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High Voltage, High Current Battery Charger Works with All Converter Topologies, Any Battery Configuration

Eko Lisuwandi

The market for rechargeable batteries in consumer electronics has reached a level of stable maturity, where designing a battery charger requires little more effort than dropping a purpose-built battery charger IC into the design. This is because the batteries in consumer electronics follow well-worn standards, with popular configurations, float voltages, charge currents, output voltages and charge algorithms. Even so, there is an ever-growing demand for batteries that don't fit these standard molds. Much of this demand is driven by

industrial green initiatives, coupled with a general move to portable equipment in medical and other specialized fields.

Dedicated charger ICs can't keep pace with the current explosion in application diversity. The growing variety of battery setups is simply too extensive, ranging from kilowatt-powered indoor forklifts and isolated medical equipment to micropower energy harvesting industrial sensors. Many applications have unique requirements for optimal energy storage, which cannot be met by existing charger ICs.

For example, there are no dedicated charger ICs on the market that can charge battery stacks with 30V or higher float voltage, provide 10A charging current, and support efficient charging in a buck-boost, boost or flyback topology. As a result, designers have turned to

(continued on page 4)



The LTC[®]4000 takes on battery charger jobs that dedicated charger ICs can't handle. It pairs with just about any DC/DC converter to produce a complete, feature-rich battery charger solution—forget cobbling together discrete components.

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EE TIMES/EDN PRESENT AWARDS

At the annual ACE Awards presentation in March, the editors of *EE Times* and *EDN* magazines presented Linear Technology the Power product ACE award for the LTC6803 battery stack monitor for hybrid/electric vehicles. The ACE Awards showcase the best in today's electronics industry, the hottest products, and celebrate the promise of talent and innovation.

The LTC6803 is a second-generation high voltage battery monitor for hybrid/electric vehicles (HEVs), electric vehicles (EVs) and other high voltage, high performance battery systems. The product is a complete battery-measuring IC that includes a 12-bit ADC, a precision voltage reference, a high voltage input multiplexer and a serial interface. Each LTC6803 can measure up to 12 individual battery cells in series. The device's proprietary design enables multiple LTC6803s to be stacked in series without opto-couplers or isolators, permitting precision voltage monitoring of every cell in long strings of series-connected batteries. The LTC6803 offers an extended cell measurement range from $-300mV$ to $5V$, enabling the LTC6803 to monitor a wide range of battery chemistries, as well as supercapacitors. It ensures accurate, safe, reliable and error-free operation in harsh automotive environments.

Also presented at the ACE Awards was the first award in a new category, the Jim Williams Contributor of the Year Award (see sidebar). This new, annual award was presented by the editors of *EDN* and *EE Times* to honor a contributor of the year to the electronics industry. This initial award for 2012 was presented to Jim Williams, in his memory, to show appreciation for his many contributions over the years that stand as examples of how to communicate, educate and mentor a community. The award was accepted by Jim's wife, Siu Williams, along with his friend and colleague of many years, Linear CTO Bob Dobkin. Jim Williams served as Staff Scientist at Linear for nearly thirty years, and was a prolific inventor, writer and mentor, both within Linear and in the broader electronics community.

EE TIMES CHINA PRESENTS ACE AWARD

Based on voting by electronic design engineers, Linear's LTC4000 high voltage controller and power manager was selected by *EE Times China* for a 2012 China ACE Award in the Power Management category. This unique device converts virtually any externally compensated DC/DC power supply into a full-featured battery charger. The LTC4000 is capable of driving typical DC/DC converter topologies, including buck, boost, buck-boost, SEPIC and flyback. The device offers precision input and charge current regulation and operates across a wide 3V to 60V input and output voltage range, compatible with a variety of different input voltage sources, battery stacks and chemistries. Applications include high power battery charger systems, high performance portable instruments, battery backup systems, industrial battery-equipped devices and notebook/subnotebook computers.

CONFERENCES & EVENTS

IDTechEx Energy Harvesting & Storage Europe 2012, Estrel Hotel and Convention Centre, Berlin, Germany, May 15–16, Booth 3—Linear will showcase its energy harvesting products, along with its Dust Networks wireless sensor networking products. Joy Weiss, President of Linear Technology's Dust Networks product group, will present "Low Power Wireless Sensor Networks Made Practical" at the conference. More at www.idtechex.com/energy-harvesting-europe/eh.asp

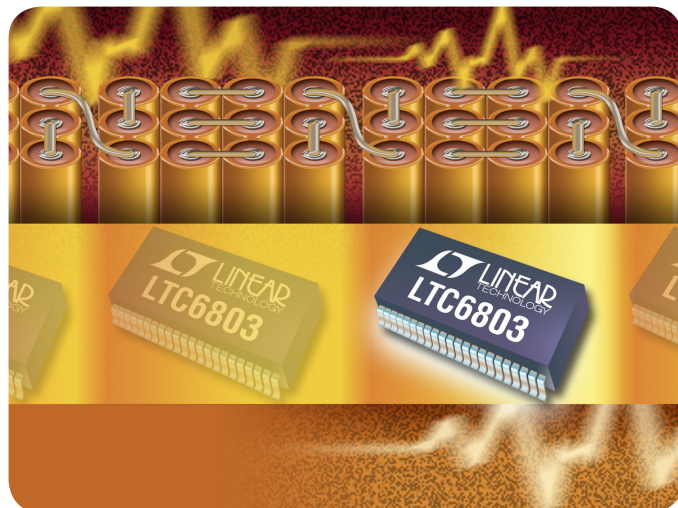
Sensors Expo & Conference, Donald E. Stephens Convention Center, Rosemont, IL, June 6-7, Booths 1020 & 1022—Linear will exhibit energy harvesting and Dust Networks wireless sensor networking products. More info at www.sensorsmag.com/sensors-expo

COMPUTER HISTORY MUSEUM EXTENDS "ANALOG LIFE" EXHIBIT

The Computer History Museum in Mountain View, California has just announced that, due to significant interest, they have decided to extend through September 15 the exhibit, "An Analog Life: Remembering Jim Williams." The centerpiece of the exhibit is the engineering workbench of Jim Williams, who was Staff Scientist at Linear Technology until his untimely death in June of last year. The museum painstakingly transported Williams' bench from his lab at Linear to the museum, where visitors can now view the bench as well as a video discussing Jim's many contributions to the world of analog technology. For more information on the exhibit, visit www.computer-history.org/highlights/analoglife/ ■

BATTERY STACK MONITORS FOR HYBRID AND ELECTRIC VEHICLES

At the annual ACE Awards presentation in March, the editors of *EE Times* and *EDN* magazines presented Linear Technology the Power products ACE Award for the LTC6803 battery stack monitor for hybrid/electric vehicles. The LTC6803 is a second generation high voltage battery monitor for hybrid/electric vehicle (HEVs), electric vehicles (EVs) and other high voltage, high performance battery systems.



Jim Williams Honored

INSPIRING, EXPLAINING, DESIGNING: JIM WILLIAMS AND ANALOG CIRCUITS*

This is a new category for the ACE Awards and was conceived a means to recognize the accomplishments of the people behind the extraordinary contributions to *EDN* and *EE Times* over the past year. Their work has broadened our understanding of the rapid advances in engineering and design, while inspiring countless engineers to reach ever higher.

It is with this in mind that the inaugural Award goes, posthumously, to Jim Williams, the consummate contributor, both in the specific content as well as in the spirit in which it was given.

At a high level, Jim was a superb analog circuit designer, one of the best. But behind his knowledge of analog circuit behavior was his ability and desire to explain these circuits and to inspire others with the marvels analog circuits could perform. For Jim, circuit design was a form of art. His first article ran in *EDN* in 1975, and his articles immediately became a source of information and inspiration for circuit design engineers, continuing through 2011 with his last two articles appearing after his death in June.

Did you know there's a popular blog called "Reading Jim Williams"?¹ Jim's friend Dr. Kent Lundberg started this blog as a tribute to Jim's 62 application notes for Linear Technology. Kent is reading each one and commenting on Jim's circuit design decisions, as well

as including Jim's "remarkable quotes." For most of us, when we think of "app note" we tend to think "company commercial." Jim seemed to approach all of his writings, both his company app notes as well as his many contributed articles for *EDN*, as teaching moments. He ended one of his app notes with a paraphrase of Einstein, "everything should be as simple as possible, but not too simple."

As *EDN* editor Paul Rako said of Jim's writing,² "[His] articles always stressed understanding. Jim did not condescend and write down to us. He never tried to impress you with his math or his intellect. He didn't make things complicated so you would think he was smart. He made things look simple. That is why he was brilliant. Anyone can learn a bunch of jargon and a few tricks and secrets and try to act smarter than you. Jim was the exact opposite. He took the trouble to describe the basic principles of what was going on. Then he showed you how to achieve the goals your designs needed to achieve."

That is why Jim is the first winner of the Contributor of the Year Award, and that is also why it has been renamed the, "*EETimes/EDN: Jim Williams Memorial 'Contributor of the Year' Award.*" Jim will forever be an example of what contributing to the engineering community is all about.

Notes

* This article is courtesy of *EDN* magazine.

¹ <http://readingjimwilliams.blogspot.com>

² http://www.edn.com/article/518496-Analog_guru_Jim_Williams_dies_after_stroke.php

The LTC4000 battery charger fills the gap between applications supported by easy-to-use dedicated charger ICs and those that would otherwise require complex discrete solutions. The LTC4000 uses a 2-IC model to bring single-IC simplicity to a wide range of charger solutions.

(LTC4000, continued from page 1)

relatively cumbersome discrete component solutions, essentially returning to the pre-charger-IC dark ages. Although discrete solutions can satisfy many charger requirements, they cannot match the ease-of-use and compact nature of dedicated charger ICs. Designers demand a solution that retains the simplicity of a dedicated charger IC with the versatility of discrete component solutions.

Linear's LTC4000 battery charger fills the gap between applications supported by easy-to-use dedicated charger ICs and those that would otherwise require complex discrete solutions. The LTC4000 retains the simplicity of a dedicated single-IC charger, but uses a 2-IC model to match the applications versatility of discrete solutions. It can be paired with any DC/DC or AC/DC converter topology, including but not limited to buck, boost, buck-boost, SEPIC and flyback.

The LTC4000's wide input voltage range (3V–60V) and virtually unlimited current capability produces efficient, high performance, full-featured battery chargers that rival the performance of dedicated charger ICs. Figure 1 shows a typical application: the LTC4000 paired with the LTC3786 to create a 5A, 5-cell Li-ion battery charger.

FEATURE SUMMARY

The LTC4000 converts virtually any Linear Technology externally compensated DC/DC power supply into a battery charger featuring:

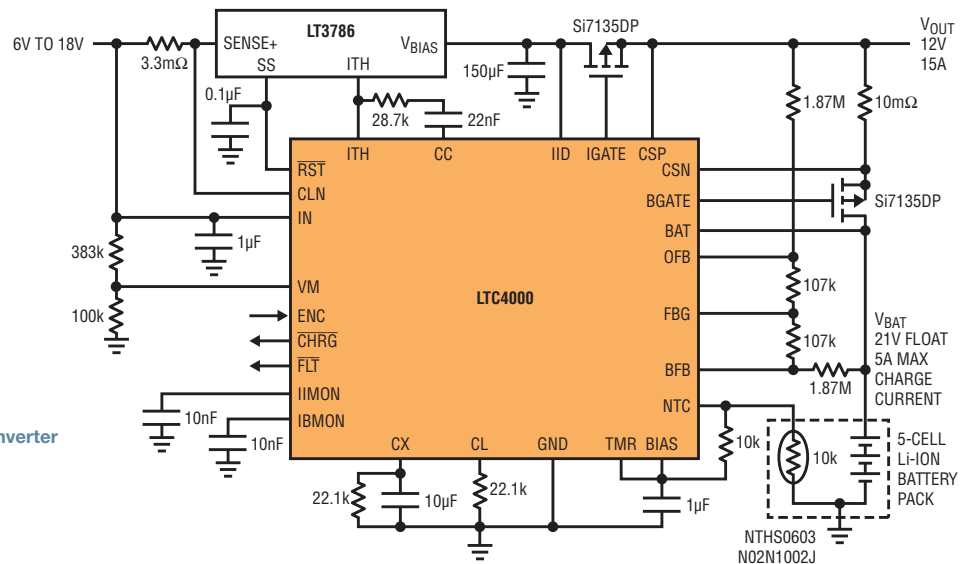
- wide input and output voltage range of 3V to 60V
- accurate ($\pm 0.25\%$) resistor programmable battery float voltage
- pin-selectable timer or current termination
- temperature qualified charging using an NTC thermistor
- automatic recharge
- C/10 trickle charge for deeply discharged cells
- bad battery detection and status indicator outputs
- precision current sense enables low sense voltages in high current applications

The LTC4000 also includes intelligent PowerPath™ control via low loss external PFETs. One external PFET is used to prevent reverse current from the battery or system output going back to the input. Another PFET is used to control battery charging and discharging.

In this case, the low loss nature of the PFETs is crucial for systems requiring high charge current for high capacity batteries. This second PFET also facilitates an instant-on feature that provides immediate downstream system power even when connected to a heavily discharged or short faulted battery.

PowerPath control preferentially provides power to the system load. When input power is limited, the system load is always prioritized over charging. Furthermore, if the system load requires more power than the input can support, the battery

Figure 1. 6V to 21V at 5A boost converter charger for five Li-ion cells



At the core of the LTC4000 are four internal error amplifiers, whose outputs combine to drive the external DC/DC converter control loop. In this way, it can control almost any battery charging cycle, regardless of chemistry and float voltage.

is used to provide additional power to satisfy the total system output load.

The LTC4000 is available in low profile 28-lead 4mm × 5mm QFN and SSOP packages.

FOUR CONTROL LOOPS KEEP THE BATTERY CHARGED AND OUTPUT IN REGULATION

At the core of the LTC4000 are four internal error amplifiers, whose outputs combine to drive the external DC/DC converter control loop. In this way, it can control almost any battery charging cycle, regardless of chemistry and float voltage.

Figure 2 shows a simplified block diagram of the four internal error amplifiers (A4-A7). Each of the four input transconductance amplifiers is responsible for a different regulation loop: input current, charge current, battery float voltage and output voltage. The output transconductance amplifier (A10) ensures that the loop requiring the lowest voltage on the ITH pin for regulation controls the external DC/DC converter.

The input current regulation loop (A4 in Figure 2) prevents the input current from exceeding the resistor programmable input current limit. This input current limit prevents the overall system from overloading the source, allowing for more predictable and reliable behavior. Furthermore, this adds an extra layer of protection to extend the life of the power components of the DC/DC converter and any sources that lack overcurrent protection.

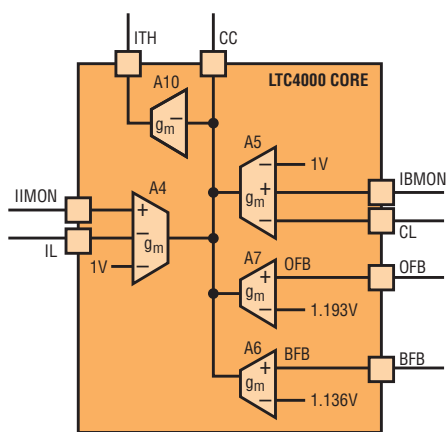


Figure 2. Simplified block diagram of the LTC4000 core—four error amplifiers with combined output

The other current regulation loop is the charge current regulation loop (A5). This loop controls the constant current phase of the charging cycle, ensuring that the charge current sensed through the charge current sense resistor does not exceed the resistor programmable full charge current.

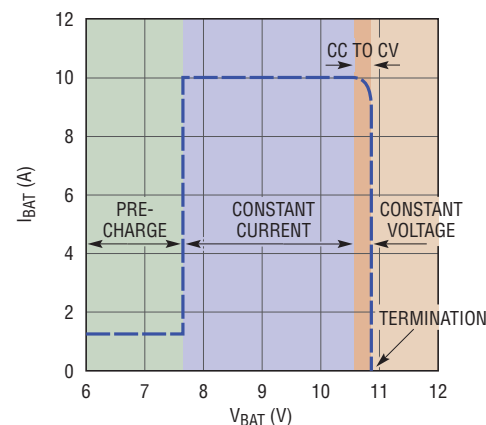
The constant current regulation loop controls charging until the battery reaches its float voltage. At this point, the battery voltage regulation loop (A6) takes over, the charge current begins to drop and the charger enters the constant voltage phase of the charging cycle.

The float voltage is programmed using the feedback resistor divider between the BAT pin and the FBG pin. The FBG pin disconnects the resistor divider load when V_{IN} is not present. This ensures that the float voltage resistor divider does not

consume battery current when the battery (connected to BAT pin) is the only available power source. For $V_{IN} \geq 3.0V$, the typical resistance from the FBG pin to GND is 100Ω .

When the battery is not being charged, nor supplying power to the load, the external PFET connected to the battery is turned off (Figure 4). In this scenario, the output voltage regulation loop (A7 in Figure 2) controls the external DC/DC converter. The output voltage regulation loop is similar to the battery voltage regulation loop. This loop regulates the voltage at the CSP pin based on the feedback resistor divider between the CSP pin and the FBG pin. This output voltage regulation is important to ensure that the system output voltage remains well regulated when the battery is disconnected from the load.

Figure 3. Battery charging phases for 3 series LiFePO₄ cells with the circuit shown in Figure 1



The LTC4000's PowerPath control feature consists of two functions: the input ideal diode control, providing a low loss ideal diode function from DC/DC converter to the output; and the battery PowerPath control, providing a smart PowerPath route between the system output and the battery.

POWERPATH CONTROL

The other important feature of the LTC4000 is PowerPath control, which consists of two functions: the input ideal diode control, providing a low loss ideal diode function from DC/DC converter to the output; and the battery PowerPath control, providing a smart PowerPath route between the system output and the battery.

The input ideal diode feature provides low loss conduction from the output of the DC/DC converter (IID pin—anode) to the system output (CSP pin—cathode). Low loss conduction is important for efficiency and heat management in high current systems. This feature also prevents reverse current from the system output to the DC/DC converter. Such reverse current causes unnecessary drain on the battery and in some cases may result in undesirable DC/DC converter behavior. This ideal diode behavior is achieved by controlling an external PFET (M1) whose gate is connected to the IGATE pin (Figure 4).

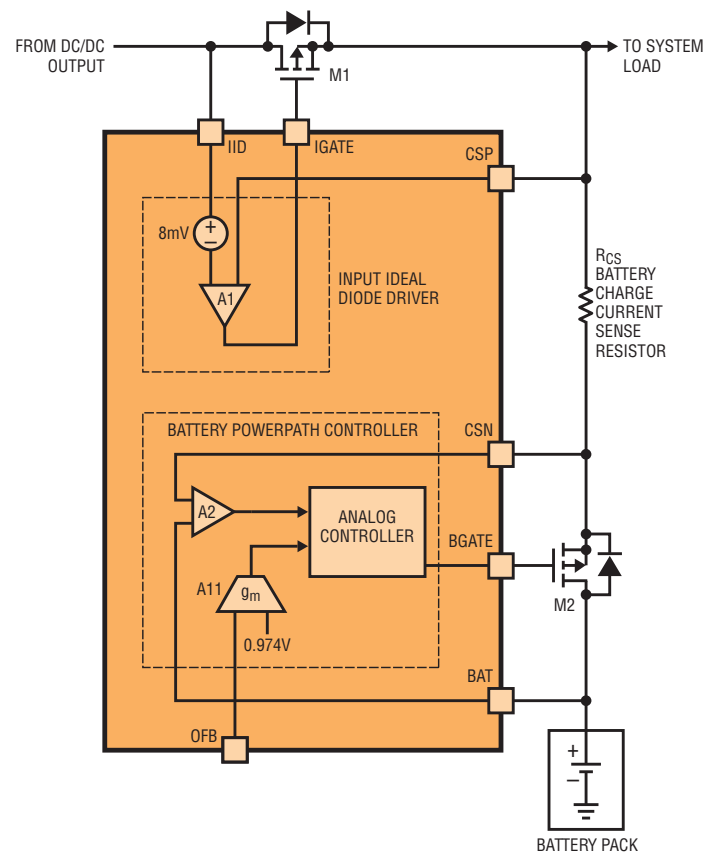
The PowerPath controller of the external PFET connected to the BGATE pin is similar to the input ideal diode controller driving the IGATE pin (Figure 4). When not charging, the PMOS behaves as an ideal diode between the BAT (anode) and the CSN (cathode) pins. The ideal diode behavior allows the battery to provide current to the system load when the DC/DC output is in current limit or the DC/DC is slow to react to an immediate load increase at the output. This feature ensures a stable system output voltage.

In addition to the ideal diode behavior, BGATE allows current to flow from the CSN pin to the BAT pin during charging. There are two regions of operation when current is flowing from the CSN pin to the BAT pin. The first is when charging into a heavily discharged battery (battery voltage is below the INSTANT ON threshold, $V_{BAT(INST ON)}$). In this region of operation, the controller (A11 in Figure 4) regulates the voltage at the system output to approximately 86% of the final float voltage level. This feature provides a system output voltage significantly higher than the battery voltage when charging

into a heavily discharged battery. This INSTANT ON feature allows the LTC4000 to provide sufficient voltage at the system output independent of the battery voltage.

The second region of operation occurs when the battery feedback voltage is greater than or equal to the INSTANT ON threshold. In this region, the BGATE pin is driven low to allow the PMOS to turn completely on, reducing any power dissipation due to the charge current.

Figure 4. Input ideal diode and battery PowerPath controller



The LTC4000 has broad applications versatility—it can be paired with a DC/DC converter to produce a battery charger for any battery configuration.

APPLICATIONS

The LTC4000 has broad applications versatility—it can be paired with a DC/DC converter to produce a battery charger for any battery configuration. The following applications illustrate this versatility.

High Voltage, High Current Charger

Building a complete charging system with the LTC4000 and a DC/DC converter is as easy as using a dedicated charger IC. Figure 5 shows the LTC4000 controlling an LT3845A buck converter in a charger designed for a 3S LiFePO₄ battery pack (3S refers to three cells in a series configuration). The LT3845A buck converter is selected for its simplicity and high, 60V input voltage capability.

Each of the LiFePO₄ cells has a typical float voltage of 3.6V, resulting in an overall float voltage of 10.8V. The 10.8V float voltage is set by $R_{BFB1} = 133k$ and $R_{BFB2} = 1.13M$. Once the float voltage is set, the value of R_{OFB1} and R_{OFB2} are

determined—this sets the output voltage when charging is terminated. Here, R_{OFB2} is set at 127k and R_{OFB1} at 1.15M to set the output regulation voltage at 12V.

