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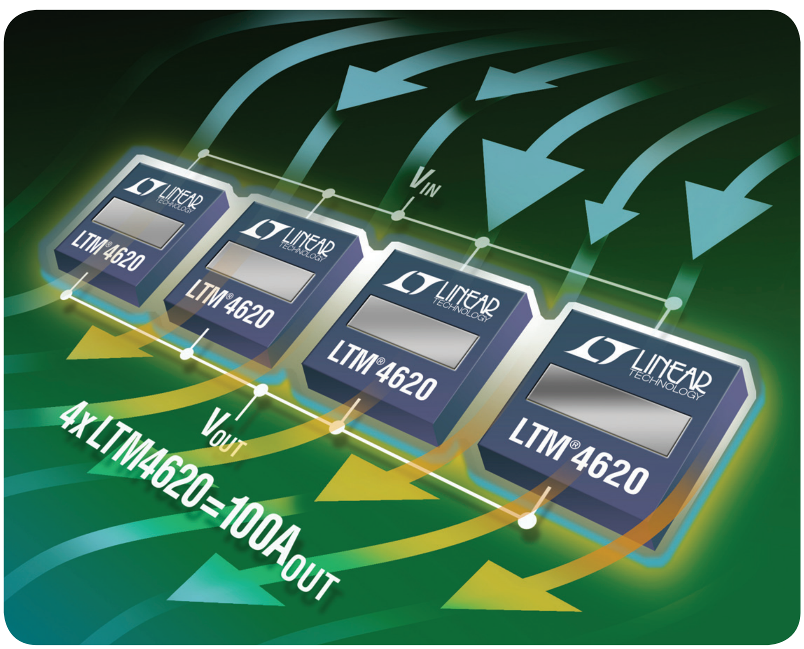
IN THIS ISSUE

Real Power Density: 26A µModule Regulator Keeps Cool in Tight Spaces

Eddie Beville

Each generation of high end processors, FPGAs and ASICs demands more power, but even as power supplies are expected to carry significantly heavier loads, they are given less board space to do so. It is now common for POL (point-of-load) supplies to produce multiple voltage rails at tens of amps to over a hundred amps at low, ≤1V, output voltages, and in less space than the generation before.



The LTM®4620 µModule® regulator enables high current power supplies to fit tight spaces. Thermal management is built into the package to prevent hot spots on the board, a common problem with POL power supplies.

Supplies that must support high load currents and fit in tight spaces are often judged primarily on their *power density*, or watts/cm². Indeed, many of the latest packaged power supplies and discrete solutions proclaim impressively high power densities—power supply manufacturers seem to be able to squeeze more and more power from smaller packages. Unfortunately, there is a big problem lurking behind amazing increases in power density. That problem is heat (see sidebar, page 4).

Heat dissipation is a significant problem at high currents and low voltages. In many systems, cranking up the power density actually compounds the problem, because more power in less space also pumps up the density of power losses—more *heat* in less space. It is not enough to simply squeeze a high power supply onto a board—the solution must also be carefully evaluated with regard to power loss and thermal resistance—two parameters that can make or break an otherwise good regulator. Claims of high power density can be

(continued on page 4)

Linear in the News

In this issue...

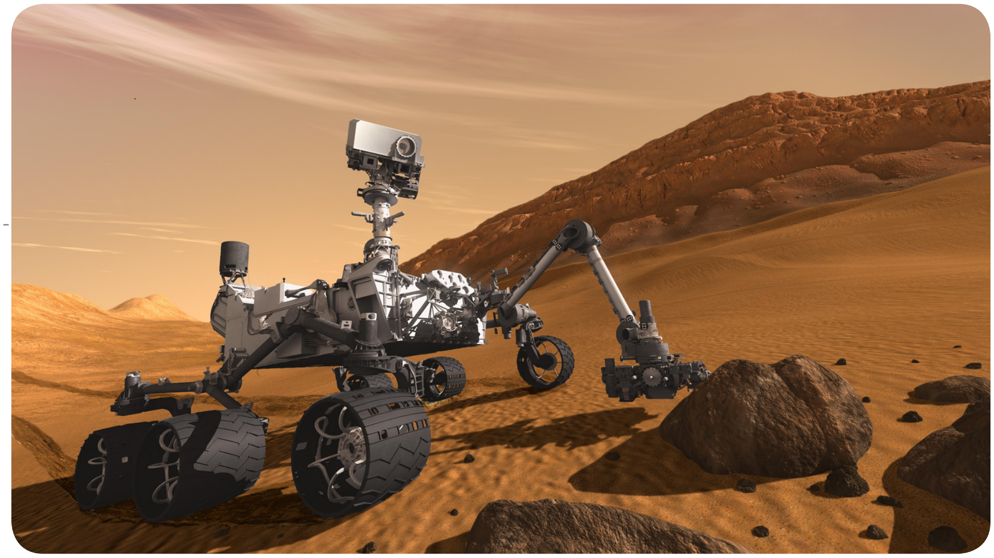
LINEAR ON MARS

The recent groundbreaking mission to Mars, launched by NASA's Jet Propulsion Laboratory (JPL), was powered in part by Linear Technology products. Linear's high performance analog semiconductors are used in the Mars Science Laboratory (Curiosity) rover to enable collection of vast amounts of data, including detailed visual images of the Martian landscape and precise readings to assist scientists in assessing the geology and history of Mars. NASA stated that the goal of the mission is to help determine whether Mars ever had conditions favorable for supporting life and whether life could have existed on the red planet.

The Linear Technology devices were selected for the Mars program based on their performance, precision and reliability, as well as their ability to survive the harsh environment in flight and on the Martian surface. Linear Technology products are used in the Mars Curiosity rover and in the spacecraft that delivered it to Mars. These include power switching regulators to deliver power to the rover instruments, analog to digital converters for camera motion control to allow the rover to "see" the Martian landscape and digitize the images for their long journey back to earth, and operational amplifiers to amplify signals to precise levels for accurate delivery of data on the composition of the red planet.

"We are proud to continue our 20-year partnership with the NASA Space program with the current Mars mission," stated Linear CEO Lothar Maier. "With over 200 Linear Technology devices in the current Mars expedition, we continue to provide analog products with the highest performance and reliability, whatever the operating conditions or application. As the breathtaking images and valuable data come back from Mars, we are honored to contribute to this historic effort."

In addition to the numerous Linear Technology devices in the current Mars Curiosity rover, Linear products were part of the Spirit and Opportunity rovers, which landed on Mars in 2004, as well as Mars Global Surveyor, Mars Pathfinder, Cassini, Deep Space 1, and Mars Odyssey. Linear Technology provides NASA/JPL with analog integrated circuits that demonstrate the highest performance, precision, and reliability in extremely small packages. Linear products were delivered in radiation hardened versions. Linear's expertise in high precision analog circuits provides enabling technology for the sophisticated scientific instruments and communications systems in the Mars rover and spacecraft.



LINEAR TECHNOLOGY DEVICES PROBE MARS
Linear Technology devices used in the Mars Curiosity rover include power switching regulators to deliver power to the rover instruments, ADCs for camera motion control to allow the rovers to "see" the Martian landscape and digitize the images for their long journey back to earth, and operational amplifiers to amplify signals to precise levels for accurate delivery of data on the composition of the red planet.

WIRELESS SENSOR NETWORK PRODUCTS ANNOUNCED

This month Linear is making the first formal announcement of products from the company's acquisition of Dust Networks®, a provider of low power wireless sensor network (WSN) technology. Dust Networks pioneered SmartMesh™ networks that comprise a self-forming mesh of nodes, or "motes," which collect and relay data, and a network manager that monitors and manages network performance and sends data to the host application. This technology is now the basis for a number of seminal networking standards. The hallmark of Dust Networks' technology is that it combines low power, standards-based radio technology, time diversity, frequency diversity and physical diversity—to assure reliability, scalability, wire-free power source flexibility and ease-of-use. All motes in a SmartMesh network—even the routing nodes—are designed to run on batteries for years, allowing the ultimate flexibility in placing sensors exactly where they need to go with low cost "peel and stick" installations.

Dust Networks' customers range from the world's largest industrial process automation and control providers such as GE and Emerson, to innovative, green companies such as Vigilent and Streetline Networks. Dust Networks' technology can be found in a variety of monitoring and control solutions, including data center energy management, renewable energy, remote monitoring and transportation.

Joy Weiss, President of Linear Technology's Dust Networks product group, stated, "Our primary goal is to enable our customers to confidently place sensors anywhere data needs to be gleaned, cost effectively and requiring minimum background in wireless networks. The advent of SmartMesh systems featuring Eterna™ and the addition of IP-enabled wireless sensor networks reflect Linear's continued commitment to that goal."

CONFERENCES & EVENTS

Energy Harvesting & Storage Conference, Hyatt Regency Crystal City at Ronald Reagan Washington National Airport, Washington, DC, November 7-8, 2012, Booths 4 & 9—Linear will showcase its Dust Networks wireless sensor network products as well as energy harvesting products. Linear's Joy Weiss will present "Low Power WSN Made Practical" and Jim Noon will speak on the topic, "Untapped Potential: Energy Harvesting Solutions." More info at www.idtechex.com/energy-harvesting-usa/eh.asp

Electronica 2012, Messe München, Munich, Germany, November 13-16, 2012, Hall A4, Booth 538—Linear will exhibit its broad range of analog products, with particular focus on industrial and automotive applications. More info at www.electronica.de/en/home

Wireless Congress Systems & Applications, International Congress Center, Munich, Germany, November 14–15, 2012—Joy Weiss, President of Linear's Dust Networks product group speaking on "Low Power Wireless Sensing" in Session 7a, Wireless Sensor Networks at 11:15 am, November 15. More info at www.wireless-congress.com

The Battery Show 2012, Suburban Collection Showplace, Novi, Michigan, November 13-15, 2012, Booth B664—Linear will show its battery stack monitor and power management products. Presentation by Mike Kultgen, "The Key Battery Management Electronics for Maximum Pack Performance," Sapphire/Ruby Ballroom, 3:30 pm, November 14. More info at www.thebatteryshow.com ■

Claims of high power density can be impressive, but high power density is meaningless if the heat produced by the supply is not effectively managed. The LTM4620 solves the *real* power density problem by squeezing a complete dual output regulator in a package uniquely designed to simplify thermal management.

(LTM4620, continued from page 1)

impressive, but the promises made by these claims are empty if the heat produced by the supply is not effectively managed.

The LTM4620 solves the *real* power density problem by squeezing a complete dual output regulator into a 15mm × 15mm × 4.41mm LGA package that is uniquely designed to minimize thermal resistance and thus simplify thermal management. The package includes an internal heat sink and other cutting edge features that yield effective top and bottom heat sinking, allowing it to run at maximum load currents, even in elevated temperature environments.

Figure 1 shows the LTM4620 15mm × 15mm × 4.41mm LGA package.

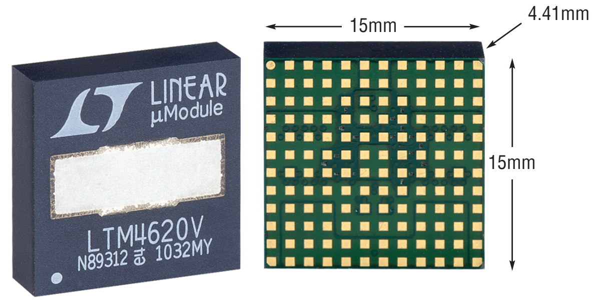


Figure 1. The LTM4620 LGA package includes thermal contacts on the top and bottom that connect to a unique internal heat sink, which keeps internal components cool by minimizing the internal thermal resistance.

A single device can deliver two independent outputs at 13A (Figure 4) or a single output at 26A (Figure 5). Multiple LTM4620s can be combined to produce from 50A to more than 100A (Figure 7).

The Real Cost of Power Density

PAY ATTENTION TO THE HEAT

Unwanted heat is a major challenge facing designers of high performance electronics systems. Modern processors, FPGAs, and custom ASICs dissipate increasing amounts of power as their temperature increases. To compensate for these power losses, power supplies must increase their power output. This, in turn, increases the power dissipation of the power supplies, contributing additional heat to an already hot system, and so on. Unless the heat is evacuated fast enough, the temperature of the entire system can elevate to the point where most components must be derated to compensate.

System and thermal engineers expend significant time and energy modeling and evaluating complex electronic systems to remove unwanted heat from the system. Fans, cold plates, heat sinks and even cooling bath submersion are all strategies that engineers have implemented to overcome the heat. Cooling size, weight, maintenance and cost become a significant portion of the engineering and manufacturing budget.

As systems add features and performance, the heat can only rise. Most processors and power supplies run about as efficiently as they can, and cooling systems are expensive mitigation. So simplification and cost savings must be found by improving power dissipation at the component level. The problem is that most compact packaged power solutions either dissipate too much power or their thermal resistance is too high—there is no way to effectively remove enough heat to operate them at elevated temperature without significant derating.

POWER DENSITY NUMBERS NOT AS IMPRESSIVE AS THEY APPEAR

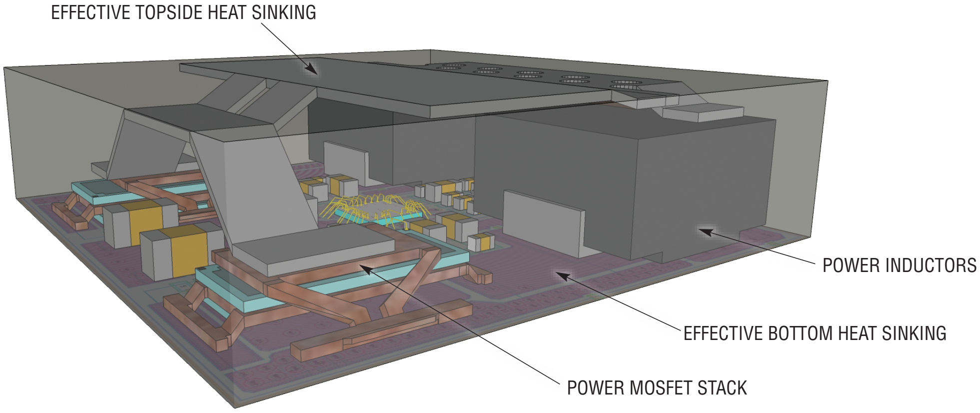
The term *high power density DC/DC regulator* is misleading because it does not address the behavior of the device with respect to temperature. System designers often look to satisfy a watts/cm^2 requirement, and power supply manufacturers are happy to oblige with impressive power density numbers. Even so, hidden in any device's data sheet are temperature-related values that can be more important than the quoted power density.

For example, consider a 2cm × 1cm DC/DC regulator that delivers 54W to a load. This calculates to an impressive rated power density of 27W/cm^2. This number *should* satisfy the power and size requirements of some designers. What's often forgotten, though, is power dissipation, which translates into rising board temperature. The key piece of information is listed in the data sheet as the DC/DC regulator's thermal impedance, including the values for the package's junction-to-case, junction-to-air and junction-to-PCB thermal impedances.

