the use of high voltage rated components for downstream DC/DC converters and linear regulators.

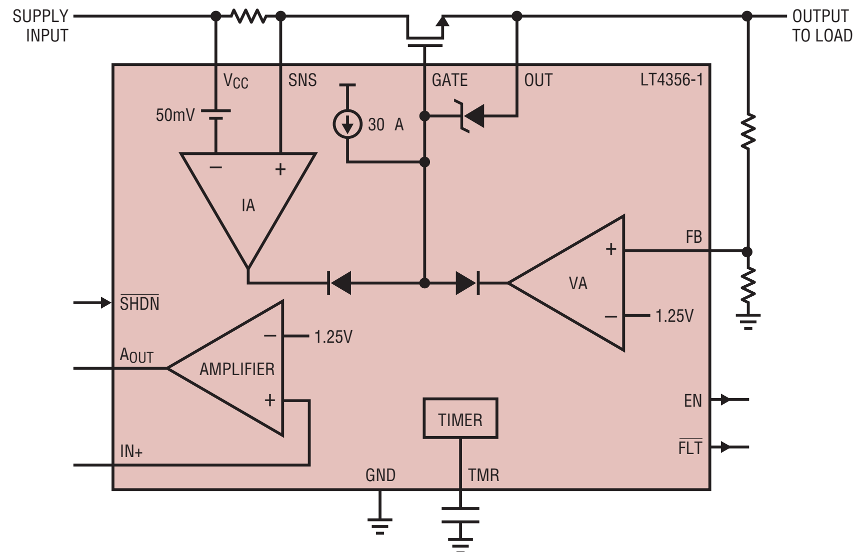


Figure 1. Block diagram of the LT4356

The LT4356 surge stopper eliminates the need for bulky filtering components by isolating low voltage circuitry from damaging spikes and surges found in automotive, avionic and industrial systems. The LT4356 also guards against overloads and short circuits, and withstands input voltage reversal.

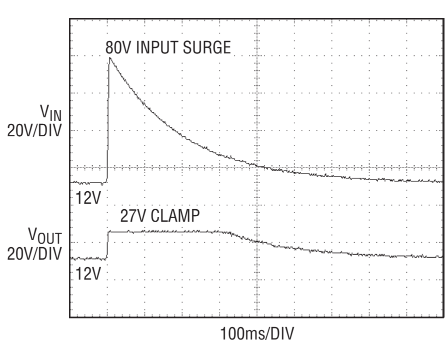


Figure 2. During overcurrent or overvoltage conditions, the current amplifier (IA) or the voltage amplifier (VA) is called into action, appropriately limiting the output current or voltage. In the case of an overvoltage condition, the load circuit continues to operate, noticing little more than a slight increase in supply voltage.

The LT4356 surge stopper eliminates the need for bulky filtering components by isolating low voltage circuitry from damaging spikes and surges found in automotive, avionic and industrial systems. The LT4356 also guards against overloads and short circuits, and withstands input voltage reversal.

Figure 1 shows a functional block diagram of the LT4356. Under normal operating conditions, it drives the gate of an N-channel MOSFET pass device fully on so that its presence is of no consequence to the load circuitry. The MOSFET is called into duty as a series limiter in case of overvoltage or overcurrent conditions. If the input voltage rises above a regulation point set by the FB divider, the voltage amplifier VA drives the MOSFET as a linear regulator, limiting the output voltage to the prescribed value and allowing the load circuitry to continue operating, uninterrupted. To protect the MOSFET and load from short circuits, the LT4356 includes current limiting.

Operation

When power is first applied, or when the LT4356 is activated by allowing $\overline{\text{SHDN}}$ to pull itself high, the MOSFET is turned on gradually by slowly driving the gate high. This soft-start minimizes the effects of dynamic loading on the input supply. Once the MOSFET is

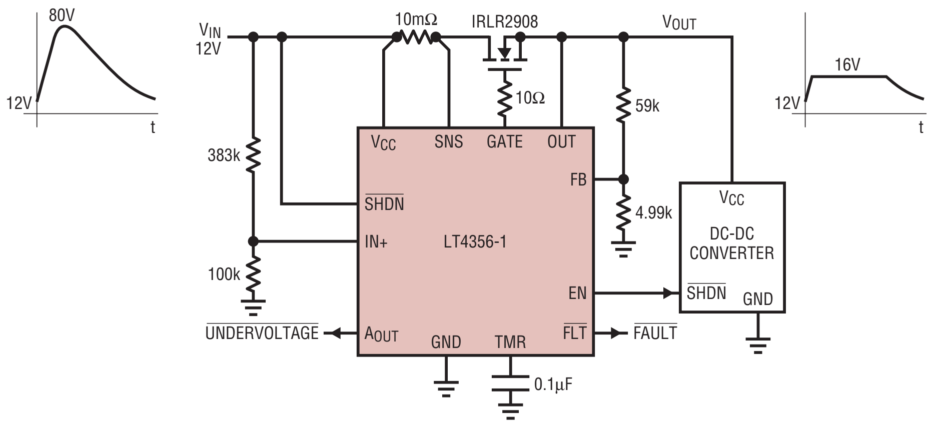


Figure 3. The spare amplifier is configured to monitor the input voltage and indicate undervoltage through the AOUT pin.

fully on (V_{DS} < 700mV), the EN pin goes high to activate the load circuitry, such as a microprocessor.

During overcurrent or overvoltage conditions, the current amplifier (IA) or the voltage amplifier (VA) is called into action, appropriately limiting the output current or voltage. In the case of an overvoltage condition, the load circuit continues to operate, noticing little more than a slight increase in supply voltage as illustrated in Figure 2. The load circuit may continue operating if, in the case of a current overload, sufficient output voltage is available. The timer capacitor ramps up whenever output limiting occurs, regardless of cause. If the condition persists long enough for the TMR pin to reach 1.25V, the $\overline{FAULT}$ pin goes low to give early warning to downstream circuitry of impending power loss. At 1.35V the timer shuts down the MOSFET and waits for a cool-down interval before attempting to restart.

By using the LT4356's GATE output to drive a second, reverse-connected MOSFET, the conventional Schottky blocking diode and its voltage and power losses can be eliminated.

Another feature of the LT4356 is the spare amplifier (AMP), which may be used as a power good comparator, input voltage monitor or low dropout linear regulator. In shutdown the supply current is reduced to 5μA, permitting use in applications where the device is left permanently connected to a battery supply.

In the circuit of Figure 3, the output voltage is set to 16V by an external resistive divider. The spare amplifier is configured to monitor the input voltage and indicate undervoltage through the AOUT pin. The EN pin activates the downstream load after the MOSFET is fully on.

Reverse Battery Protection

To protect against reverse inputs, a Schottky blocking diode is often included in the power path of an electronic system. This diode not only consumes power, it also reduces the operating voltage range, particularly with low input voltages such as an automotive condition known as "cold crank." By using the LT4356's GATE output to drive a second, reverse-connected MOSFET, the conventional Schottky blocking diode and its voltage and power losses can be eliminated.

Figure 4 shows a reverse protected circuit with the second MOSFET. Under normal operating conditions with a positive input, Q2 is enhanced by the GATE pin and is fully on, as is Q1. Q3 is off and plays no role. If the input connections are reversed and a

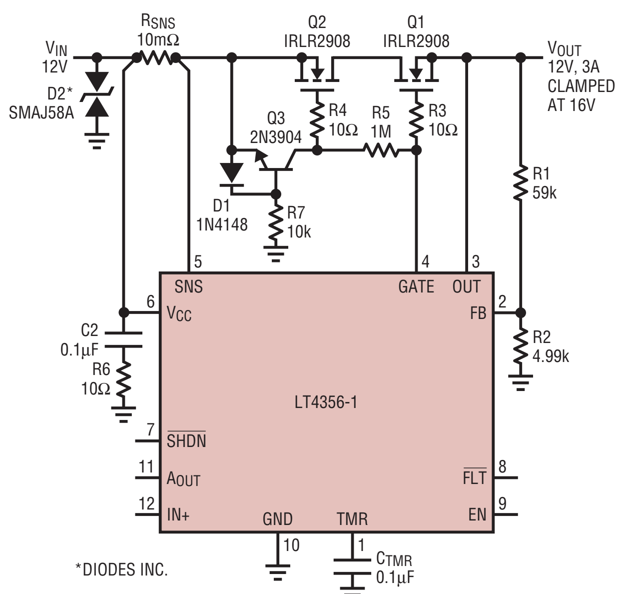


Figure 4. A reverse protected circuit with the second MOSFET

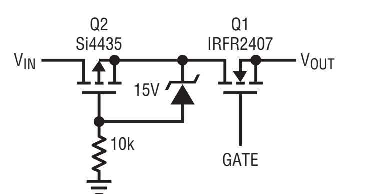


Figure 5. Low loss reverse blocking is also possible with a P-channel MOSFET

negative voltage reaches the LT4356, Q3 turns on and drags Q2's gate down to the negative input, thus isolating Q1 and points downstream from the negative voltage. The LT4356's V_{CC}, SNS and $\overline{SHDN}$ pins are protected from voltages of up to minus $30V_{DC}$ without damage.

Low loss reverse blocking is also possible with a P-channel MOSFET, as shown in Figure 5. In both cases there is no need for the blocking MOSFET, Q2, to be rated at a voltage any higher than the anticipated negative input.

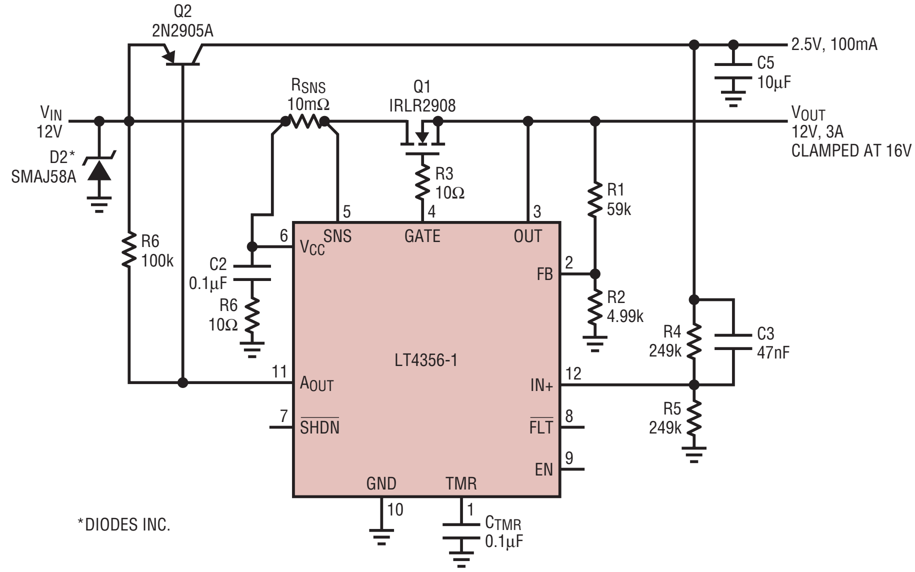


Figure 6. The LT4356's internal spare amplifier can drive an external PNP to provide another supply rail.

Auxiliary Output Voltage

The internal spare amplifier can drive an external PNP to provide another supply rail, as shown in Figure 6. With 2mA available from the AOUT pin, this PNP based linear regulator can supply 100mA of current as an auxiliary, regulated output. The spare amplifier also finds use as an undervoltage monitor (keeping an eye on the input voltage as shown in Figure 3), or as glue for other power system tasks. The next section shows how the spare amplifier is configured as a power good comparator.