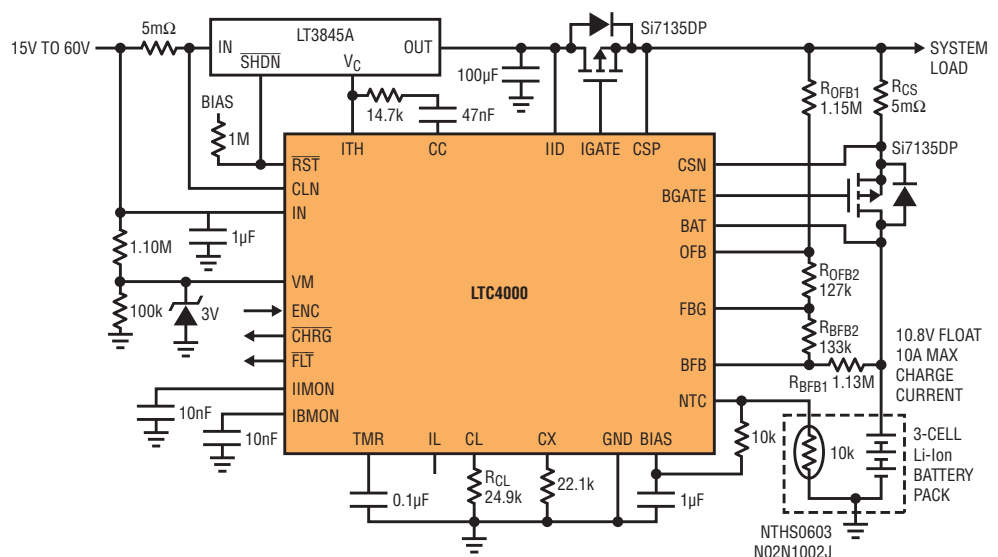
After setting the float and output voltages, set the full charge current for the battery. In this particular example, the full charge current is set to 10A using an R_{CS} value of 5m Ω and an R_{CL} value of 24.9k. The regulated sense voltage across R_{CS} should be as large as possible for the highest accuracy. However, a larger sense voltage causes R_{CS} to dissipate more power. Since the charge current regulation error amplifier has a maximum regulation level of 1V, this means that the regulated sense voltage across R_{CS} is limited to a maximum of 50mV ($=1V/20$). For a 10A charge current, the maximum power dissipation on this sense resistor is 0.5W.

Any value of R_{CL} that is larger than 20k will not affect the full charge current

level, but as long as it is less than 200k, it affects the regulated trickle charge current level. In this example, the 24.9k value is chosen to set the trickle charge current level at 1.25A. Trickle charging can occur at the beginning of a charge cycle when the voltage at the battery is less than 68% of the float voltage. This trickle charge feature is especially important for lithium-ion batteries, as they require a smaller current (typically <20% of full charge current) to safely and gradually bring the battery voltage higher before supplying them with the full charge current.

The only other regulation loop with a set point is the input current regulation loop. Using a similar method to setting R_{CS} , in this example R_{IS} is set to 5m Ω and the IL pin is left floating (internally pulled to a voltage above 1V) to set a maximum input current limit of 10A.

Figure 5. 48V to 10.8V at 10A buck converter charger for 3-series LiFePO₄ battery pack



Building a complete charging system with the LTC4000 and a DC/DC converter is nearly as easy as using a dedicated charger IC. Just a few resistors and capacitors are needed to set the float voltage, charge current, input current limit and charge termination (current level or timer termination).

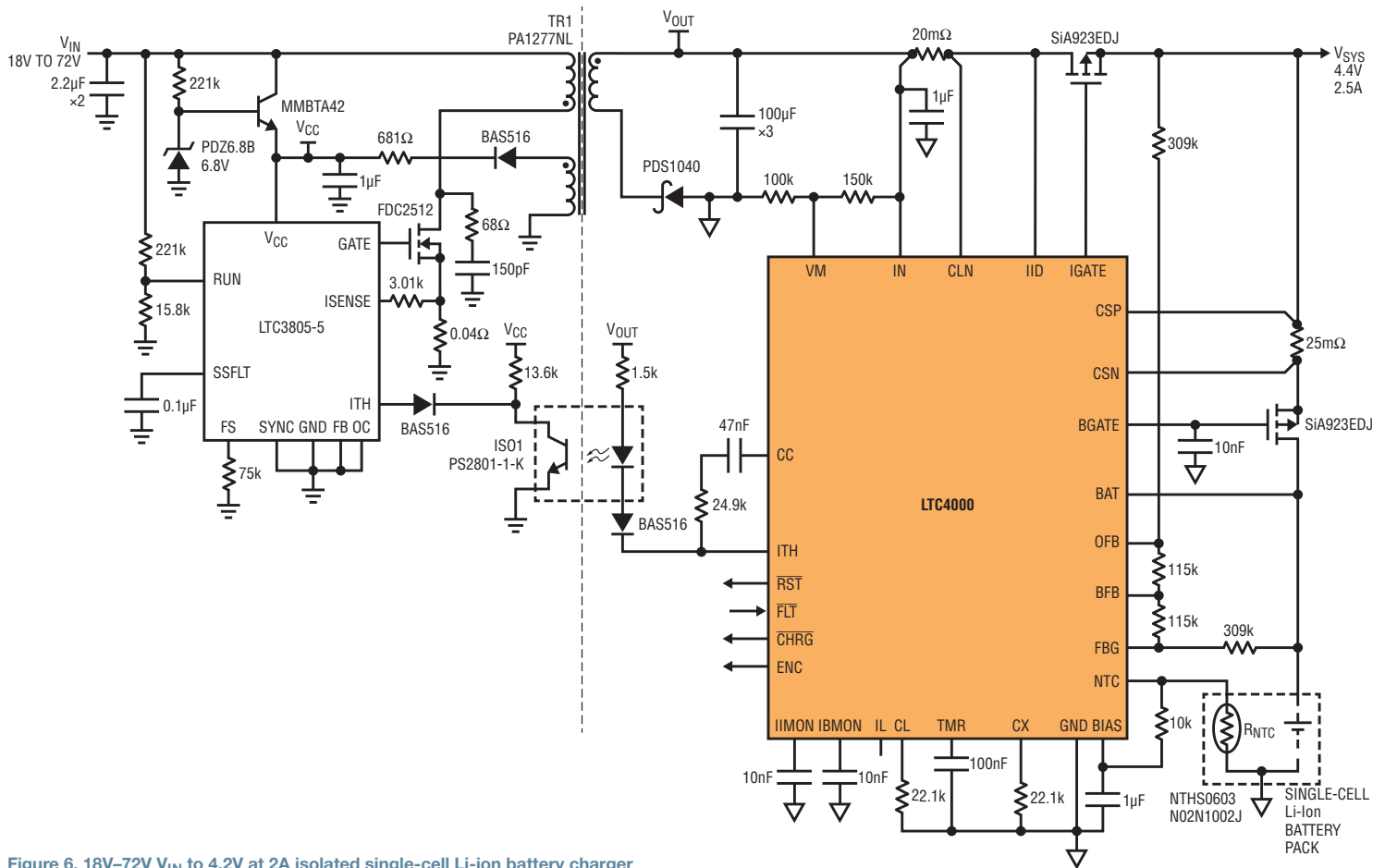


Figure 6. 18V–72V V_{IN} to 4.2V at 2A isolated single-cell Li-ion battery charger

The four simple steps described here are sufficient to customize an LTC4000 charging solution to charge many generic battery configurations. To customize the solution further, a few other component values can be chosen to program the charge termination algorithm. LTC4000 offers both timer termination and charge current level termination.

With charge current level termination, the charging process is terminated when the charge current level drops

(in the constant voltage mode) to the level programmed at the CX pin.

With timer termination, the charging process continues in the constant voltage mode until a time period programmed with a capacitor on the TMR pin expires. In this example, the LTC4000 is set up with a timer termination period of 2.9h using a 0.1 μ F capacitor connected to the TMR pin. The 22.1k resistor connected to the CX pin sets a 1A charge current level,

at which point the charge status indicator pin (\overline{CHRG}) assumes a high-Z state.

LTC4000 offers temperature-qualified charging via the NTC pin. A negative temperature coefficient (NTC) resistor, thermally coupled to the battery, is connected in a resistor divider network between the BIAS, NTC and GND pins. This NTC resistor allows charging to be paused when the battery temperature is outside a particular range. In this example, the battery temperature range is set between

With the LTC4000, the task of designing an isolated charger is reduced to selecting the appropriate isolated converter, choosing PFETs and determining the values of some resistors and capacitors.

-1.5°C to 41.5°C. Temperature-qualified charging protects batteries from hazardous charging conditions, such as extreme hot or cold, which can potentially damage the batteries and shorten their life.

The only remaining components that may need to be customized are the series resistor and capacitor compensation network between the CC and ITH pins, as well as the resistor divider network connected to the VM pin. As starting values, the compensation network can be set to a 10k resistor in series with a 100nF capacitor. It can then be optimized by looking at the time domain response to small signal perturbation for each of the four regulation loops. In this example, the final optimized values are 14.7k and 47nF.

The VM pin is an input to a comparator with a threshold set at 1.193V. When the voltage at this pin is below the threshold, the $\overline{\text{RST}}$ pin is driven low. When it is above the threshold, the $\overline{\text{RST}}$ pin assumes a high-Z state. By connecting the $\overline{\text{RST}}$ pin to the DC/DC RUN or $\overline{\text{SHDN}}$ pin, this comparator provides a simple and accurate UVLO (undervoltage lockout) signal that can be used to start the external converter. In this example, the input UVLO level is set to 14.3V. Setting a minimum voltage ensures that the input to the converter is within its operating range before it is allowed to start up. This in turn allows for a more consistent and predictable power-up behavior of the overall charging solution.

A discrete solution with similar features to the 10A/3-cell LiFePO₄ battery charger

would have required at least two high side current sense amplifiers, four operational amplifiers as well as two high voltage ideal diode controllers. Each of these would need to be tested and qualified separately to ensure compatibility of their specifications such as common mode range, speed and input supply voltage range. Furthermore a discrete solution would require a microprocessor to handle charging algorithm.

As shown in the example, the LTC4000 eliminates these components and the need to test them. Design is simplified to choosing an appropriate DC/DC converter for the voltage and power requirement, and a few passive components—mostly resistors to set the important charger system parameters.

Isolated Battery Charger

Figure 6 shows the LTC4000 paired with the LTC3805-5 to build an isolated single cell Li-ion charger with 2A charging current. This application shows the power of the LTC4000 to create a unique battery charger solution using readily available DC/DC converters of practically any topology. This simple LTC4000-based solution eliminates the need to design a complex discrete solution.

With the LTC4000, the task of designing an isolated charger is reduced to selecting the appropriate isolated converter, choosing PFETs and determining the values of some resistors and capacitors. For the application shown in Figure 6, we use the LTC3805-5 isolated flyback converter with a high input voltage

capability. Two relatively low voltage PFETs are used for PowerPath control since only voltages less than 6V appear on the secondary side. The only unique connection in this particular application is the use of the opto-coupler to deliver the ITH feedback signal from the LTC4000 on the secondary side to the ITH pin of the LTC3805-5 on the primary side.

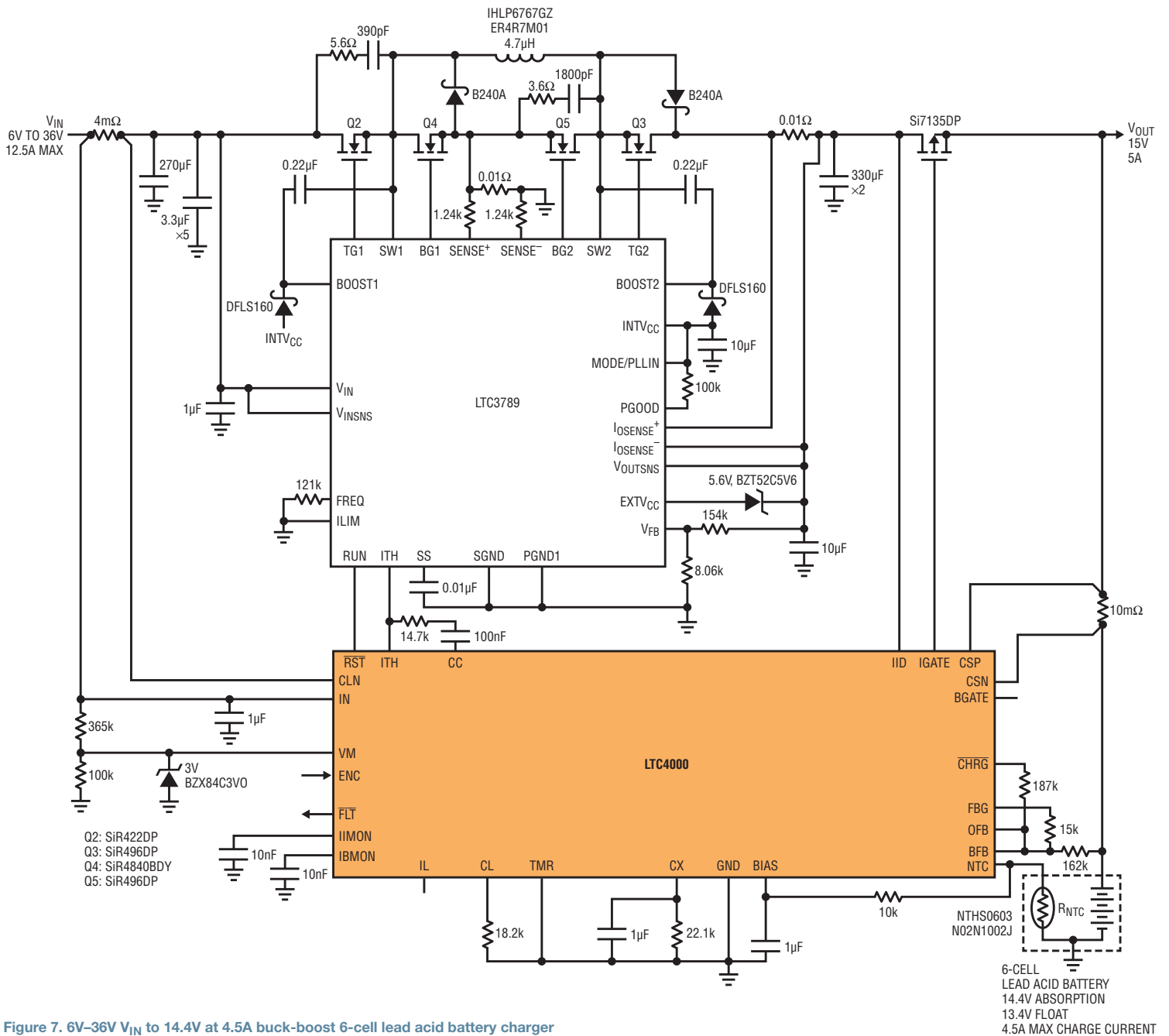
The resulting charger is capable of charging a single cell Li-ion battery (4.2V float) at 2A in an isolated environment. The system has a wide input range of 18V to 72V with a 2.9h charging termination time as well as a 220mA trickle charge current.

The overall solution limits the total system output current to 2.5A in a controlled manner. By preventing current overload of the primary, the input current limit provides an extra level of protection for the power components and provides greater overall system reliability.

High Voltage Buck-Boost Battery Charger

Another unique, but commonly requested battery charger solution is a buck-boost battery charger. Again, there is no dedicated IC solution currently available. Figure 7 shows the LTC4000 paired with the LTC3789 to create a full-featured buck-boost 12V lead acid battery charger.

The buck-boost topology allows the battery to be charged from a voltage lower or higher than its float voltage, easing the battery and input voltage choice in the system design. The number of battery cells in series can then be optimized for other system parameters or perhaps the



pricing and availability of such battery packs. Similarly, the flexibility and simplicity of programming the charge current by setting the values of two resistors (R_{CS} and R_{CL}) also further ease the battery capacity choice in the system design.

The overall charging solution of the LTC4000 and LTC3789 pairing shown above is capable of charging a 12V lead acid battery (14.4V absorption and 13.4V float)

at 4.5A from an input source voltage that can range from 6V to 36V. The system is programmed with an input current limit of 12.5A, allowing load sharing between the input and the battery if a system load demands more than 12.5A from the input. This feature is especially important at the lower end of the source voltage range, where input current increases rapidly to meet increasing output power demands.

The charger solution shown here provides no termination, allowing continuous constant voltage charging at the final float voltage of 13.4V. Connecting the \overline{CHRG} pin to the BFB pin through the 187k resistor implements a 2-stage charging algorithm (absorption and float) common for lead acid batteries. The overall charging algorithm first charges to an absorption level of 14.4V until the charge current drops to 500mA. At this point

The LTC4000's wide input voltage range (3V–60V) and virtually unlimited current capability allow it to be combined with just about any power converter to form an efficient and high performance full-featured battery charger typically occupying less than 3.6cm².

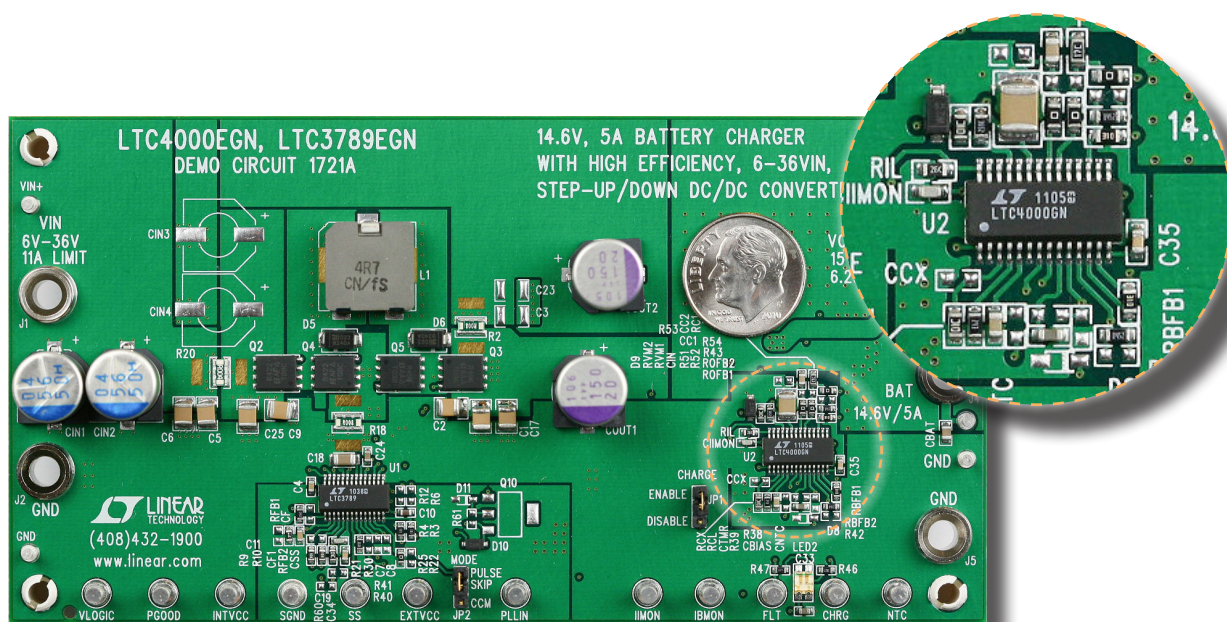


Figure 8. Demonstration circuit showing a complete battery charger formed by pairing the LTC4000 and LTC3789

the $\overline{\text{CHRG}}$ pin assumes a high-Z state, changing the feedback resistor network connected to the BFB pin. In this way the battery charger enters final float constant voltage mode with a final float target of 13.4V. If the battery drops below 13.1V (recharge threshold), the $\overline{\text{CHRG}}$ pin turns low impedance again and the battery charger is again set to charge the battery to the absorption level of 14.4V.

Because this is a buck-boost charger setup, a battery stack with any float voltage between 3V to 36V can be supported with a simple adjustment of the resistor dividers and the PFET choice. Similar changes allow the battery charge current to be programmed from a few milliamps to tens of amps.

Figure 8 shows a demo board of the LTC4000 and LTC3789 pairing. Note that the required space occupied by the LTC4000 and its passive components is small, occupying an area less than 3.6cm². This allows for a compact charging solution for virtually any battery.

CONCLUSION

Increases in demand for alternative energy sources, coupled with an explosion in portable industrial and medical applications, have resulted in the need for a wide variety of rechargeable-battery-powered systems. Many of these systems have requirements that dedicated battery charger ICs—geared to specific battery chemistries/configurations and input/output voltages—cannot meet. Discrete solutions can satisfy the needs of these systems, but

such solutions are more difficult to implement, occupy considerably more PC board space and require significantly more design time than dedicated IC solutions.

The LTC4000 battery charger fills the gap between applications supported by easy-to-use dedicated charger ICs and those supported by more complex discrete solutions. The LTC4000's wide input voltage range (3V–60V) and virtually unlimited current capability enable pairing with any DC/DC or AC/DC converter topology, including buck, boost, buck-boost, SEPIC and flyback. When paired with the right power converter, the LTC4000 forms an efficient and high performance full-featured battery charger typically occupying less than 3.6cm². ■

Dual Output Monolithic Supply with Integrated 3A Power Switches and Operation to 2.5MHz in a 7mm × 4mm DFN

Mehdi Alimadadi

There is no shortage of ICs to help designers build switching DC/DC switching power supplies. Choices range from versatile controllers requiring a number of external components, to fully integrated, monolithic solutions that benefit from a low external parts count to minimize overall solution size. The LT8582 dual-channel converter offers the versatility of a controller IC in a complete, monolithic dual-channel solution.

The LT8582 integrates two complete, independent converters, including high power 3A, 42V power switches. It can operate up to 2.5MHz, and with its tiny 7mm × 4mm DFN package, fits into the smallest spaces. It includes several features that give designers the ability to optimize the converter, such as soft-start, single-pin feedback, single-resistor frequency setting, master/slave power switches, separate maximum commanded and fault current limits, external PFET control for output or input disconnect, FAULT protection, PG pin for power supply sequencing, and CLKOUT signal for out-of-phase synchronizing and die temperature monitoring.

FLEXIBILITY AND SIMPLICITY

Each channel of the LT8582 can be independently configured in a boost, SEPIC, inverting or flyback topology. Figure 1 shows a few common combinations that could be used in commercial or industrial applications, such as local power supplies, LCD/E-ink displays, and engine control units (ECU).

The LT8582 is rugged, with solid performance. Even with all of its advanced features, it is easy to use—designers can choose to apply features to fit a variety of applications. Its wide input operating voltage of 2.5V to 22V, and

the 3A, 42V switches on each channel add to the versatility of the chip.

HIGH SWITCHING FREQUENCY

The LT8582's constant frequency oscillator, programmable from 200kHz to 2.5MHz using one resistor, employs frequency foldback to better control the inductor current during converter start-up. This wide frequency range allows the switching noise to be placed so that sensitive frequencies are avoided. While lower switching frequencies offer better efficiency, higher switching frequencies help reduce the size of passive components. The switching frequency can be synchronized to an external clock by connecting a clock signal to the SYNC pin. Grounding the SYNC pin enables the internal oscillator.