To continue with this example, this regulator has another attractive attribute: it operates at an impressive efficiency of 90%. Even at such high efficiency, it dissipates 6W while delivering 54W to the output in a package with 20ºC/W junction-to-air thermal impedance. Multiply 6W by 20ºC/W and the result is a 120ºC rise above the ambient temperature. At a 45ºC ambient temperature, the junction temperature of the package of this DC/DC regulator rises to 165ºC. This is far above the typical maximum temperature specified for most silicon ICs, which is roughly 120ºC. Using this power supply at its maximum rating would require extensive cooling to keep the junction temperature at a value below 120ºC.

Even if a DC/DC regulator addresses all of the electrical and power requirements of the system, if it fails to meet the basic thermal guidelines, or proves too costly when heat-mitigation measures are taken into account, all the impressive electrical specifications are moot. Evaluating the thermal performance of a DC/DC regulator can be as important as judging it on volts, amps and centimeters.

The internal power MOSFETs are stacked in a proprietary lead frame to produce high power density, low interconnect resistance, and high thermal conductivity to both the top *and* bottom of the device. Everything is topped off with a proprietary internal heat sink.



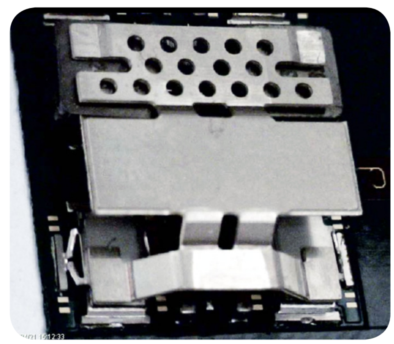


Figure 2. LTM4620 side view rendering and photo of an unmolded LTM4620 showing topside heat sink

UNIQUE PACKAGE DESIGN ACHIEVES TRUE HIGH POWER DENSITY

The LTM4620 is designed from the ground up to produce dual or single outputs at high power density with easy-to-manage thermal characteristics. Unlike other high power density solutions, it is truly self-contained, requiring no unwieldy heat sinks or liquid cooling to run at maximum load current.

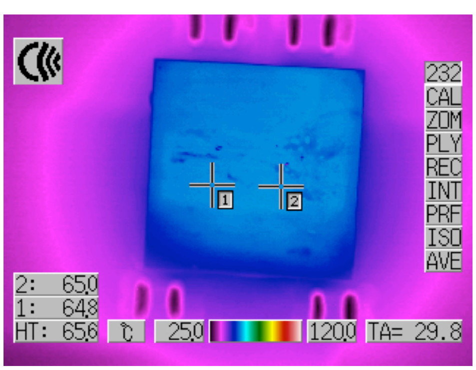
Figure 2 shows a side view rendering and a top view photo of an unmolded LTM4620. The package consists of a highly thermal conductive BT substrate with adequate copper layers for current carrying capacity and low thermal resistance to the system board. The internal power MOSFETs are stacked in a proprietary lead frame to produce high power density, low interconnect resistance, and high thermal conductivity to both the top *and* bottom of the device. Everything is topped off with a proprietary internal heat sink that attaches directly to the power MOSFET stacks and the power inductors for effective topside heat sinking.

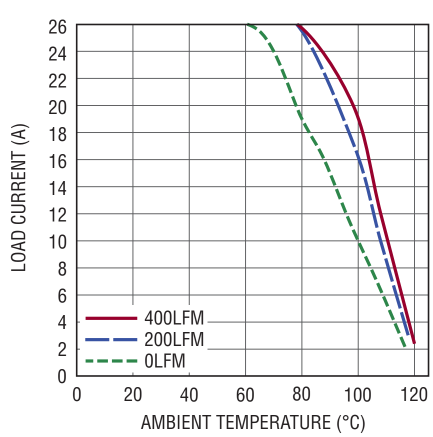
See it in Action

Go to video.linear.com/126 to see the impressive performance of the LTM4620. The videos here show real lab bench setup and measurement of short-circuit protection, thermal behavior and temperature rise at 26A and 100A, heat sink attachment and precision current sharing at start-up, steady state and shutdown.

The construction of the heat sink and the mold encapsulation keeps the part running cool even when thermal management is simply forced air flow across the top of the package. For a more robust solution, an external heat sink can be attached to the topside exposed metal for even better thermal management.

Figure 3. LTM4620 thermal image and derating curve





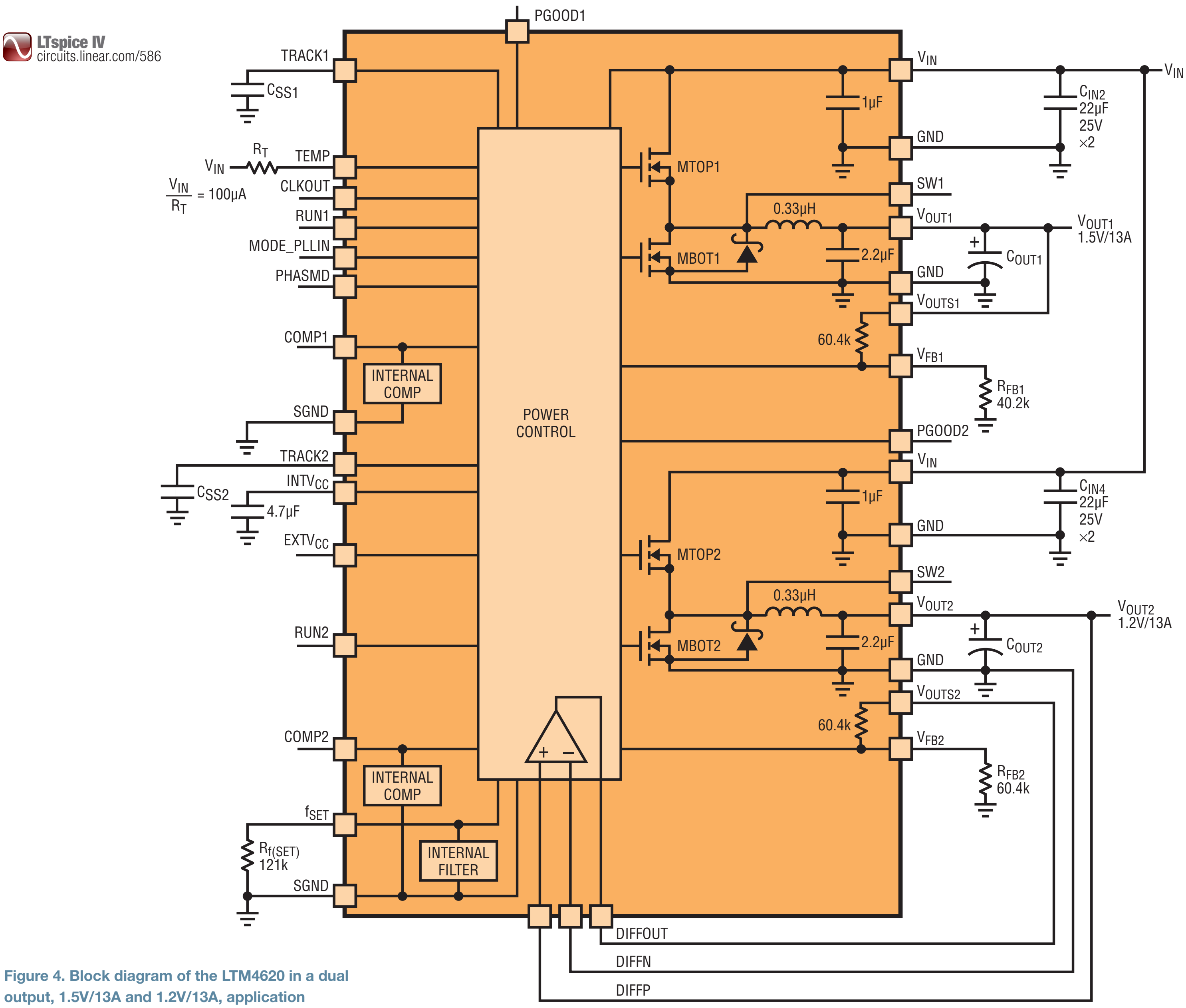


Figure 4. Block diagram of the LTM4620 in a dual output, 1.5V/13A and 1.2V/13A, application

Figure 3 shows a LTM4620 thermal image and a derating curve for a 12V to 1V at 26A design. The temperature rise is only 35°C above ambient with no heat sink and 200LFM of airflow. The derating curve shows that maximum load is available to ~80°C, well beyond the 65°C that the thermal image shows for the full-running part.

This result reveals the real merits of a thermally enhanced high density power regulator solution. The unique package design allows the part to not only produce high power in tight spots, but it can do so without contributing significantly to the heat problem or requiring derating. Few, if any other high power density solutions can make this claim without adding expensive heat-mitigating components and strategies.

DUAL 13A REGULATOR

Figure 4 shows a simplified block diagram of the LTM4620 μModule regulator in a dual output design. Its two internal high performance synchronous buck regulators produce 1.2V and 1.5V rails, each with 13A load current capability. The input voltage range is 4.5V to 16V.

The output voltage range of the LTM4620 is 0.6V to 2.5V, and 0.6V to 5.5V for the LTM4620A. Total output accuracy is ±1.5%, with 100% factory-tested accurate current sharing, fast transient response, multiphase parallel operation with self-clocking and programmable phase shift, frequency synchronization, and an accurate remote sense amplifier. Protection features include output

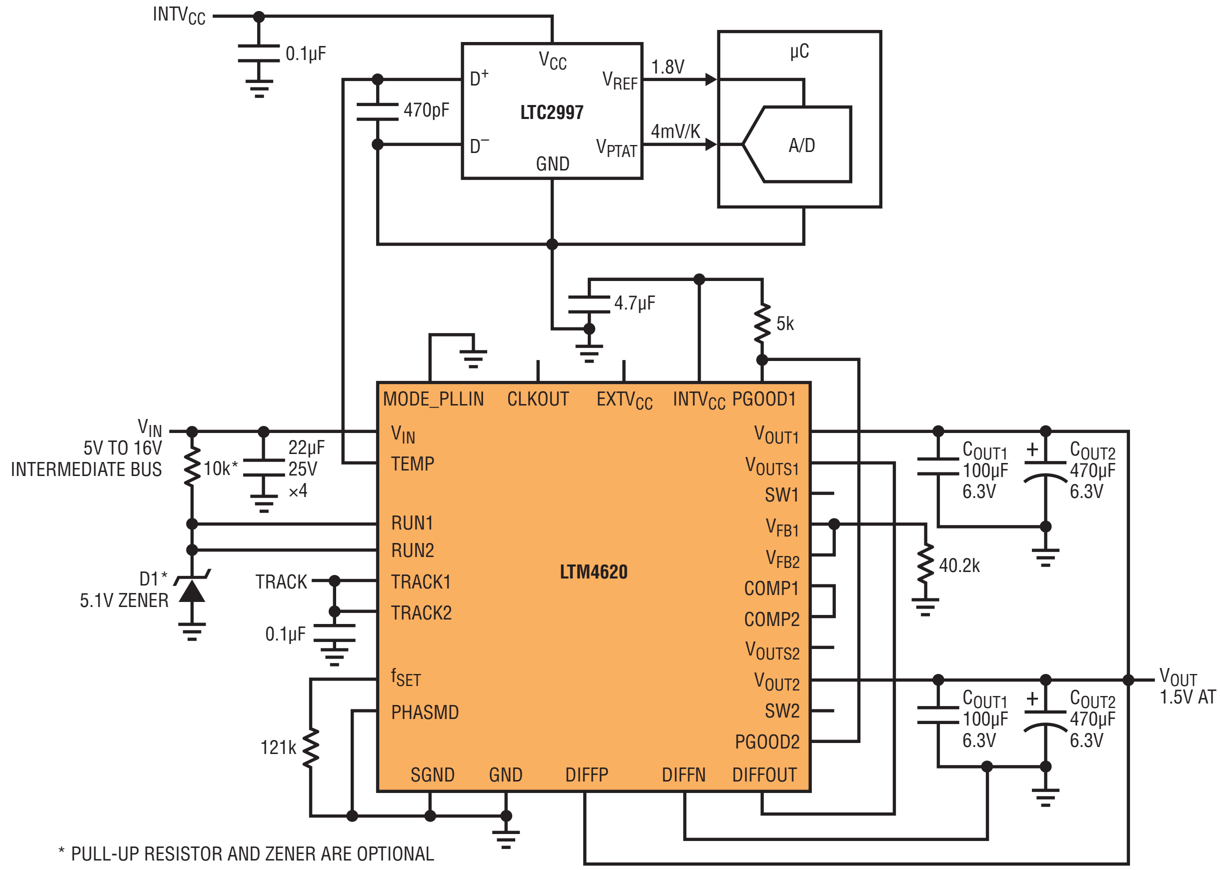


Figure 5. The two outputs of the LTM4620 can be tied together to produce a 2-phase, 2-parallel-channel, design that yields 1.5V at 26A. Internal diode temperature monitoring is provided through the LTC2997.

overvoltage protection feedback referred, foldback overcurrent protection, and internal temperature diode monitoring.

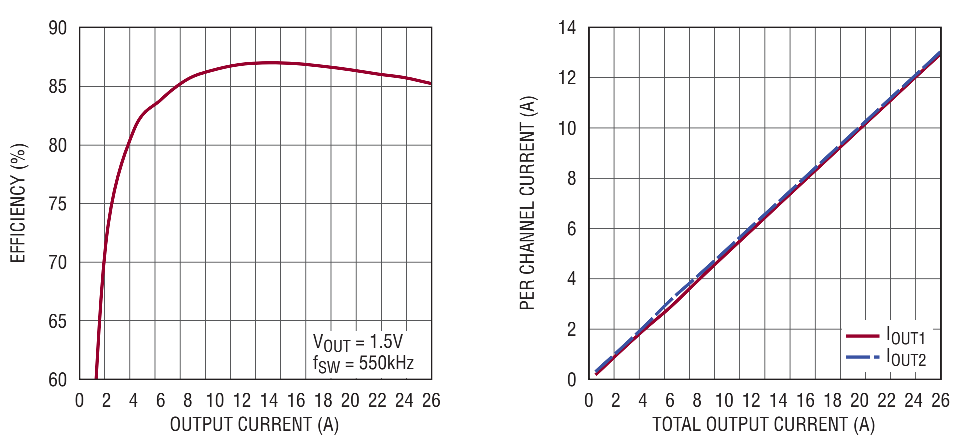
1.5V AT 26A IN 15mm² WITH EASY THERMAL MANAGEMENT

Figure 5 shows a 1.5V at 26A solution that combines the LTM4620's two output channels in a parallel 2-phase design. The RUN, TRACK, COMP, V_{FB}, PGOOD and V_{OUT} pins are tied together to implement parallel operation. This design also features a LTC®2997 temperature sensor that monitors the LTM4620's internal temperature diode.

Figure 6 shows the 1.5V efficiency for the 2-phase parallel output and the current sharing of the two channels. 86% efficiency is very good for such a high density, high step-down ratio solution, and thermal results are as good or better than the 1V solution shown in Figure 3. The temperature rise is well controlled due to the low θ_{JA} thermal resistance after board mount. Effective top and bottom heat sinking enables the LTM4620 to operate at full power with low temperature rise.