Inrush Control

A wide operating range (4V to 80V) and accurate current limit (10% maximum) suit the LT4356 for use as a high voltage Hot Swap™ controller, as shown in Figure 7. The gate capacitor, C1, and the controlled gate current set the slew rate at the GATE pin. The slew rate and output capacitor, CL, set the inrush current at start-up. The spare amplifier is configured as a power good comparator, monitoring the output voltage. R7 adds hysteresis to eliminate motorboating.

During an overcurrent event, the current limit loop regulates the voltage across the V_{CC} and SNS pins to 50mV and starts the timer. After timeout, the pass transistor turns off and remains off until the overcurrent condition has passed and a cool down period has elapsed. Under conditions of overcurrent, MOSFET safe operating area stress increases as the drain-source voltage drop increases. The LT4356 monitors V_{DS} and shortens the timer interval in proportion to increasing V_{DS}. This way a brief, minor overload may persist for a longer time interval than a highly stressful output short circuit condition, ensuring the MOSFET operates within its safe operating area.

While MOSFET protection is important, the real benefit of current limit is recognized only after surviving a short circuit: the upstream fuse also survives, and need not be replaced.

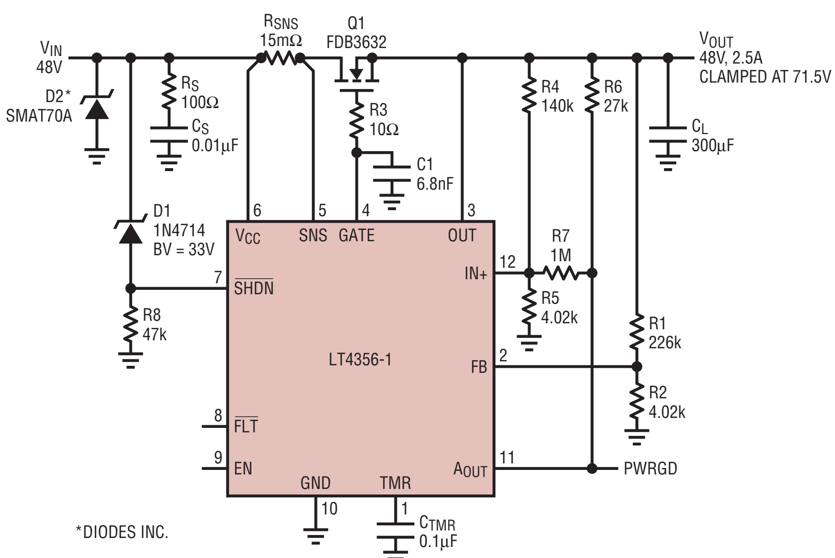


Figure 7. High voltage Hot Swap™ controller

Conclusion

The electronic content in automotive and industrial systems is becoming increasingly plentiful and sophisticated, yet power sources remain riddled with spikes and surges. As more and more features are packed into the electronics, less and less space is available for conventional methods of filtering, clamping and rejecting the noise. The LT4356 surge stopper offers a means for reducing the necessary board space, while at the same time cutting the heat dissipation and voltage loss associated with blocking diodes and filter inductors. Higher efficiency and wider usable voltage range allow more functionality to be incorporated into space-constrained products.

USB Compatible Li-Ion Battery Charger and Dual Buck Regulators in a Single 3mm × 3mm QFN

by Aspiyan Gazder

Introduction

Manufacturers of handheld devices such as MP3 players are always looking to reduce system size and cost, even as they increase performance and functionality. The only way to do so is to integrate functions at the IC level. For applications powered from a single Li-Ion cell, the LTC3559 provides a single chip solution that charges a Li-Ion cell while efficiently generating two supply voltage rails to power the device.

The LTC3559 is a USB compatible battery charger and two monolithic synchronous buck regulators integrated into a low profile 3mm × 3mm 16-lead QFN package. The battery charger has all the features that a stand alone battery charger might offer, such as an NTC input for temperature qualified charging, internal timer termination and bad battery detection. A constant current/constant voltage algorithm is employed to charge a battery. Only a single resistor at the PROG pin is required to program the charge current up to 950mA. The HPWR input provides the flexibility to deliver either 100% or 20% of the programmed charge current. For applications operating from a USB source, charge current can be programmed to either 100mA or 500mA per USB specifications.

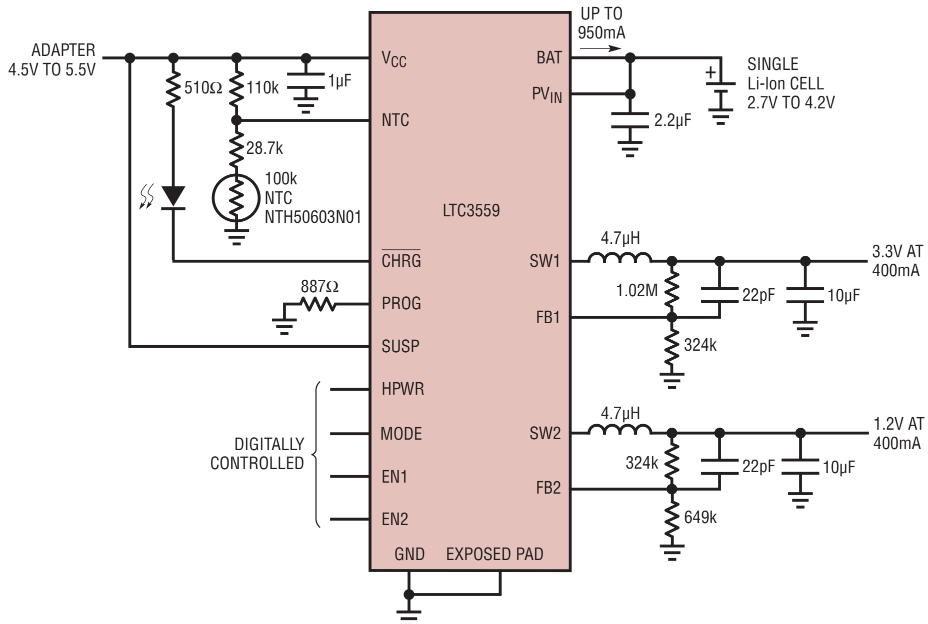


Figure 1. Full featured USB battery charger and dual buck regulator in one 3mm × 3mm IC

The two buck regulators have a current mode architecture, which provides a quick response to load steps. To meet the noise and power requirements of a variety of applications, the buck regulators can be operated in either Burst Mode operation or pulse skipping mode. The buck regulators also have a soft start feature that prevents large inrush currents at start up.

At high load currents, the buck regulator operates as a constant frequency PWM controlled regulator. At light load currents, pulse skipping is the normal behavior for a switching regulator when the inductor current is not allowed to reverse.

To improve efficiency in light load conditions, the LTC3559 offers Burst Mode operation. When in Burst Mode operation, the buck regulator automatically switches between fixed frequency PWM control or hysteretic control, as a function of the load current. At light loads, the regulator has an output capacitor charging phase followed by a sleep phase. During the sleep phase, most of the buck regulators' circuitry is powered down, saving battery power. As the load current increases, the sleep time decreases to the point where the buck regulator switches to a constant frequency PWM operating mode—equivalent to pulse skipping mode at higher output currents.

Figure 1 shows the LTC3559 with the NTC input biased using three resistors. A 3-resistor bias provides the user

DESIGN IDEAS

with the flexibility to program both the upper and lower battery temperature points that are considered safe for charging the battery. In this example, the NTC hot and cold trip points are set for approximately 55°C and 0°C, respectively.

One of the buck regulators is programmed for 3.3V at its output. When the BAT pin voltage approaches 3.3V, the buck regulator operates in dropout. An LED at the $\overline{CHRG}$ pin gives a visual indication of the battery charge status.

Figure 2 shows an actual circuit similar to that shown in Figure 1, illustrating how little board space is required to build a full featured LTC3559 application. Figure 3 shows how much more efficient Burst Mode operation is at light loads as compared to pulse skipping mode.

A basic sequencer function can be built for the buck regulator outputs by driving the enable pin on one buck regulator with the output of the other buck regulator. For proper operation, the BAT and PV_{IN} pins must be tied together. If a buck regulator is enabled while the battery is charging, the net current charging the battery will be lower than the actual programmed value.

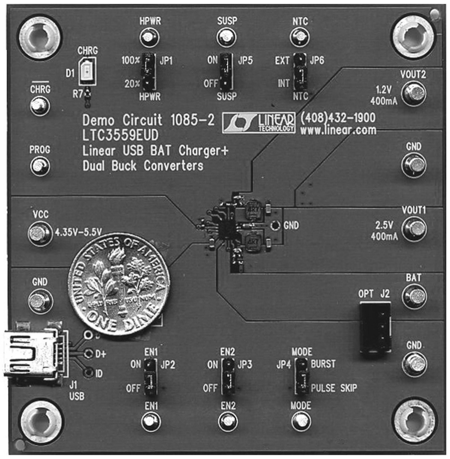


Figure 2. A USB battery charger and two buck regulators small enough to fit in the latest cell phones, PDAs and MP3 players

Figure 4 helps to explain this scenario. The current being delivered at the BAT pin is 500mA. Both buck regulators are enabled. The sum of the average input currents being drawn by both buck regulators is 200mA. This makes the effective battery charging current only 300mA. If the HPWR pin were tied low, the BAT pin current would be only 100mA. With the buck regulator conditions unchanged, this would cause the battery to discharge at 100mA.

Conclusion

The LTC3559 is ideally suited for space-constrained applications that are powered from a single Li-Ion cell and that need multiple voltage supply rails. The high switching frequency allows the use of small low profile external inductors. The high efficiency buck regulators and Burst Mode operation combine to maximize battery life, extending battery operation time between charge cycles.

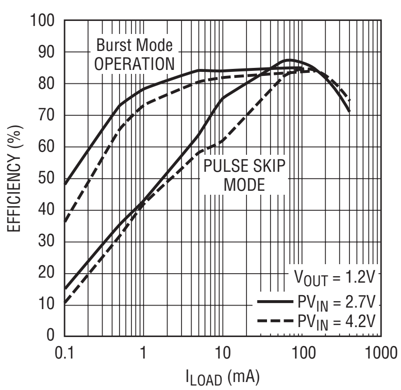


Figure 3. Buck regulator efficiency

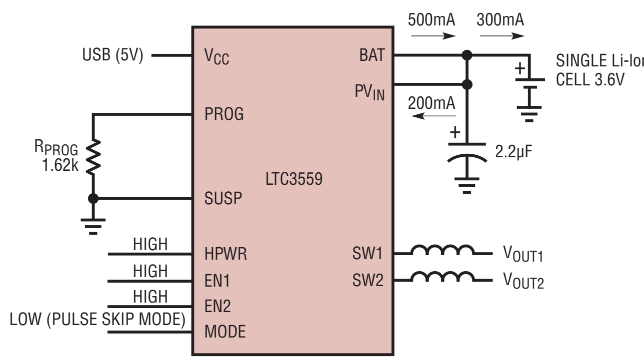


Figure 4. The net current charging the battery depends on the operating mode of the buck regulators.

LT3580, continued from page 10

voltages where these problems might occur.

The shutdown pin comparator has voltage hysteresis with typical thresholds of 1.32V (rising) and 1.29V (falling). Resistor R_{UVLO2} is optional but can be included to reduce overall UVLO voltage variation caused by variations in $\overline{SHDN}$ pin current. A good choice for R_{UVLO2} is 10k ±1%. After choosing a value for R_{UVLO2}, R_{UVLO1} can be determined from either of the following:

$$R_{UVLO1} = \frac{V_{IN}+ - 1.32V}{\left(\frac{1.32V}{R_{UVLO2}}\right) + 11.6\mu A}$$

or

$$R_{UVLO1} = \frac{V_{IN}- - 1.29V}{\left(\frac{1.29V}{R_{UVLO2}}\right) + 11.6\mu A}$$

where V_{IN}+ and V_{IN}- are the V_{IN} voltages when rising or falling respectively.