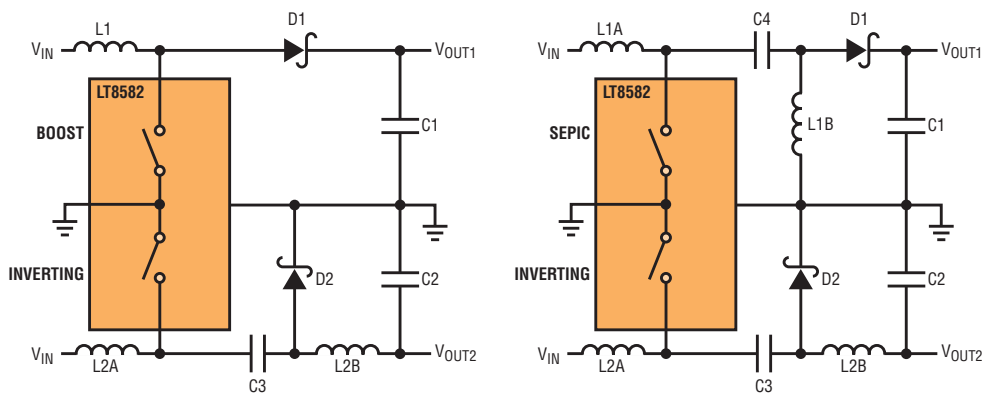
CLKOUT PIN, SYNCHRONIZING AND TEMPERATURE MONITORING

The LT8582 has two CLKOUT signals, one for each channel. CLKOUT for channel 1 has a fixed 50% duty cycle and is 180° out of phase with the power switch. This can be used to synchronize channel 2 antiphase to channel 1, reducing the converter's overall input current ripple. The CLKOUT signal for channel 2 features a duty cycle that varies with die temperature (3% per 10°C) and is in phase with the power switch. This can be used for monitoring the die temperature.

FAULT PROTECTION AND THE GATE PIN

The LT8582 has internal circuitry to detect switch overcurrent, V_{IN} overvoltage and die overtemperature ($> \sim 165^{\circ}\text{C}$). The chip's

Figure 1. Common dual power topology combinations



The LT8582 integrates two complete, independent converters, including high power 3A, 42V power switches. It can operate up to 2.5MHz, and with its tiny 7mm × 4mm DFN package, fits into the smallest spaces.

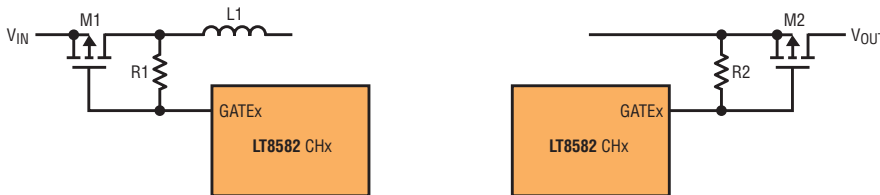


Figure 2. Controlling external PFETs for input disconnect (left) and output disconnect (right)

GATE pin is a pull-down current source and can control an external PFET during the fault. The external PFET can disconnect the input or the output, as shown in Figure 2.

When a fault is detected, the LT8582 stops switching and the GATE pin becomes high impedance. The external PFET is then turned off by the external R_{GATE} resistor. The R_{GATE} resistor must be selected so that sufficient V_{GS} is available for the PFET to fully enhance into triode under normal operation. When the fault is removed, the LT8582 enters a timeout period, allowing components to cool down before a restart sequence begins.

Reverse input voltage protection and output short circuit protection can be achieved, as shown in Figure 3, using two external PFETs and the GATE pin. At start-up, the channel's supply voltage is provided through the body diode of M2 while M1 keeps the power path disconnected. When the GATE pin is pulled down, both PFETs turn on. If the input voltage is reversed, the channel and the power path are disconnected from the input supply by M1. The GATE pin can be left floating when not in use.

Another use of the GATE pin is to limit the converter start-up current. During start-up, the GATE pin current increases linearly with SS pin voltage, to a maximum current of ~1mA when the SS voltage exceeds 500mV. This allows the external PFET to slowly turn on and gradually ramp up the output voltage. Together with frequency foldback and soft-start,

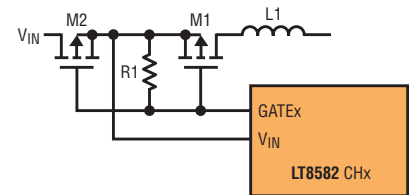


Figure 3. Reverse battery and output short protection

this feature allows converter start-up to be very smooth, even for hot-plug events.

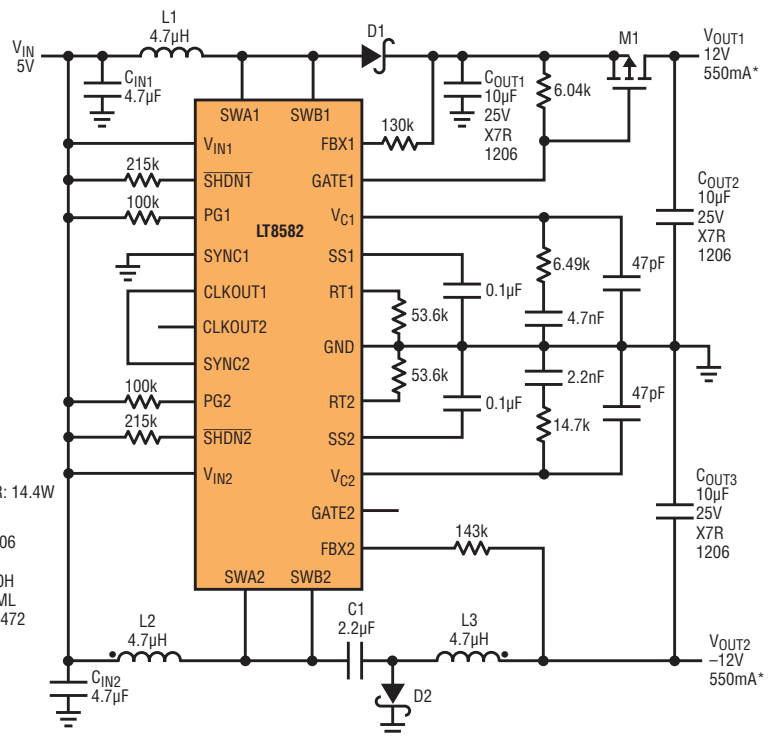
Figure 4 illustrates how the GATE pin provides short-circuit protection for a boost converter. The circuit produces ±12V output from 5V input supply by utilizing channel 1 of the chip as a boost converter and channel 2 as a dual inductor, inverting converter.

Figure 4. A 1.5MHz +5V to ±12V dual converter using one LT8582



*MAX TOTAL OUTPUT POWER: 14.4W

C_{IN1}, C_{IN2}: 4.7µF, 16V, X7R, 1206
C1: 2.2µF 25V, X7R, 1206
L1: COILCRAFT XAL6060-472ML
L2, L3: COILCRAFT MSD7342-472
M1: FAIRCHILD FDMC510P



Each channel of the LT8582 can be independently configured in a boost, SEPIC, inverting or flyback topology.

A common weak point of the boost topology is that it has a direct DC path from input to output through the inductor and diode. An output short can result in an uncontrolled increase of current through the converter, likely destroying one or more components in the DC path and the power switch if it switches during this time. The LT8582 addresses this issue by disconnecting the DC path if the part senses an overcurrent condition.

For the dual inductor inverting and SEPIC topologies, because of the series capacitor in the power path, there is no direct DC path between input and output and the external PFET is not required.

The circuit in Figure 4 is running at a high switching frequency of 1.5MHz. If thermal issues arise, using larger ground planes and better air flow helps remove extra heat.

MASTER/SLAVE POWER SWITCH

Each channel of the LT8582 incorporates a master and a slave switch, which are rated at 1.7A and 1.3A, respectively. The switches are driven in phase and only the current through the master switch is sensed by the internal current comparator. Normally, these switches are tied together; when separated, they can be used for building high voltage charge pumps, as shown in Figure 5. The charge pump

Figure 5. High voltage VFD and filament bias supplies

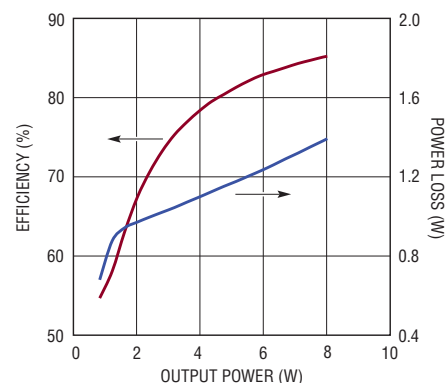
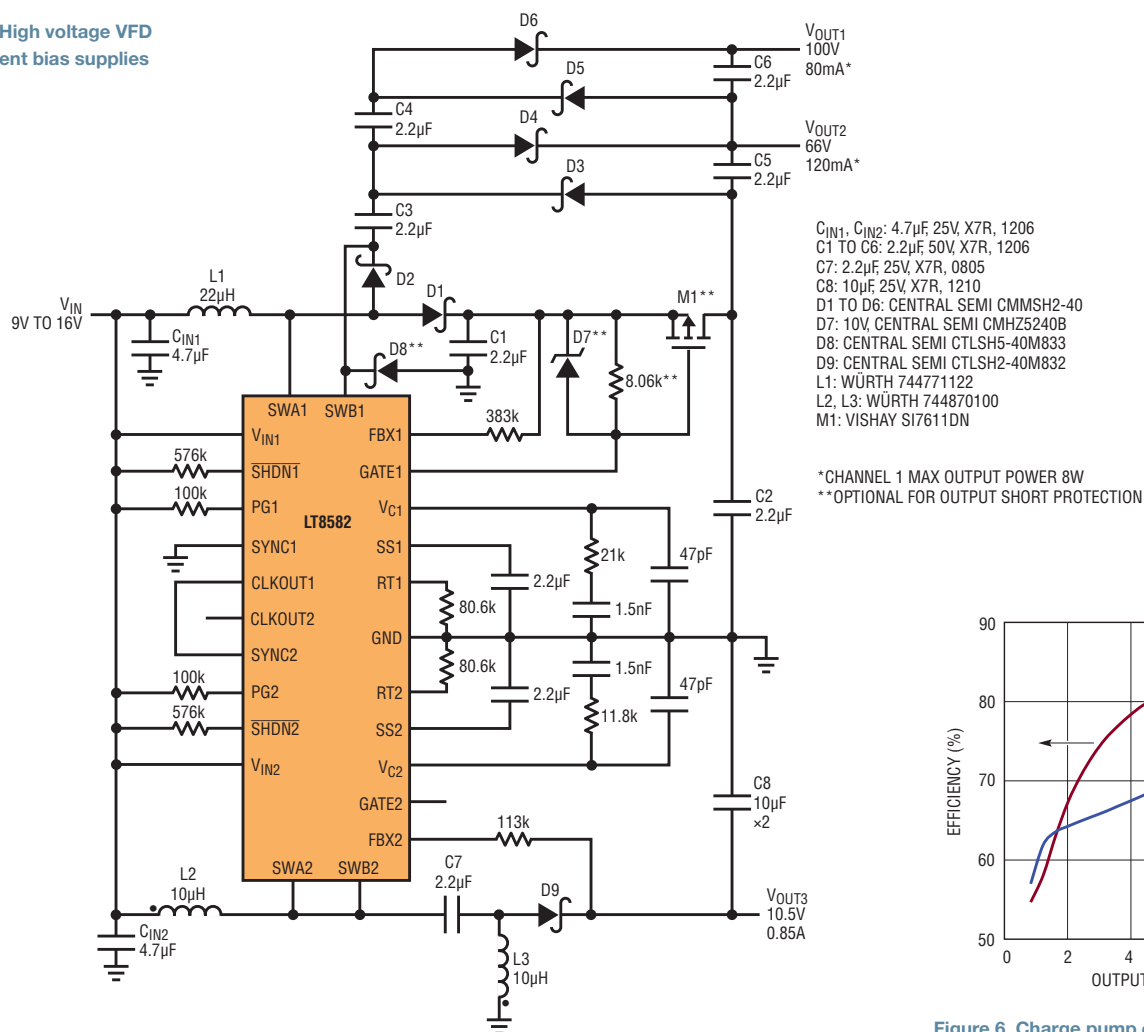
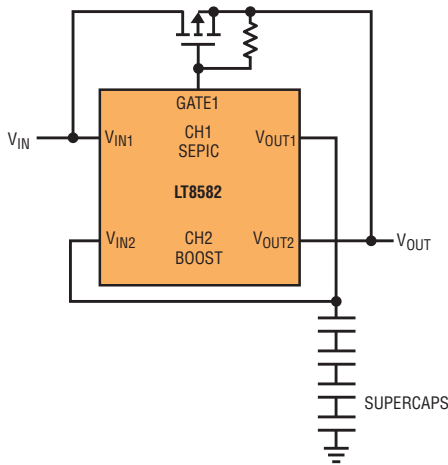


Figure 6. Charge pump efficiency vs output power

Normally, the master and slave switches of each channel are tied together; when separated, they can be used for building high voltage charge pumps. The high output voltage can be used for low current loads such as vacuum fluorescent displays (VFDs). In this case, the second channel of the LT8582 can be configured as a SEPIC converter to bias the filament of the VFD.

Figure 7. Charging/discharging supercapacitors in a backup power supply



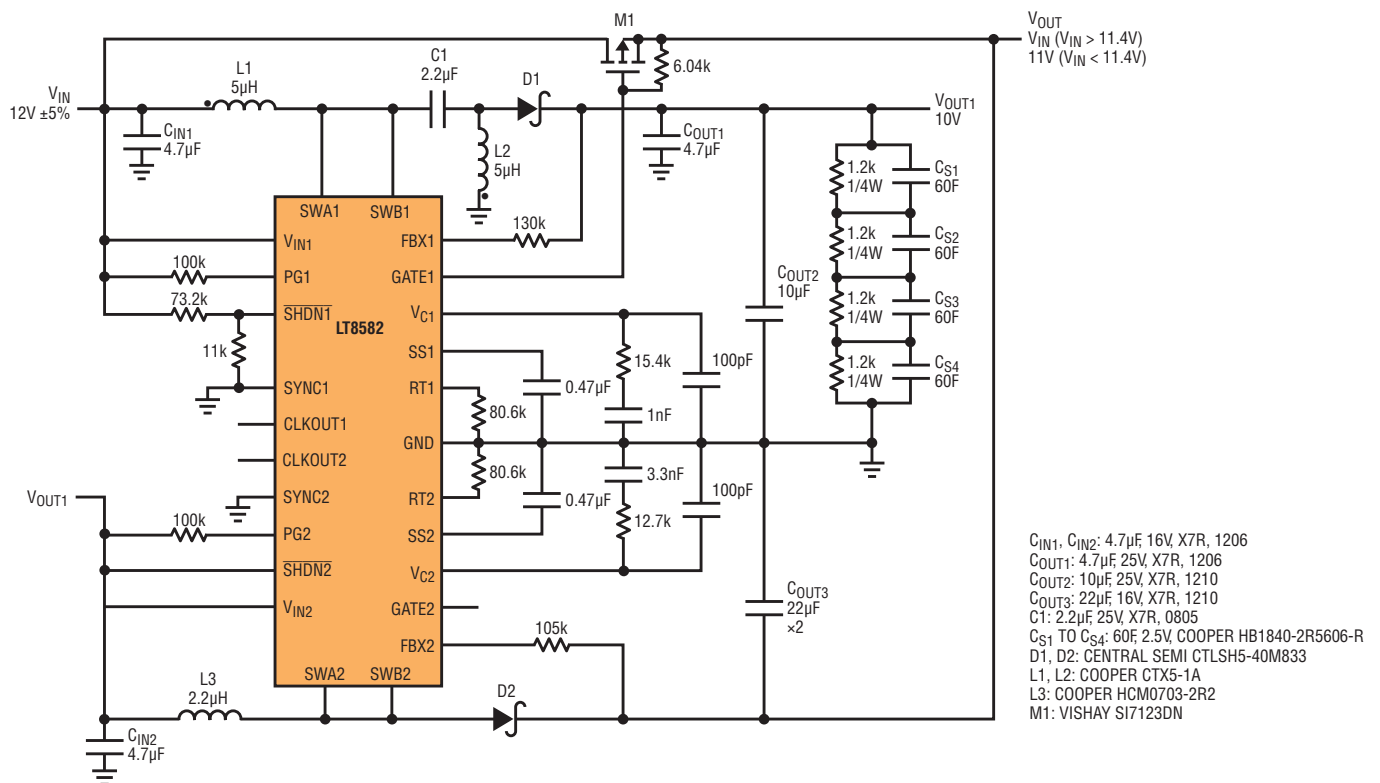
circuit generates output voltages that are higher than what the IC can tolerate.

The first stage of the charge pump circuit is based on boost topology and uses the channel's master switch. The channel's slave switch is used to drive the other charge pump stages, multiplying the output voltage of the boost stage. The benefit of this configuration is that the master switch is immune from capacitive current spikes, allowing the LT8582 to sense the inductor current distinctly. Moreover, the charge pump diodes do

not need series resistors that are typically used to limit the capacitive current spikes.

The high output voltage can be used for low current loads such as vacuum fluorescent displays (VFDs). In this case, the second channel of the LT8582 can be configured as a SEPIC converter to bias the filament of the VFD. Here, the master and slave switches of channel 2 can be tied together to increase output current. Figure 6 shows the efficiency of the charge pump circuit at various power levels.

Figure 8. Backup power supply using supercapacitors



The V_C current limit feature can be used in situations where the load voltage may be low for an extended period of time, such as when charging supercapacitors.

FAULT AND V_C CURRENT LIMITS

The LT8582 has two distinct current limits: the V_C current limit, which is the maximum current that can be commanded, and the FAULT current limit, which is the maximum current in case of converter overcurrent. The FAULT current limit is internally set higher than the V_C current limit. When the FAULT current limit is reached, the chip goes into fault mode and stops switching. However, when the V_C current limit is reached, the chip reduces the switch duty cycle, reducing the output voltage.

The V_C current limit feature can be used in situations where the load voltage may be low for an extended period of time, such as when charging supercapacitors. Figure 7 demonstrates how the V_C current limit along with the GATE pin can be used to build a backup power supply using one LT8582 and a bank of four supercapacitors.

The actual circuit is shown in Figure 8. Here, channel 1 of the LT8582 is configured as a SEPIC converter and is used to charge the supercapacitor bank when V_{IN} is

present. At this time, the GATE pin of channel 1 is enabled and the external PFET provides a path for the load current from the input to the output. Once the input supply is disconnected, channel 2 of the LT8582 which is configured as a boost converter, provides voltage to the load without any delay, while the external PFET disconnects the input from the output, preventing energy from going back into V_{IN} .

The complete backup power supply circuit is shown in Figure 8. With the component values shown, the supercapacitor bank is charged to 10V when V_{IN} is above $\sim 11.4V$. Once V_{IN} falls below $\sim 11.2V$, the circuit holds up V_{OUT} at 11V for about 90 seconds with 500mA of load current. The waveforms of interest during charging/discharging the supercapacitors are shown in Figure 9.

PG PIN AND EVENT-BASED SEQUENCING

The PG pin is an open drain active high pin that indicates the output voltage is close to regulation. For most applications

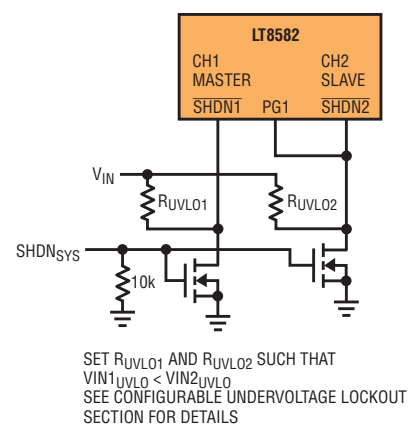


Figure 10. Sequenced power supplies

this corresponds to an output voltage 8% from the target output voltage. The \overline{SHDN} pin is used to enable/disable the channel. Driving the \overline{SHDN} pin to ground disables the channel while driving \overline{SHDN} above 1.3V enables the channel.

Figure 10 shows how these two pins can be used to turn on power supplies in sequence as may be required in systems with multiple voltage levels. When channel 1's output voltage is close to regulation, the PG pin of channel 1 releases channel 2's \overline{SHDN} pin, which enables channel 2. To ensure that the status of channel 1's PG pin is valid while it is being sensed by channel 2, channel 1 has to become active first, i.e., V_{IN1} UVLO should be set lower than V_{IN2} UVLO. To provide a global shutdown signal for the system, the $SHDN_{SYS}$ signal drives two NFETs that disable both channels when it is high.

The complete circuit diagram and start-up waveforms are presented in Figures 11 and 12.

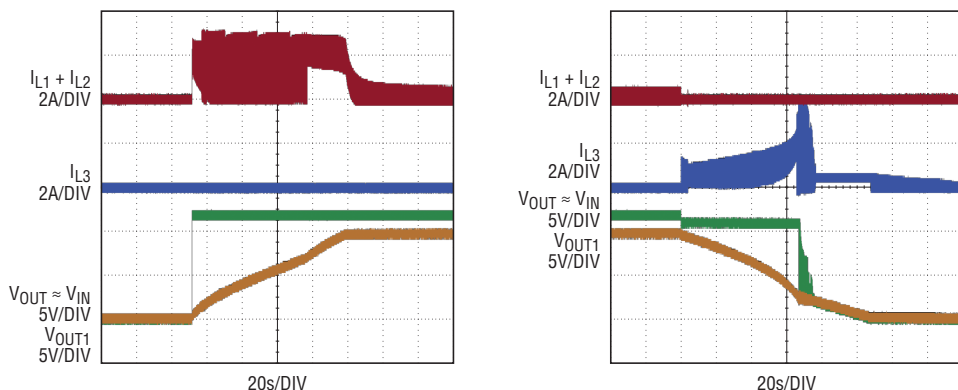


Figure 9. Waveforms of interest during charging (left) and discharging (right) the supercapacitors

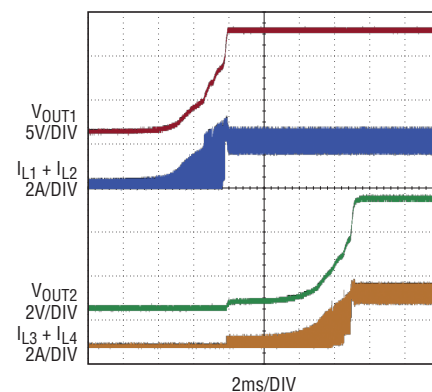
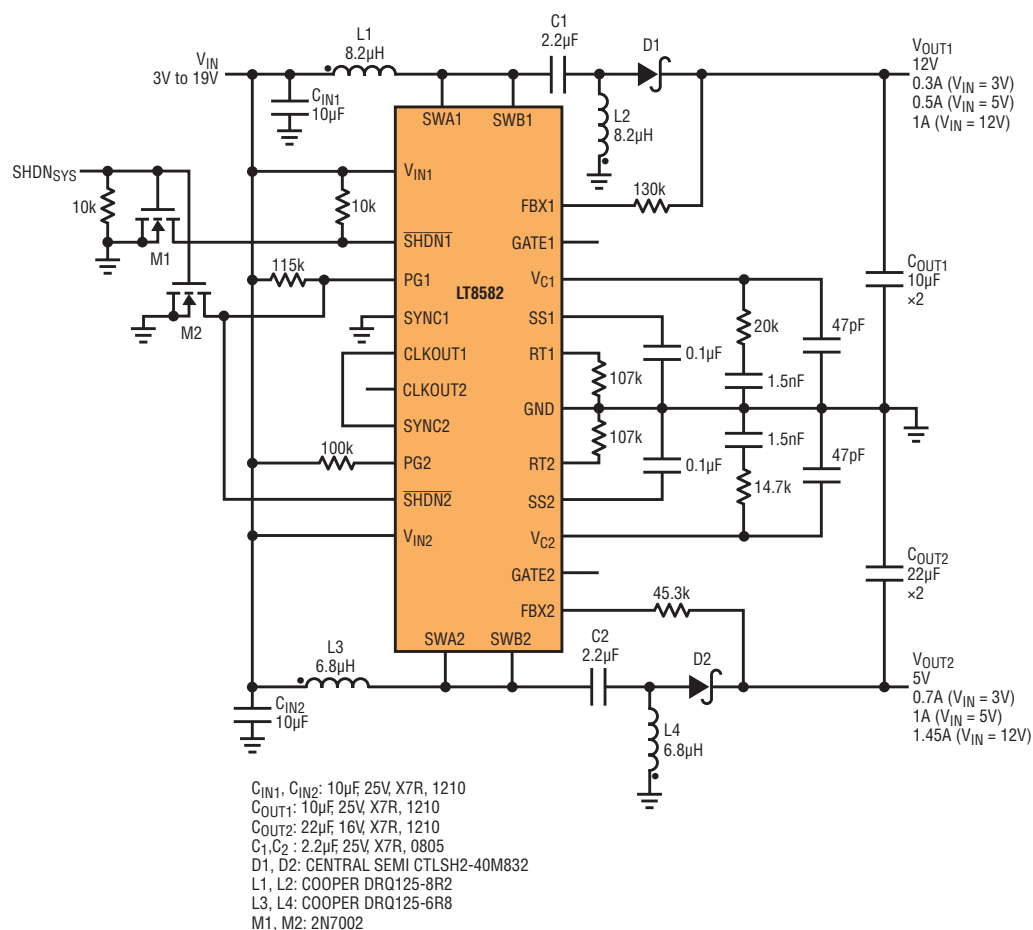


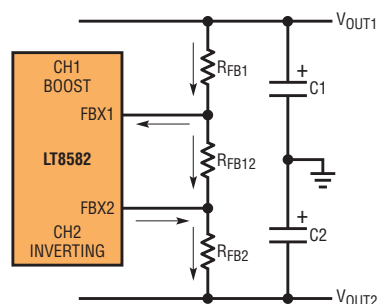
Figure 12. Start-up waveforms at $V_{IN} = 12V$

Figure 11. Sequenced 12V and 5V dual outputs

FB PIN AND SINGLE RESISTOR VOLTAGE FEEDBACK

The LT8582 needs only one feedback pin for both positive and negative output voltages. In addition, only one external resistor from V_{OUT} to FB is required

Figure 13. Tracking power supplies using one extra resistor



to set the output voltage. The internal feedback circuitry automatically selects the correct reference voltage, 1.204V or 7mV for topologies with positive or negative outputs, respectively.