Figure 6 shows the well-balanced current sharing of V_{OUT1} and V_{OUT2}. The LTM4620's internal controller is accurately trimmed and tested for output current sharing.

Figure 6. Efficiency and current sharing of 2-phase, single output 26A design shown in Figure 5



The LTM4620 µModule regulator is a true high density power solution. It differentiates itself in a crowded field of "high power density" regulators because it manages heat, the fatal flaw for many proclaimed high density "solutions."

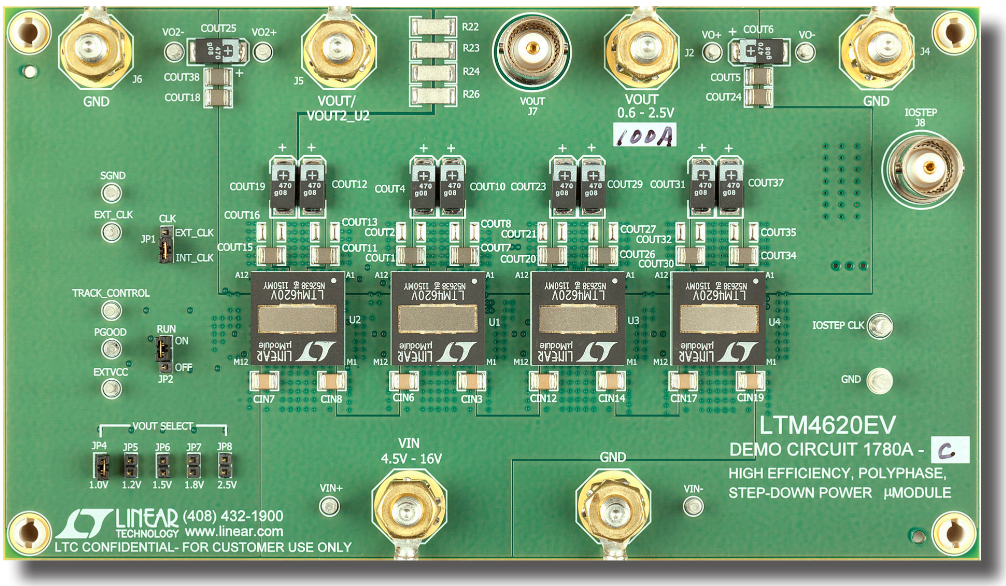


Figure 7. Four µModule regulators combined in an 8-phase parallel design support 100A

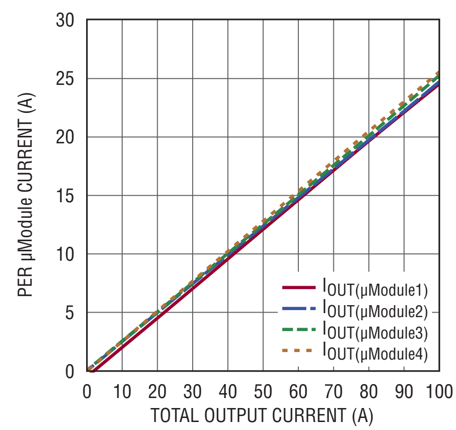


Figure 8. Current sharing for the four LTM4620s combined in a 100A design shown in Figure 7

The LTM4620's current mode architecture yields high efficiency and fast transient response—top requirements for low voltage core power supplies for high performance processors, FPGAs and custom ASICs. Outstanding initial output voltage accuracy and the differential remote sensing result in accurate DC voltage regulation at the load point.

The unique thermal capabilities of the LTM4620 and its tight current sharing capabilities make it possible to easily scale the output above 100A (see Figure 7). No external clock sources are needed to set up multiphase operation—the CLKIN and CLKOUT pins produce internal programmable phase shifting for paralleled channels. The LTM4620 supports either external frequency synchronization or internal onboard clocking.

REAL POWER DENSITY: 100A IN UNDER 50mm² WITH AIR COOLING

Figure 7 shows four µModule regulators combined in parallel to produce an 8-phase, 100A design. Figure 8 shows the balanced current sharing for all four regulators. As shown in Figure 7 the entire 100A solution only takes about 1.95 square inches of board space. Even at this high current, a simple heat sink and air flow can be applied across the top of all four modules to remove enough power loss to require no derating. Releasing heat out of the topside also helps keep the system board cool to minimize the heating effect on other components.

CONCLUSION

The LTM4620 µModule regulator is a true high density power solution. It differentiates itself in a the field of high power density regulators because it manages heat, the fatal flaw for many proclaimed high density solutions. It features two high performance regulators housed inside a superior thermal package, which makes possible high power designs that fit into tight spaces—with minimal external cooling. Built-in multiphase clocking and factory-tested accurate current sharing allow easy scaling of the output current to 25A, 50A, and 100A+. The LTM4620's unique thermal properties allow full power operation at elevated ambient temperatures. ■

Multiple Power Sources No Problem for 1A, Low Noise Buck-Boost Converter with 1.8V–5.5V Input Voltage Range

Genesia Bertelle

Users expect their portable devices to operate from a range of power sources including USB, wall adapters and various types of batteries—alkaline, lithium-ion and $LiFePO_4$. The LTC®3536 monolithic synchronous buck-boost converter easily accommodates a variety of power sources by efficiently operating in both buck and boost modes from an input voltage range of 1.8V to 5.5V. No complicated topology is required to accommodate power source inputs above, below or equal to the output.

The LTC3536 utilizes a proprietary switching algorithm that provides seamless transitions between buck and boost modes while simultaneously optimizing efficiency and minimizing noise over all operating conditions. This advanced control algorithm uses only a single inductor, which greatly simplifies the power supply design and minimizes the total PCB footprint. As a result, the LTC3536 easily fits lithium-ion/polymer, 2-3 cell alkaline/NiMH and lithium phosphate battery applications, which often require a supply voltage that is somewhere in the middle of the battery voltage range. In such cases, the high efficiency and extended input operating range of the LTC3536 offer greatly improved battery run time and design versatility.

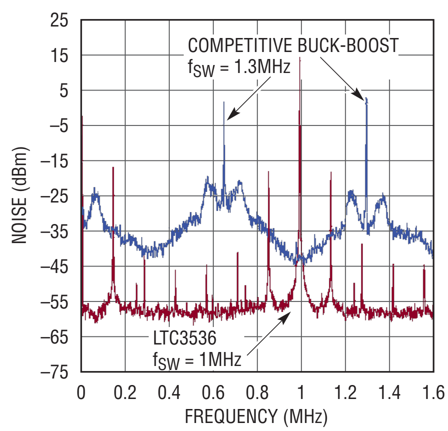


Figure 1. Worst-case spectral comparison of the LTC3536 and typical competitor's part. Note the much lower noise floor exhibited by the LTC3536 and its lower integrated subharmonic noise.

DESIGN VERSATILITY

At 3.3V output, a load current of up to 1A can be supported over the entire lithium-ion input voltage range; 300mA of load current is supported when the input is 1.8V. The 1% accurate output voltage is programmable from 1.8V to 5.5V via an external resistor divider.

The switching frequency of the LTC3536 is user programmable from 300kHz to 2MHz via a single external resistor, allowing the converter to be optimized to meet the space and efficiency requirements of each particular application. The default frequency is set to 1.2MHz by tying the RT pin to V_{IN}. The switching frequency can also be synchronized to an external clock applied to the MODE/SYNC pin. In case of synchronization, the free running frequency of the oscillator can be programmed slower or faster than the external clock frequency.

External resistors and capacitors provide compensation of the feedback loop, enabling the frequency response to be adjusted to suit a wide array of external components. This flexibility allows for rapid output voltage transient response regardless of inductor value and output capacitor size.

Depending on the application requirements, a designer can prioritize light load efficiency or minimize supply noise by choosing from two operating modes: Burst Mode® operation and PWM operation, which can be enabled via a dedicated pin.

Burst Mode operation is an efficient solution for low current conditions. It reduces the amount of switching to the minimum level required to support the load, thereby minimizing the power supply switching losses. Sometimes noise suppression is of higher importance and PWM operation, though not as efficient as Burst Mode operation at light loads, maintains a steady frequency, making it easier to reduce noise and RF interference. The output current capability in Burst Mode operation is lower than in PWM mode. Therefore, higher load current applications require that the MODE/SYNC pin be driven externally to enter PWM mode operation.

The LTC3536 includes robust V_{OUT} short circuit protection. If V_{OUT} is shorted to ground, the inductor current decays very slowly during a single switching cycle. During a short-circuit condition, the LTC3536 reduces its peak current limit

The LTC3536 utilizes a proprietary switching algorithm that provides seamless transitions between buck and boost modes while simultaneously optimizing efficiency and minimizing noise over all operating conditions. This advanced control algorithm uses only a single inductor, greatly simplifying power supply design and minimizing the total PCB footprint.

to a safe level and forces the device to enter PWM mode, guaranteeing a smooth recovery when the output short is released.

NOISE PERFORMANCE

Many applications are sensitive to noise generated by switching converters. The LTC3536 uses a low noise switching architecture to reduce unwanted subharmonic frequencies. Subharmonic noise or jitter is difficult to filter and can interfere with other sensitive circuitry, and is most prominent when V_{IN} and V_{OUT} are approximately equal. Some buck-boost converters operating in this region produce pulse-width and frequency jitter. The LTC3536 employs Linear Technology's latest generation buck-boost PWM modulation circuitry, which dramatically minimizes jitter, satisfying the demanding requirements of noise-sensitive RF applications.

Figure 1 shows worst-case spectral comparisons of the LTC3536 (switching frequency 1MHz) and a competitive buck-boost converter (switching frequency 1.3MHz) that does not feature the low noise architecture of the LTC3536.

The worst-case condition is achieved by placing a fixed 1A load on the output and slowly increasing or decreasing the input voltage until the highest harmonic content in the converter spectrum was observed.

The LTC3536 exhibits the expected single large magnitude tone at its switching frequency of 1MHz, but note that the total integrated noise is very low when compared to the competition.

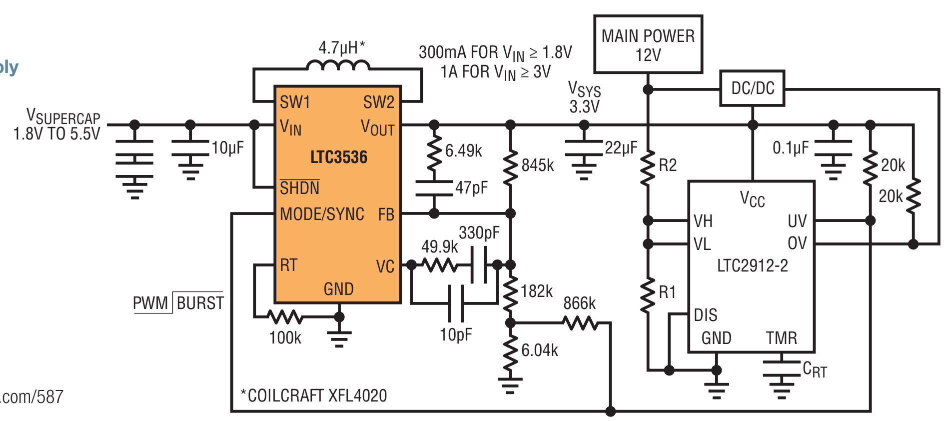
Remember, this test is specifically designed to produce absolute worst-case subharmonic peaks for the LTC3536—if the input voltage is slightly higher or lower, the magnitudes of the subharmonics are much smaller. In contrast, in the competing buck-boost, there is less reduction in subharmonic content over a much wider input voltage range. Also, it exhibits a much higher noise floor than the LTC3536, indicative of significant pulse-width jitter and potential noise interference issues.

SUPERCAPACITOR BACKUP POWER

The LTC3536 includes a soft-start circuit to minimize the inrush current transient during power-up. If at start-up the output voltage is already pre-charged, the internal soft-start is skipped and the LTC3536 immediately enters the mode of operation that has been set on the MODE pin. If the MODE pin is tied high and Burst Mode operation is selected, the output voltage is regulated smoothly to the target voltage value without discharging the output.

This feature makes the LTC3536 ideal for supercapacitor-powered backup power supply systems, as shown in Figure 2. In this application, two series of supercapacitors are charged to 5V during normal operation to provide the needed backup energy in case the primary power fails. As long as the primary power is present, the LTC3536 remains in Burst Mode operation with very low quiescent current, minimizing drain on the backup storage capacitor. The MODE pin is used to change from Burst Mode to PWM mode operation when primary power is interrupted.

Figure 2. Supercapacitor-based backup power supply



LTspice IV
circuits.linear.com/587

The LTC3536 maintains an accurate output voltage with input voltages above or below the output. Its programmable switching frequency and internal low $R_{DS(ON)}$ power switches, in combination with low noise architecture, enable the LTC3536 to offer high performance, compact and highly efficient solutions.

Figure 3. Solar panel application

LTspice IV circuits.linear.com/588

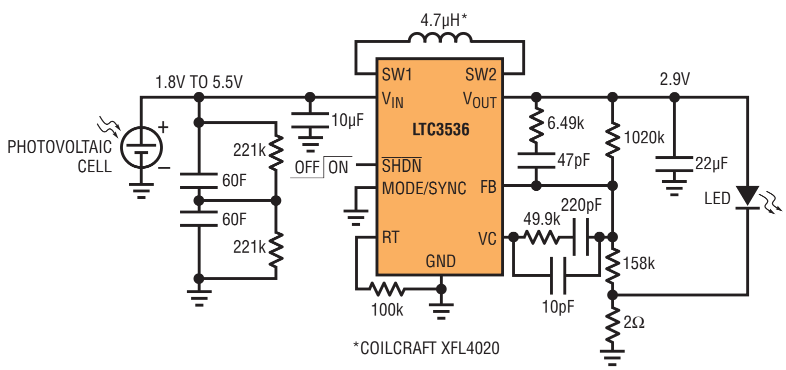
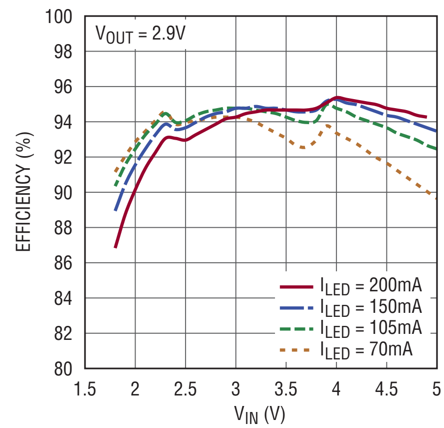


Figure 4. Efficiency of the solar panel application in Figure 3



LTC3536 in backup mode can provide a regulated 3.3V at a constant 1A load for input voltages higher than 3V, and it can operate down to V_{IN} at 1.8V at a constant 300mA, while maintaining V_{OUT} at 3.3V. By covering the voltage range of the supercapacitor, the supply maximizes operating time, allowing systems enough time to recover or perform housekeeping tasks before shutting down.

SOLAR-POWERED LED DRIVER

The power generated by a solar cell varies significantly with lighting conditions. So a rechargeable storage device, such a supercapacitor, is required to provide continuous power when the solar cell is insufficiently illuminated. Although it has much less charge storage capacity compared to a battery, a supercapacitor requires significantly less maintenance, is easy to charge and its cycle lifetime is orders of magnitude longer than a battery.