Conclusion

The LT3580 is a smart choice for many DC/DC converter applications. It's packed with features without compromising performance or ease of use and is available in tiny 8-lead packages. The accurate and adjustable clock, 2A/42V power switch, wide input voltage range, integrated soft-start and a configurable $\overline{SHDN}$ pin make the LT3580 an ideal choice for many DC power supply needs. For additional information and a complete data sheet visit www.linear.com.

Entire RGB LED Driver Fits in Miniscule 3mm × 2mm Package

by Zachary Lewko

Introduction

The LTC3212 charge pump RGB LED driver is an ideal solution for highly space-constrained portable devices such as cellular phones, PDAs, digital cameras and media players. The LTC3212 features an internal low noise charge pump utilizing a single external flying capacitor. This charge pump operates in 1× mode until one of the LEDs drops out of regulation, after which it switches to 2× mode, automatically maintaining proper LED current while reducing power loss and minimizing switching noise. The LTC3212 is designed with flexibility in mind and can be used for driving RGB backlights, keypad back lighting, or a general purpose LED such as a multicolor status indication LED.

Battery/Supply Voltage

The LTC3212 is designed to operate from 2.7V to 5.5V inputs, making it an ideal LED driver for battery powered and USB powered devices.

The LTC3212's charge pump is enabled when it is necessary to prevent an LED driver from dropping out of regulation. This reduces losses and minimizes noise by keeping the charge pump operating in 1× mode as long as possible. Once the charge pump is operating in 2× mode, the control algorithm ensures switching noise is reduced by limiting the slew rate of the flying capacitor pins and by reducing the ripple current on the input supply.

The part has a soft-start circuit which prevents large inrush currents on start-up and during a mode switch. The CPO pin has short circuit protection to protect the part in the event of a short on the charge pump output. The CPO output is switched to high impedance mode when the part enters shutdown mode.

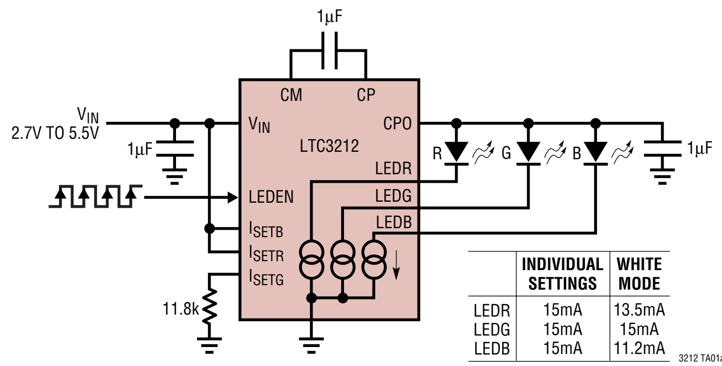


Figure 1. The LTC3212 LED RGB LED driver with minimal external components

Compact Solution

With a minimum setup the LTC3212 can be configured to use only four external components, three capacitors and one resistor (see Figure 1). These few external components along with the small 3mm × 2mm package make the LTC3212 ideal for space constrained applications as shown in Figure 2.

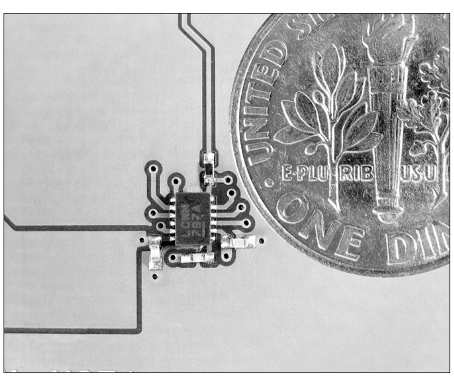


Figure 2. A typical LTC3212 RGB LED driver occupies minimal board real estate.

LED Control

The LTC3212 is programmed using a single wire interface, making it very easy to integrate into applications where the controlling device has limited pins available. The LTC3212 can be programmed to enable any combination of the red, green and blue LEDs, resulting in seven colors from the RGB LED (see Table 1). When all of the LEDs are enabled the currents are automatically adjusted to a ratio that results in white light.

Table 1. LTC3212 Programming Table

Pulses	Red	Blue	Green
0	off	off	off
1	off	off	**ON**
2	off	**ON**	off
3	off	**ON**	**ON**
4	**ON**	off	off
5	**ON**	off	**ON**
6	**ON**	**ON**	off
7+	White Mode		

Intensity Setting

The operating currents of the LEDs can all be the same, two the same, or they can all be configured independently—requiring one, two or three external resistors, respectively. If independent control of an LED is not needed, tie its I_{SET} pin to V_{IN} and the current defaults to the setting of the I_{SETG} resistor.

Conclusion

The LTC3212 is an RGB LED driver optimized to be a simple and compact solution for driving an RGB LED from a 2.7V to 5.5V supply. The LTC3212 is well suited for applications requiring an LED driver with accurate programmable current sources, and compact, low noise operation.

USB Power Manager with High Voltage 2A Bat-Track Buck Regulator

by Nancy Sun

Introduction

Personal navigation devices, HDD-based media players, automotive accessories, and other handheld products draw on an array of power sources for recharging their batteries. These sources include USB (nominally 5V), low voltage wall adapters (4.5-5.5V), high voltage wall adapters (12V–24V), FireWire (8V–33V) and automotive batteries (nominally 12V). The large supply of available sources leads to an increasing need for handheld devices that can accept a wide range of multiple input voltages without the need for myriad external power adapters.

The LTC4090 is designed to accommodate both USB and high voltage sources by integrating a high voltage 2A switching buck regulator, a USB input, a PowerPath™ controller and a linear battery charger into a compact, thermally enhanced 3mm × 6mm package. Figure 1 shows a complete solution that fits into less than 3cm^2 with all components on one side of the PCB (Figure 2).

Complete PowerPath Controller

The LTC4090 is a complete PowerPath controller for battery powered applications. It is designed to receive power from a USB input (or 5V wall adapter), a high voltage source, and a single-cell Li-Ion battery. The PowerPath controller distributes the available power, with the load on the OUT pin taking precedence and any remaining current used to charge the Li-Ion battery. The high voltage input takes priority over the USB input (i.e., if both HVIN and IN are connected to power sources, load current and charge current are provided by the HVIN input). Figure 3 shows a simplified block diagram of the PowerPath operation.

USB Input Current Limit

Power supplies with limited current capability (such as USB) should be connected to the IN pin, which has a programmable current limit. The input current limit is programmed using a single external resistor, R_{CLPROG}, from the CLPROG pin to ground. In Figure 1, a 2.1kΩ CLPROG resistor has been chosen to program the input current limit to 476mA in high power mode (when the HPWR pin is pulled high) or 95mA in low power mode (when the HPWR pin is pulled low). This ensures that the application complies with the USB specification. The sum of battery charge current and the load current (which takes priority) will not exceed the programmed input current limit.

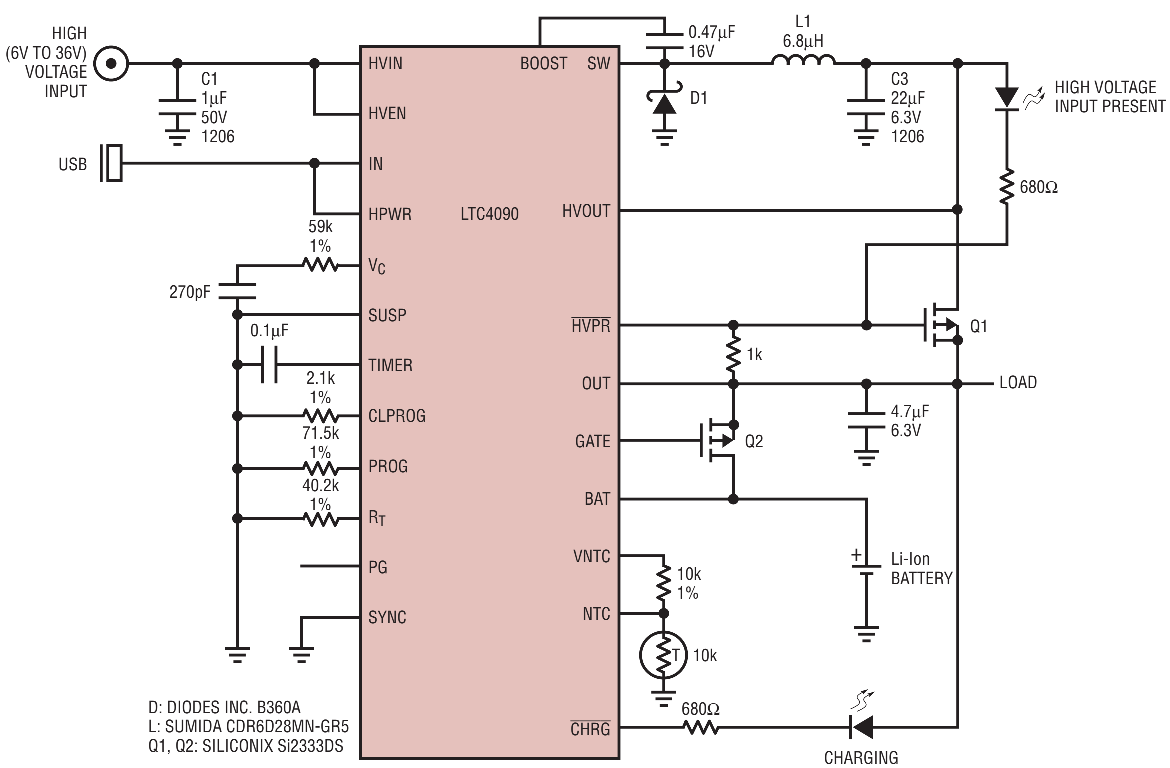


Figure 1. Li-Ion battery charger accepts both USB and high voltage inputs

Ideal Diode from BAT to OUT

An ideal diode function automatically delivers power to the load via the ideal diode circuit between the BAT and OUT pins when the load current exceeds the programmed input current limit or when the battery is the only supply available. Powering the load through the ideal diode instead of connecting the load directly to the battery allows a fully charged battery to remain fully charged until external power is removed. The LTC4090 has a 215mΩ internal ideal diode as well as a controller for an optional external ideal diode. In Figure 1, an external P-channel MOSFET, Q2, is shown from BAT to OUT and serves to further increase the conductance of the ideal diode.

High Voltage Buck Regulator

The LTC4090 has an operating input voltage range of 6V to 36V and can withstand voltage transients of up to 60V. The buck converter output, HVOUT, maintains approximately 300mV across the battery charger from OUT to BAT so that the battery can be efficiently charged with the linear charger. The minimum V_{HVOUT} is 3.6V to ensure the system can operate even if the battery is excessively discharged. As shown in Figure 1, an external PFET, Q1, between HVOUT and OUT is controlled by the $\overline{HVPR}$ pin and allows OUT to supply power to the load and to charge the battery. The buck converter is capable of up to 2A of output current.