This feedback structure can be used to design simple tracking power supplies without using a tracking controller chip. As shown in Figure 13, only one extra resistor connected between the two feedback pins of LT8582 is needed for this.

R_{FB1} , R_{FB12} and R_{FB2} form a resistor voltage divider. The more current through them, the better the tracking. Thus, the current through the connecting

resistor R_{FB12} must be relatively higher than the FB1 and FB2 currents, so:

$$I_{FB12} = \frac{1.204 - 7m}{R_{FB12}} \gg 83.3\mu$$

After selecting R_{FB12} , the feedback resistors R_{FB1} and R_{FB2} can be calculated as follows:

$$R_{FB1} = \frac{V_{OUT1} - 1.204}{83.3\mu + \frac{1.197}{R_{FB12}}}$$

$$R_{FB2} = \frac{7m - V_{OUT2}}{83.3\mu + \frac{1.197}{R_{FB12}}}$$

For the circuit shown in Figure 14, plotting the output voltages vs load currents yields Figure 15.

The LT8582 only needs one feedback pin for both positive and negative output voltages. In addition, only one external resistor from V_{OUT} to FB is needed to set the output voltage. The internal feedback circuitry automatically selects the correct reference voltage, 1.204V or 7mV for topologies with positive or negative outputs, respectively.

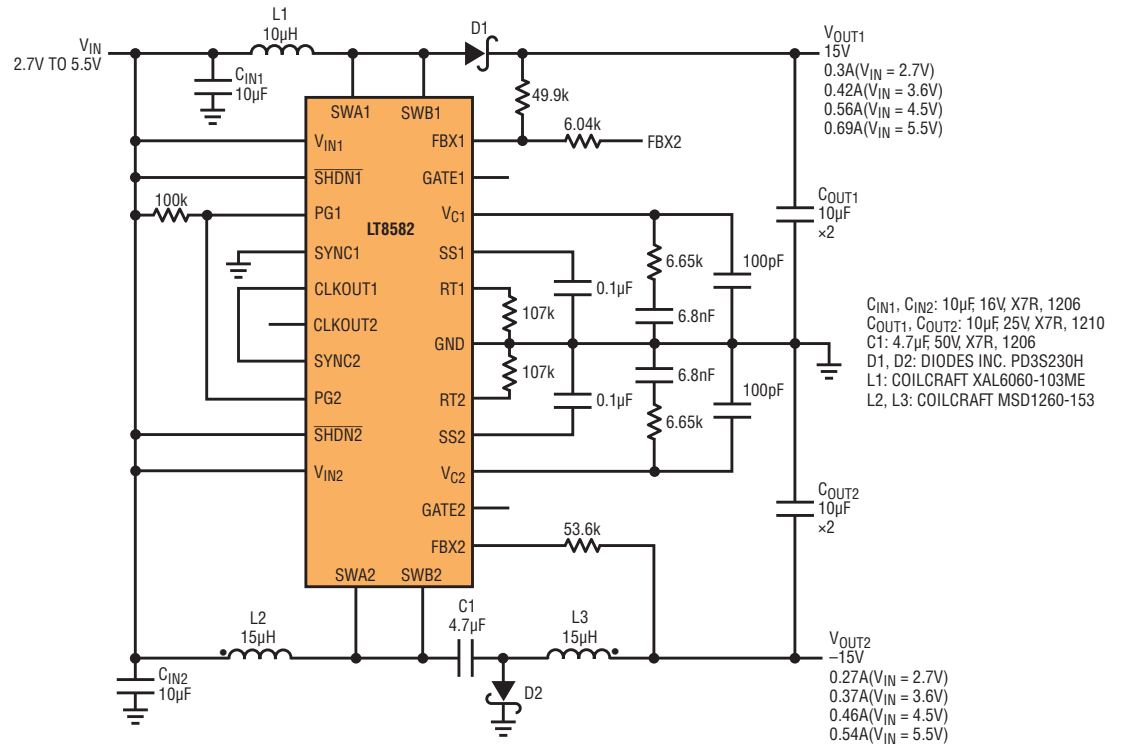


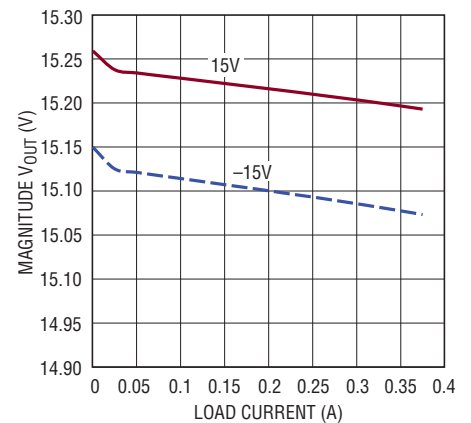
Figure 14. Dual tracking power supplies using one LT8582

CONCLUSION

The LT8582 is a dual independent monolithic converter with two 3A, 42V power switches. In addition to popular features such as soft-start, single-pin feedback and single-resistor oscillator, it includes unique features such as the master/slave power switches, separate maximum commanded and fault current limits, external PFET control for output or input disconnect, FAULT protection, PG pin for power supply sequencing, and CLKOUT signal for out-of-phase synchronizing and die temperature monitoring. These features enable the LT8582 to be used in a variety of applications, from typical dual rail voltage regulators to supercapacitor backup supplies.

The LT8582 is easy to use and robust. Because of its high switching frequency and monolithic structure, it can be used to fit power converters into the tightest spaces. The LT8582 is available in a tiny 24-pin 7mm \times 4mm DFN package. ■

Figure 15. Tracking output voltages vs load current (load between the two outputs)



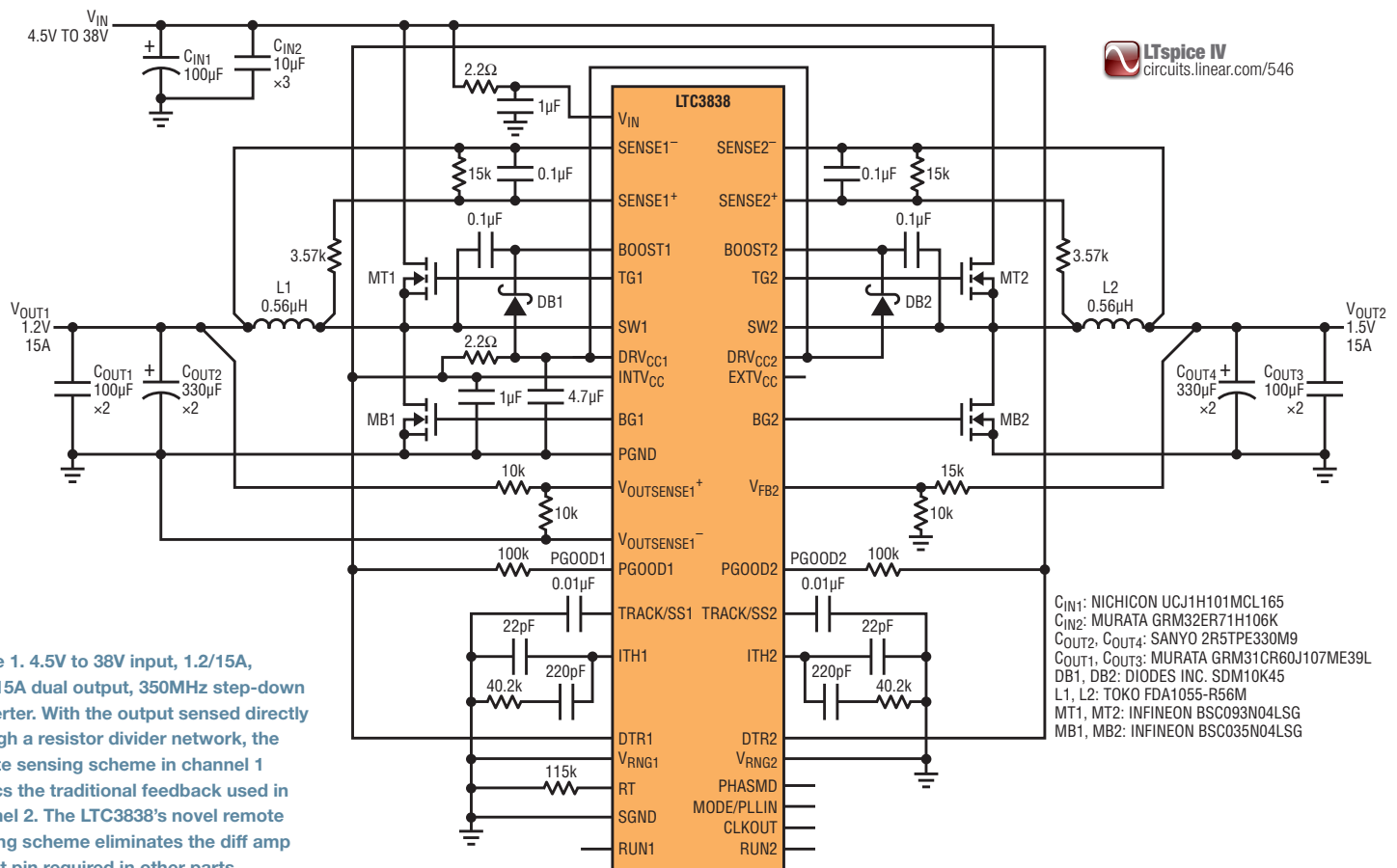
2MHz Dual DC/DC Controller Halves Settling Time of Load Release Transients, Features 0.67% Differential V_{OUT} Accuracy and Is Primed for High Step-Down Ratios

Shuo Chen and Terry Groom

Electrical conditions once considered extreme are now the norm. Modern electronic systems demand high currents and very low voltages that can appear to a DC/DC converter as an intermittent electrical short. It is not uncommon for sub-0.9V power supply rails to demand 25A or more. In this environment, tight total differential regulation accuracy is critical to achieve the demanding voltage tolerances required to power core processors and large ASICs. In addition, PCB and component size constraints have driven up converter operating frequencies to enable the use of smaller components.

The LTC3838 and LTC3839 controllers are designed to meet the needs of the most demanding low output voltage, high load current applications. Both feature superior differential regulation accuracy and fast transient response. The controlled on-time architecture yields minimum on-times as low as 30ns and is capable of switching frequencies from 200kHz to 2MHz with synchronization to an external clock.

In addition to architectural advantages, the proprietary detect transient release (DTR) feature improves the transient



The LTC3838 and LTC3839 controllers are designed to meet the needs of the most demanding low output voltage, high load current applications. Both feature superior differential regulation accuracy and fast transient response.

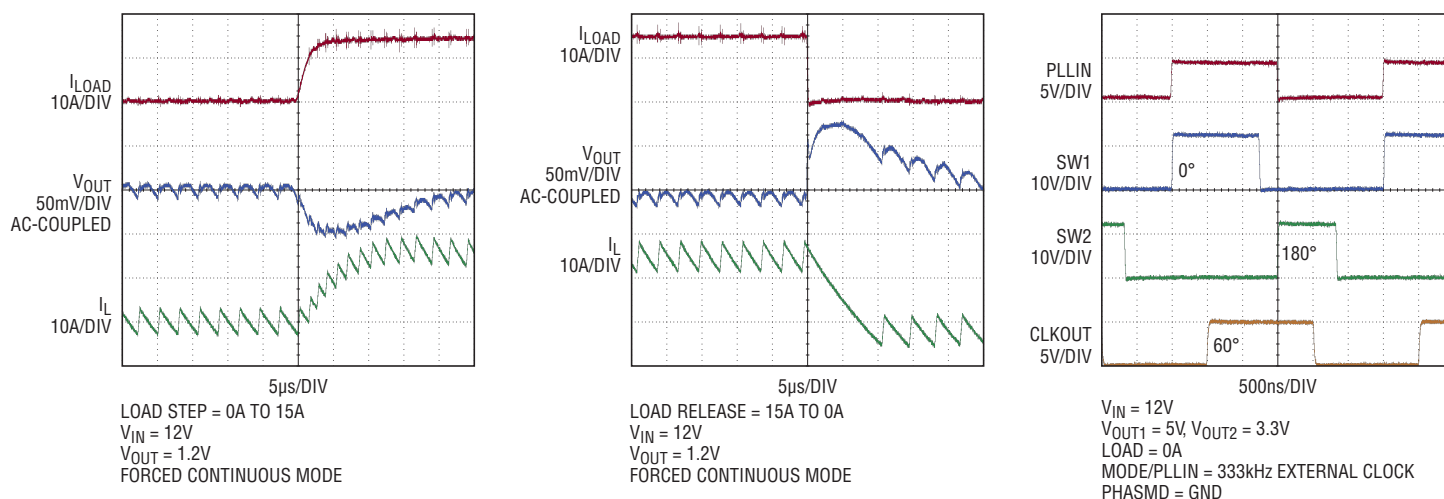


Figure 2. Switching frequency is constant and phase locked during steady state, but fast transient performance is achieved by momentarily adjusting the switching frequency: increasing it on a load step; decreasing it on a load release.

performance in high step-down ratio, low output voltage applications. This enables the LTC3838/LTC3839 to maintain accuracy and respond to load transients faster than other topologies.

In high output current supplies applications, it is important that *overall* regulation accuracy is well understood. To this end, the LTC3838 and LTC3839 internally combine the output differential amplifier and error amplifier and specify DC, line and load regulation output voltage errors as a single lumped parameter. This allows the LTC3838 and LTC3839 to achieve a level of total differential accuracy unavailable in other controllers.

The LTC3838 and LTC3839 make high frequency switching practical in a high input voltage, low output voltage converter. Both devices can produce high step-down ratios at high switching frequencies while maintaining high efficiency at heavy load

currents—previously challenging due to greater switching losses and limitations inherent in other architectures. For instance, in the typical 12V input to 3.3V/25A output application shown in Figure 3, the LTC3838/LTC3839 delivers a peak efficiency of 93% at 2MHz.

FLEXIBLE DUAL/SINGLE OUTPUT, HIGH ACCURACY REMOTE SENSE

The LTC3838's dual channels can be configured for either dual- or single-output applications, whereas the LTC3839 is dedicated for single-output applications. Both convert an input of 4.5V to 38V (40V abs max) down to outputs of 0.6V to 5.5V (6V abs max) in applications with per-channel currents up to 25A.

Their remotely sensed differential feedback has a voltage regulation accuracy of $\pm 0.67\%$ —where the remote power ground can deviate as much as $\pm 500mV$.

The LTC3838's second channel can provide an independent $\pm 1\%$ output, or together with the first channel, serve as one of the PolyPhase® channels for a single-output, higher current application. For higher load currents, or to maximize efficiency, multiple LTC3838s and LTC3839s can be paralleled for up to 12-phases.

FAST TRANSIENT PERFORMANCE, CONSTANT FREQUENCY

The LTC3838 and LTC3839 employ the new *controlled* on-time, valley current mode architecture, primed for fast transient performance. This architecture retains the benefits of a constant on-time controller: it responds to sudden load increases by a sequence of consecutive on-time pulses with a very short 90ns off-time in between, without having to wait until the next switching cycle like that of a fixed frequency controller. During a load release, the LTC3838/LTC3839 delays the turn-on of the top FET until inductor current drops

The controlled on-time architecture yields minimum on-times as low as 30ns and makes high frequency switching practical in a high input voltage, low output voltage converter, while maintaining high efficiency at heavy load currents.

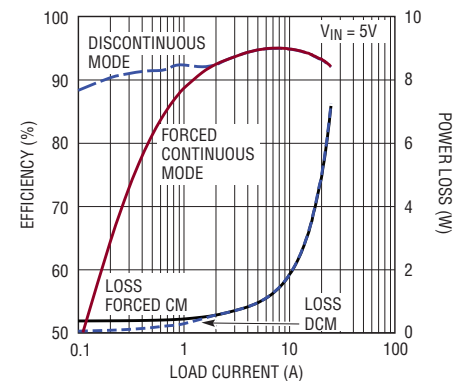
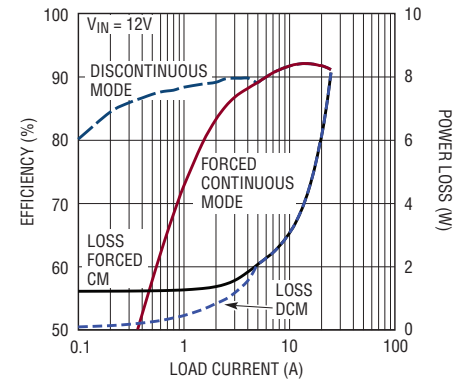
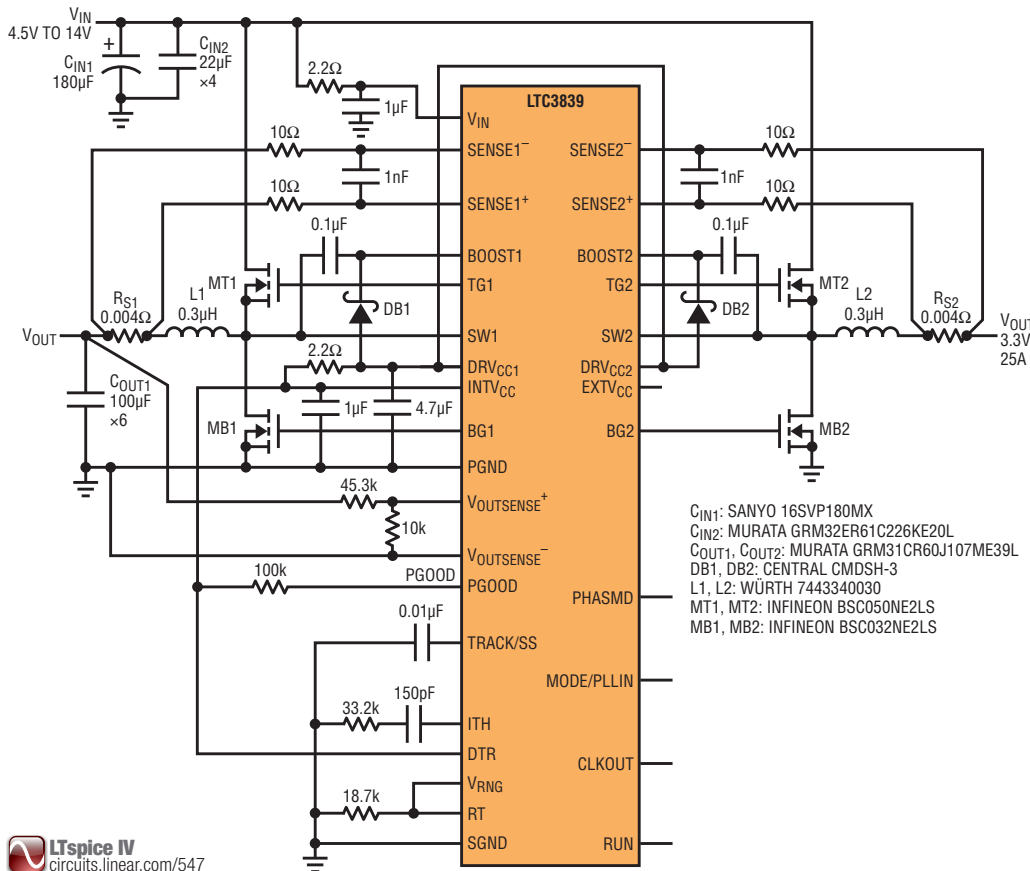


Figure 3. A 2MHz, 3.3V/25A step-down converter. The LTC3838/LTC3839 can operate at switching frequencies above the AM radio band ($f_{sw} > 1.8\text{MHz}$). The high switching frequency permits the use of inductors of very small footprint, so that the entire circuit can fit within a 0.9in^2 area with both sides populated. The peak efficiency is 95%, and full load efficiency well above 90% at 25A, even at a frequency of 2MHz.

to desired value, preventing overcharging the output capacitor. Once the transient condition subsides, the switching frequency quickly returns to the programmed nominal or external clock frequency.

Meanwhile, the on-time is adjusted (hence *controlled* on-time) so that the switching frequency is constant during steady-state operation, synchronized to its internal programmable or an external

clock, to mimic a fixed frequency controller with predictable switching noise.

HIGH AND WIDE STEP-DOWN RATIO, SWITCHING FREQUENCY

The LTC3838/LTC3839's 30ns minimum on-time (60ns effective on-time with dead-time delays) enables low duty cycles for high V_{IN} to low V_{OUT} applications, even while the part operates at high frequency. The 90ns minimum off-time

helps achieve high duty cycle operation and avoid output dropout when V_{IN} is only slightly above the regulated V_{OUT} .