The storage device can be combined with the LTC3536 buck-boost DC/DC converter, which is designed to simplify the task of harvesting and managing energy from low input voltage such as photovoltaic cells. LTC3536 can work down to input voltages as low as 1.8V, and provides very high efficiency over a wide range of input voltages above or below the output voltage.

Figure 3 shows an application for an LED driver supplied with a solar cell for an emergency LED torch. When the torch is off, the LTC3536 is in shutdown. The quiescent current of less than 1µA minimizes supercapacitor drain when the ambient light is no longer available.

When the LED torch is switched on, the LTC3536 is turned on via the $\overline{\text{SHDN}}$ pin to supply 105mA constant load current to the LED. Figure 4 shows the high efficiency of this supply, enabling a slow discharge of the two series 60F capacitors down to 1.8V. The LTC3536 regulates the output and the LED current, guaranteeing light for 14 minutes if the supercap is charged up to 5V. It is possible to extend this time by increasing the supercap value or using a battery with an adequate charge control.

CONCLUSION

The LTC3536 maintains an accurate output voltage with input voltages above or below the output. Its programmable switching frequency and internal low $R_{DS(ON)}$ power switches, in combination with low noise architecture, enable the LTC3536 to offer high performance, compact and highly efficient solutions. ■

Surge Stopper with Ideal Diode Protects Input and Output

Zhizhong Hou

Power systems in automobile and industrial applications must cope with short duration high voltage surges, maintaining regulation at the load, while protecting sensitive circuitry from dangerous transients. One common protection scheme involves a series iron core inductor and high value electrolytic bypass capacitor, augmented by a high power transient voltage suppressor (TVS) and fuse. This heavy-handed approach takes significant board real estate—the bulky inductor and capacitor are often the tallest components in the system. Even this protection scheme cannot protect against reverse input potentials or supply brownouts—possible scenarios in automotive environments. To protect against these events and maintain the output voltage, designers add a blocking diode, but the additional voltage drop in the diode increases power losses.

The LTC4364 is a complete control solution for load protection and output holdup in a small footprint, eliminating bulky components and undesirable voltage drops. Figure 1 shows a functional block diagram of the LTC4364. The part drives two back-to-back N-channel pass transistors: one protects against voltage surges and maintains a regulated voltage to the output (M1 in Figure 1), while the other acts as an ideal diode for reverse input protection and output holdup (M2 in Figure 1).

The LTC4364 also guards against overloads and short circuits, withstands output voltage reversal, holds off the MOSFETs in input undervoltage conditions and inhibits turn-on or auto-retry in input overvoltage conditions. A shutdown mode reduces the supply current to as low as 10µA.

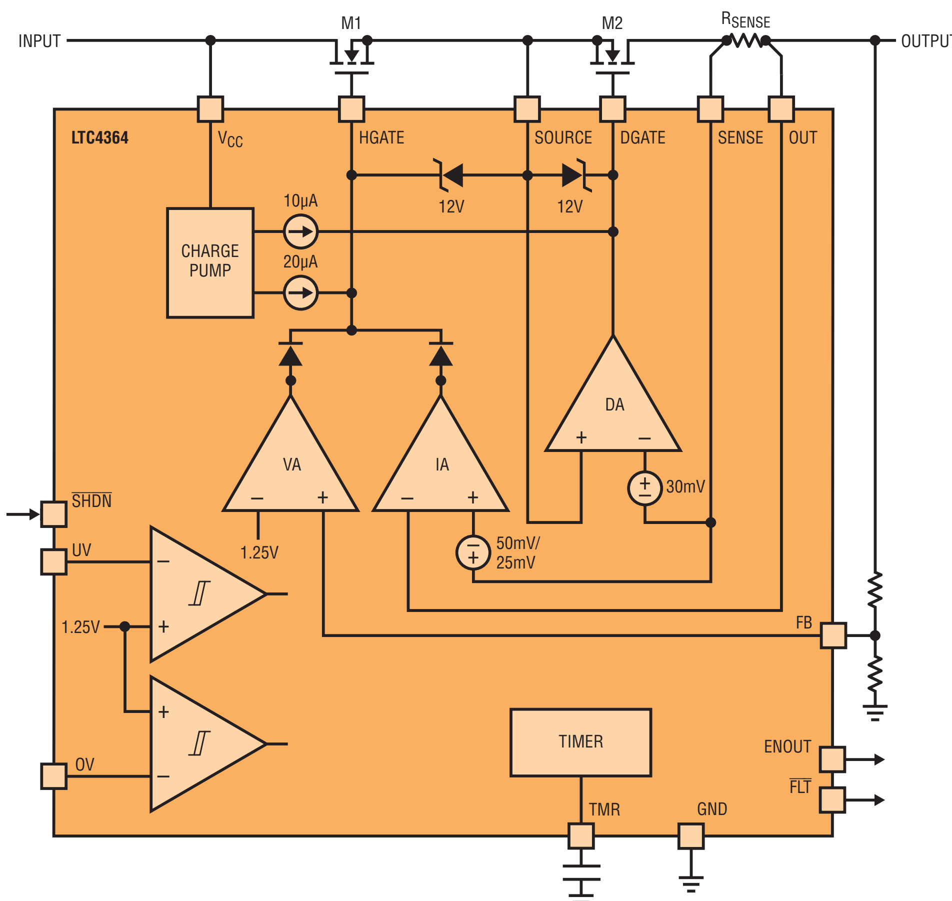


Figure 1. Simplified block diagram of the LTC4364

The LTC4364 is a complete control solution for load protection and output holdup in a small footprint, eliminating bulky components and undesirable voltage drops.

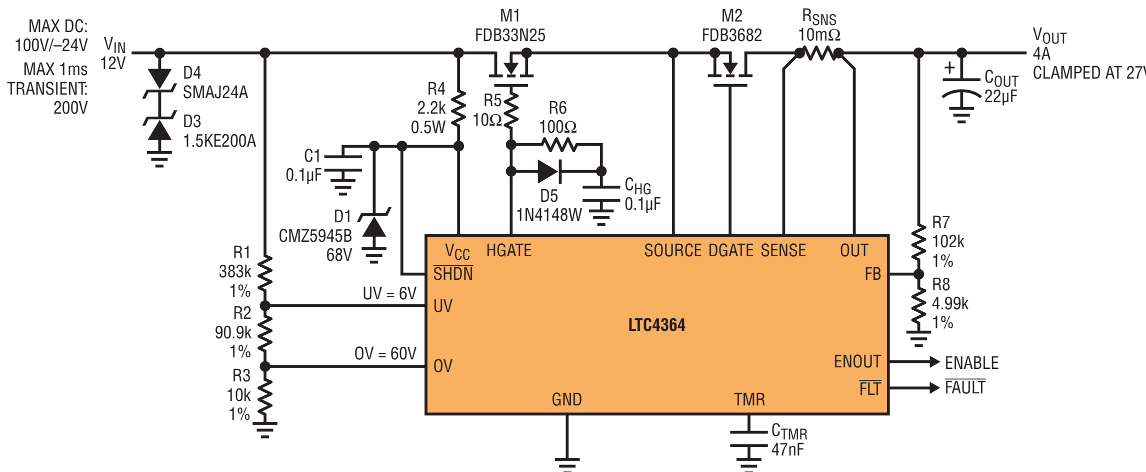


Figure 2. Surge stopper with reverse current protection withstands 200V/–24V transients at V_{IN}.

ADVANCED SURGE STOPPER WITHSTANDS HIGHER VOLTAGES AND ENSURES SAFE OPERATION

Figure 2 shows a typical application of the LTC4364. Under normal operating conditions, the LTC4364 drives the surge stopper N-channel MOSFET (M1) fully on and regulates the V_{DS} of the ideal diode N-channel MOSFET (M2) to 30mV so that the voltage drop from the input supply to the load circuitry is minimized. Once V_{OUT} rises to 0.7V below V_{IN}, the ENOUT pin goes high to activate the load circuitry.

During an input voltage surge, the LTC4364 regulates the HGATE pin, clamping the output voltage through MOSFET M1 and a resistive divider so that the FB pin voltage is maintained at 1.25V. The load circuit continues to operate, with little more than a modest increase in supply voltage as illustrated in Figure 3.

In the case of a current overload, the LTC4364 limits the output current through M1 so that the voltage across the SENSE and OUT pins is maintained at 50mV (when OUT > 2.5V). For a severe output short when OUT is below 1.5V, the current limit sense voltage folds back to 25mV for additional protection of the MOSFET (Figure 4).

The timer capacitor ramps up whenever output limiting occurs (either overvoltage as shown in Figure 5 or overcurrent). If the condition persists long enough for the TMR pin to reach 1.25V, the FAULT pin goes low to give early warning to downstream circuitry of impending power loss. At 1.35V the timer turns off the MOSFETs and waits for a cooldown interval before attempting to restart.

The LTC4364 monitors voltage across the MOSFET and shortens the turn-off timer interval in proportion to increasing $V_{CC} - V_{OUT}$. In this way a highly stressful

Figure 3. The LTC4364 regulates output at 27V while load circuit continues to operate in the face of a 92V input spike.

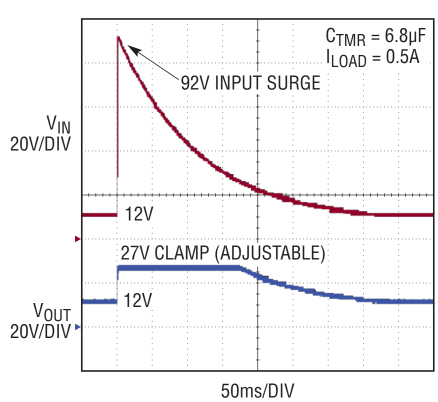
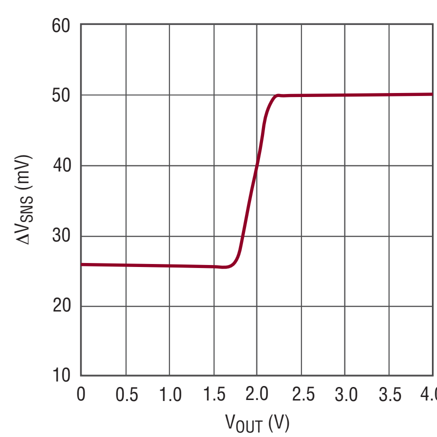


Figure 4. A 2:1 foldback of current limit reduces MOSFET stress upon severe output short.



An important feature of the LTC4364 is that a current limiting device such as a resistor can be placed between the input supply and the V_{CC} pin. Now supply transients at the V_{CC} pin can be either filtered with a capacitor or clamped by a Zener diode. If a proper MOSFET is selected, this scheme makes it possible to withstand supply transients much higher than 100V.

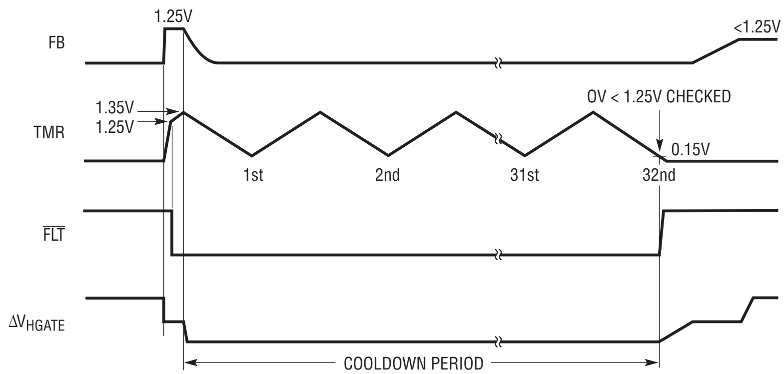


Figure 5. The LTC4364-2 auto-retry timer sequence following an overvoltage fault provides a very long cooldown period (0.1% duty cycle).

output short-circuit condition lasts for a shorter time interval than a brief, minor overload, helping ensure the MOSFET operates within its safe operating area.

The LTC4364 features a very low restart duty cycle of about 0.1% in either overvoltage or overcurrent conditions, ensuring the MOSFET cools down before restarting following a turn-off caused by fault. Figure 5 demonstrates the auto-retry timer sequence of the LTC4364-2 following an overvoltage fault.

An important feature of the LTC4364 is that a current limiting device such as a resistor (R4 in Figure 2) can be placed between the input supply and the V_{CC} pin. Now supply transients at the V_{CC} pin can be either filtered with a capacitor (C1 in Figure 2) or clamped by a Zener diode (D1 in Figure 2). If a proper MOSFET M1 is selected, this scheme makes it possible to withstand supply transients much higher than 100V. The circuit in Figure 2 can withstand supply transients up to 200V.

Figure 6. Input UV and OV monitors can be configured to block start-up into an overvoltage condition.

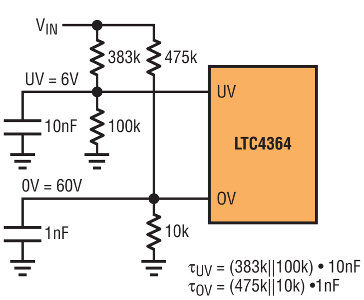
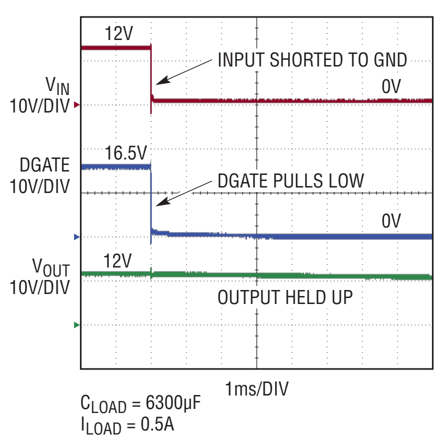
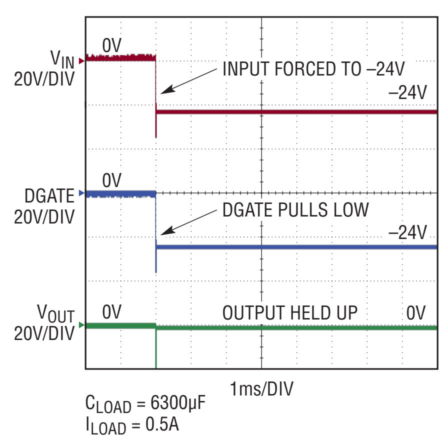


Figure 7. LTC4364 input protection:
a. Upon an input short or brownout, the DGATE pin pulls low, shutting down the ideal diode MOSFET and holding up the output voltage.



b. In reverse input conditions, the DGATE pins pulls to the SOURCE pin, keeping the ideal diode MOSFET off and cutting off back feeding.



The LTC4364 also guards against overloads and short circuits, withstands output voltage reversal, holds off the MOSFETs in input undervoltage conditions and inhibits turn-on or auto-retry in input overvoltage conditions. A shutdown mode reduces the supply current to as low as 10µA.