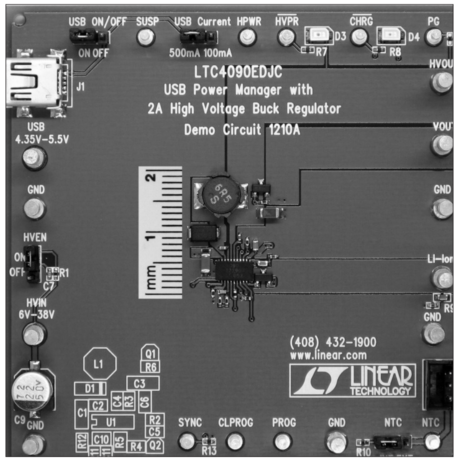


Figure 2. A complete LTC4090-based USB Power Manager with a 2A high voltage buck regulator fits into 3cm².

Battery Charger Features

The LTC4090 battery charger uses a unique constant-current, constant-voltage, constant-temperature charge algorithm with programmable charge current up to 1.5A and a final float voltage of 4.2V ±0.8%. The maximum charge current is programmed using a single external resistor, R_{PROG}, from the PROG pin to ground. In Figure 1, a 71.5k PROG resistor programs the maximum charge current to 700mA. However, in the case where only a USB input is present, charge current is reduced to ensure that the programmed input current limit is not exceeded. For the circuit in Figure 1, when only a USB input is present, the actual maximum charge current is reduced to 476mA.

In typical operation, the charge cycle begins in constant-current mode. A strong pull-down on the $\overline{CHRG}$ pin indicates that the battery is charging. In constant current mode, the charge current is set by R_{PROG}. When the battery approaches the final float voltage of 4.2V, the charge current starts to de-

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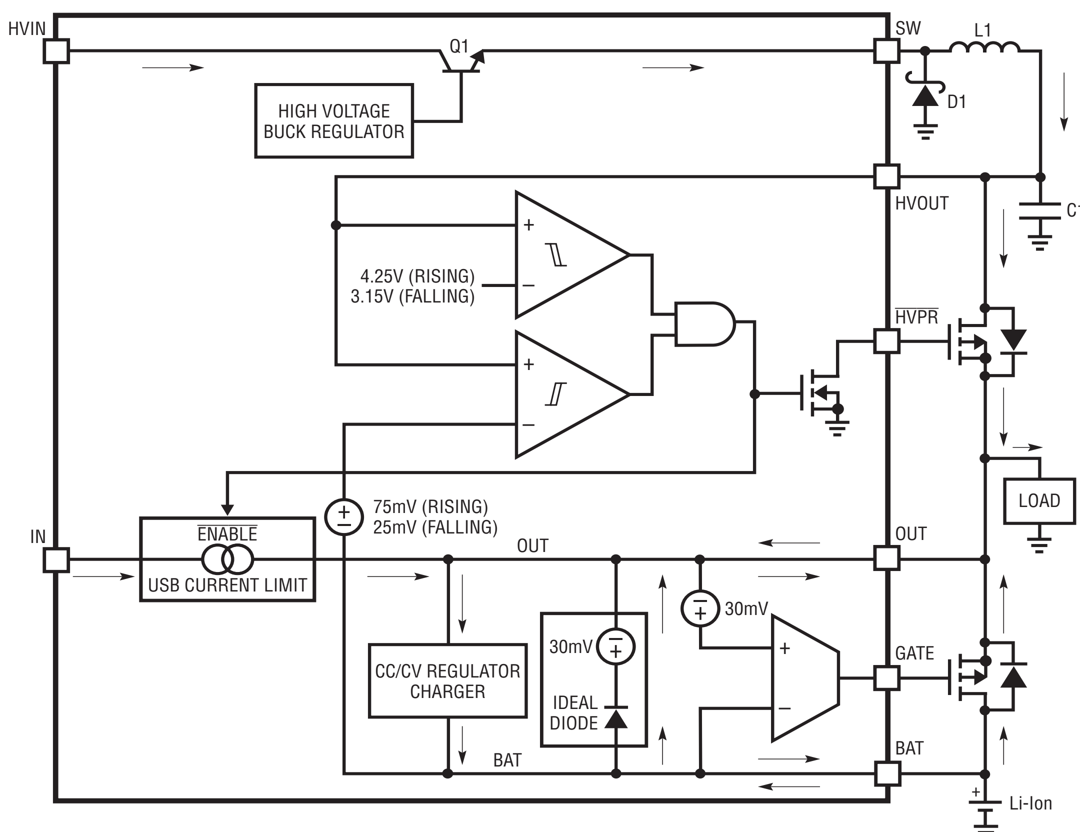

Figure 3. Simplified block diagram of the LTC4090 PowerPath operation

Complete 3-Rail Power Supply in a 4mm × 4mm QFN Package

by John Canfield

Introduction

Battery-powered portable electronic devices such as portable media players, handheld PCs, and GPS receivers typically require several internal power supply rails: a 3.0V or 3.3V supply for audio, motor drivers, and micro hard disk drives; a 1.2V or 1.5V rail for a logic core; and often a 1.8V supply to support Flash memory. For devices supplied by a Li-Ion battery, the power system is further complicated by the fact that the 3.0/3.3V output rail lies within the discharge voltage range of the battery, thereby mandating a power supply solution that can step the input voltage up or down depending on the battery's state of charge. In addition, most systems require specific power-up sequencing between the multiple output voltage rails to ensure consistent and reliable system initialization.

Figures 1 and 2 show how all of these requirements can be met with a single tiny IC and relatively few additional components. The heart of this complete power supply system is the LTC3520, which includes a high-efficiency, internal 1A buck-boost converter, a 600mA synchronous buck converter and an LDO controller, all in a 4mm × 4mm QFN package.

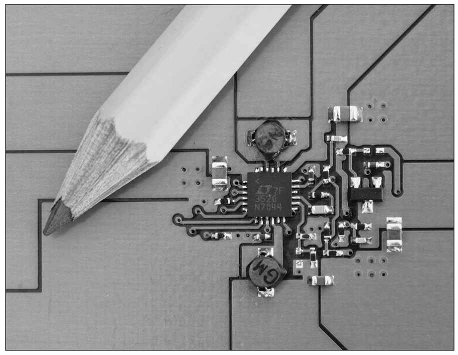

Figure 1. Complete triple-output supply: Li-Ion to 3.3V, 1.8V, and 1.5V

The LTC3520's buck-boost converter utilizes an advanced switching algorithm to precisely regulate the output voltage with input voltages that are above, below, or even equal to the output voltage. Mode transitions occur seamlessly and high efficiency and low noise performance are maintained across all operational modes. The synchronous buck converter operates with current-mode control and is internally compensated to reduce the number of external components. If the input voltage falls below the minimum buck regulation voltage, the buck converter automatically transitions to low dropout mode to extend battery life. Pin-selectable Burst Mode® operation improves light-load efficiency and reduces the no-load input current for both converters to only 70µA.

The extensive array of programmable features on the LTC3520 provide the flexibility needed to meet the requirements of a wide range of applications. Both the buck and buck-boost converters are controlled by a common oscillator. A single external resistor sets the switching frequency, making it possible to optimize efficiency and application size. Both converters feature voltage mode soft-start with ramp rates which are independently set via small external capacitors. The output voltage of each converter is programmed via an external resistor divider. The buck-boost output voltage

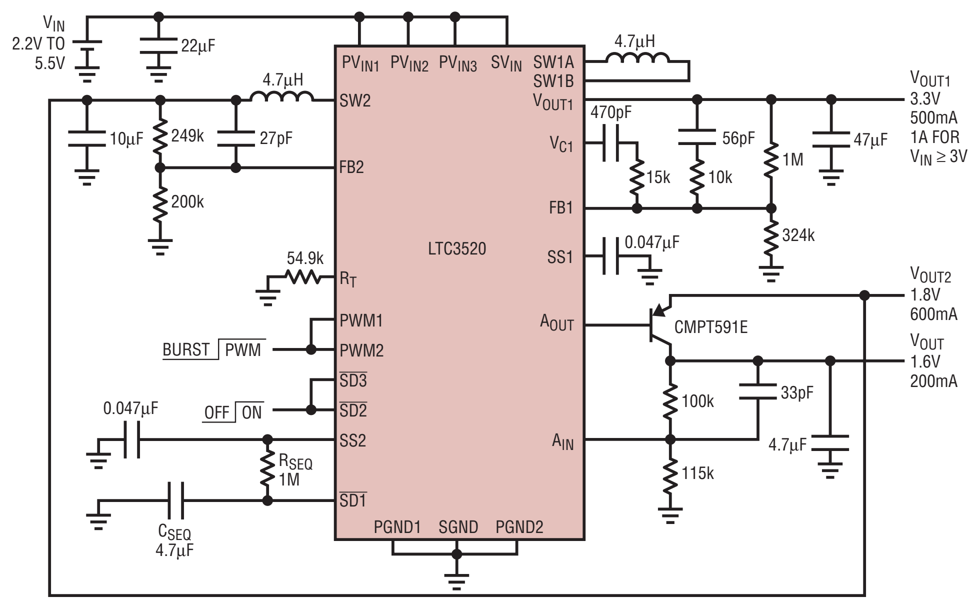

Figure 2. Sequenced start-up, triple-output converter

can be set as high as 5.25V or as low as 2.2V. When configured for a 3.3V output, the buck-boost can provide up to 1A load current for input voltages greater than 3V and supports a 500mA load down to an input voltage of 2.2V. The buck converter delivers up to 600mA and its output can be set as low as 0.8V.

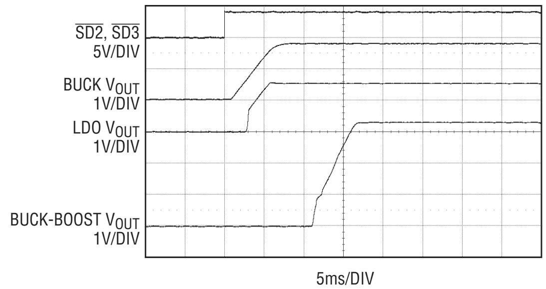

Figure 3. Output voltages during sequenced start-up

Three Output Rails with Sequenced Start-Up

In many applications, the low voltage rails that supply the logic core and memory must be powered and in regulation before the higher voltage supply for the peripheral devices is activated. This provides time for the processor to initialize and control the states of its logic outputs to ensure reliable and consistent initialization of the system. Figure 2 shows power-up sequencing achieved by using the buck converter soft-start pin to enable the buck-boost via the $\overline{SD1}$ pin after a programmable delay created by the RC filter composed of resistor R_{SEQ} and capacitor C_{SEQ}.

Figure 3 shows the output voltages for this application circuit during start-up. The buck output voltage begins its soft-start period soon after the rising edge of $\overline{SD2}$ and the LDO output rises coincident with the buck output. Approximately 5ms after the buck reaches regulation, the buck-boost soft-start commences. The length of this delay can be adjusted via the time constant of the RC filter, while the ramp rate of each converter's soft-start can be independently controlled by the value of the respective soft-start capacitor. In shutdown, $\overline{SD2}$ is held low, which internally forces $\overline{SS2}$ low, thereby ensuring the buck-boost converter remains disabled as well.

Low Battery and Power-Good Detection

In applications where the third output rail is not required, the LDO controller can be used instead as a general purpose comparator. One possibility is to utilize the uncommitted amplifier as a low battery indicator with the circuit shown in Figure 4a. The low battery output can then be used to provide the system processor with feedback on the state of the battery. The uncommitted amplifier is not disabled by the undervoltage lockout, which allows the low-battery indicator to remain functional down to 1.6V typically, well below the undervoltage lockout threshold of the LTC3520.