The LTC3838 and LTC3839 are capable of a full decade programmable switching frequency from 200kHz to 2MHz. They can be synchronized to external clocks of $\pm 30\%$ of the programmed frequency.



In addition to the LTC3838/LTC3839's architectural advantages, the proprietary detect transient release (DTR) feature improves the transient performance in low output voltage applications. This enables these parts to maintain accuracy and respond to load transients faster than other topologies.

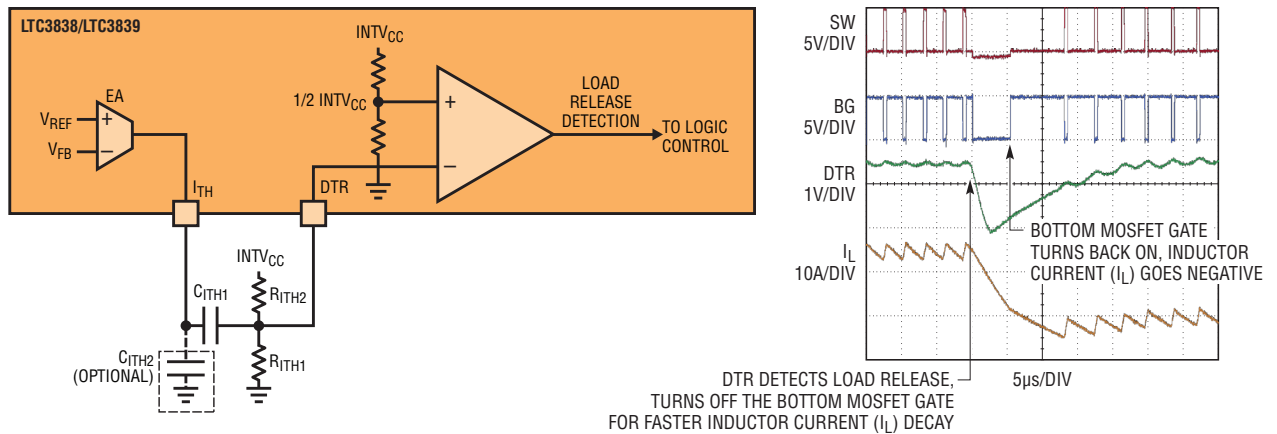


Figure 4. Transient detection is done through the detect-transient (DTR) pin, which is DC-biased slightly above $\frac{1}{2}$ $INTV_{CC}$, and AC-coupled to I_{TH} pin through the compensation capacitor C_{ITH1} . The equivalent compensation resistance $R_{ITH} = R_{ITH1} \parallel R_{ITH2}$.

NOVEL TRANSIENT DETECTION REDUCES LOAD-RELEASE V_{OUT} OVERSHOOT

As the output voltage becomes lower and the v_{IN} -to- v_{OUT} step-down ratio increases, a major challenge is to limit the overshoot in v_{OUT} during a fast load current drop. An innovative feature of the LTC3838/LTC3839 is to detect “load-release” transients indirectly by monitoring the I_{TH} negative slew rate.

The detection is done through the detect-transient (DTR) pin that is coupled to I_{TH} pin through the compensation capacitor. At steady state, the DTR pin remains slightly higher than the detection threshold (half of the voltage on $INTV_{CC}$ pin) with a voltage divider of the compensation resistors from $INTV_{CC}$ to SGND.

In the event of a sudden drop of load current, the output voltage overshoots and I_{TH} slews down quickly. If the DTR pin drops below half of $INTV_{CC}$, the

LTC3838/LTC3839 temporarily turns off the bottom MOSFET, and the inductor current flows through the body diode of the bottom MOSFET. This increases the reverse voltage drop across the inductor, allowing the inductor current to drop to zero faster,

lowering the v_{OUT} overshoot by reducing overcharging of the output capacitor.

Once the inductor current reaches zero, the bottom MOSFET turns back on to pull the inductor current to negative, discharging the output capacitor to recover regulation.

Figure 5. Load-release detect transient (DTR) feature significantly reduces V_{OUT} overshoot and time to recover regulation. (Shades are obtained with infinite persistence on oscilloscope triggered at load release steps.)

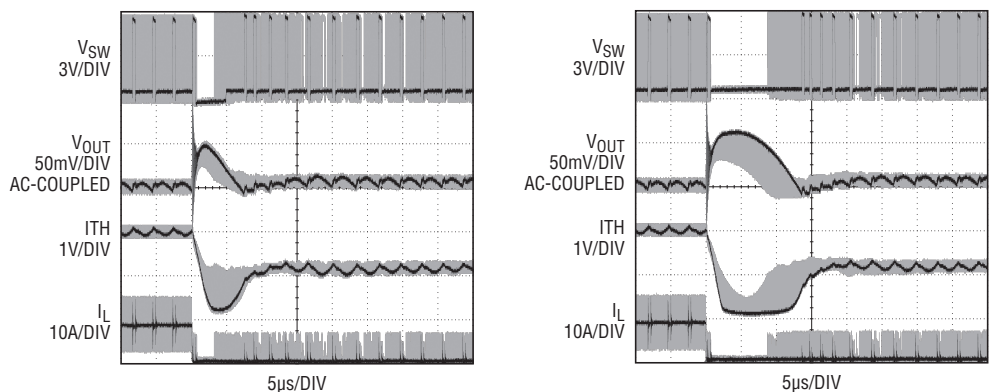


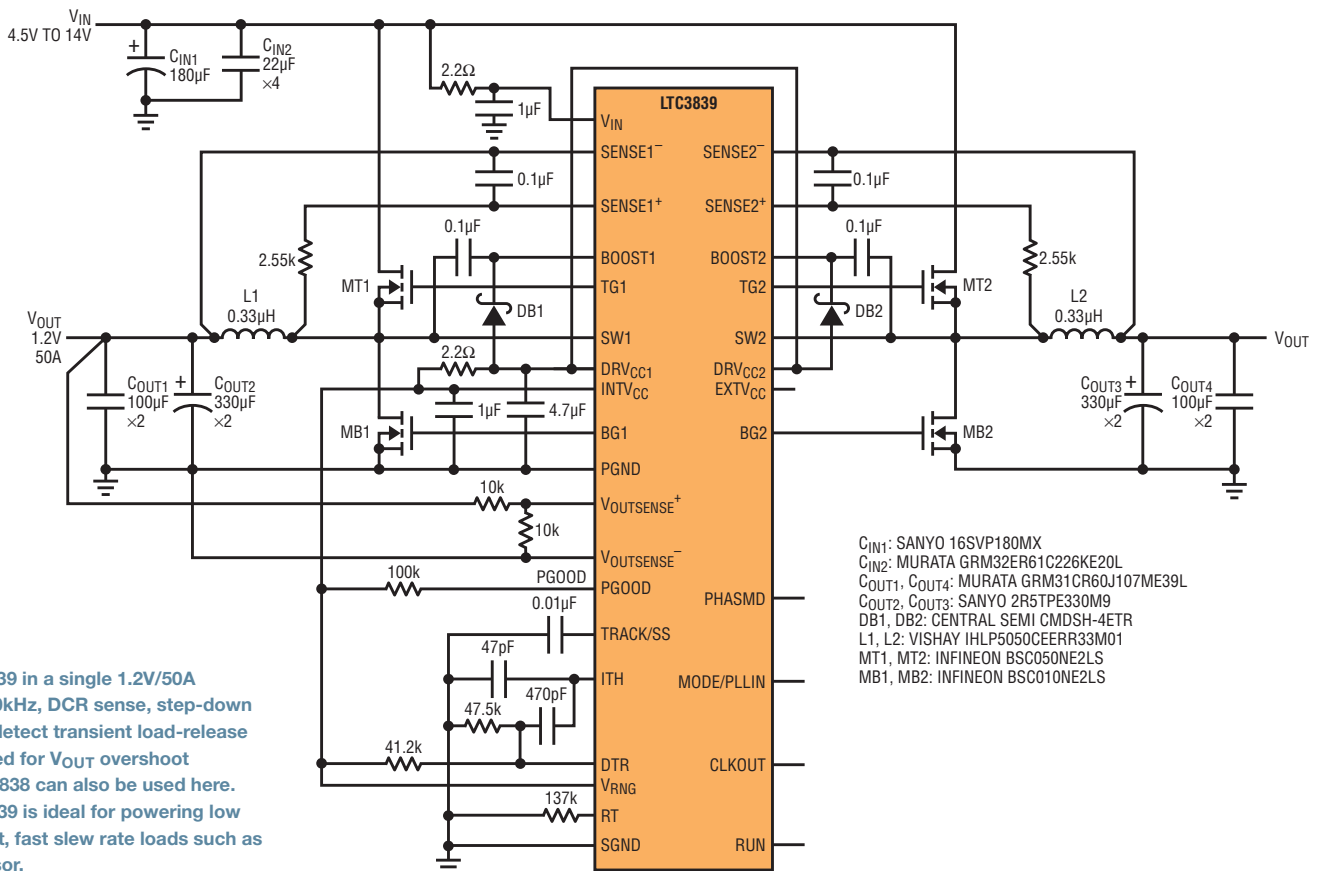
FIGURE 1 CIRCUIT, CHANNEL 1 MODIFIED:
 • $R_{FB2} = 0\Omega$, $V_{RNG2} = SGND$, $C_{ITH1} = 120pF$, $C_{ITH2} = 0pF$,
 • FROM DTR1 PIN: $R_{ITH1/2} = 46.4k\Omega$ TO SGND, $42.2k\Omega$ TO $INTV_{CC}$
 $V_{IN} = 5V$, LOAD RELEASE = 15A TO 5A, $V_{OUT} = 0.6V$

- CONNECTION FROM $R_{ITH1/2}$ AND C_{ITH1} TO DTR1 PIN REMOVED
- DTR1 PIN TIED TO $INTV_{CC}$

The LTC3838 and LTC3839 are based on and have all features of the single-channel controller LTC3833. For a full discussion of the features shared with LTC3833, refer to the cover article, "Fast, Accurate Step-Down DC/

DC Controller Converts 24V Directly to 1.8V at 2MHz" in the *LT Journal of Analog Innovation*, October 2011 (Volume 21 Number 3). Download at cds.linear.com/docs/LT%20Journal/LTJournal-V21N3-2011-10.pdf

For More Information



CONCLUSION

The LTC3838 and LTC3839 are high performance, feature-rich, 2-phase, synchronous step-down DC/DC controllers that excel at meeting the performance demands of high current, low voltage loads, in either dual or single output applications.

Their controlled on-time architecture retains the fast response and low on-time of traditional constant on-time controllers, and allows for constant frequency and external clock synchronization.

Other unique features include novel remote output sensing, which

allows for a $\pm 500\text{mV}$ remote ground, and load-release transient detection for overshoot reduction.

In addition, LTC3838 and LTC3839 include popular features, such as:

- external v_{CC} power pin for loss reduction in the controller
- continuously programmable range of current limits for flexibility with either R_{SENSE} or inductor DCR sensing
- selectable light load operating modes: discontinuous operation (similar to Burst Mode® operation) for higher

efficiency, or forced continuous operation for constant frequency

- overvoltage protection and current limit foldback
- soft-start/rail tracking, PGOOD, and RUN pins for each output.

The LTC3838 is offered in 38-pin QFN (5mm \times 7mm) and TSSOP packages. The LTC3839 is offered in a 32-pin QFN (5mm \times 5mm). All packages have exposed pads for enhanced thermal performance. ■

Current Mode Switching Supply with Ultralow Inductor DCR Sensing for High Efficiency and High Reliability

Jian Li, Haoran Wu and Gina Le

Current mode switching supplies have several advantages over voltage-mode switching supplies: (1) high reliability with fast, cycle-by-cycle current sensing and protection; (2) simple and reliable loop compensation—stable with all ceramic output capacitors; (3) easy and accurate current sharing in high current PolyPhase supplies. In high current applications, power losses in the current sensing component are a concern, so the resistance of the sense component must be as low as possible. The problem is that low resistance sensing elements produce reduced signal-to-noise ratios, such that switching jitter becomes an issue in high current, high density applications.

The LTC3866 solves this problem by making it possible to build reliable current mode switching supplies with $<0.5\text{m}\Omega$ current sensing resistance. This single-phase synchronous buck controller drives all N-channel power MOSFET switches with onboard gate drivers. It employs a unique architecture that enhances the signal-to-noise ratio of the current sense signal, allowing the use of a very low DC resistance (DCR) power inductor or low value current sensing resistor to maximize efficiency in high current applications. This feature reduces the switching jitter commonly found in low DCR applications.

The controller has a wide 4.5V–38V input range, remote output voltage sensing with accurate 0.5% reference, programmable and temperature-compensated current limit when using inductor DCR sensing, short-circuit soft recovery without overshoot, and chip thermal shutdown.

The LTC3866 facilitates the design of high efficiency, high power density and high reliability solutions for telecom systems, industrial and medical instruments, and DC power distribution systems. The controller is available in a low thermal

Figure 1. LTC3866 current sensing scheme with ultralow inductor DCR. High current paths are shown with thicker lines.

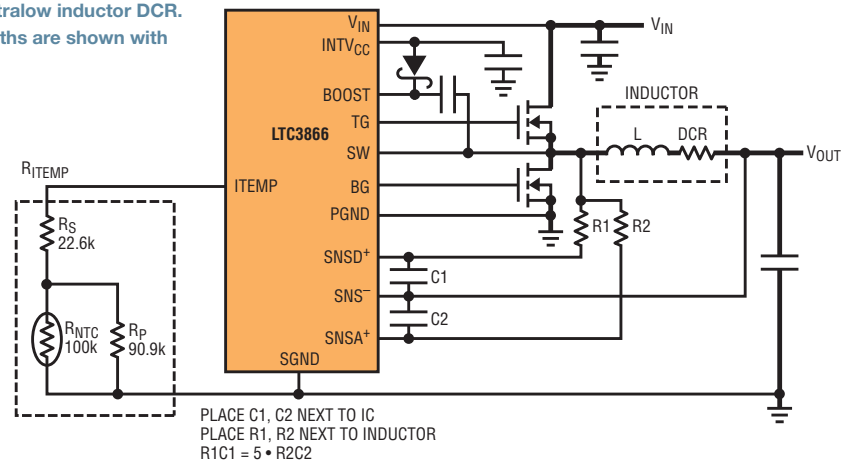
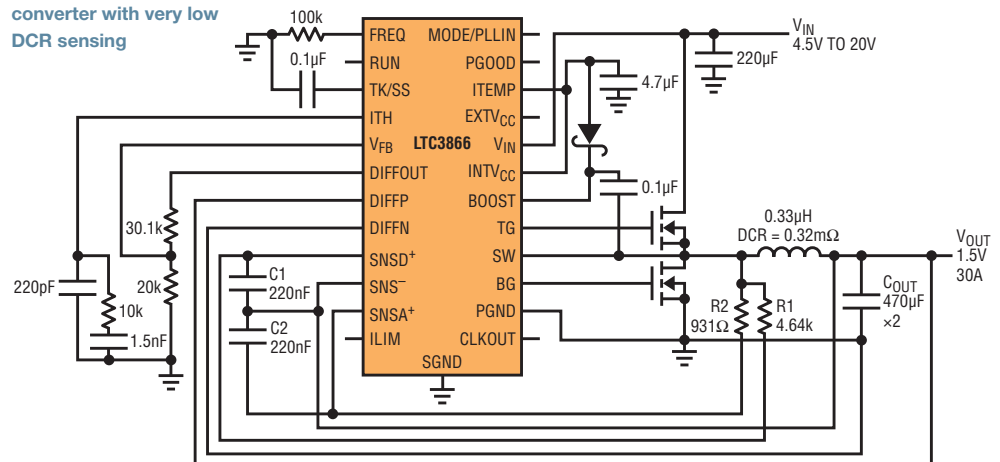


Figure 2. High efficiency, 1.5V/30A step-down converter with very low DCR sensing



The LTC3866 employs a unique architecture that enhances the signal-to-noise ratio of the current sense signal, allowing the use of a very low DC resistance (DCR) power inductor or low value current sensing resistor to maximize efficiency in high current applications.

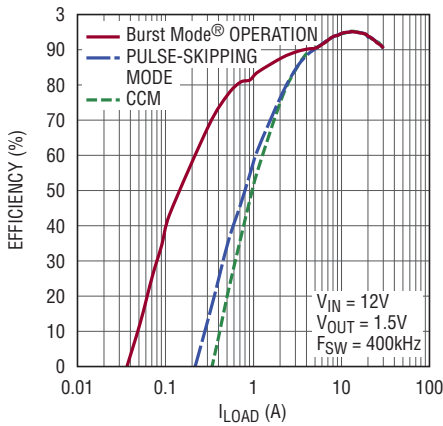


Figure 3. Efficiency of the circuit in Figure 2

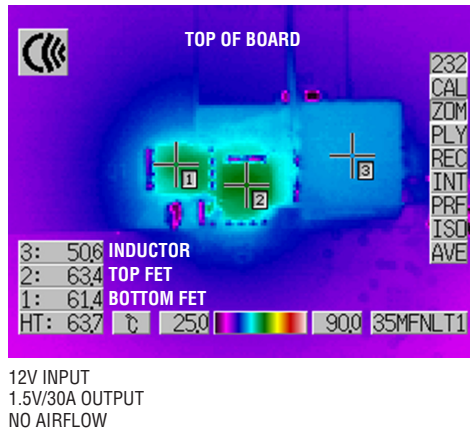


Figure 4. Thermal test of the circuit in Figure 2

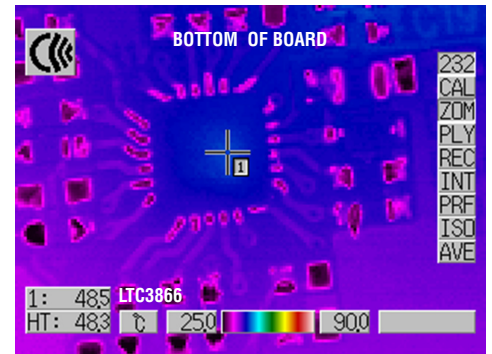


Figure 6. Short circuit test

impedance 24-lead 4mm × 4mm QFN and 24-lead exposed pad FE packages.

FEATURES

The LTC3866 uses a constant frequency peak current mode control architecture, guaranteeing cycle-by-cycle peak current limit and current sharing between different power supplies.

It is especially well suited to low voltage, high current supplies because of a unique architecture that enhances the signal-to-noise ratio of the current sense circuit. This allows it to operate with the small sense signals produced by very low DCR, 1mΩ or less, inductors, which improve power efficiency in high current supplies. The improved SNR minimizes

jitter due to switching noise, which could corrupt the signal. The LTC3866 can sense a DCR value as low as 0.2mΩ with careful PCB layout, though in this extreme situation, the additional PCB and solder resistance should be considered.

As shown in Figure 1, the LTC3866 comprises two positive sense pins, SNSD+ and SNSA+, to acquire signals and processes

Figure 5. Switching node jitter comparison at 12V input, 1.5V/25A output

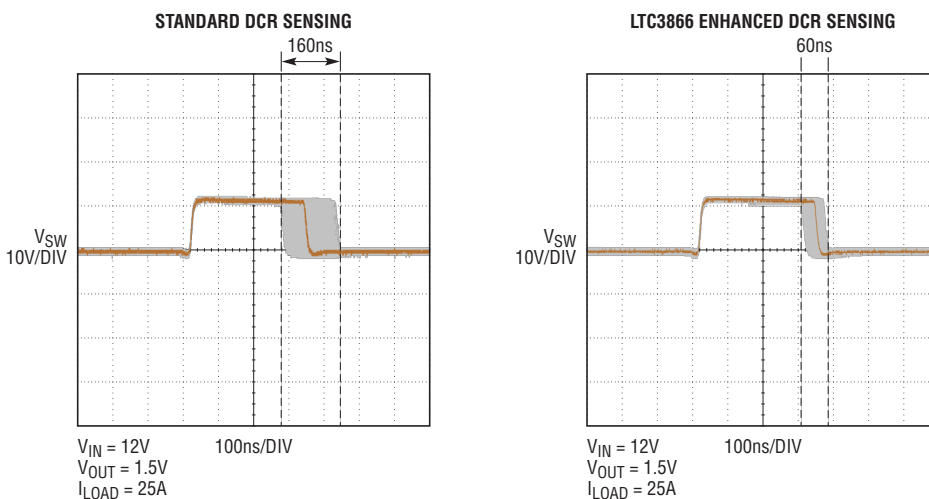
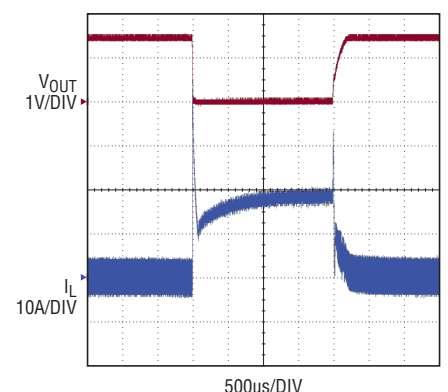


Figure 6. Short circuit test



them internally to provide a 14dB (5×) signal-to-noise ratio improvement in response to low voltage sense signals. The current limit threshold is still a function of the inductor peak current and its DCR value, and can be accurately set from 10mV to 30mV in a 5mV steps with the ILIM pin. The part-to-part current limit error is only about 1mV over the full temperature range.

The filter time constant, $R_1 \cdot C_1$, of the SNSD+ path should equal the L/DCR of the output inductor, while the filter at SNSA+ path should have a bandwidth five times larger than SNSD+, namely

$R_2 \cdot C_2 = R_1 \cdot C_1/5$. An additional, optional temperature compensation circuit guarantees the accurate current limit over a wide temperature range, especially important in DCR sensing.