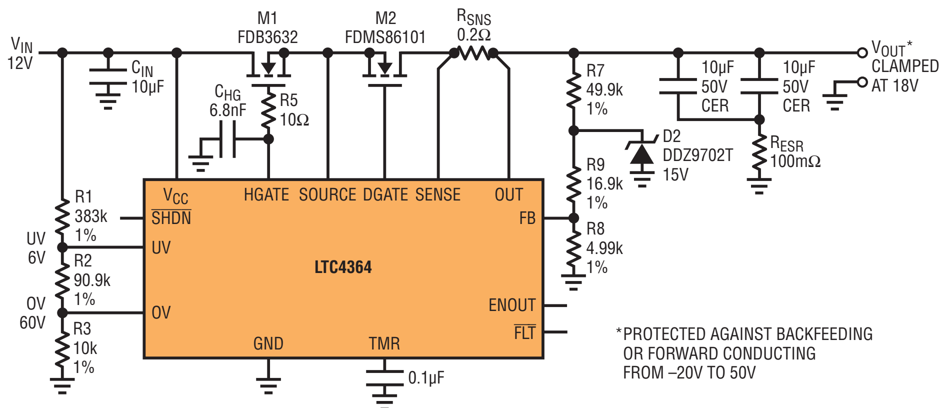


Figure 8. LTC4364 offers built-in output port protection against overvoltage, short or reverse voltage.

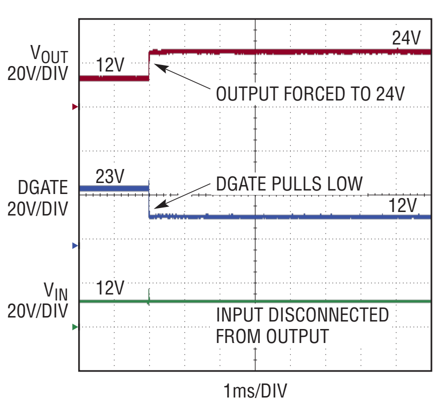
INPUT VOLTAGE MONITORING PREVENTS UNWANTED TURN-ON

The LTC4364 detects input undervoltage conditions such as low battery using the UV pin, and keeps the MOSFETs off if the UV pin voltage is below 1.25V. The LTC4364 also monitors input overvoltage conditions and holds off the MOSFETs for start-up or restart following an output fault condition.

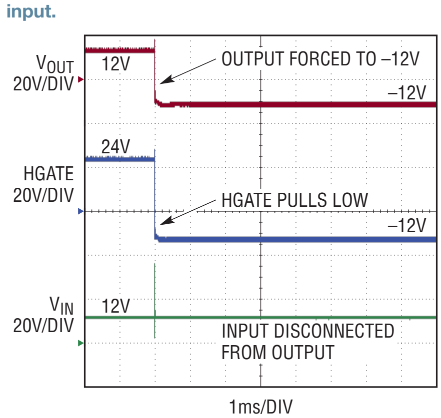
At power-up, if the OV pin voltage is higher than 1.25V before the 100µs power-on-reset delay expires, or before the UV pin voltage rises above 1.25V, the MOSFETs remain off until the OV pin voltage drops below 1.25V. This feature allows prevention of start-up when a board is inserted into an overvoltage supply by using two separate resistive dividers with appropriate filtering capacitors for the OV and UV pins (Figure 6).

After start-up, under normal conditions, a subsequent input overvoltage condition does not turn off the MOSFETs, but rather blocks auto-retry following an output fault. If the OV pin voltage is above 1.25V when the cooldown timer cycle ends following a fault, the MOSFETs remain off until the input overvoltage condition is cleared.

Figure 9. LTC4364 output port protection:
a. When output is forced above input, the DGATE pin pulls low to cut off back feeding.



b. When output is forced below the GND potential, the HGATE pin pulls to the SOURCE pin, cutting off forward conduction and saving battery power at input.



IDEAL DIODE PROTECTS AGAINST REVERSE INPUT AND BROWNOUT WITH MINISCULE VOLTAGE DROP

To protect against reverse inputs, a Schottky blocking diode is often included in the power path of an electronic system. This diode not only consumes power but also reduces the operating voltage available to the load circuitry, particularly significant with low input voltages, such as during an automotive cold crank condition. The LTC4364 eliminates the conventional Schottky blocking diode and its voltage and power losses by including

The LTC4364 is a compact and complete solution to limit and regulate voltage and current to protect sensitive load circuitry against dangerous supply transients, including those over 100V.

the DGATE pin to drive a second, reverse-connected MOSFET (M2 in Figure 2).

In normal operating conditions, the LTC4354 regulates the forward voltage drop (V_{DS} of M2) to only 30mV. If the load current is large enough to result in more than a 30mV forward voltage drop, M2 is driven fully on and its V_{DS} is equal to $R_{DS(ON)} \bullet I_{LOAD}$.

In the event of an input short or a power supply failure, reverse current temporarily flows through M2. The LTC4364 detects the reverse voltage drop and immediately turns off M2, minimizing discharging of the output reservoir capacitor and holding up the output voltage. Figure 7a shows the result of a 12V input supply shorted to ground. The LTC4364 responds to this condition by pulling the DGATE pin low, cutting off the reverse current path so the output voltage is held up.

In a reverse battery connection, the LTC4364 shorts the DGATE pin to the SOURCE pin (that follows the input) without the need of external components, keeping M2 off and disconnecting the load circuitry from the input as shown in Figure 7b. The V_{CC}, $\overline{SHDN}$, UV, OV, HGATE, SOURCE and DGATE pins can all withstand up to 100V above and 40V below the GND potential.

BUILT-IN OUTPUT PORT PROTECTION

When the output is on a connector as shown in Figure 8, it could experience overvoltage, short-circuit or reverse voltage. The LTC4364 protects the load circuitry and input supply against those conditions with several features:

- If the output port is plugged into a supply that is higher than the input, the ideal diode MOSFET M2 turns off to cut the back feeding path open as shown in Figure 9a.
- If the output port is shorted to ground, the HGATE pin first regulates the forward current to the current limit and then turns off MOSFET M1 if the fault times out.
- If a reverse supply is applied to the output port, the LTC4364 turns off the pass MOSFET M1 once the OUT pin voltage drops below the GND potential, cutting the forward conducting current path open and avoiding battery drainage at the input.

Figure 9b shows the result when a –12V supply is applied to the output. The LTC4364 immediately shorts the HGATE pin to the SOURCE pin (that follows output), turning MOSFET M1 off so the input supply is disconnected from the faulty output.

The OUT and SENSE pins of the LTC4364 can withstand up to 100V above and 20V below the GND potential. For applications where the output port could be forced below ground, ceramic bypass capacitors with proper voltage ratings should be used at the output to stabilize the voltage and current limiting loops and to minimize capacitive feedthrough of input transients (see Figure 8). A low leakage diode (D2 in Figure 8) should be used to protect the FB pin.

CONCLUSION

The LTC4364 is a compact and complete solution to limit and regulate voltage and current to protect sensitive load circuitry against dangerous supply transients, including those over 100V. It is an easy-to-implement, high performance alternative to the traditionally bulky protection circuits in automotive and industrial systems.

The LTC4364's integrated ideal diode driver holds up output voltage during input short, supply brownout, or reverse input while cutting the voltage loss associated with blocking diodes. The built-in output port protection is useful when the output is on the connector side. Its feature set is rounded out by input UV and OV monitoring and a low current shutdown mode. ■

DC/DC Controller Combines Digital Power System Management with Analog Control Loop for ±0.5% V_{OUT} Accuracy

Hellmuth Witte

The LTC3883/-1 is a versatile, single channel, PolyPhase® capable, buck controller with digital power system management, high performance analog control loop, on-chip drivers, remote output voltage sensing and inductor temperature sensing. To minimize solution size and cost, the LTC3883/-1 features Linear's patent pending auto-calibration routine to measure the DC resistance of the inductor to obtain accurate output current measurements when the cycle-by-cycle current is measured across the inductor (lossless DCR sensing). The LTC3883/-1 is based on the popular dual channel LTC3880/-1, described in the January 2012 issue of *LT Journal*.

DIGITAL POWER MANAGEMENT

In today's data center systems the challenge is to "go green" by becoming as efficient as possible at all levels of the system—including the point of load, the board, rack and even installation levels. For instance, overall system power consumption can be reduced by routing the workflow to as few servers as possible, shutting down servers that are not needed at the time. The only way to do this and meet system performance targets (compute speed, data rate, etc.) is to implement a comprehensive digital power management system that monitors real-time power-consumption data at all levels.

In the past, designers have cobbled together digital power management solutions using a grab bag of ICs including supervisors, sequencers, DACs and ADCs. In addition to the inherent complexity of such solutions, they lack easy expandability, requiring significant up front planning for future system upgrades. The LTC3883/-1 eliminates this complexity by combining all digital power management functions in the DC/DC controller. The result is an easy-to-use, robust and flexible point-of-load (POL) power management solution.

Figure 1. Digital power system management using the LTC3883.

The LTC3883/-1 can operate autonomously or communicate via an industry-standard I^2C serial bus with a system host processor for command, control and to report telemetry. This makes it possible to monitor critical operating information directly from the LTC3883/-1 such as real-time voltages, currents and temperatures, which can used to dynamically optimize system performance and reliability.

Access to this data makes it possible to predict power system failures and take preventive or mediation measures.

Important regulator parameters—such as output voltages and current limits, margining voltages, overvoltage and undervoltage supervisory limits, start-up characteristics and timing and fault responses—can also all be directly

The LTC3883/-1 can operate autonomously or communicate via an industry-standard I²C serial bus with a system host processor for command, control and to report telemetry.

programmed via the serial bus, instead of using external components such as resistors, sequencers, and monitoring ICs.

Digital power system management makes it possible to quickly and efficiently develop complex multirail systems. Design is further simplified by the LTpowerPlay™ software, which enables PC-based board monitoring and parametric adjustments. This allows a designer to debug and perform in-circuit testing (ICT) without any circuit board rewiring or component modification.

FEATURE OVERVIEW

The LTC3883/-1 is a single output synchronous step-down DC/DC controller with integrated power FET gate drivers and an analog current mode control loop that is PolyPhase capable to six phases. The frequency can be set from 250kHz to 1MHz, and if an external oscillator is available, the internal phase-locked loop enables the LTC3883/-1 to synchronize with any frequencies within the same range.

The LTC3883/-1 features optimized gate driver dead times to minimize switching losses and body diode conduction, thus maintaining high efficiency in all operating conditions. It supports a wide V_{IN} range of 4.5V to 24V and a V_{OUT} range of 0.5V to 5.5V. The precision reference, 12-bit DAC, and temperature-compensated analog current mode control loop yield ±0.5% DC output voltage accuracy, and an integrated high side input current sense amplifier allows for accurate input current sensing and auto-calibration of the inductor DCR.

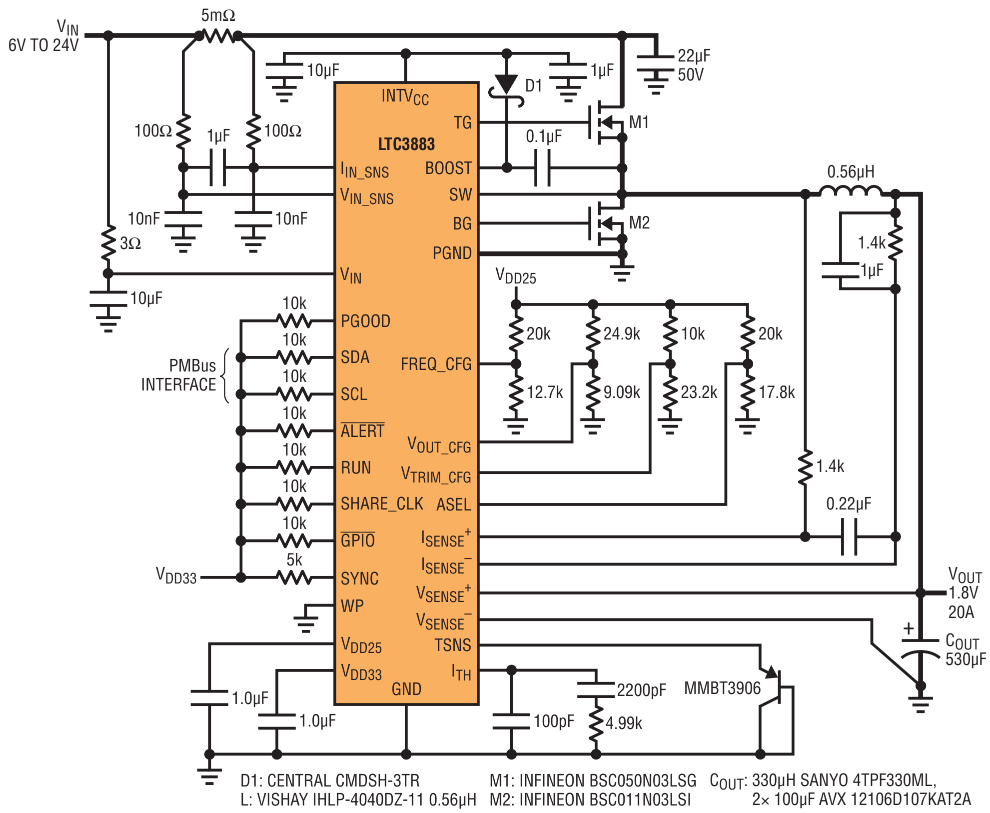


Figure 2. High efficiency 500kHz 1.8V step-down converter with DCR sense

A 16-bit data acquisition system provides digital read back of input and output voltages and currents, duty cycle and temperature. Peak values of important measurements can be read back by the user. Critical controller parameters can be programmed via the PMBus. Fault logging capability includes an interrupt flag and a black box recorder in nonvolatile memory that stores the operating conditions immediately prior to a fault.

The hallmark of the LTC3883 is an on-chip LDO regulator for increased integration, whereas the LTC3883-1 is powered from an external 5V bias voltage for increased efficiency. Both parts are available in a thermally enhanced 32-lead 5mm × 5mm QFN package with either a –40°C to 105°C operating junction temperature range (E-grade) or a –40°C to 125°C operating junction temperature range (I-grade).

High performance PMBus controllers, such as the LTC3883/-1, and companion ICs, such as the LTC2978, work together efficiently and seamlessly to meet the strict digital power management requirements for today's sophisticated circuit boards.

PMBus CONTROL

The LTC3883/-1 PMBus interface allows digital programming of critical power supply parameters as well as the read back of important real-time conditions. Parameter configurations can be downloaded to the internal EEPROM using Linear Technology's LTpowerPlay development software. Figure 5 shows the PC-based LTpowerPlay development platform with a USB to I^2C/SMBus/PMBus adapter. Once a part is configured as desired, it will operate autonomously without control from the host, so no further firmware or microcontroller is required.