It is also possible to use the uncommitted amplifier as a high accuracy power-good indicator for either the buck or buck-boost output rail. The resultant power-good signal can then be utilized to enable the opposite channel, providing high accuracy supply sequencing. For example, the circuit shown in Figure 4b creates a power-good output for the buck converter and initiates the buck-boost converter only after the buck output reaches the power-good threshold set by resistors R_1 and R_2.

USB-Powered Triple-Output Supply

The USB specification mandates that the output voltage provided by a high power port be maintained in the range of 4.75 to 5.25V. However, once resistive drops in the USB cable and connectors are taken into account, along with the potential voltage drop across an upstream bus-powered hub, a USB peripheral must be able to function with input voltages over a wider range of 4.25 to 5.25V. Furthermore, the input voltage seen by the peripheral can vary dynamically between these limits based on the particular cable, host, and load current being drawn. In such applications, the buck-boost converter of the LTC3520 can provide a restored 5V output rail independent of loading and cable resistance. Additionally, the buck converter and LDO can be configured to provide two lower voltage outputs, such as 3.3V and 1.8V logic supplies. If both of these additional voltage outputs are not required, the uncommitted amplifier can instead be configured to monitor the input USB voltage to inform the processor of the presence of a valid USB input voltage level.

Conclusion

With its small size, flexible programmability, and high efficiency, the LTC3520 is well suited to meet the multiple output power supply needs of most Li-Ion powered electronic devices. In addition, the LTC3520 is ideal for systems powered from USB or low voltage wall adapters, which require an output voltage rail that lies within the expected input voltage range due to resistive drops in the supply path.

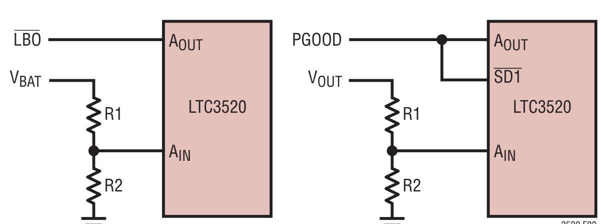

Figure 4. Implementation of low battery and power-good indicators

I^2C Quad Buck Regulator Packs Performance, Functionality, Versatility and Adaptability in a 3mm × 3mm QFN

by Joe Panganiban

Introduction

The LTC3562 is an I^2C quadruple step-down regulator composed of four extremely versatile monolithic buck converters. Two 600mA and two 400mA highly adjustable step-down regulators provide a total of 2A of available output current, all packed inside a 3mm × 3mm QFN package. All four regulators are 2.25MHz, constant-frequency, current mode switching buck converters whose output voltages and operating modes can be independently adjusted through I^2C control. The 2.7V to 5.5V input voltage range makes it ideally suited for single Li-Ion battery-powered applications requiring multiple independent voltage supply rails.

I^2C Programmable Operating Modes

All four LTC3562 step-down regulators have the unique ability to be programmed into four distinct operating modes to satisfy the various noise/power demands of a variety of applications. These four modes are pulse skipping mode, Burst Mode operation, forced Burst Mode operation, and LDO mode.

Pulse skipping mode allows the regulator to skip pulses at light load currents, providing very low output voltage ripple while maintaining high efficiency. Burst Mode operation and forced Burst Mode operation deliver bursts of current to the buck output and regulate the output voltage through hysteretic control, giving the highest efficiency at low load currents. In LDO mode, the bucks are converted to DC linear regulators and deliver continuous power from the switch pins through the inductor, providing the lowest possible output noise as well as the lowest no-load quiescent current.

I^2C Programmable Output Voltages

Another unique feature of the LTC3562 is its ability to adjust the output voltage of each regulator through I^2C control. The chip contains two different flavors of output adjustable regulators. The Type A regulators (R600A, R400A) have programmable feedback servo voltages, while the Type B regulators (R600B, R400B) have directly programmable output voltages that do not need external programming resistors.

The Type A regulators use external feedback resistors to set the output voltage based on a programmable feedback servo voltage. The feedback voltage values can be programmed from 800mV (full scale) down to 425mV in 25mV steps. This results in 16 possible feedback servo voltages, and thus 16 different output voltage settings for the same external programming resistors.

Table 1. Feature comparison of the LTC3562's four integrated regulators (two 600mA and two 400mA)

	R600A	R400A	R600B	R400B
Type	A	A	B	B
Output Current	600mA	400mA	600mA	400mA
I^2C Programmable Operating Modes	Pulse Skip Burst Forced Burst LDO	Pulse Skip Burst Forced Burst LDO	Pulse Skip Burst Forced Burst LDO	Pulse Skip Burst Forced Burst LDO
Feedback Servo Voltage	I^2C Programmable 425mV–800mV 25mV steps (16 settings)	I^2C Programmable 425mV–800mV 25mV steps (16 settings)	600mV (Fixed)	600mV (Fixed)
Output Voltage	Adjustable using External Resistors	Adjustable using External Resistors	I^2C Programmable 600mV–3.775V 25mV steps (128 settings)	I^2C Programmable 600mV–3.775V 25mV steps (128 settings)
RUN Pins	Yes	Yes	No	No

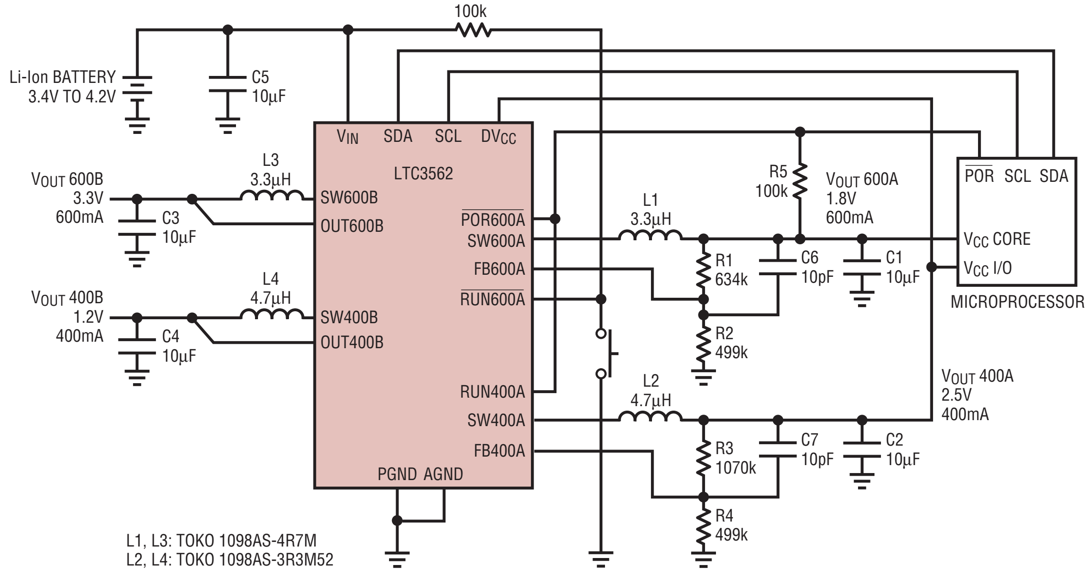

Figure 1. The LTC3562 configured in a quad step-down converter with pushbutton control and power sequencing.

The Type B regulators (R600B, R400B) do not require external programming resistors at all because they are integrated inside the chip. These internal feedback resistors not only save valuable board space, they are also I²C programmable. The values of the internal feedback resistors can be adjusted through I²C control to directly program the regulator output voltages from 0.6V to 3.775V in 25mV increments. That is 128 possible output voltage settings for each Type B regulator.

RUN pins and Default Settings

I²C applications generally have a microprocessor in charge of the I²C communications between the various system blocks. A multi-channel buck converter such as the LTC3562 provides an excellent solution for efficiently stepping down the microprocessor's core and I/O supply voltages from a higher input supply or battery. At the surface, using an I²C controllable voltage converter to generate the microprocessor's power supplies seems to pose a bootstrap problem at system start-up. If the microprocessor initially has no power and thus there is no I²C control, what programs the LTC3562's output to the proper voltage for the patiently waiting microprocessor?

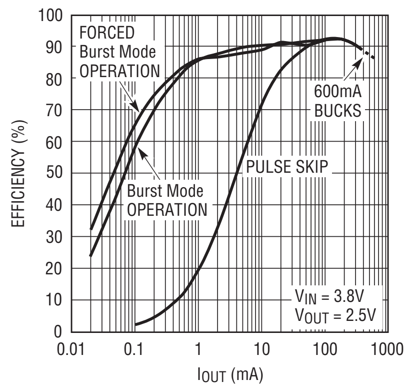

Figure 2. Efficiency of the 2.5V regulator

The LTC3562 gets around this start-up issue by providing individual RUN pins for the two Type A regulators. These RUN pins bypass the I²C controls and enable the regulators if I²C is unavailable. When a RUN pin is used, the corresponding Type A regulator is enabled in a default setting, which is 800mV for the feedback voltage and pulse skipping mode for the operating mode. Once I²C becomes available to the system, these default settings can always be modified on the fly through I²C.

Pushbutton Control and Power Sequencing

Figure 1 shows an application circuit that uses the LTC3562 to power the core and I/O supplies of a system microprocessor. The RUN pin of R600A connects to a pushbutton circuit with a pull-up resistor used to power on the system. When the button is pushed, the RUN pin goes low which enables R600A to ramp up the power supply for the microprocessor's core. The RUN pin of R400A is tied to R600A's power-on-reset output signal (POR600A). Once R600A reaches regulation, POR600A goes high after a 230ms time delay, which would then enable R400A to power the I/O supply of the microprocessor.

After both the core and I/O supplies are up, the microprocessor could then communicate back to the LTC3562 through I²C to program the part such that it keeps R600A enabled even after the pushbutton stimulus is removed. The microprocessor then can enable regulators R600B and R400B in any mode and program the output voltages to desired levels.

Low Power Adaptability

The ability to change the operating modes and output voltages at any time allows the LTC3562 to adapt to the constantly changing demands of many high performance systems. An example of this adaptability would be during lower power standby operation in handheld battery-powered systems. When going into standby mode, the regulators can be programmed into Burst Mode operation or forced Burst

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μModule Regulators Shrink Power Supply Size *and* Design Effort

by David Ng

Introduction

When it comes to high density, efficient power supplies, switching regulators are a top choice, but what if a project lacks sufficient design resources to properly layout and test a switching power supply circuit? Like any other system, switching power supplies require component selection, derating, simulation, prototyping, board layout, analysis and design verification testing. Design engineers should focus on the guts of the new whiz-bang gadget, not the power supply to run it.

The LTM8020, LTM8022 and LTM8023 are three μModule regulators that require minimal design effort and only a few inexpensive passive components to make a complete power supply. The modules are small, accept a wide input operating range and can produce 0.2A, 1A and 2A, respectively.

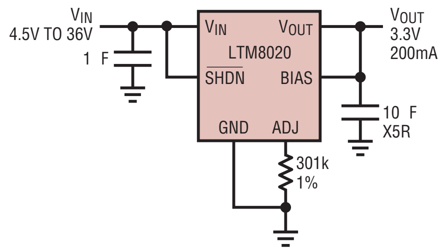

Figure 1. Generate 3.3V at 200mA with the LTM8020, two caps and a resistor

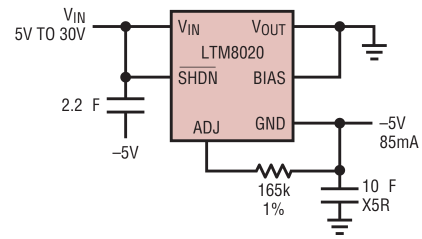

Figure 2. A simple reconfiguration of the μModule generates a negative output

The LTM8020, LTM8022 and LTM8023 are three μModule regulators that require minimal design effort and only a few inexpensive passive components to make a complete power supply.