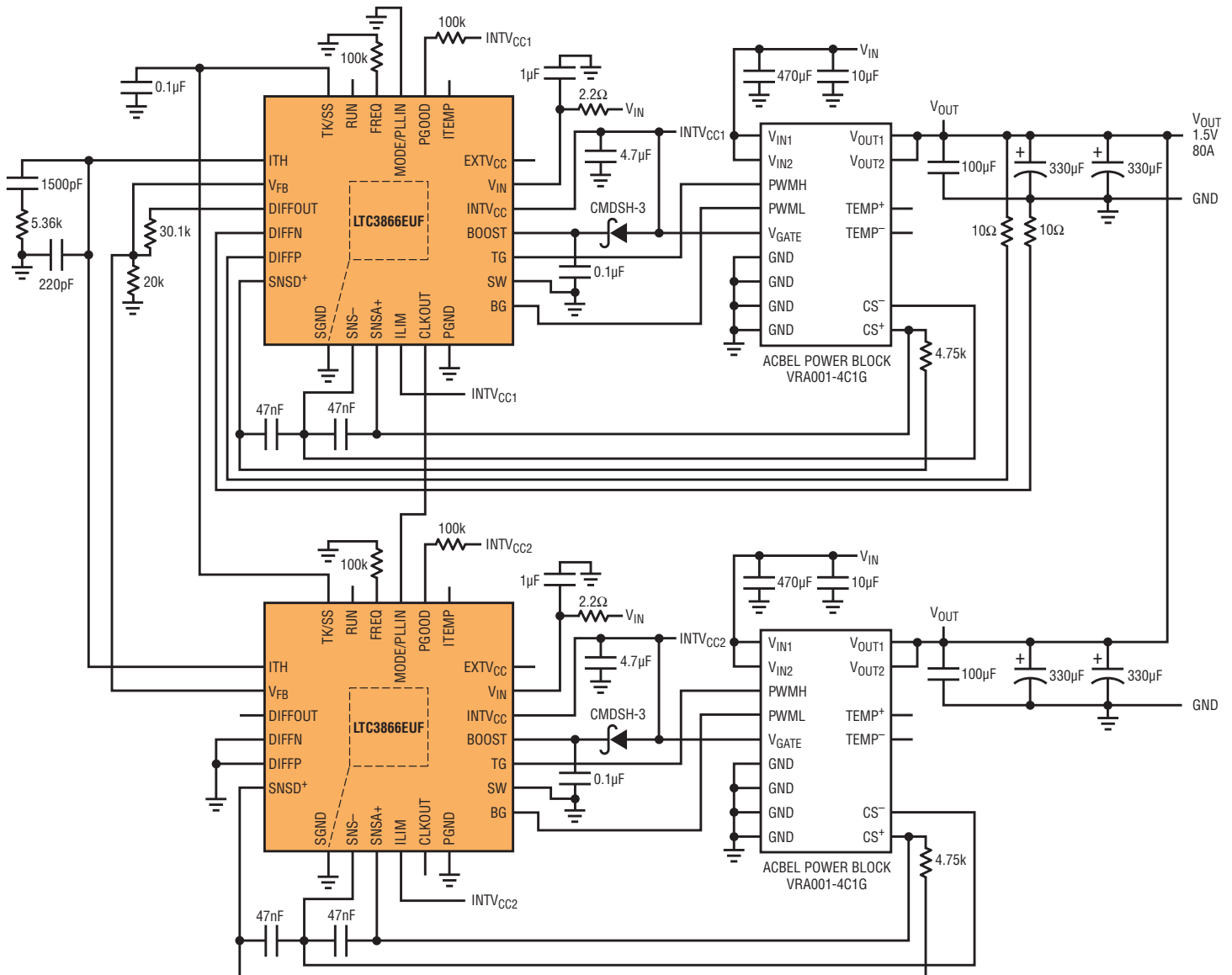
The LTC3866 also features a precise 0.6V reference with a guaranteed limit of $\pm 0.5\%$ that provides an accurate output voltage from 0.6V to 3.5V. Its differential remote V_{OUT} sensing amplifier makes the LTC3866 ideal for low voltage, high current applications.

APPLICATIONS

Figure 2 shows a high efficiency, 1.5V/30A step-down converter with very low DCR sensing. An inductor with $DCR = 0.32m\Omega$ is used in this design to maximize efficiency.

The efficiency in different operation modes is shown in Figure 3. The full load efficiency is as high as 90.3% at 12V input voltage. It is about 1.4% improvement over the supply using a 1mΩ sense resistor with the same power stage design. The hot spot (bottom MOSFET) temperature rise is only 39.6°C without any

Figure 7. A high efficiency, 1.5V/80A power supply based on parallel LTC3866s and power blocks



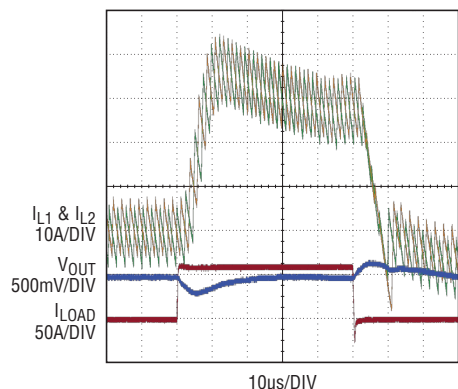


Figure 8. Current sharing performance of the 1.5V/80A supply in Figure 7

airflow, as shown in Figure 4, where the ambient temperature is about 23.8°C.

The unique design improves the efficiency, as well as the noise sensitivity. The worst case switching node jitter is reduced by 60%, as shown in Figure 5, with a very low 0.32mΩ inductor DCR.

Another unique feature of LTC3866 is short-circuit soft recovery. The internal soft recovery circuit guarantees that there is no overshoot when the power supply recovers from a short-circuit condition as shown in Figure 6.

The LTC3866 can be used with a power block for a more compact design and very high current. Figure 7 shows a dual-phase, high efficiency, 1.5V/80A power supply based on a 2× parallel LTC3866 + power block scheme. Although the DCR of the inductor in the power block is only 0.53mΩ, the current sharing performance is excellent in both DC and transient conditions, as shown in Figure 8.

In applications where higher value DCR inductor or R_{SENSE} is used, the LTC3866 can be used like any typical current mode controller by disabling the SNSD+ pin, shorting it to ground. An R_{SENSE} resistor or a RC filter can be used to sense the

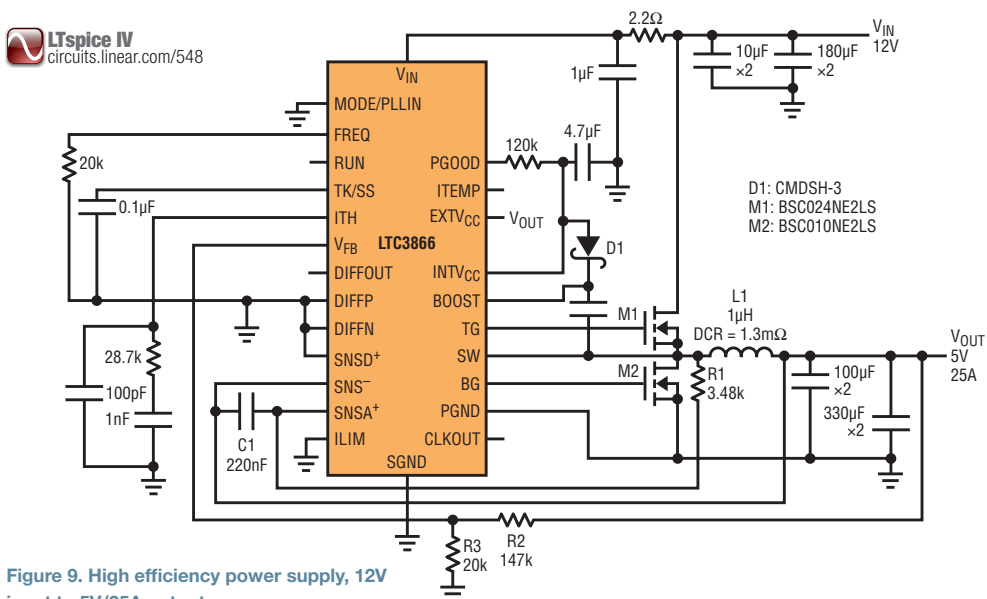


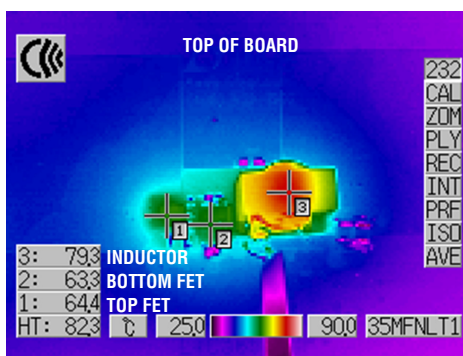
Figure 9. High efficiency power supply, 12V input to 5V/25A output

output inductor signal and connect to the SNSA+ pin. If the RC filter is used, its time constant, $R \cdot C$, is set equal to L/DCR of the output inductor. In these applications, the current limit, $V_{SENSE(MAX)}$, is five times larger for the specified ILIM, and the operating voltage range of SNSA+ and SNS- is 0V to 5.25V. Without using the internal differential amplifier, the output voltage of 5V can be generated as shown in Figure 9. The thermal test shows that the hot spot (the inductor) temperature is about 57.3°C at full load without any airflow, as shown in Figure 10, where the ambient temperature is 25°C.

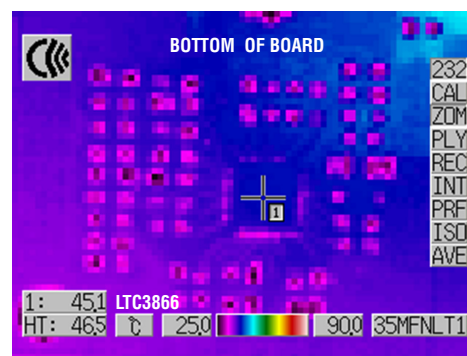
CONCLUSION

The LTC3866 delivers an outsized set of features for its small 4mm × 4mm 24-pin QFN package. The unique, ultralow DCR current sensing with current mode control makes the LTC3866 a good fit for low voltage, high current applications with high efficiency and high reliability. Tracking, strong on-chip drivers, multichip operation and external sync capability fill out its menu of features. The LTC3866 is ideal for computer and telecom systems, industrial and medical instruments, and DC power distribution systems. ■

Figure 10. Thermal test of the circuit in Figure 9



13V INPUT
5V/25A OUTPUT
NO AIRFLOW



Digital Power Management Reduces Energy Costs While Improving System Performance

Andy Gardner

Today's designers of networking equipment are expected to push the limits of performance and add functionality under the pressure of vanishingly short development times and tight cost constraints. Increasing network system functionality adds ASICs and processors, each requiring several voltage rails, resulting in line cards with dozens of rail voltages. The challenge with so many rails is to optimize hardware utilization so that overall power consumption is minimized.

To meet this need, digital power management is fast emerging as a key requirement in complex high reliability applications. Digital power management allows complex multirail systems to be efficiently debugged via PC-based software tools, avoiding time-consuming hardware changes. Software-based in-circuit testing (ICT) and board bring-up is much easier than in a traditional hardware ECN approach since firmware changes can be made on a PC, without touching the board. Digital power management gives designers real-time telemetry data and fault logs, enabling fast diagnosis of power system failures and implementation of corrective action.

Perhaps most significantly, DC/DC converters with digital management functionality allow designers to develop green power systems that optimize energy usage while meeting system performance targets (compute speed, data rate, etc.). Optimization can be implemented at

the point of load, at the board, rack and even at installation levels, reducing both infrastructure costs and the total cost of ownership over the life of the product.

This article shows how performance, reliability and energy efficiency are improved in network switches and routers, base stations and servers, as well as industrial and medical equipment through the use of the LTC2974 quad-channel digital power management IC.

SEQUENCE ANY NUMBER OF SUPPLIES; ADD SUPPLIES AT WILL

The LTC2974 simplifies the sequencing of any number of supplies. By using a time-based algorithm, users can dynamically sequence supplies on and off in any order. Sequencing across multiple LTC2974s is also possible using the 1-wire share-clock bus and one or more of the bidirectional fault pins (see Figure 2). This approach greatly simplifies system design because channels can be sequenced in any order, regardless of which LTC2974 provides control. Additional LTC2974s can be added at any time without concern for system constraints, such as a limited supply of daughter-card connector pins.

Power-up sequencing can be triggered in response to a variety of conditions. For example, the LTC2974s can auto-sequence when the downstream DC/DC POL converters' intermediate bus voltages exceed a particular turn-on voltage. Alternatively,

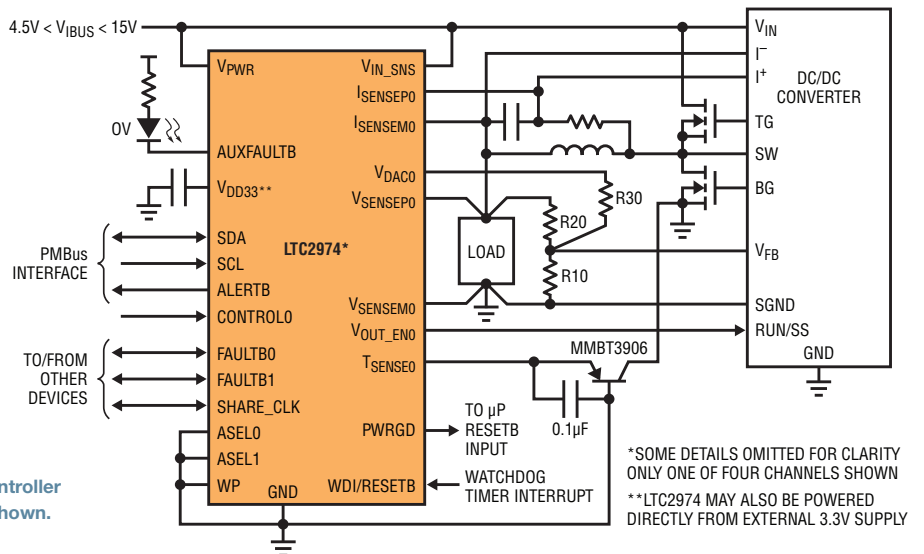


Figure 1. Quad power supply controller with EEPROM. One channel is shown.

By using a time-based algorithm, users can dynamically sequence supplies on and off in any order. Sequencing across multiple LTC2974s is also possible using the 1-wire share-clock bus and one or more of the bidirectional fault pins. This approach greatly simplifies system design since channels can be sequenced in any order, regardless of which LTC2974 provides control. Additional LTC2974s can be added at any time.

on sequencing can be initiated in response to the rising- or falling-edge of the control pin input. Immediate turn-off or off-sequencing in response to a fault condition is also available. Sequencing can also be initiated by a simple I²C command. The LTC2974 supports any combination of these conditions.

ROBUST SYSTEMS REQUIRE VERSATILE FAULT MANAGEMENT

The bidirectional fault pins can be used to establish fault response dependencies between channels. For instance, on sequencing can be aborted for one or more channels in the event of short-circuit. The overvalue and undervalue limit thresholds and response times of the voltage and current supervisors are all programmable. In addition, input voltage, die temperature, and four external diode temperatures are also monitored. If any of these quantities exceed their over- or undervalue limits, the LTC2974 can be set to respond in a number of ways, including immediate latching, deglitched latching, and latching with retry.

An integrated watchdog timer is available for supervising external microcontrollers. Two timeout intervals are available: the first watchdog interval and subsequent intervals. This makes it possible to specify a longer timeout interval for the microcontroller just after the assertion of the power good signal. If a watchdog fault occurs, the LTC2974 can be configured to reset the microcontroller for a predetermined amount of time before reasserting the power good output.

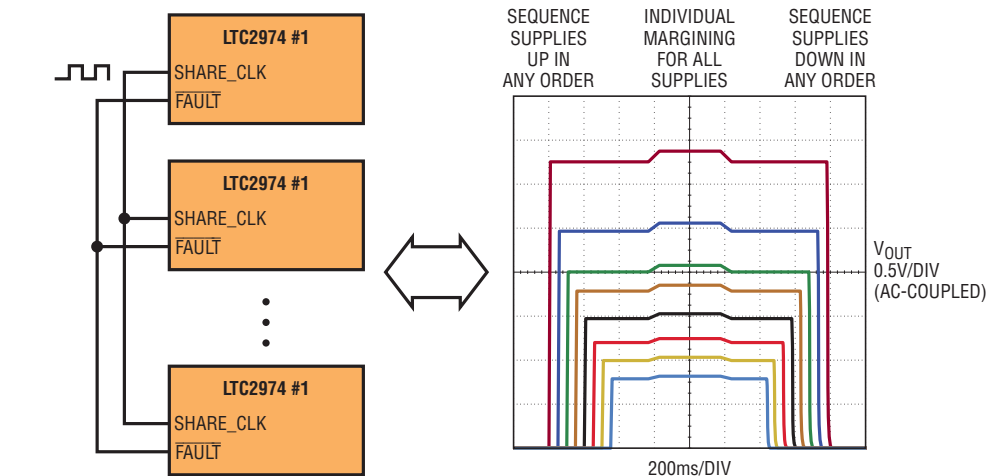


Figure 2. Multiple LTC2974s can be cascaded seamlessly using only two connections.

IMPROVE MANUFACTURING YIELDS WITH ACCURATE VOLTAGE MONITORING

As voltages drop below 1.8V, many off-the-shelf modules have trouble meeting output voltage accuracy requirements over temperature. Absolute accuracy requirements of less than $\pm 10\text{mV}$ are now common, making it necessary to trim the output voltage in manufacturing, a time-consuming process.

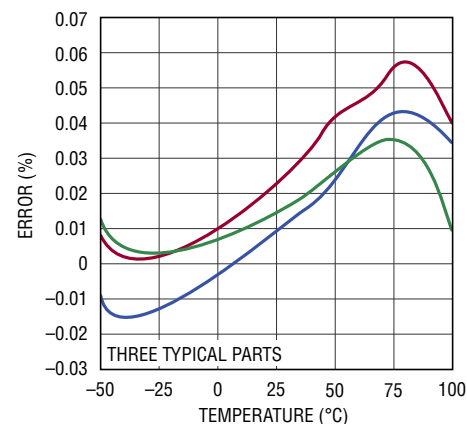
OEMs must margin test to ensure that they ship dependable systems in the face of drifting rail voltages, which can result in significant manufacturing yield fall-out. A far better solution to this problem embraces the reality of inaccurate power modules, and enables the system to *self-trim in the field*. The LTC2974's digital servo loop minimizes rail-voltage drift by externally trimming the module's output voltage to better than $\pm 0.25\%$ accuracy over temperature (see Figure 3). In addition to improving manufacturing

yields, the digital servo loop makes it easier to source power modules by avoiding the limitation of module accuracy.

ROBUST SYSTEMS A RESULT OF EASY MARGINING

The LTC2974's digital servo loop 10-bit DACs allow users to margin power supplies over a wide range while maintaining high resolution for applications such as Shmoo

Figure 3. The LTC2974 offers excellent voltage servo accuracy over temperature.



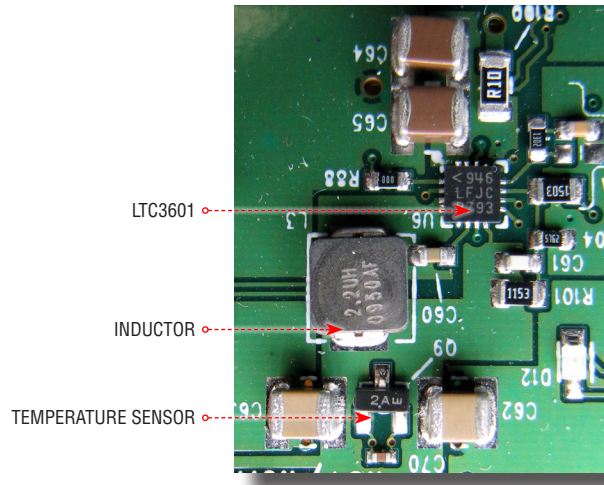
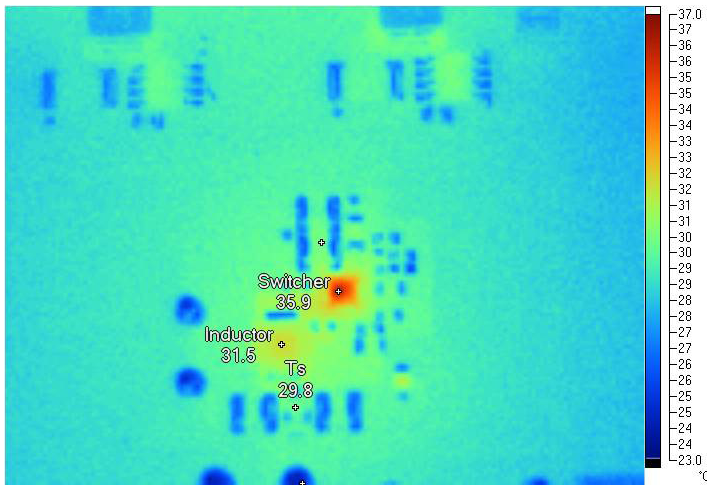


Figure 4. Thermal image of a DC/DC converter showing the difference between the actual inductor temperature and the temperature sensing point.

plotting. Margining is controlled over the I²C interface with a single command, and the margin DAC outputs are connected to the feedback nodes or trim inputs of the DC/DC converters via a resistor. The value of this resistor sets a hardware limit on the range over which the output voltage can be margined, an important safeguard for power supplies under software control.

ACCURATE, TEMP COMPENSATED, DCR LOAD CURRENT MONITORING

To achieve the desired savings in power consumption, it is necessary to characterize the loads during all modes of operation. FPGA users optimize their code to minimize power while ASIC users adjust core voltages depending on throughput

requirements. Accurate real-time telemetry greatly simplifies this task.

Using the LTC2974, system health can be determined from the voltage, current and temperature status registers, while the multiplexed, 16-bit $\Delta\Sigma$ ADC monitors input and output voltages, output currents, and internal and external diode temperatures.

With the trend to lower and lower core voltages, accurate measurement of load currents has become a challenge, since the use of a precision current sense resistor can lead to unacceptable power losses. One option is to use the DC resistance of the inductor (DCR) as a current shunt element. This has several advantages, including zero additional power loss, lower

circuit complexity and cost. However, the strong temperature dependence of the inductor resistance and the difficulty in measuring the exact inductor core temperature invariably introduces errors in current measurement (see Figure 4).

The LTC2974 makes accurate DCR sensing possible with a patent-pending temperature compensation algorithm that compensates for the thermal gradient from the sense diode to the inductor's core, as well as the time lag that occurs between changes in inductor current and temperature (see Figure 5). This capability, combined with the LTC2974's low noise 16-bit $\Delta\Sigma$ ADC, enable accurate measurement of load currents using inductors with vanishingly small DCR (see Figure 6).

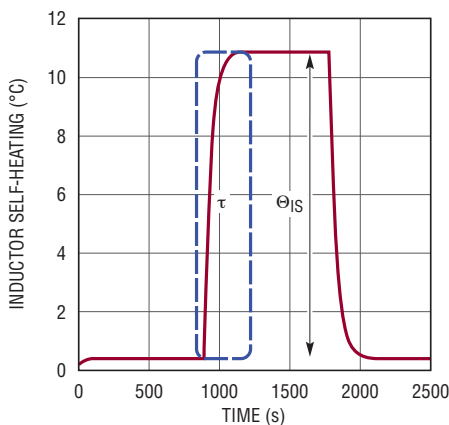


Figure 5. LTC2974 compensates for inductor self-heating using thermal resistance and delay parameters.

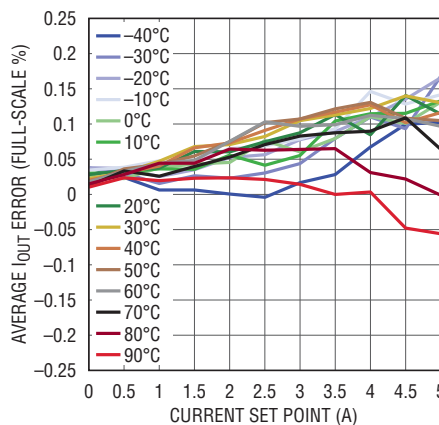


Figure 6. Total current measurement error of the LTC2974 for a DC/DC converter across the full range of temperature and output current.