The PMBus enables programming of the following power supply parameters:

- Output voltage and margin voltages
- Temperature-compensated current limit threshold based on inductor temperature
- Switching frequency
- Overvoltage and undervoltage high speed supervisor thresholds
- Output voltage on/off time delays
- Output voltage rise/fall times
- Input voltage on/off thresholds
- Output rail on/off
- Output rail margin high/margin low
- Responses to internal/external faults
- Fault propagation

The PMBus allow the user to monitor the following power supply conditions:

- Output/input voltage
- Output/input current
- Internal die temperature
- External inductor temperature
- Part status
- Fault status
- System status
- Peak output current
- Peak output voltage
- Peak internal/external temperature
- Fault log status

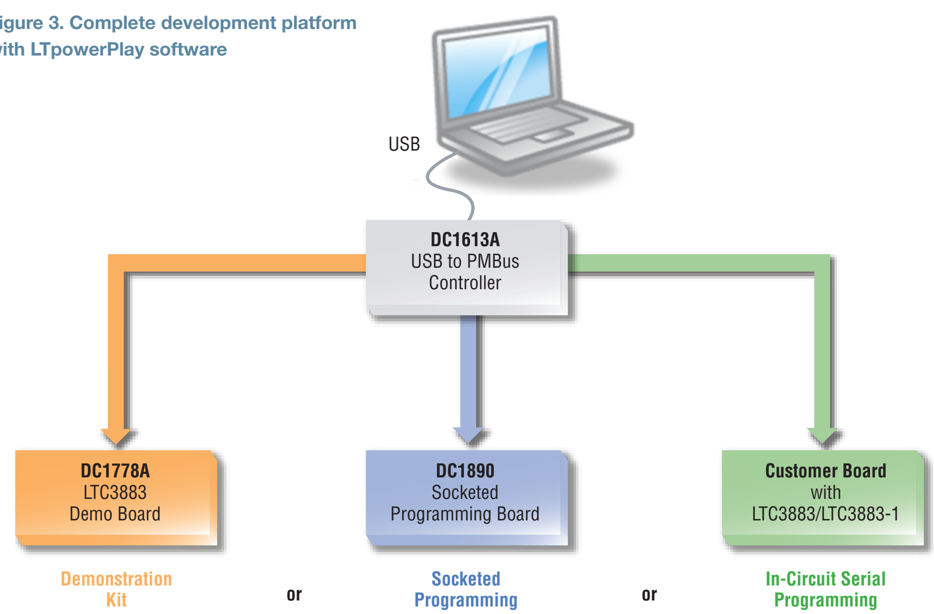
ANALOG CONTROL LOOP

The LTC3883/-1 is digitally programmable for numerous functions including the output voltage, current limit set point and sequencing. The control loop, though, remains purely analog, offering optimum loop stability and transient response without the quantization effect of a digital control loop.

Figure 4 compares the ramp curves of a controller IC with an analog feedback control loop to one with a digital feedback control loop. The analog loop has a smooth ramp, whereas the digital loop has discrete steps that can result in stability problems, slower transient response, more required output capacitance in some applications and higher output ripple and jitter on the PWM control signals due to quantization effects.

The current mode control loop produces the best loop stability, cycle-by-cycle current limit, and fast and accurate responses to line and load transients. The simple loop compensation is independent of operating conditions and converter configuration. Continuous, discontinuous, and Burst Mode® inductor current control are all supported.

Figure 3. Complete development platform with LTpowerPlay software



Digital power system management makes it possible to quickly and efficiently develop complex multirail systems. Design is further simplified by LTpowerPlay software, which enables PC-based board monitoring and parametric adjustments.

AUTO-CALIBRATION OF INDUCTOR DCR

Using the DC resistance of the inductor instead of a sense resistor to sense the output current of a DC/DC converter has several advantages, including reduced power loss, and lower circuit complexity and cost. However, any difference between the specified nominal inductor DCR and the actual inductor DCR causes a proportional error in the measured output current, and in the peak current limit.

The tolerance of the inductor DCR from its nominal value can be measured and compensated for by the LTC3883/-1 using Linear's patent pending algorithm. Just complete a simple 180ms calibration procedure via PMBus command while the converter is in a steady state condition with a large enough load current to allow for accurate input and output current measurements.

The inductor temperature is accurately measured by the LTC3883/-1 to maintain an accurate current read back over the entire operating temperature range. The LTC3883 dynamically models the temperature rise from the external temperature sensor to the inductor core to account for the self-heating effect of the inductor. This patent pending algorithm simplifies the placement requirements of the external temperature sensor and compensates for the significant steady state and transient temperature error from the inductor core to the primary heat sink.

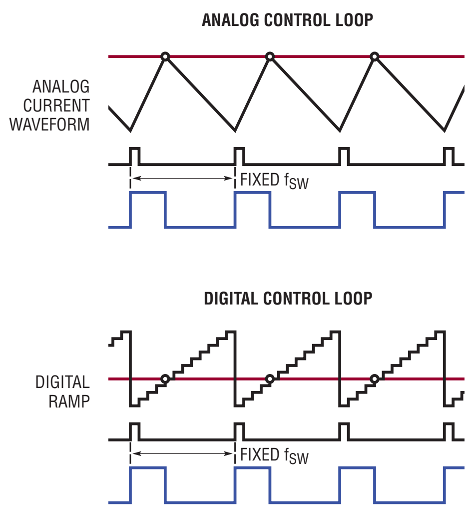


Figure 4. The LTC3883's analog control loop vs a digital control loop. The analog loop has a smooth ramp, whereas the digital loop has discrete steps that can result in stability problems, slower transient response, more required output capacitance in some applications and higher output ripple and jitter on the PWM control signals due to quantization effects.

MULTIPLE IC SYSTEMS

Large multirail power boards are normally comprised of an isolated intermediate bus converter, which converts –48V from the backplane to a lower intermediate bus voltage (IBV), typically 12V, which is distributed around a PC card. Individual point-of-load (POL) DC-DC converters step down the IBV to the required rail voltages, which normally range from 0.5V to 5V with output currents ranging anywhere from 0.5A to 120A. These boards are densely populated and the digital power system management circuitry cannot afford to take up much PC board real estate.

High performance LTC PMBus controllers, such as the LTC3883/-1, and companion ICs, such as the LTC2978, work together efficiently and seamlessly to meet the strict digital power management requirements for today's sophisticated circuit boards. These include sequencing, voltage accuracy, overcurrent and overvoltage limits, margining, supervision and fault control. Any combination of these devices makes sequencing design an easy process for any number of supplies. By using a time-based algorithm, users can dynamically sequence rails on and off in any order with a simple programmable delay. Sequencing across multiple chips is made possible using the 1-wire SHARE_CLK bus and one or more of the bidirectional general purpose IO ($\overline{\text{GPIO}}$) pins.

LTPOWERPLAY SOFTWARE

LTpowerPlay software makes it easy to control and monitor multiple Linear PMBus-enabled devices simultaneously. Modify the DC/DC controller configuration in real time by downloading system parameters to the internal EEPROM of the LTC3883/-1. This reduces design development time by allowing system configurations to be adjusted in software rather than resorting to the draconian tasks of swapping components and manually rewiring boards. Figure 5 shows how output voltage, OV/UV protection limits, and on/off ramps are controlled. The waveform displays the soft-start and soft-stop of the output voltage. Warning and fault conditions are also shown.

LTpowerPlay

LTpowerPlay software is available for free at www.llinear.com/ltpowerplay

LTpowerPlay software makes it easy to control and monitor multiple Linear PMBus enabled devices simultaneously. Modify the DC/DC controller configuration in real time by downloading system parameters to the LTC3883/-1 internal EEPROM.

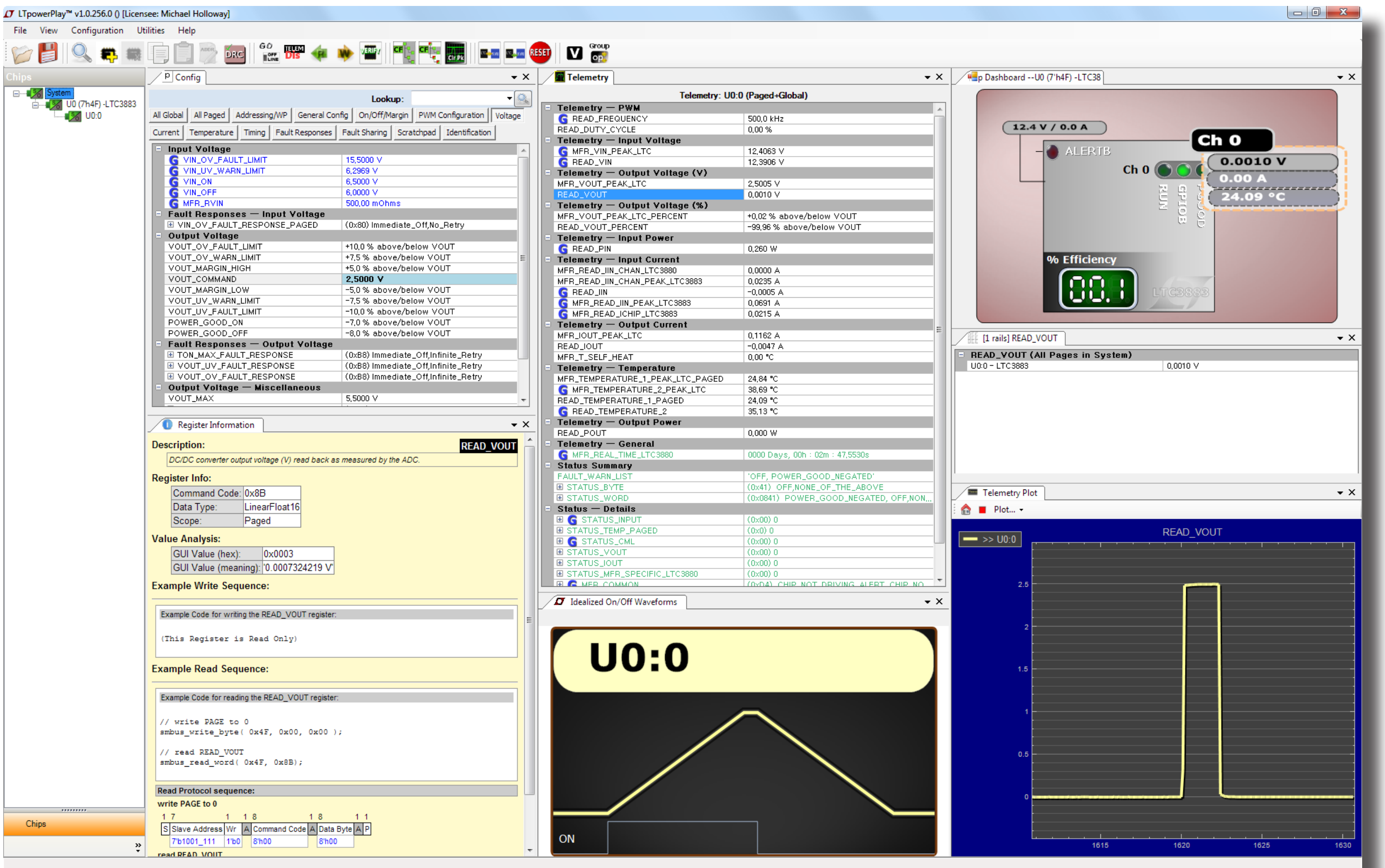


Figure 5. Power systems simplified. LTpowerPlay puts complete power supply control at your fingertips.

CONCLUSION

The LTC3883/-1 combines high performance analog switching regulation with precision data conversion and a flexible digital interface. Multiple LTC3883s can be used in parallel with other devices to easily create optimized multiple-rail digital power systems.

All Linear PMBus products are supported by the LTpowerPlay software development system, which helps board designers quickly debug systems. LTpowerPlay can be used to monitor, control and adjust supply voltages, limits and sequencing. Production margin testing is easily performed using a couple of standard PMBus commands. Combining the LTC3883/-1 with other Linear PMBus products is the best way to quickly bring to market digitally controlled power supplies. ■

60V, 4-Switch Synchronous Buck-Boost Controller Regulates Voltage from Wide Ranging Inputs and Charges Batteries at 98.5% Efficiency at 100W+

Keith Szolusha

The LT®3791-1 is a 4-switch synchronous buck-boost DC/DC converter that regulates both constant voltage and constant current at up to 98.5% efficiency using only a single inductor. It can deliver well over a hundred watts and features a 60V input and output rating, making it an ideal DC/DC voltage regulator and battery charger when both step-up and step-down conversion is needed. In addition to the high voltage, power and efficiency, it features short-circuit protection, a SYNC pin for synchronization to an external clock, a CLKOUT pin for driving an external SYNC pin or for parallel operation, OVLO (overvoltage lockout), $\overline{\text{SHORT}}$ output flag, $\overline{\text{C/10}}$ detection and output flag for battery chargers, and a CCM pin for discontinuous or continuous conduction mode. The inclusion of DCM (discontinuous conduction mode) increases light load efficiency and prevents reverse current when it is undesirable.

120W, 24V 5A OUTPUT BUCK-BOOST VOLTAGE REGULATOR

The buck-boost converter shown in Figure 1 regulates 24V with 0A–5A load at up to 98.5% efficiency (Figure 2). It operates from an input voltage range of 12V to 58V. Adjustable undervoltage and overvoltage lockout protect the circuit. It has short-circuit protection and the $\overline{\text{SHORT}}$ output flag indicates when there is a short circuit on the output. It features DCM operation at light load for lowest power consumption and reverse current protection. R_{OUT} limits the output current during both

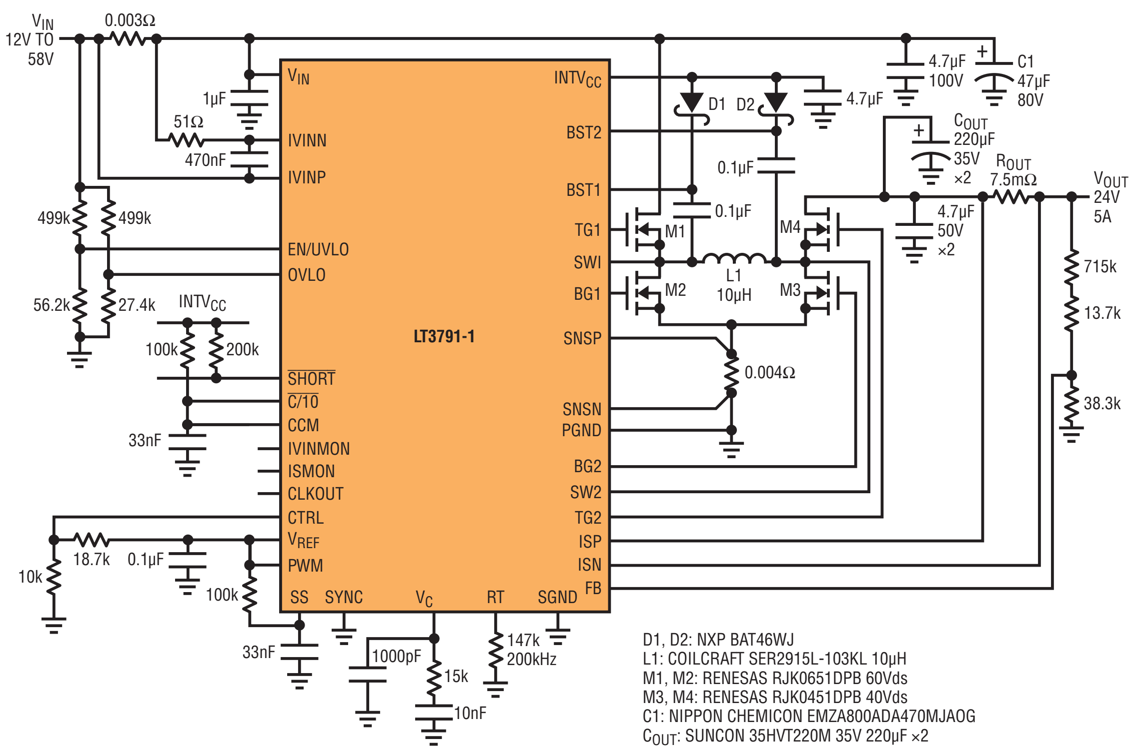


Figure 1. 120W 24V 5A output buck-boost voltage regulator accepts a 12V–58V input

LTspice IV
circuits.linear.com/589

The LT3791-1 can regulate both constant voltage and constant current. Large capacitive loads such as supercapacitors and batteries require constant current charging until they are charged up to a termination voltage, at which point they require constant voltage regulation. The LT3791-1 easily satisfies this requirement.