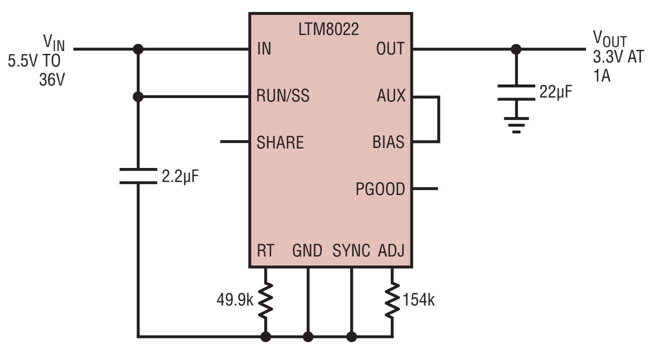

Figure 3. Produce 3.3V at 1A with LTM8022 and just four passive components

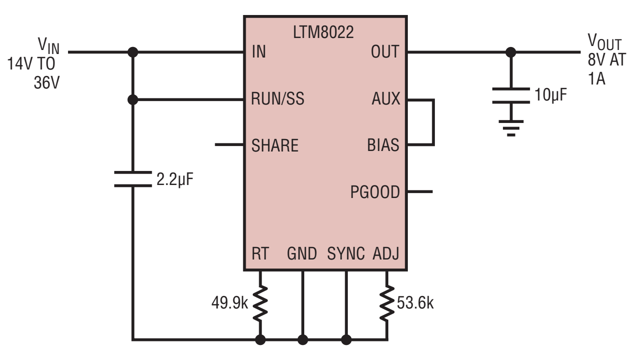

Figure 4. The LTM8022 can produce 8V, too

Tiny, Self-Contained, 200mA Power Supply

The LTM8020 is small, with a package measuring only 6.25mm × 6.25mm × 2.32mm, but it accepts a wide 4V to 36V input voltage range, and can produce up to 1W for output voltages between 1.25V and 5V at 200mA. At light loads, Burst Mode operation keeps quiescent current to 50μA at no load. The current draw is less than 1μA when shut down. As seen in Figure 1, a complete LTM8020 power supply requires only an input capacitor, output capacitor and a single resistor to set the output voltage.

Negative Power Supply with Few Components

Being a self-contained design, the LTM8020 can be easily configured to generate a negative voltage. Figure 2 shows is an example of how to use the LTM8020 to generate –5V at 85mA from an input range of 4.5V to 30V. The part does not operate as a true buck converter in this configuration, so the maximum output current is less than that achievable in the buck configuration.

If You Need More Power…

The LTM8022 comes in a larger 11.25mm × 9mm × 2.82mm package than the LTM8020, but boasts a wider input range, 3.6V–36V, and output range, 0.8V–10V, for loads up to 1A. It also includes more control features, including a RUN/SS pin, synchronization, user adjustable switching frequency and a SHARE pin for paralleling modules. The LTM8022 also employs Burst Mode operation, drawing only 50µA quiescent current at no load while maintaining only 30mV of output voltage ripple. Like the LTM8020, the quiescent current when shut down is less than 1µA. The schematic is very simple, with examples of 3.3V and 8V output designs shown in Figures 3 and 4, respectively.

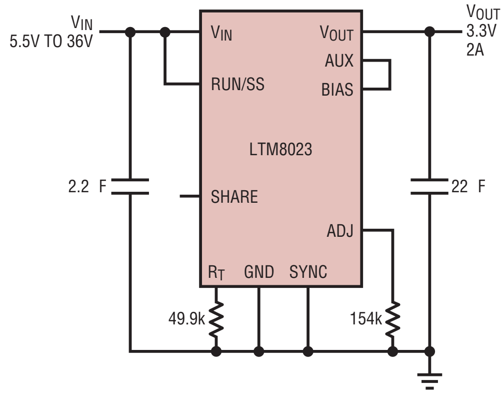

Figure 5. The LTM8023 produces 3.3V at 2A with the same footprint and components required for the LTM8022 producing 1A.

…Or, Even More Power…

The LTM8023 is the big brother of the LTM8022, capable of producing up to 2A of output current. The LTM8023 has the same input, output voltage range, and control features as the LTM8022. It also features Burst Mode operation and low quiescent current. The LTM8022 and LTM8023 share the same footprint and pin pattern, so even if you start a design with the LTM8022 but later find that you need more current, you can simply drop in the LTM8023. In most cases, the design will use identical passive components as the LTM8022, as seen in the 3.3V example in Figure 5.

Table 1. Summary of LTM8000 series µModule regulators

Part Number	V_{IN} Range	Max Load	V_{OUT} Range	Size
LTM8020EV	4V to 36V	200mA	1.25V to 5V	6.25 × 6.25 × 2.32mm
LTM8022EV	3.6V to 36V	1A	0.8V to 10V	11.25 × 9 × 2.82mm
LMT8023EV	3.6V to 36V	2A	0.8V to 10V	11.25 × 9 × 2.82mm

Conclusion

The LTM8020, LTM8022 and LTM8023 µModule regulators make power supply development fast and easy. Their broad input and output voltage ranges, load capabilities and small size (see Table 1) make them readily fit into a wide variety of applications.

LTC3562, continued from page 35

Mode operation to maximize power efficiency at light loads. Under no-load conditions, the regulators can also be programmed into LDO mode, which provides the lowest quiescent current (all four regulators in LDO mode only draw a combined 80µA for the entire chip).

To save even more power, the LTC3562 can be programmed to reduce the regulators' output voltages in Burst Mode operation or forced Burst Mode operation during light load conditions. Since power dissipation is directly proportional to the supply voltage multiplied by the load current, dropping the supply voltage effectively reduces the circuit's total power dissipation. If the output load is resistive in nature, reducing the supply voltages has an even greater effect, since power dissipation in the load is proportional to the supply voltage squared.

Conclusion

The LTC3562 is a highly flexible I^2C quad step-down converter composed of two 600mA and two 400mA buck regulators in a 3mm × 3mm QFN package. The output voltages of the regulators can be switched on the fly using servo control or I^2C control. Each regulator can also be switched on the fly into four possible high efficiency or low-noise operating modes. This is a perfect device for high performance applications that require constant control of the power supply. It can also be used to simplify design, build and test cycles, since output voltages can easily be changed without changing components.

LTC3813 and LTC3814-5, continued from page 21

the output is drawing full load. Its efficiency is shown in Figure 7.

Conclusion

The LTC3813 and LTC3814-5's synchronous architecture and high voltage capability make them ideally suited for high voltage high power boost converters. They decrease complexity by eliminating the requirement for a large diode package and heat sink to dissipate its high power loss. Programmable frequency and current limit, wide output voltage range, and ability to drive logic-level or higher threshold MOSFETs provide maximum flexibility in using them for a variety of boost applications. Other features such as such as strong gate drivers to minimize transition losses, an accurate voltage reference, accurate cycle-by-cycle current limit, and an on-chip bias supply controller make the LTC3813 and LTC3814-5 the obvious choice for high performance, high power boost converters.

Small, High Efficiency Solution Drives Two Piezo Motors

Wei Gu

Introduction

Piezoelectric motors are used in digital cameras for autofocus, zooming and optical image stabilization. They are relatively small, lightweight and efficient, but they also require a complicated driving scheme. Traditionally, this challenge has been met with the use of separate circuits, including a step-up converter and an oversized generic full bridge drive IC. The resulting high component count and large board space are especially problematic in the design of cameras for ever shrinking cell phones. The LT3572 solves these problems by combining a step-up regulator and a dual full bridge driver in a 4mm × 4mm QFN package.

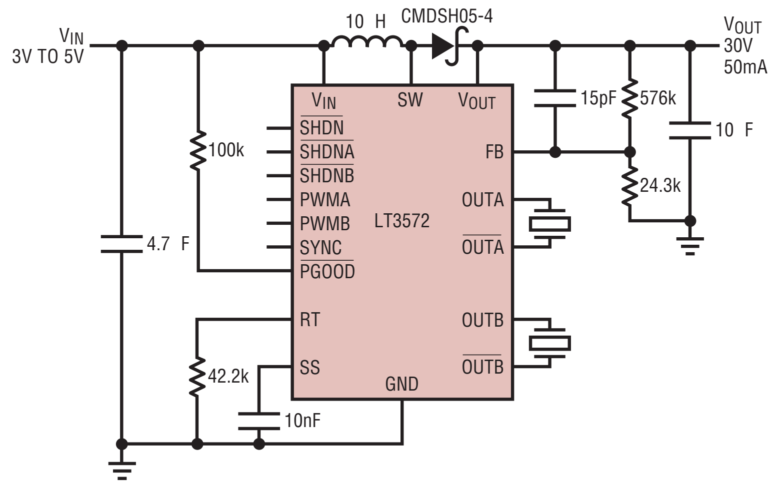

Figure 1. A typical LT3572 Piezo motor drive circuit

A Simple Integrated Solution to Drive Two Piezo Motors

Figure 1 shows a typical LT3572 Piezo motor drive circuit. A step-up converter with a high efficiency internal switch is used to generate 30V from a low voltage power source such as a Li-Ion battery or any input power source within the part's wide input voltage range of 2.7V to 10V . The LT3572 uses a peak current mode control architecture, which improves line and load transient response compared to other schemes. The switching frequency is adjustable from 500kHz to 2.5MHz, set either by an external resistor or synchronized to an external clock source of up to 2.5MHz. This allows selection of the optimum frequency for any given design. The soft-start feature limits the inrush current drawn from the supply upon start-up. A $\overline{\text{PGOOD}}$ pin indicates when the output of the step-up converter is in regulation and the Piezo drivers can start switching. The step-up converter and both Piezo drivers have their own shutdown control.

The high output voltage of the step-up converter, adjustable up to 40V, is available for the drivers at the OUT pin. The LT3572 is capable of independently driving two Piezo motors with two input PWM signals. The motors respond accordingly based on the duty cycle and the frequency of the PWM signals. The drivers operate in an H-bridge fashion, where the OUTA and OUTB pins are the same polarity as the PWMA and PWMB pins respectively and the $\overline{\text{OUTA}}$ and $\overline{\text{OUTB}}$ pins are inverted from PWMA and PWMB respectively. Each H-bridge can drive a 2.2nF capacitor with rise and fall times less than 100ns. Figure 2 shows a typical layout. The LT3572 is available in a small 4mm × 4mm QFN package.

The LT3572 uses a peak current mode control architecture, which improves line and load transient response compared to other schemes. The switching frequency is adjustable from 500kHz to 2.5MHz, set either by an external resistor or synchronized to an external clock source of up to 2.5MHz. This allows selection of the optimum frequency for any given design.

Conclusion

The LT3572 is a complete Piezo motor drive solution with a built-in high efficiency 40V, 1.2A internal switch and integrated dual 500mA full bridge drivers. It includes other features to minimize the application footprint, including fixed frequency, soft-start, and internal compensation.