PC-BASED DESIGN AND FAULT DIAGNOSTICS

When used in conjunction with LTpowerPlay™ software, the LTC2974's fault and warning registers allow designers (and field users) to determine the status of their power infrastructure at a glance (see Figure 7). Status information, uptime, and the last 500ms of ADC telemetry are available in a data log. In the event a channel is disabled in response to a fault, the LTC2974's data log can be dumped into protected EEPROM. This 255-byte block of data is held in non-volatile memory until it is cleared with an I²C command.

Figure 7 shows the data log contents viewed in LTpowerPlay's LTC2974 interface. In this way, the LTC2974 provides a complete snapshot of the state of the power system immediately preceding the critical fault, thus making it possible to isolate root cause well after the fact. This is an invaluable feature for debugging both prerelease characterization and in-field failures in high reliability systems.

STANDALONE OPERATION

The easy-to-use PC-based LTpowerPlay software allows users to configure the LTC2974 via a USB interface and a dongle card. LTpowerPlay software, which is free and downloadable, takes much of the coding out of the development process and improves time-to-market by allowing the

designer to configure all device parameters within an intuitive framework.

Once a device configuration has been finalized, the designer can save the parameters to a file and upload it to the Linear Technology factory. Linear can use the file to preprogram parts, thus allowing customers to bring up their boards with maximum ease. When the onboard EEPROM has been configured, the LTC2974 is capable of complete autonomous operation without the need for custom software. Furthermore, the addition of one tiny connector allows LTpowerPlay software to communicate with the LTC2974 in-system, providing field users access to telemetry, system status and the fault log as needed.

CONCLUSION

The LTC2974 digital power manager brings unprecedented parametric accuracy, a rich feature set and an expandable modular architecture to high availability systems. Design of complex multirail systems is simplified with the LTC2974. It uses an industry-standard PMBus interface, it interfaces directly with high powered, free PC-based LTpowerPlay control software, and it includes an integrated EEPROM for complete customization. Design your application with the LTpowerPlay design tool and simply upload the configuration to the Linear Technology factory. Linear can use your custom configuration to produce pre-programmed devices ready-to-use in your application. ■

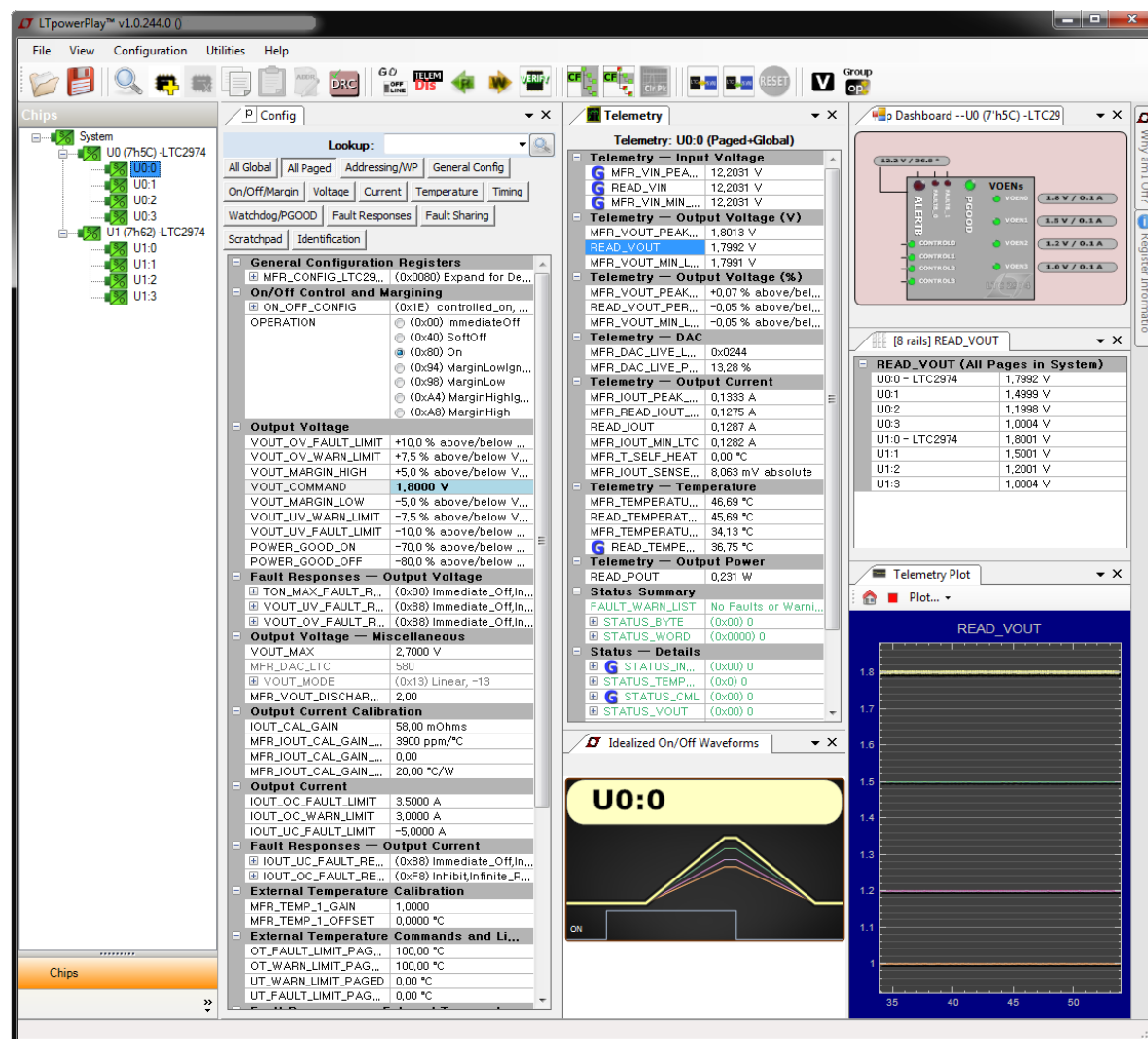


Figure 7. LTpowerPlay software allows the designer to plug a PC into the system via a tiny connector, enabling the power-management system to be completely configured and controlled without writing a single line of code.

What's New with LTspice IV?

Gabino Alonso



Stepping Parameters
in LTspice IV

Follow @LTspice on Twitter for up-to-date information on models, demo circuits, events and user tips: www.twitter.com/LTspice

NEW HOW-TO VIDEOS

Stepping Parameters video.linear.com/103

There are two ways to examine a circuit by changing the value of a parameter. You can manually enter each value, then resimulate the circuit, or you can use the .STEP command to sweep across a range of values in a single simulation run for a side-by-side comparison. This video provides an overview of the basic steps for using the .STEP command to perform repeated analysis of a circuit.

FULLY DIFFERENTIAL OPERATIONAL AMPLIFIER DEMO CIRCUITS (from Tyler Hutchison)

Analyzing and interfacing with fully differential op amps in simulation may prove more complicated than with familiar, single-ended output op amps. These demo circuits provide examples of interfacing to fully differential amplifiers

including single-ended and differential impedance matching, noise analyses, mixer and high speed ADC signal chain models, and gain modification of fixed-gain amplifiers with external resistors.

- **LTC6400-20:** Single-ended impedance matching for fully differential amplifiers www.linear.com/LTC6400-20
- **LTC6400-20:** Differential impedance matching for fully differential amplifiers www.linear.com/LTC6400-20
- **LTC6400-20:** Noise simulation for fully differential amplifiers www.linear.com/LTC6400-20
- **LTC6401-8:** Unity gain for fully differential amplifiers with internal feedback resistors www.linear.com/LTC6401-8
- **LTC6404-1:** Impedance matching and noise measurements for fully differential amplifiers www.linear.com/LTC6404

- **LTC6405:** Fully differential ADC driver with simplified mixer and ADC models www.linear.com/LTC6405

NEW DEMO CIRCUITS

µModule Regulators

- **LTM®8048:** Isolated µModule DC/DC converter with LDO post regulator (4V–30V to 6V at 100mA & 5V at 100mA) www.linear.com/LTM8048
- **LTM8052:** 36V, 5A, 2-quadrant CVCC step-down µModule regulator (6V–36V to 2.5V at ±5A) www.linear.com/LTM8052

Switching Regulators

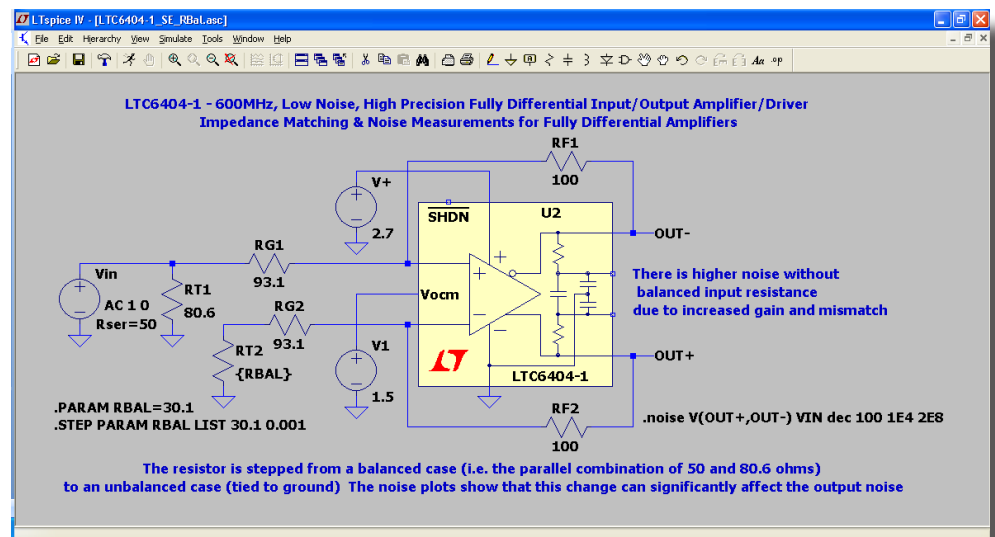
- **LT3758:** High efficiency SEPIC (8V–72V to 5V at 2A) www.linear.com/LT3758
- **LT3759:** Boost with low input voltage range (1.8V–4.5V to 5V at 2A) www.linear.com/LT3759
- **LT3759:** SEPIC with wide input voltage range (2.8V–36V to 12V at 1A) www.linear.com/LT3759

What is LTspice IV?

LTspice® IV is a high performance SPICE simulator, schematic capture and waveform viewer designed to speed the process of power supply design. LTspice IV adds enhancements and models to SPICE, significantly reducing simulation time compared to typical SPICE simulators, allowing one to view waveforms for most switching regulators in minutes compared to hours for other SPICE simulators.

LTspice IV is available free from Linear Technology at www.linear.com/LTspice. Included in the download is a complete working version of LTspice IV, macro models for Linear Technology's power products, over 200 op amp models, as well as models for resistors, transistors and MOSFETs.

Download this demo circuit showing impedance matching and noise measurements for fully differential amplifiers www.linear.com/LTC6404



- **LTC4000/LTC3891:** High voltage high current step-down, PowerPath controller & Li-ion battery charger (24V–60V to 16.8V at 6A) www.linear.com/LTC4000

Amplifiers, References, Comparators and TimerBlox® ICs

- **LT6108/LTC6994:** Energy-tripped circuit breaker with automatic delayed retry (5V–80V input, 500mA threshold) www.linear.com/LT6108

NEW DEVICE MACRO MODELS

Switching Regulators

- **LT8582:** Dual 3A boost/inverting/SEPIC DC/DC converter with fault protection www.linear.com/LT8582
- **LTC3103:** 1.8 μ A quiescent current, 15V, 300mA synchronous step-down DC/DC converter www.linear.com/LTC3103
- **LTC3115V-1:** 40V, 2A synchronous buck-boost DC/DC converter www.linear.com/LTC3115-1
- **LTC3613:** 24V, 15A monolithic step-down regulator with differential output sensing www.linear.com/LTC3613
- **LTC3839:** Fast, accurate, 2-phase, single-output step-down DC/DC controller with differential output sensing www.linear.com/LTC3839
- **LTC3866:** Current mode synchronous controller for sub-m Ω DCR sensing www.linear.com/LTC3866
- **LTC3876:** Dual DC/DC controller for DDR power with differential VDDQ sensing and ± 50 mA VTT reference <http://www.linear.com/LTC3876>

Hot Swap™ Controllers and Surge Stoppers

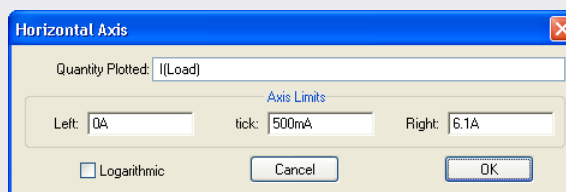
- **LTC4232:** 5A integrated Hot Swap controller www.linear.com/LTC4232
- **LTC4366:** High voltage surge stopper www.linear.com/LTC4366 ■

PARAMETRIC PLOTS

Plotting results in LTspice IV is as easy as clicking on a node to show voltage, or a component to show current—the trace is then displayed in the waveform viewer. In transient analysis, the horizontal axis defaults to showing time, but you can always change the horizontal axis to show other quantities (such as current) to validate model parameters.

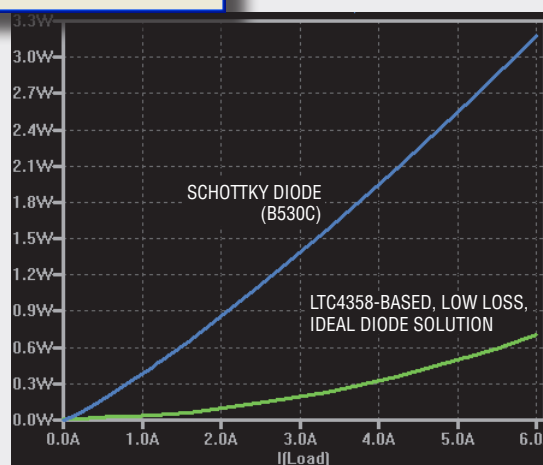
To change the default settings of the x-axis:

1. Click on a node/component to plot its voltage/current in the waveform viewer.
2. Move the cursor to the horizontal axis of the waveform viewer (the cursor will turn into a ruler) and left-click.
3. In the Horizontal Axis dialog, enter an expression for the “Quantity Plotted.”
4. Click OK.



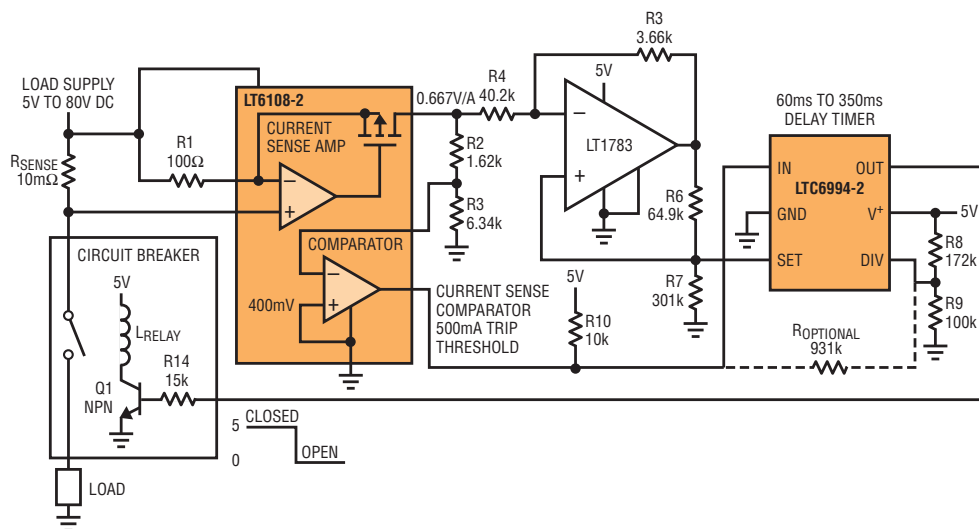
Happy simulations!

This parametric plot compares the instantaneous power dissipation (Alt + click on component) of an LTC4358 5A ideal diode to a Schottky diode. In this example, the quantity plotted on the horizontal axis has been changed from the default of “time” to “load current.” The resulting plot confirms the advantage of the LTC4358 as a low loss replacement to Schottky diodes in high current diode applications. More information is available at www.linear.com/LTC4358.



Power User Tip

Download the LTspice IV demonstration circuit for this energy-tripped circuit breaker with automatic delayed retry at www.linear.com/LT6108



Dual Monolithic Ideal Diode Extends Battery Run Time and Prioritizes Power Sources with Glitch-Free Switchover

Joshua Yee

Mobile devices increasingly rely on several power sources that must be interchangeable on the fly, such as a wall adapter and a backup battery, where switchover between sources must be transparent and immediate. The simplest scheme for switching between two power sources is a simple diode-OR, but at higher current levels, power losses in the diode are a problem. To minimize power losses and maximize battery run time, replace the Schottkys in a traditional diode-OR with the LTC4415 dual monolithic ideal diode.

The LTC4415 efficiently and intelligently switches between two power sources in an input voltage range of 1.7V–5.5V. When used in the diode-OR application as shown in Figure 1, LTC4415 delivers load current through ideal diode D1 from the wall adapter until its voltage drops below the 4.5V switchover threshold set by the resistor divider on EN1/EN2. Once D1 is disabled, the battery delivers load current through D2 instead. $\overline{STAT1}$ and $\overline{STAT2}$ indicate which ideal diode is conducting.

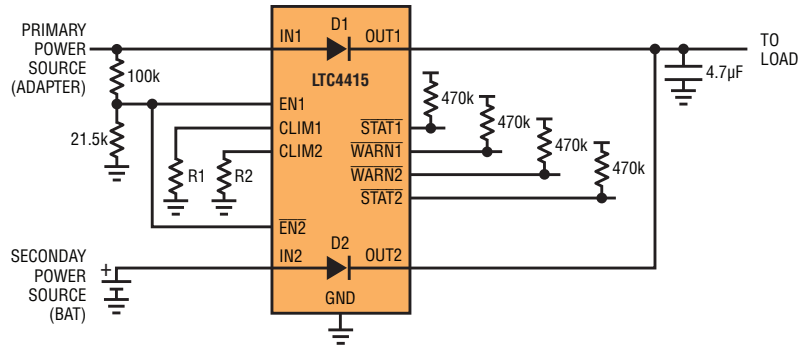


Figure 1. Automatic ideal diode switchover between wall adapter and battery

FEATURES

Figure 2 shows that the LTC4415 conducts with a regulated forward voltage drop of 15mV when the load current is below 500mA, an improvement of >28mV compared to the LTC4413. Once the load current climbs above that, LTC4415 operates with an on-resistance of 50mΩ, a 140mΩ improvement over the LTC4413 in this region. At 4A, the LTC4415 produces a mere 200mV forward drop, a reduction of over 50% compared to a typical

Schottky diode, which would produce a forward drop greater than 400mV. Because of its low forward voltage drop, LTC4415 dissipates less than half the power of a typical, low reverse leakage Schottky diode at 4A and less than a quarter at 2A, as shown in Figure 3.

Another useful feature of the LTC4415 is short-circuit protection. The current limit of LTC4415 can be adjusted up to 4A with R1 and R2. Eliminating R1 and R2, and grounding CLIM1 and CLIM2,

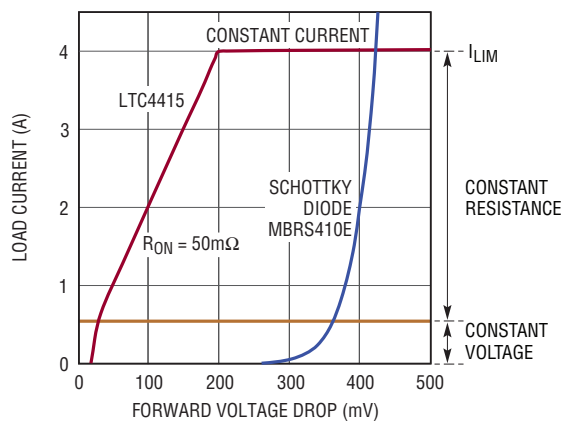


Figure 2. The LTC4415 I-V curve and regions of operation vs a typical Schottky diode

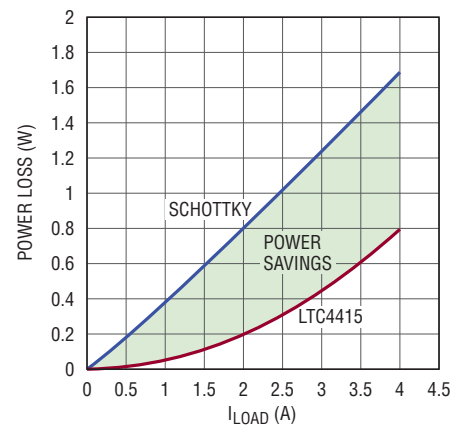


Figure 3. The LTC4415 dissipates only 800mW at 4A, which is over 50% lower than the 1700mW dissipated by a Schottky diode

The LTC4415 is an easy-to-use, high performance ideal-diode-OR solution for instantaneous power supply switchover. It requires as few as four external resistors and one output capacitor.

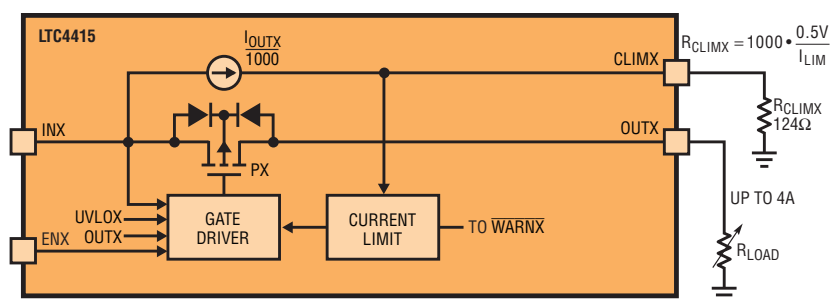


Figure 4. Current limit detection inside the LTC4415 for each channel

instead triggers the internal limit at 6A. Current limit is accomplished by a novel approach that allows the LTC4415 to both detect the load current and simultaneously produce a scaled analog voltage for load current monitoring across the same current limit resistor. Figure 4 shows a simplified block diagram. This eliminates series losses, and saves board space and BOM costs associated with a current sense resistor and amplifier circuit.

LTC4415 P-channel MOSFETs are optimized for minimal on-resistance with rapid switchover between sources

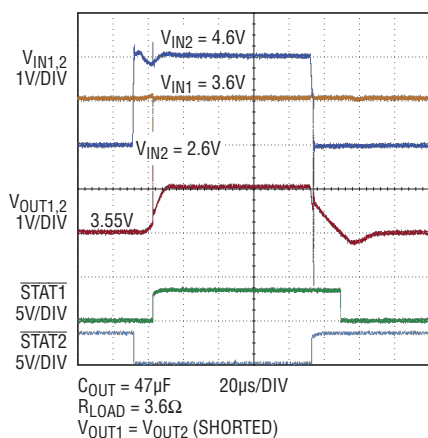


Figure 5. Rapid path switchover with only 5% transient voltage dip

without any appreciable load droop. Figure 5 shows the LTC4415 switching between input sources of different voltages, with only a 200mV transient dip and recovery within 20µs. Note that transient voltage spikes are usually caused by inductive connections. This can be reduced with short leads, proper layout technique, and input and output bypass capacitors with appropriate ESR.