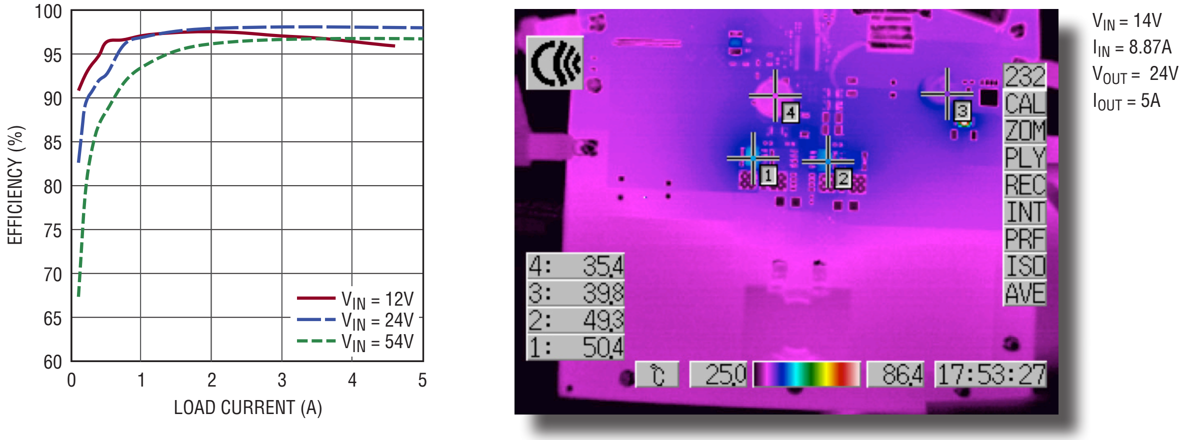


Figure 2. Efficiency and worst case thermal results for the 24V converter in Figure 1

a short circuit and an overload situation, making this a robust application.

The 14V, 10A voltage regulator in Figure 3 takes a slightly different approach. It runs in CCM throughout its entire load current range 0A–10A to provide the lowest EMI at light load. It is still very efficient. The circuit retains short-circuit protection even though R_{OUT} is replaced with a short. The main switch sense resistor RSW limits the short-circuit current at a higher level than R_{OUT}, but hiccup mode during short-circuit limits the power consumption of the IC, maintaining a low temperature rise on the components during a short. When DCM is not needed, R_{OUT} may not be necessary and removing R_{OUT} slightly increases circuit efficiency. OVLO is tied to the output to limit the output voltage transient during a 10A to 0A transition. This protects both the output capacitors and M3 and M4 switches from overvoltage.

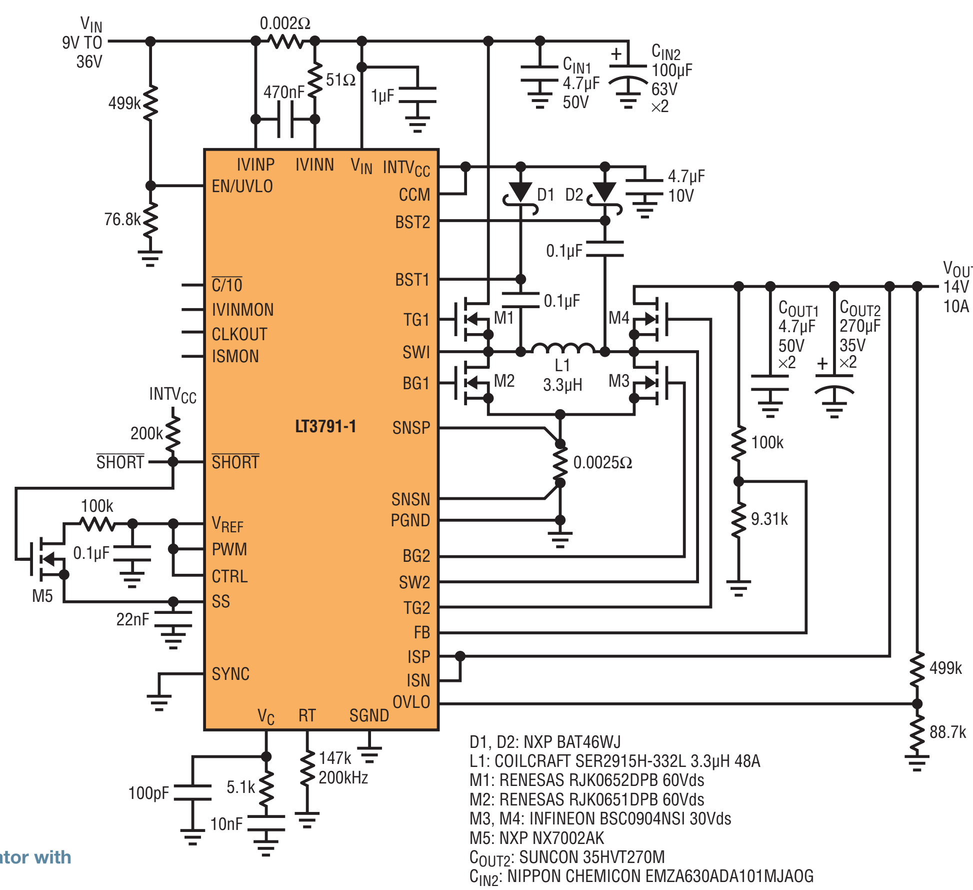


Figure 3. 140W (14V, 10A) CCM buck-boost voltage regulator with 9V–56V input has output OVLO for transient protection.

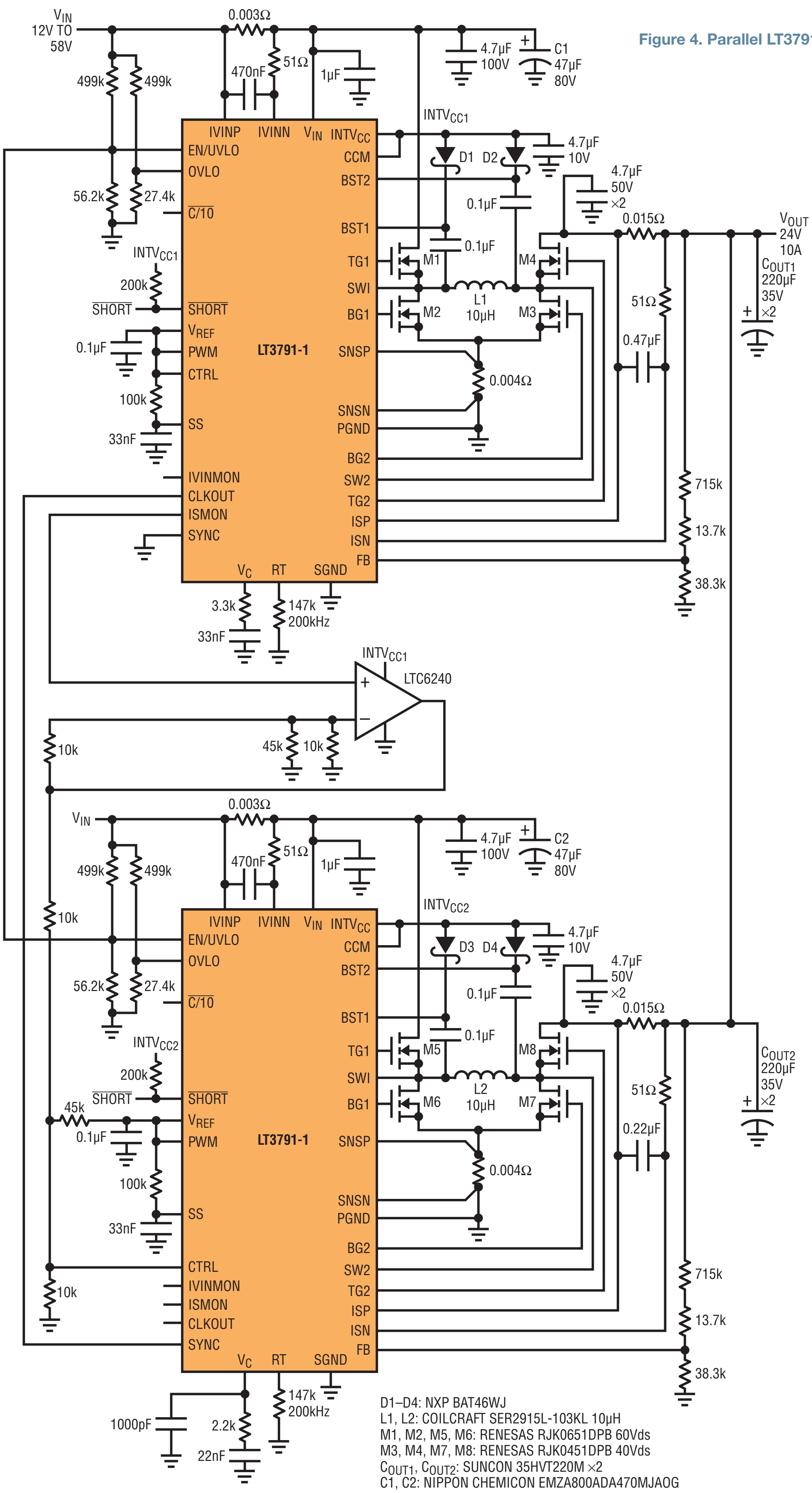


Figure 4. Parallel LT3791-1s in a 240W application

PARALLEL CONVERTERS FOR HIGH POWER USING CLKOUT AND SYNC

The LT3791-1 has a CLKOUT output that can be used to synchronize other converters to its own clock with a 180° phase shift. By tying the CLKOUT of one converter to the SYNC input of another, the maximum output power is doubled while the output ripple is reduced.

Figure 4 shows a 24V, 10A regulator formed by running two LT3791-1s in parallel. By using two parallel circuits, the maximum temperature rise seen on any one discrete component is only 28°C on the M3 and M7 MOSFETs at the lowest V_{IN}. The top converter (master) in Figure 4 commands the current level provided by the bottom (slave) converter. The ISMON output of the master indicates how much current the master is providing, and by connecting ISMON to the CTRL input of the slave, the slave is forced to follow the master. A single op amp is needed to provide the simple 200mV level shift needed to match the CTRL input to the ISMON output levels. The master converter runs in constant voltage regulation while the slave converter is running in constant current regulation. Note that the output voltage of the slave is set slightly higher (28V) so that the voltage feedback loop of the slave is not in regulation for it to be able to follow the master.

The LT3791-1 features both continuous conduction mode (CCM) and discontinuous conduction mode (DCM). CCM provides continuous switching at light load and inductor current can be either positive or negative. When the LT3791-1 enters DCM operation at light load, it prevents backward running current (negative inductor current) and light load power dissipation is minimized.

100W+ 2.5A BUCK-BOOST 36V SLA BATTERY CHARGER

The LT3791-1 can regulate both constant voltage and constant current. Large capacitive loads such as supercapacitors and batteries require constant current charging until they are charged up to a termination voltage, at which point they require constant voltage regulation. The LT3791-1 easily satisfies this requirement. As an example, the buck-boost converter shown in Figure 5 charges a 36V 12Ah SLA battery at 44V with 2.5A DC from a 9V-to-58V input. DCM operation prevents reverse battery current when the output load is overcharged, protecting the circuit from large negative currents.

In some battery charger applications, once termination voltage is reached and charge current tails off, a standby or float voltage regulation level is needed that is different from the charge voltage. The $\overline{C/10}$ detection level of the LT3791-1 provides this capability. In the circuit in Figure 3 the $\overline{C/10}$ function drops the battery voltage from charging (44V) to float (41V) when the battery is near full charge. When the battery voltage is then pulled down from an increased load, the voltage feedback loop returns the charger to its charge state of 44V.

The LT3791-1 can be tailored to charge a range of battery chemistries and capacities from a variety of input sources regardless of the voltage relationship between them. Furthermore, a microcontroller can be used to create a maximum power point tracking (MPPT) charger from a solar panel. The output diagnostics ISMON and IVINMON and current control pin CTRL make it easy to create a high power solar panel battery charger.