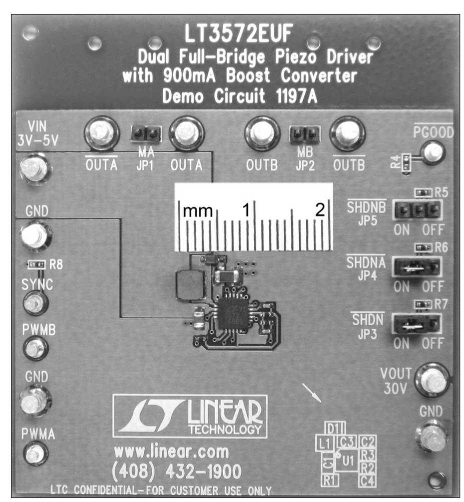

Figure 2. Typical layout for the Figure 1 converter

New Device Cameos

I^2C ADC Guarantees 16-Bit Performance in 3mm × 2mm Package

The LTC2453 is a 16-bit I^2C-compatible delta sigma analog-to-digital converter (ADC) in an ultra-tiny 3mm × 2mm DFN package. Its tiny size, low power and guaranteed 16-bit resolution improves performance of portable instruments and sensors. Operating from a single 2.7V to 5.5V supply, the LTC2453 is capable of measuring a differential input up to ±V_{CC}. This wide input range is ideal for measuring a wide variety of single-ended or differential sensors.

The versatile LTC2453 achieves excellent 16-bit DC performance of 2LSB integral nonlinearity error, 1.4µV_{RMS} transition noise and 0.01% gain error. The LTC2453 has an internal oscillator and allows up to 60 conversions per second, making it easy to measure temperature, pressure, voltage or other low frequency sensor outputs. The LTC2453 draws 800µA of supply current at the 60Hz maximum sample rate. After each conversion, supply current is reduced to less than 0.2µA, further preserving battery power. If the user samples the device once a second, the LTC2453 dissipates only 40µW from a 3V supply.

The LTC2453 communicates via a simple I^2C-compatible 2-wire interface, reducing the number of I/O lines required to read data, making the LTC2453 ideal for tiny, space-constrained applications. The LTC2453 includes continuous internal offset and full-scale calibration of the input signal, ensuring accuracy over time and over the full operating temperature range. Linear's No Latency Delta-Sigma™ design allows the ADC to multiplex several inputs with no delay in reading the output data. The LTC2453 incorporates a proprietary sampling network that reduces the dynamic input current to less than 50nA, making a wide range of external input protection and filter circuits possible.

SoftSpan 16-/14-/12-Bit Current Output DACs Draw Less than 1µA Supply Current

The LTC2751 is a family of extremely low power, software-programmable 16-/14-/12-bit digital-to-analog converters (DACs). These current output DACs typically draw only 0.7µA of supply current (2µA max), while generating an output swing up to ±10V. Six unique output voltage ranges can be programmed via SoftSpan™ software, including two unipolar ranges (0V to 5V, 0V to 10V) and four bipolar ranges (±10V, ±5V, ±2.5V, -2.5V to +7.5V). Software programmability eliminates the need for expensive precision resistors, gain stages and manual jumper switching.

The LTC2751-16 offers accurate DC specifications, including ±1LSB(max) INL and DNL over the –40°C to 85°C industrial temperature range. With its precision linearity and supply current less than 1µA, the LTC2751-16 can be used in DC precision positioning systems, high-resolution gain and offset adjustment applications, and portable instrumentation.

The LTC2751-16 also offers excellent AC specifications, including full-scale settling time of only 2µs and low 2nV•s glitch impulse, which is key for AC applications such as waveform generation. Low glitch reduces the transient voltages between code changes in the DAC. Fast settling and low glitch reduce harmonic distortion, making it possible to produce higher frequency, lower noise output waveforms.

The LTC2751 DACs use a bidirectional input/output parallel interface that allows readback of any internal register, as well as the DAC output span setting. A power-on reset circuit returns the DAC output to 0V when power is first applied and a CLR pin asynchronously clears the DAC to 0V in any output range.

The LTC2751 DACs are available in pin-compatible 16-bit, 14-bit, and 12-bit QFN-38 (5mm × 7mm) packages.

More Choices in Very High Speed ADC Drivers

The LTC6400/LTC6401 is a family of very high speed differential amplifiers, suitable for driving signals of up to 300MHz into high performance pipeline ADCs. Versions of these parts with gains from 8dB to 26dB are now available. The "dash" number behind the part name signifies the voltage gain in dB. For example, the LTC6400-26 has a voltage gain of 26dB (or 20V/V). The LTC6401-8 has a voltage gain of 8dB (or 2.5V/V). The LTC6400-20 and LTC6401-20 (voltage gain of 20dB) were described in greater detail in an earlier Design Feature. The difference between the LTC6400 and LTC6401 part numbers is that the LTC6400 consumes more DC power but has lower distortion especially at signal frequencies above 140MHz. The LTC6401 consumes less DC power and is recommended for low distortion applications with signal frequencies up to 140MHz. Both versions have the same low noise performance. Inside each IC is a differential op amp with input-referred noise density of $1nV/\sqrt{Hz}$. The gain is set internally by means of on-chip resistors. The lower gain versions have lower output noise (because the op amp noise is multiplied by less gain) but the higher gain versions have a higher gain-bandwidth product (because the bandwidth remains the same even though the gain is higher).

Typical applications that benefit from these parts are IF-sampling communications receivers where high linearity is needed to avoid 'blockers' from intermodulating into nearby bands. For example, at 140MHz the intermodulation distortion of a $2V_{P-P}$ signal is as low as –93dBc. Previously, the only other way to achieve such performance was through very power hungry RF gain blocks with OIP3s of >50dBm. The LTC6400 saves power, space and BOM cost compared to older solutions.

All members of the family are pin-compatible and come in a 3mm × 3mm

QFN package. The parts operate from a 3V or 3.3V supply voltage and over the –40°C to 85°C temperature range.

Tiny Dual Input Li-Ion Charger Integrates USB and Wall Adapter Paths

The LTC4097 is a full-featured Li-Ion/Polymer battery charger capable of charging from either a USB port or a wall adapter without the need for an external multiplexer. Packaged in a tiny 3mm × 2mm DFN, the LTC4097 includes independently programmable charge current for both inputs, programmable termination current, an NTC battery temperature qualification input, automatic recharge and more. The LTC4097 is the smallest IC in a growing line of dual input Li-Ion chargers including the LTC4075, LTC4075HVX, LTC4076, LTC4077, and LTC4096.

Many portable applications—including digital cameras, PDAs, mobile phones, and personal media players—can be charged from a USB port while exchanging data with a host computer, along with the option of faster charging via a 5V wall adapter. In such a 2-input system, a single-input charger requires an external multiplexer if a different charge current is needed for each type of input. On the other hand, the LTC4097 Li-ion charger accomplishes this task with complete integration, thus avoiding the cost and board-space requirements of a multiplexer and related components. In addition to independent charge current programming for each input, the LTC4097 includes a convenient digital input (HPWR) to switch between low power (100mA) and high power (500mA) modes while powered from a USB port.

The LTC4097 packs these features into a tiny package without sacrificing performance. Charge current is regulated to an accurate 6% and final float voltage is held to a tight ±0.5%. Furthermore, the termination current is accurate to within a handful of milliamps of the programmed value.

This unique combination of small size, full feature set, and high performance make the LTC4097 ideally suited for portable applications requiring two different charging input sources; particularly, if one of those sources is a USB port.

2.7GHz, 60dB Mean-Squared Power Detector Responds in 500ns

A new wide dynamic range mean-squared RF detector from Linear Technology sets a new level of accuracy and speed performance. The LT5570 provides accurate RMS (Root-Mean-Squared) power measurement of a 40MHz to 2.7GHz AC signal over 60dB dynamic range, even with a modulation crest-factor of up to 12dB. It offers best-in-class measurement accuracy of ±0.5dB over its full dynamic range and over a temperature range of –40°C to 85°C. Moreover, the device allows exceptionally fast response with a full-scale rise time of 500ns.

As nascent next-generation wireless standards such as mobile WiMAX and LTE (Long-Term Evolution) adopt more complex modulation schemes, combining OFDM (Orthogonal Frequency Division Multiplexing) and QAM (Quadrature Amplitude Modulation) to boost the data rate, it becomes increasingly difficult to accurately measure these high crest-factor signals. This problem is not just confined to wireless infrastructure, as many other wireless systems are similarly constrained by limited spectrum bandwidth. As a result, there is an ongoing need for higher order modulation to increase data rates. Cable networks, microwave datalinks, satellite communications, and military radios have similar needs, and the LT5570 is designed to meet these emerging challenges.

The LT5570 provides a DC output proportional to the RMS value of the input signal power. Even if the input waveform has high crest-factor content, such as a 4-carrier W-CDMA modulated waveform, its RMS conformance accuracy is typically within 0.2dB, compared to that of a CW (continuous waveform) power. The device offers 61dB dynamic range at 880MHz, and 51dB at 2.14GHz. Its linear DC output is proportional to the input power in dBm with a scaling factor of 36.5mV/dB, typical. Minimum sensitivity is –53dBm at 880MHz, and –43dBm at 2.14GHz. The device offers exceptional linearity, deviating less than ±0.5 dB from the ideal log-linear straight line, and over the device's operating temperature extremes.

The LT5570 operates from a single 5V supply, drawing a quiescent supply current of 26.5mA. A shutdown feature is provided, reducing supply current to 0.1µA.

The device comes in a 10-lead 3mm × 3mm DFN surface mount package.

Single/Dual/Quad/Octal Precision Voltage Monitors Guaranteed to 125°C

A family of single, dual, quad, and octal voltage monitors are now guaranteed to operate across –40°C to 125°C. The LTC2910, LTC2912, LTC2913 and LTC2914 all feature a threshold accuracy of ±1.5% over the automotive temperature range, allowing them to accurately monitor single-channel point-of-load or multichannel applications. These voltage monitors are all offered in tiny leaded and leadless packages and draw very little quiescent current. Set via external resistors, the entire family includes power supply glitch filtering that ensures predictable reset operation without false triggering. Each monitor also includes an adjustable reset timer and reset output that signals an undervoltage (UV) or overvoltage (OV) condition.

The LTC2910 monitors eight low voltage adjustable UV inputs and the LTC2914 monitors four adjustable inputs for OV, UV or negative voltages. Both the LTC2910 and LTC2914 draw just 70µA and are available in 16-lead SSOP and 5mm × 3mm DFN packages. The LTC2913 monitors two input channels for OV and UV conditions, draws only 60µA, and is offered in 10-lead MSOP and 3mm × 3mm DFN packages. The LTC2912 monitors a single supply for OV and UV conditions, with only 40µA of supply current, and is offered in 8-lead TSOT and 3mm × 2mm DFN packages.

The LTC2910, LTC2912, LTC2913, and LTC2914 automotive grade voltage monitors are all available today.

Precision Dual/Quad CMOS Rail-to-Rail Input/Output Amplifiers

The LTC6081 and LTC6082 are dual and quad low offset, low drift, low noise CMOS operational amplifiers with rail-to-rail input and output swings. The 70µV maximum offset, 1pA input bias current, 120dB open loop gain and 1.3μV_{P-P} 0.1Hz to 10Hz noise make it perfect for precision signal conditioning.

The LTC6081 and LTC6082 features 100dB CMRR and 98dB PSRR. Each amplifier consumes only 330µA of current on a 3V supply. The 10-lead DFN has an independent shutdown function that reduces each amplifier's supply current to 1µA. The LTC6081 and LTC6082 are specified for power supply voltages of 3V and 5V from –40°C to 125°C. The dual LTC6081 is available in 8-lead MSOP and 10-lead DFN10 packages. The quad LTC6082 is available in 16-lead SSOP and DFN packages.

0V to 44V Input Range Precision Current Sense Amplifier

The LTC6105 is a micropower, precision, current sense amplifier. The LT6105 monitors unidirectional current via the voltage across an external sense resistor. Any gain between 1V/V to 100V/V can be configured with external resistors. A minimum slew rate of 2V/µs ensures fast response to unexpected current changes.