For status monitoring purposes, the active-low signals of $\overline{\text{STATX}}$ and $\overline{\text{WARNX}}$ provide feedback to a digital controller/processor. $\overline{\text{STATX}}$ reflects conduction

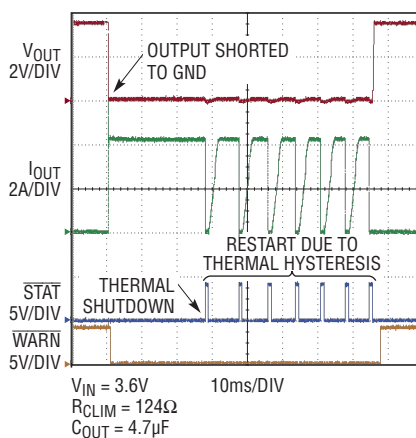


Figure 6. Current limit warning and thermal shutdown on output short circuit

status of a given channel. It can also be used to detect failure of a source. $\overline{\text{WARNX}}$ serves the dual purpose of indicating if a path is in current limit—when $\overline{\text{STATX}}$ is also low—or in thermal shutdown.

Thermal shutdown is triggered when die temperature exceeds 160°C. Figure 6 shows how these two signals reflect the system behavior when a path transitions back and forth between current limit and thermal shutdown. For about 25ms after the output is shorted, the current limit is active and $\overline{\text{WARNX}}$ stays low. Then $\overline{\text{STATX}}$ goes high as thermal shutdown is triggered. Restart occurs as the device cools below 140°C, but shuts down repeatedly due to the persistent short.

CONCLUSION

The LTC4415 is an easy-to-use, high performance ideal-diode-OR solution for instantaneous power supply switchover. It requires as few as four external resistors and one output capacitor. The low power loss and status monitoring makes LTC4415 an obvious choice in applications requiring dual diodes with built-in protection features. LTC4415 is offered in both 3mm × 5mm 16-pin DFN and MSOP packages. ■

Single-IC Supercapacitor-Based Power Supply Backup Solution

Ashish Kirtania

Supercapacitors are used in an increasing number of applications that require a ready source of backup energy that can be called on to provide short-term power when regular input power is lost. In these applications, supercapacitors have a number of advantages over traditional energy storage devices such as batteries, including low maintenance requirements, virtually unlimited cycle life, and low effective series resistance. The LTC3226 simplifies the design of supercapacitor-powered backup application with a single-IC solution that charges the supercapacitor when input power is available, and then delivers energy from the supercapacitor to the load when nominal input power fails.

DESCRIPTION

Figure 1 shows a typical 3.3V backup supply application in which the main power path from the input source to the load goes through the external PFET. As long as input power is available, the LTC3226 maintains the supercapacitor stack at a full 5V charge. If the input voltage falls below 3.15V, the 1.2F supercapacitor stack becomes the supply, supporting a 2A load at 3.3V for 600ms (See Figure 2). Achieving a seamless transition from main supply to backup storage requires four principal

circuit components: a dual mode (1x/2x) charge pump with automatic cell balance and cell voltage clamp, an LDO to supply the load current during backup, an ideal diode controller to prevent the LDO from back-driving the input supply, and a power-fail comparator to detect the input voltage threshold below which a backup needs to be initiated.

The dual-mode constant-frequency (900kHz) low noise charge pump charges the supercapacitor stack to an externally

programmed target voltage. The input current to the charge pump is programmed by an external resistor between the PROG pin and GND. At the beginning of a charge cycle, when the CPO pin voltage is less than V_{IN} , the charge pump operates in 1x mode, acting like a pass element, and the charge current is approximately equal to the programmed input current. As the CPO pin voltage rises to within 200mV of V_{IN} , the charge pump enters 2x mode (voltage doubler) and the charge current drops to half of the programmed input current.

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Figure 1. 3.3V backup supply

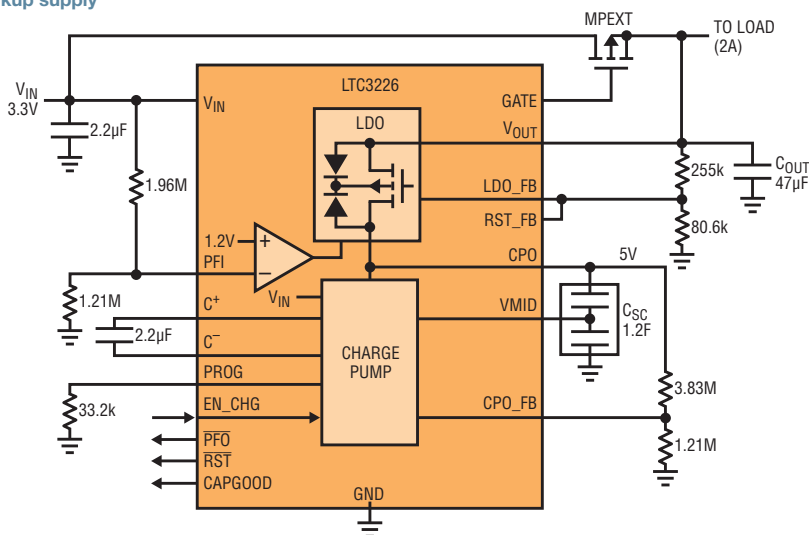
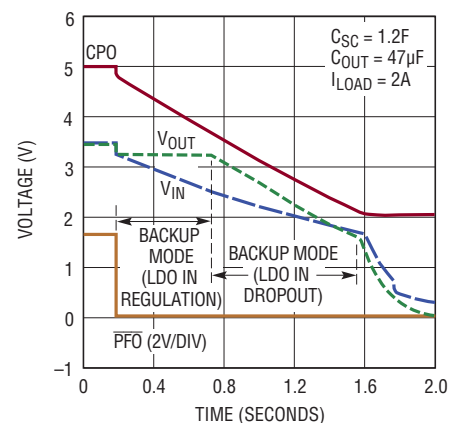


Figure 2. 3.3V backup supply timing diagram



μModule Converters Take the Hassle Out of Designing Isolated Power Supplies

David Ng

Sometimes a system needs a little bit of isolated power, but designing an isolated power supply is rarely easy. The nature of isolated supplies makes them complicated and touchy, resulting in late nights and long weekends spent on design and debug. The LTM8047 and LTM8048 μModule converters take the hassle out of designing isolated power supplies, placing a flyback regulator in a compact 9mm × 11.25mm × 4.92mm BGA RoHS compliant package. The controller, power switching and rectification elements, as well as transformer and isolated feedback circuitry are all integrated. Both parts operate from 3.1V to 32V inputs and produce over 1W of isolated power. The LTM8048 is identical to the LTM8047, but adds an integrated 300mA linear post regulator.

Designing with the LTM8047 and LTM8048 is easy. Figure 1 shows a complete LTM8047-based isolated power supply, requiring only the addition of capacitors for input, output, and biasing, and a resistor to set the output voltage. The LTM8048 requires only one more component: a resistor to set the voltage of the LDO output, as shown in Figure 2.

As is the case with most flyback converters, the output voltage can be above or below the input, accommodating a wide range of operating conditions. And, as is nature of flyback converters, the amount of current that the LTM8047 and LTM8048 can deliver depends on the input voltage. Figure 3 shows the load capability of a typical LTM8047 at 2.5V, 3.3V and 5V outputs. The LTM8048 features the same load capability.

The linear post regulator integrated into the LTM8048 is a high performance 300mA device, boasting a low dropout of less than 450mV at room temp, full load. As shown in Figure 4, the output noise and ripple of the post

Figure 1. The LTM8047 only requires four additional components to implement an isolated 5V power supply that accepts a 3.1V–29V input.

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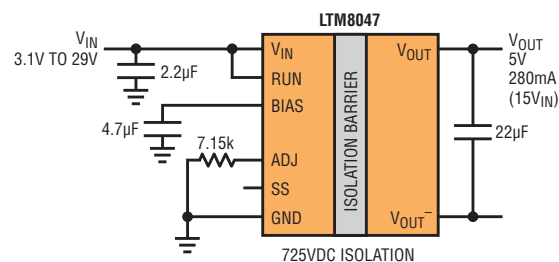


Figure 2. The LTM8048 is the LTM8047 with the addition of an LDO post regulator.

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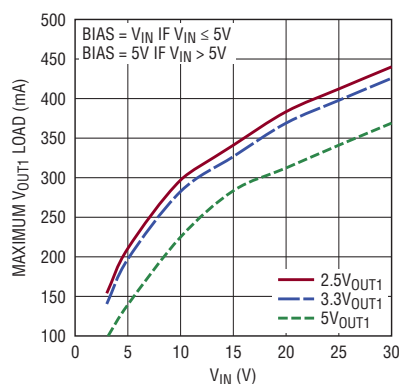
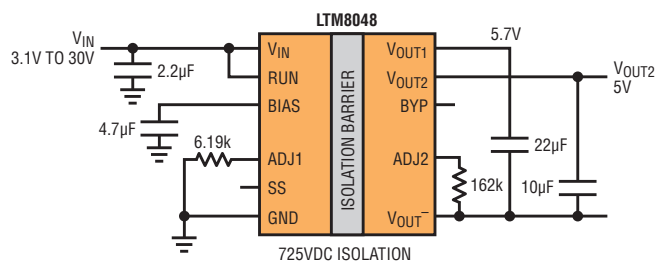


Figure 3. Maximum load capability of the LTM8047 and LTM8048 depends on the input voltage.

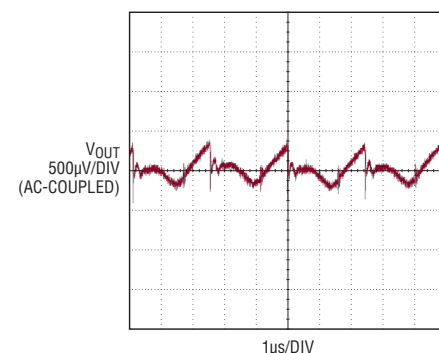


Figure 4. The output noise of the LTM8048 post regulator is less than 1mV.

The LTM8047 and LTM8048 are two flyback μ Module converters that can be used to produce more than 1W of isolated power from a small, easy-to-use, 9mm \times 11.25mm \times 4.92mm BGA package.

regulator is less than 1mV. These measurements were taken using a 150MHz HP-461A differential amplifier.

The LTM8047 and LTM8048 both integrate a transformer that is rated for 725VDC isolation. Every isolated μ Module converter is factory tested for 100% reliability, with 725V applied in one direction for one second, followed by the reverse voltage for one second.

For flexibility, there is no circuitry connected between the primary and secondary, so if a safety capacitor or other elements are required for a system, they can be added. This flexibility allows various configurations of the output. As shown in Figure 5, for example, two LTM8047s can be combined to deliver individually regulated positive and negative outputs.

CONCLUSION

The LTM8047 and LTM8048 are two flyback μ Module converters that can be used to produce more than 1W of isolated power from a small, easy-to-use, 9mm \times 11.25mm \times 4.92mm BGA package. The LTM8048 is nearly identical to the LTM8047, but with an integrated high performance post regulator. ■

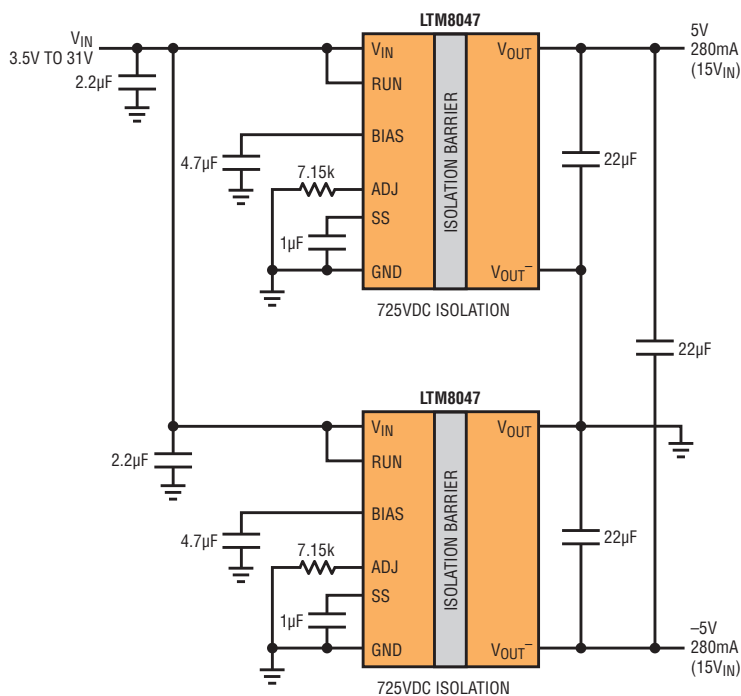


Figure 5. Use two LTM8047 converters to produce $\pm 5V$ from a 3.5V–31V input.

LTC3226, from page 38

One of the limitations of supercapacitors is low cell voltage, typically 2.7V, requiring a series connection of two cells for 5V applications. Since supercapacitors have more self-discharge due to leakage than most batteries, they require cell balancing to prevent overcharging of one of the series capacitors. The LTC3226 charge pump is equipped with an active balancer circuit, thus eliminating the need for external balancing resistors. However, since this balancer has limited source and sink capability, the charge pump is equipped with voltage clamp circuitry which constantly monitors cell

voltages during the charging process and prevents the cells from overcharging.

A fast comparator detects when the input voltage falls unacceptably low and enables the LDO which powers the load from the supercapacitors. This power-fail threshold is programmed by an external resistor divider via the PFI pin. The output of the PFI comparator drives an open-drain output on the \overline{PFO} pin to indicate the status of the input source. An external resistor divider to the LDO_FB pin sets the LDO output voltage.

CONCLUSION

The LTC3226 enables seamless supercapacitor-based power backup solutions by integrating the functions of a charge pump, an LDO and an ideal diode controller in a compact low profile 3mm \times 3mm 16-pin QFN package. Its low 50 μ A quiescent current and small footprint make it particularly suitable for battery powered applications, as well as 3.3V systems that require protection from short power interruptions. ■

Product Briefs

MULTIPHASE CURRENT MODE STEP-UP DC/DC CONTROLLER SUPPLIES 10V GATE DRIVE, RIDES THROUGH COLD CRANK

The LTC3862-2 is a high power multiphase current mode step-up DC/DC controller. Like its predecessors, the LTC3862 and LTC3862-1, the -2 uses a constant frequency, peak current mode architecture with two channels operating 180° out of phase. It retains popular features, including adjustable slope compensation gain, max duty cycle and leading edge blanking, programmable frequency with an external resistor (75kHz to 500kHz) or SYNC to an external clock with a phase-lockable fixed frequency of 50kHz to 650kHz. The PHASEMODE control pin enables 2-, 3-, 4-, 6-, or 12- phase operation.

The internal LDO regulates to 10V, the same as the LTC3861-1, optimizing the gate drive for most automotive and industrial grade power MOSFETs. But unlike the LTC3861-1, the undervoltage lockout (UVLO) falling threshold is reduced to 4V from the original 7V. UVLO shuts off the circuit when there is not enough gate drive. Lowering it provides compatibility with the most efficient 10V gate drive MOSFETs, while allowing the part to regulate even when the input voltage dips below 10V (as when an engine is turned on).

The LTC3862-2 also has improved current sense matching, channel-to-channel and chip-to-chip. Maximum current sense threshold matching is reduced from $\pm 10\text{mV}$ to $\pm 7.5\text{mV}$. This allows sharing of thermal dissipation more evenly between phases.

3.5A LiFePO₄ CHARGING SOLUTION WITH ADVANCED TELEMETRY

The LTC4156 is a 3.5A high power, high efficiency, monolithic charging solution designed for lithium iron phosphate cells. In addition to the rich feature set found on all Linear Technology lithium chargers, the LTC4156 includes extensive telemetry and configurability via a 2-wire I²C/SMBus port.

The LTC4156 features four I²C programmable float voltages between 3.45V and 3.8V tailored to the LiFePO₄ chemistry. The input current limit can be programmed via I²C or resistor to a USB-compliant value of 100mA, 500mA or 900mA, or up to 3A for high power wall adapter sources. A second circuit monitors the input voltage to the LTC4156 and reduces input current as necessary to maintain sufficient voltage when connected through undersized resistive cabling.

Charge current is programmed independently from input current, also through I²C or a resistor. For deeply discharged batteries, the LTC4156 supports instant-on operation to provide 3.2V to the system power rail immediately on application of external power.

The LTC4156 autonomously suspends charging when the cell temperature is beyond a fixed safety limit. For the LTC4156, the range has been extended to 0°C–60°C to take advantage of LiFePO₄ chemistry's increased tolerance to extreme operating conditions. The actual cell temperature is constantly measured by an integrated ADC converter and may be queried at any time via the I²C interface. Charge status, input power status, numerous fault conditions, and many other telemetry items are also constantly available to the system, either by polling or via an integrated programmable interrupt system.

Dual input power connectors, over-voltage protection, reverse voltage protection, and USB On-The-Go are all supported by the LTC4156 with minimal external components.

The LTC4156 is fully pin, component and I²C compatible with the related LTC4155 Li-ion/Li-polymer charger to facilitate painless cell chemistry changes without expensive retooling and requalification. The LTC4156 is available in a 28-lead 4mm × 5mm QFN surface mount package. ■

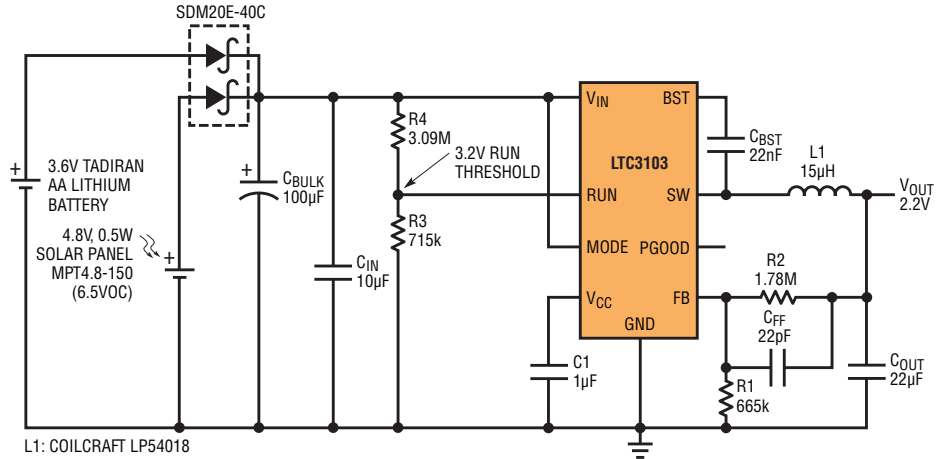
The LTC2960 is a nano-current high voltage monitor that provides supervisory reset generation and undervoltage or overvoltage detection. Low quiescent current (0.85µA) and a wide operating voltage range of 2.5V to 36V make the LTC2960 useful in multicell battery applications.

DEVICE OPTION	OUTPUT TYPE	INPUTS	RESET TIMEOUT PERIOD
LTC2960-1	36V Open Drain	ADJ/IN+	15ms/200ms
LTC2960-2	36V Open Drain	ADJ/IN-	15ms/200ms
LTC2960-3	Active Pull-up	ADJ/IN+	200ms
LTC2960-4	Active Pull-up	ADJ/IN-	200ms

SOLAR-POWERED 2.2V SUPPLY WITH Li-ION BATTERY BACKUP AND RUN THRESHOLD SET TO BATTERY MINIMUM VOLTAGE

The LTC3103 is a high efficiency, monolithic synchronous step-down converter using a current mode architecture capable of supplying 300mA of output current. Additionally, the LTC3103 includes an accurate RUN comparator, thermal overload protection, a power good output and an integrated soft-start feature to guarantee that the power system start-up is well controlled.

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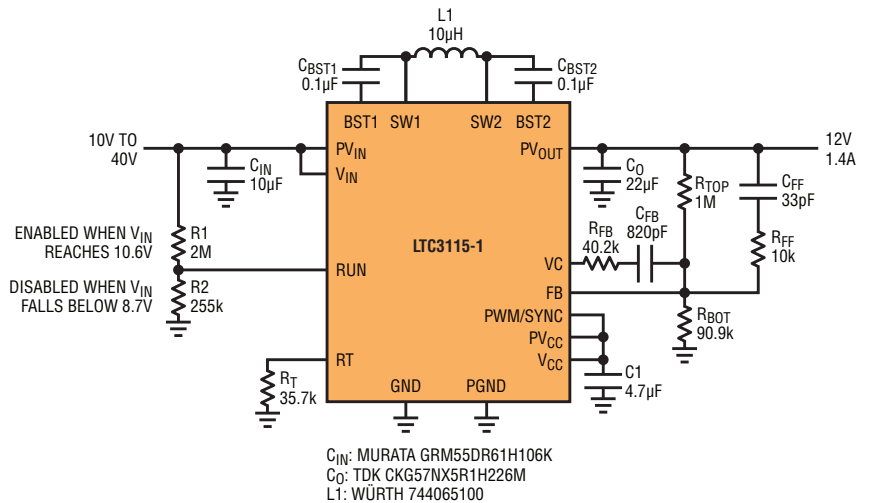


L1: COILCRAFT LP54018

INDUSTRIAL 12V 1MHZ REGULATOR WITH CUSTOM INPUT UNDERVOLTAGE LOCKOUT THRESHOLDS

The LTC3115-1 is a high voltage monolithic synchronous buck-boost DC/DC converter. Its wide 2.7V to 40V input and output voltage ranges make it well suited to a wide variety of automotive and industrial applications. A proprietary low noise switching algorithm optimizes efficiency with input voltages that are above, below or equal to the output voltage, ensuring seamless transitions between operational modes.

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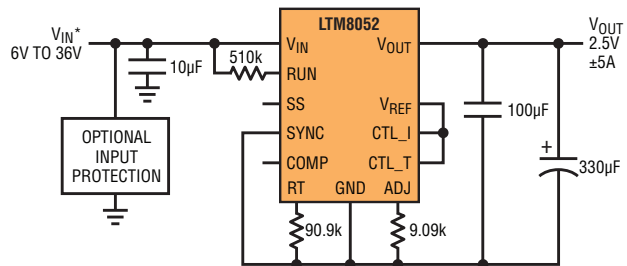


CIN: MURATA GRM55DR61H106K
 CO: TDK CKG57NX5R1H226M
 L1: WÜRTH 744065100

±5A, 2.5V (2-QUADRANT) µMODULE VOLTAGE REGULATOR

The LTM8052 is a 36VIN, 5A, 2-quadrant constant-voltage, constant-current step-down µModule regulator. Included in the package are the switching controller, power switches, inductor and support components. Operating over an input voltage range of 6V to 36V, the LTM8052 supports an output voltage range of 1.2V to 24V. The LTM8052 is able to sink or source current to maintain voltage regulation up to the positive and negative current limits.

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* INPUT VOLTAGE PROTECTION MAY BE NECESSARY WHEN THE LTM8052 IS SINKING CURRENT (SEE APPLICATIONS INFORMATION)

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