The LT6105 sense inputs have a voltage range that extends from –0.3V to 44V and can withstand a differential voltage of the full supply. This makes it possible to monitor the voltage across a MOSFET switch or a fuse of a nearly depleted battery. The device can also withstand a reverse-battery condition on the inputs. CMRR and PSRR are in excess of 100dB coupled with low 300µV input offset voltage, and maximum sense voltage of 1V will allow a wide dynamic range of current to be monitored.

The LT6105 has an independent power supply, which operates from 2.85V to 36V and draws only 150µA. When V^+ is powered down, the sense pins are biased off. This prevents loading of the monitored circuit, irrespective of the sense voltage. The LT6105 is available in a 6-lead DFN and 8-lead MSOP packages.

High Power Step-Down DC/DC Controller Draws Only 30µA in Automotive Systems

The LTC3834/-1 synchronous step-down DC/DC controller features ultralow quiescent current. Drawing only 30µA in sleep mode, the LTC3834/-1 is ideal for preserving battery energy in "always-on" automotive systems or battery-powered devices where the system remains semi-active, or when a car's engine is off. When in shutdown mode, the LTC3834/-1 draws a mere 4µA.

This controller is the latest addition to Linear Technology's lineup of over twenty ultralow quiescent current DC/DC switching regulator controllers for step-down, step-up, buck-boost, SEPIC and inverter topologies.

The input supply range of the LTC3834/-1 at 4V to 36V is wide enough to protect against high input voltage transients and it continues to operate during automotive cold crank. It can provide an output voltage from 0.8V up to 10V, making it ideal for the higher voltage supplies typically required for audio systems, satellite receivers, analog tuners and CD/DVD players.

This controller has an onboard LDO for bias power and a powerful onboard MOSFET driver to deliver up to 20A load current at efficiencies as high as 95%. The LTC3834/-1's constant frequency, current mode architecture provides excellent line and load regulation. The device features a very low dropout voltage, with up to 99% duty cycle and smoothly ramps the output voltage during start-up with its adjustable soft-start and tracking features. The operating frequency is adjustable from 250kHz to 530kHz, and can be synchronized to an external clock from 140kHz to 650kHz using its phased-locked loop (PLL). In addition, the user can select from continuous, pulse skipping or Burst Mode operation at light loads. Output overvoltage and overcurrent (short circuit) protection are integrated and the LTC3834/-1 features ±1% reference voltage accuracy over an operating temperature range of –40°C to 85°C.

The LTC3834/-1 is available in two versions. The LTC3834 version has a power-good output voltage monitor and an $EXTV_{CC}$ input that allows the IC to be powered from its output for maximum efficiency. It is also features PolyPhase® operation that enables multiple ICs to be synchronized out-of-phase to minimize the required input and output capacitances. The LTC3834 is offered in a 20-lead TSSOP and 4mm × 5mm QFN packages, whereas the LTC3834-1 is housed in the smaller 16-pin SSOP and 5mm × 3mm DFN packages.

100V High Speed Synchronous N-Channel 3A MOSFET Driver for High Efficiency Step-Down or Step-Up DC/DC Converters

The LTC4444 is a high speed, high input supply voltage (100V) synchronous MOSFET driver designed to drive upper and lower power N-Channel MOSFETs in synchronous rectified converter topologies. This driver, combined with power MOSFETs and one of Linear Technology's many DC/DC controllers, form a complete high efficiency synchronous converter.

This powerful driver can source up to 2.5A with a 1.2Ω pull-down impedance for driving the top MOSFET and source 3A with a 0.55Ω pull-down impedance for the bottom MOSFET, making it ideal for driving high gate capacitance, high current MOSFETs. The LTC4444 can also drive multiple MOSFETs in parallel for higher current applications. The fast 8ns rise time, 5ns fall time of the top MOSFET, and 6ns rise time, 3ns fall time of the bottom MOSFET when driving a 1000pF load minimize switching losses. Adaptive shoot-through protection is integrated to minimize dead time while preventing both the upper and lower MOSFETs from conducting simultaneously.

The LTC4444 is configured for two supply-independent inputs. The high side input logic signal is internally level-shifted to the bootstrap supply, which may function at up to 114V above ground. Furthermore, this part drives both upper and lower MOSFET gates over a range of 7.2V to 13.5V.

The LTC4444 is offered in a thermally enhanced MSOP-8 package.

3.3V 20Mbps 15kV RS485/RS422 Transceivers

The LTC2850, LTC2851 and LTC2852, are the latest additions to Linear Technology's family of rugged 3.3V RS485/RS422 transceivers. These devices offer a variety of advanced features for industrial, medical and automotive applications with high speed operation to 20Mbps.

High receiver input resistance supports up to 256 nodes on a single bus, while meeting RS485 load requirements. Failsafe operation guarantees a logic-high receiver output state when the inputs of the receiver are floating, shorted or terminated, but not driven. Current limiting on all driver outputs and a thermal overload shutdown feature provide protection from bus contention and short circuits. Bus pin protection on all parts exceeds ±15kV for ESD strikes with no latchup or damage.

The LTC2850 provides half-duplex operation and the LTC2851 and LTC2852 are full-duplex. They are pin-compatible with the 5V LTC485, LTC490 and LTC491 parts, respectively. Specified over commercial and industrial temperature ranges from –40C to 85C, these parts are available in SO and MSOP packages as well as tiny leadless DFN packages.

New Member Added to the LTC2908 6-Supply Monitor Family

The LTC2908-C1 is a new addition to the LTC2908 6-supply monitor family available in tiny 8-pin TSOT and DFN packages. The LTC2908-C1, along with the previously available A1 and B1 versions, provides complete, precise, space-conscious, micropower and general purpose voltage monitoring solution for any application. The inputs can be shorted together for monitoring systems with fewer than six supply voltages, and the open drain $\overline{\text{RST}}$ output of two or more LTC2908 can be wired-OR together for monitoring systems with more than six supply voltages.

The LTC2908-C1 is designed to monitor 2.5V and five positive adjustable voltages. The previously available LTC2908-A1 is designed to monitor 5V, 3.3V, 2.5V, 1.8V and two positive adjustable voltages while the LTC2908-B1 is designed to monitor 3.3V, 2.5V, 1.8V, 1.5V and two positive adjustable voltages. The LTC2908 features a low voltage positive adjustable inputs (+ADJ) with nominal threshold level at 0.5V, and a low quiescent current on the main supply (the greater of V1 or V2) of 25µA typical.

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

LTC4090, continued from page 31

crease as the battery charger switches to constant-voltage mode. When the charge current drops to 10% of the full-scale charge current, commonly referred to as the C/10 point, the open-drain charge status pin, $\overline{\text{CHRG}}$, assumes a high impedance state. An external capacitor on the TIMER pin sets the total minimum charge time. In Figure 1, a 0.1µF capacitor on the TIMER pin gives a 2.145hr minimum charge time. When this time elapses, the charge cycle terminates and the $\overline{\text{CHRG}}$ pin assumes a high impedance state, if it has not already done so.

Charge Time is Automatically Extended

The LTC4090 has a feature that automatically extends charge time if the charge current in constant current mode is reduced during the charging cycle. Reduction can be due to thermal regulation or the need to maintain the programmed input current limit. The charge time is extended inversely proportional to the actual charge current delivered to the battery. The decrease in charge current as the LTC4090 approaches constant-voltage mode is due to normal charging operation and does not affect the timer duration.

Trickle Charge and Defective Battery Detection

At the beginning of a charge cycle, if the battery voltage is below 2.9V, the charger goes into trickle charge reducing the charge current to 10% of the full-scale current. If the low battery voltage persists for one quarter of the programmed total charge time, the battery is assumed to be defective, the charge cycle is terminated and the $\overline{\text{CHRG}}$ pin output assumes a high impedance state. If for any reason the battery voltage rises above ~2.9V the charge cycle is restarted.

Conclusion

The LTC4090 combines a high voltage switching buck regulator, a full-featured Li-Ion battery charger, and a PowerPath controller in a tiny 3mm × 6mm DFN package. Its wide input voltage range, high programmable charge current, and small footprint

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Purchase products directly from Linear Technology either through the methods below or contact your local LTC sales representative or licensed distributor.

Credit Card Purchase — Your Linear Technology parts can be shipped almost anywhere in the world with your credit card purchase. Orders up to 500 pieces per item are accepted. You can call (408) 433-5723 or email orders@linear.com with questions regarding your order.

Linear Express — Purchase online with credit terms. Linear Express is your new choice for purchasing any quantity of Linear Technology parts. Credit terms are available for qualifying accounts. Minimum order is only $250.00. Call 1-866-546-3271 or email us at express@linear.com.

Product and Applications Information

At www.linear.com you will find our complete collection of product and applications information available for download. Resources include:

Data Sheets — Complete product specifications, applications information and design tips

Application Notes — In depth collection of solutions, theory and design tips for a general application area

Design Notes — Solution-specific design ideas and circuit tips

LT Chronicle — A monthly look at LTC products for specific end-markets

Product Press Releases — New products are announced constantly

Solutions Brochures — Complete solutions for automotive electronics, high speed ADCs, LED drivers, wireless infrastructure, industrial signal chain, handheld, battery charging, and communications and industrial DC/DC conversion applications.

Product Selection

The focus of Linear Technology's website is simple—to get you the information you need quickly and easily. With that goal in mind, we offer several methods of finding the product and applications information you need.

Part Number and Keyword Search — Search Linear Technology's entire library of data sheets, Application Notes and Design Notes for a specific part number or keyword.

Sortable Parametric Tables — Any of Linear Technology's product families can be viewed in table form, allowing the parts to be sorted and filtered by one or many functional parameters.

Applications Solutions — View block diagrams for a wide variety of automotive, communcations, industrial and military applications. Click on a functional block to generate a complete list of Linear Technology's product offerings for that function.

Design Support

Packaging (www.linear.com/packaging) — Visit our packaging page to view complete information for all of Linear Technology's package types. Resources include package dimensions and footprints, package cross reference, top markings, material declarations, assembly procedures and more.

Quality and Reliability (www.linear.com/quality) — The cornerstone of Linear Technology's Quality, Reliability & Service (QRS) Program is to achieve 100% customer satisfaction by producing the most technically advanced product with the best quality, on-time delivery and service. Visit our quality and reliability page to view complete reliability data for all of LTC's products and processes. Also available is complete documentation on assembly and manufacturing flows, quality and environmental certifications, test standards and documentation and failure analysis policies and procedures.

Lead Free (www.linear.com/leadfree) — A complete resource for Linear Technology's Lead (Pb) Free Program and RoHS compliance information.

Simulation and Software

Linear Technology offers several powerful simulation tools to aid engineers in designing, testing and troubleshooting their high performance analog designs.

LTspice/SwitcherCAD™ III (www.linear.com/swcad) — LTspice / SwitcherCAD III is a powerful SPICE simulator and schematic capture tool specifically designed to speed up and simplify the simulation of switching regulators. LTspice / SwitcherCAD III includes:

- Powerful SPICE simulator specifically designed for switching regulator simulation
- Complete and easy to use schematic capture and waveform viewer
- Macromodels for most of Linear Technology's switching regulators as well as models for many of LTC's high performance linear regulators, op amps, comparators, filters and more.
- Ready to use demonstration circuits for over one hundred of Linear Technology's most popular products.

FilterCAD — FilterCAD 3.0 is a computer-aided design program for creating filters with Linear Technology's filter ICs.

Noise Program — This program allows the user to calculate circuit noise using LTC op amps and determine the best LTC op amp for a low noise application.

SPICE Macromodel Library — A library includes LTC op amp SPICE macromodels for use with any SPICE simulation package.

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