DCM INCREASES EFFICIENCY AND PREVENTS REVERSE CURRENT

The LT3791-1 features both continuous conduction mode (CCM) and discontinuous conduction mode (DCM). Figure 6 shows the difference between CCM and DCM. The mode is selected by simply connecting the CCM pin to either the $INTV_{CC}$ or $\overline{C/10}$ pin. CCM provides continuous switching

Figure 5. SLA battery charger

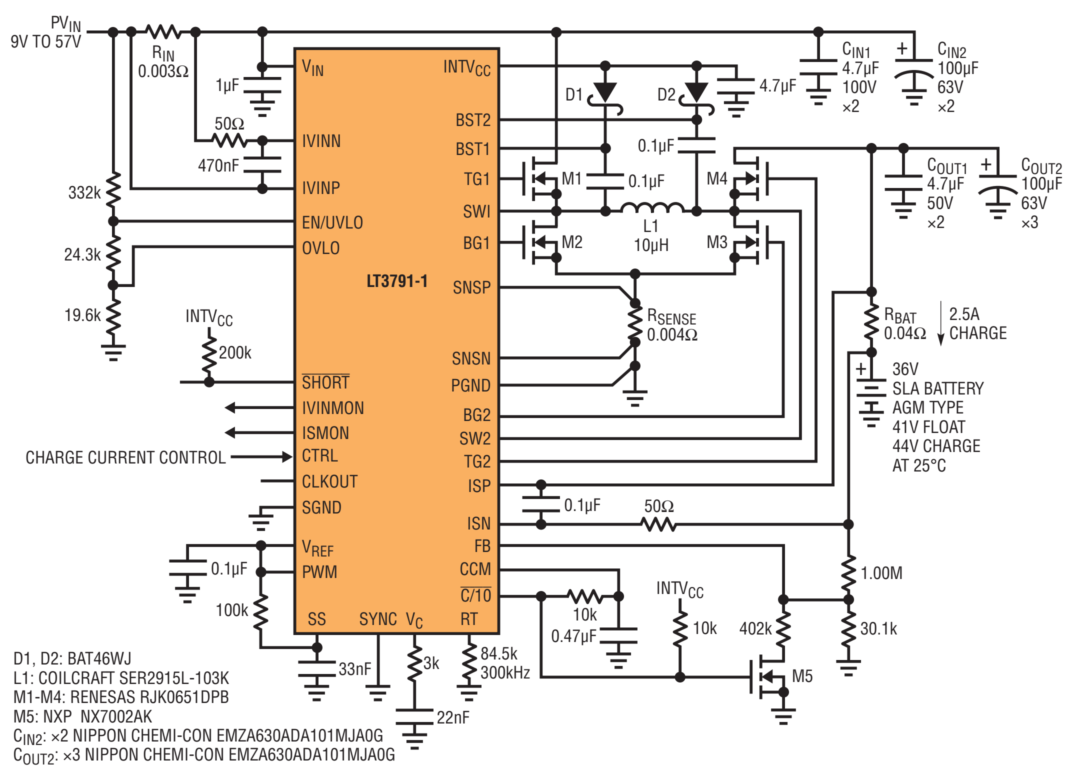
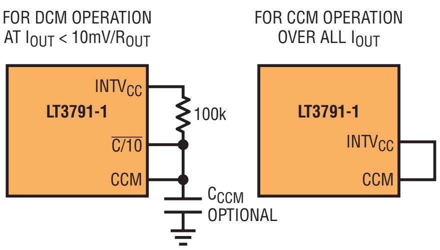
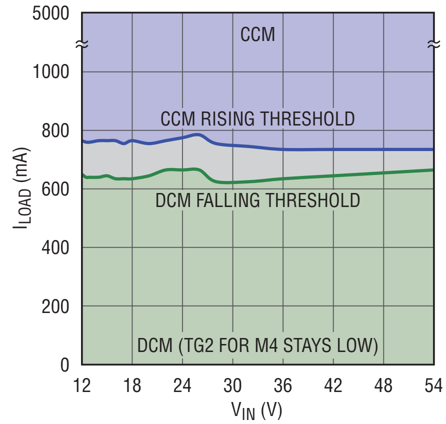


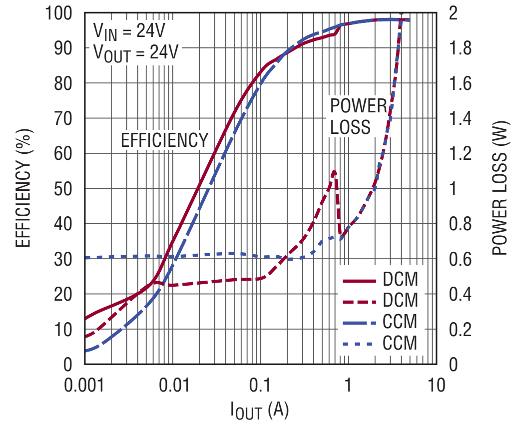
Figure 6. Overview of continuous conduction mode (CCM) for low noise and discontinuous conduction mode (DCM) for light load efficiency



a. DCM vs CCM setup



b. DCM/CCM transition thresholds remain stable as the LT3791-1 moves through boost, buck-boost and buck modes of operation.



c. DCM improves efficiency at light loads.

at light load and inductor current can be either positive or negative. Although zero-load inductor current in CCM is both positive and negative and more power is consumed than DCM, the switch node ringing associated with DCM is eliminated for those that do not want it.

When DCM is selected, the converter remains in CCM until the load drops below about 10% of the programmed maximum output current. When the LT3791-1 enters DCM operation at light load, the TG2 driver for M4 stays low and M4 no longer runs as a switch, but instead as a catch diode. This prevents backward running current (negative inductor current) and light load power dissipation is minimized.

CONCLUSION

The LT3791-1 synchronous buck-boost controller delivers over 100W at up to 98.5% efficiency to a variety of loads. Its wide, 4.7V to 60V input range and 0V to 60V output range make it powerful and versatile, and its built-in short-circuit capabilities make for robust solutions in potentially hazardous environments. CCM and DCM operation make it useful for highest efficiency or lowest noise operation at light load. Its multiple control loops make it ideal for regulating constant voltage, constant current or both. This feature-rich IC easily fulfills buck-boost requirements where other topologies fail. ■

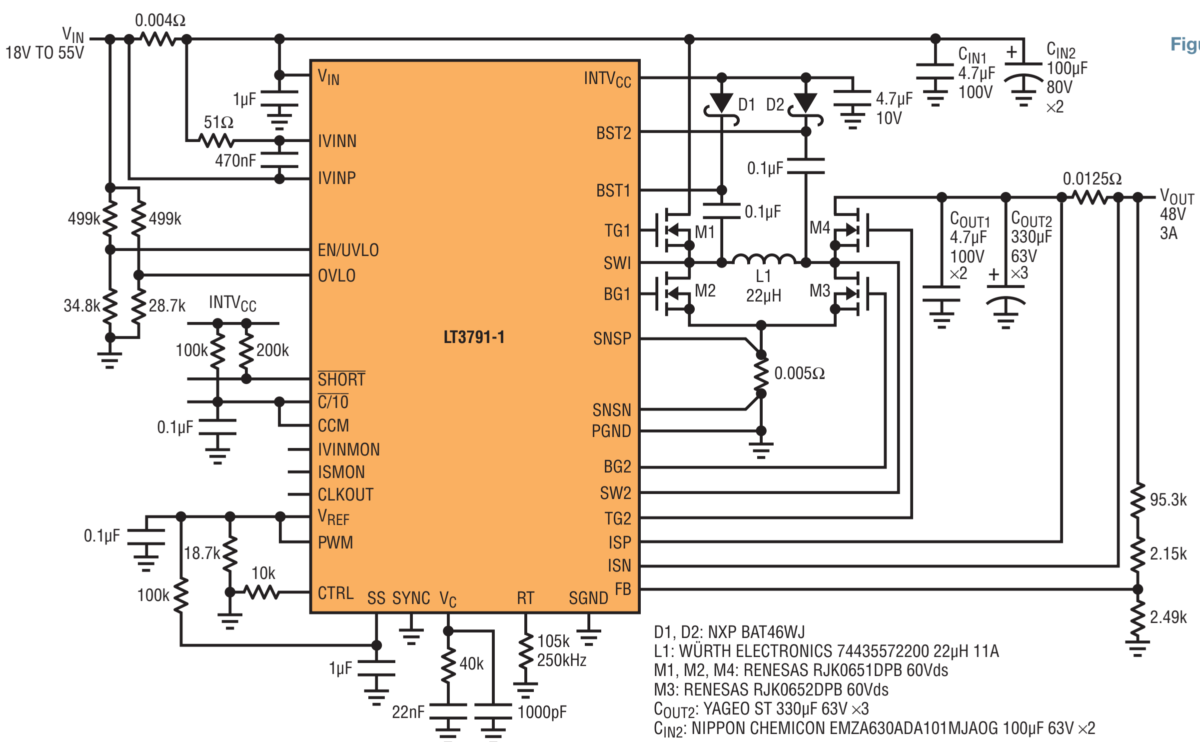


Figure 7. 48V application

100V Micropower No-Opto Isolated Flyback Converter in 5-Lead TSOT-23

Min Chen

The non-synchronous flyback topology is widely used in isolated power supplies ranging from sub-watt power levels to tens of watts. Linear's no-opto isolated flyback family dramatically simplifies isolated power supply design with proprietary primary-side sensing, which requires no opto-coupler or transformer third winding for output regulation. The new LT8300, the first micropower part in this family, significantly improves light load efficiency and reduces no-load input standby current to about 200µA.

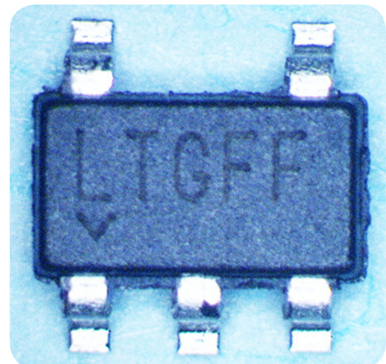


Figure 1. The LT8300 is available in a 5-lead TSOT-23 package with high voltage pin spacing between pins 4 and 5.

The LT8300 operates from an input voltage range of 6V to 100V and delivers up to 2W of isolated output power. The 150V integrated DMOS power switch eliminates the need for a snubber in most applications. By sampling the isolated output voltage directly from the primary-side flyback waveform, the LT8300 requires no opto-coupler or transformer third winding for regulation. The output voltage is set with a single external resistor.

Internal loop compensation and soft start further reduce external component count. Boundary mode operation at heavy load enables the use of small magnetics and produces excellent load regulation. Low ripple Burst Mode operation maintains high efficiency at light load while minimizing output voltage ripple. All these features are packed in a 5-lead TSOT-23 package (Figure 1) with high voltage pin spacing conforming to IPC-2221 requirement.

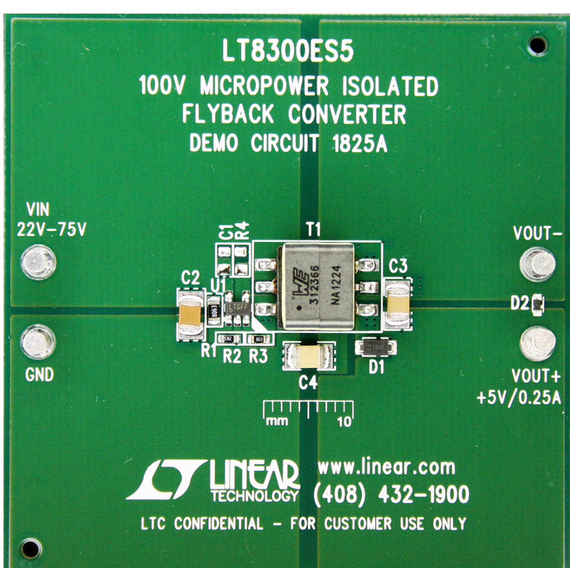


Figure 2. The LT8300 isolated flyback converter solution size is less than 1 inch by ½ inch in a standard demo board DC1825A.

PERFORMANCE AND SIMPLICITY

A complete isolated flyback solution fits into an area less than 1 by ½ inch, as shown in Figure 2. Figure 3 shows a typical LT8300 application, generating a 5V isolated output from a 36V-to-72V input. The solution only requires five external components (input capacitor, output capacitor, transformer, feedback resistor and output diode) and two optional undervoltage lockout resistors.

Although the LT8300 simplifies isolated flyback converter design, it delivers superior performance. Figure 4 shows the power efficiency (85% peak) of the 5V application in Figure 3. Figure 5 shows the load and line regulation (±0.5%) of the 5V application in Figure 3. Figures 6 and 7 show its 50mA-to-250mA load step transient and 1mA resistive load start-up waveforms, respectively.

By sampling the isolated output voltage directly from the primary-side flyback waveform, the LT8300 requires no opto-coupler or transformer third winding for regulation. The output voltage is set with a single external resistor.

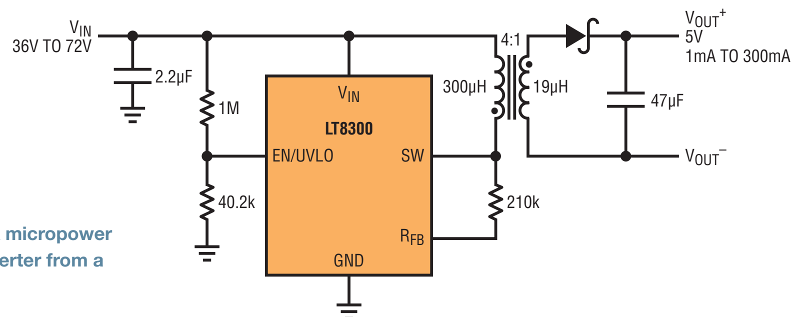


Figure 3. A 5V/300mA micropower isolated flyback converter from a 36V-to-72V input

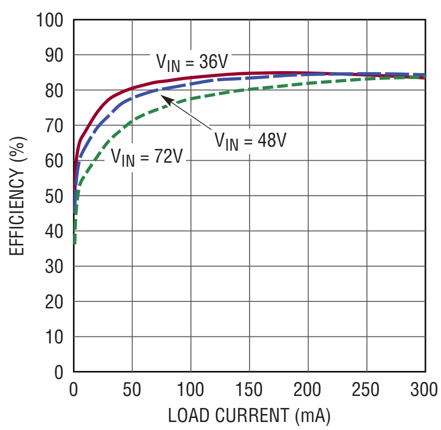


Figure 4. Power efficiency of the 5V application in Figure 3

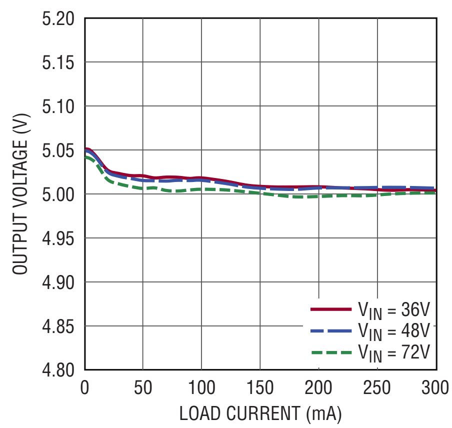


Figure 5. Output load and line regulation of the 5V application in Figure 3

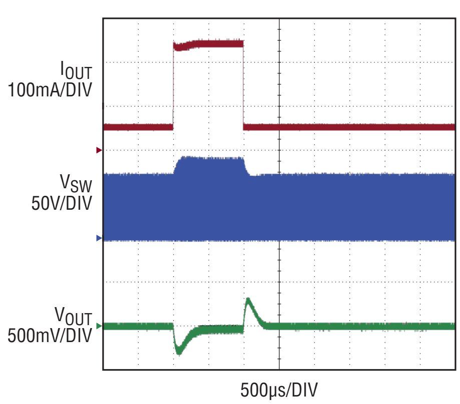


Figure 6. 50mA-to-250mA load step transient waveforms of the 5V application in Figure 3

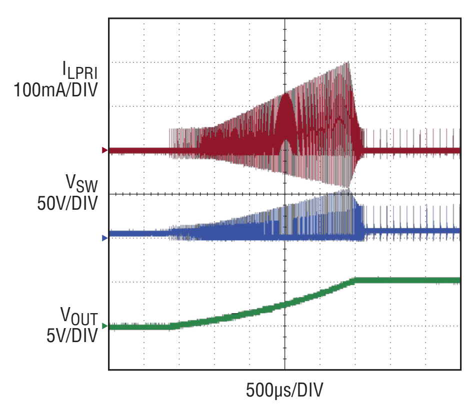


Figure 7. 1mA resistive load start-up waveforms of the 5V application in Figure 3

POST REGULATOR ELIMINATES OUTPUT TEMPERATURE VARIATION

The output voltage in a typical LT8300 application can be expressed as

$$V_{OUT} = 100\mu A \bullet \left(\frac{R_{FB}}{N_{PS}}\right) - V_F$$

The first term in the V_{OUT} equation does not have temperature dependence, but the output diode forward voltage V_F has a significant negative temperature coefficient (–1mV/°C to –2mV/°C). Such a negative temperature coefficient produces approximately 200mV to 300mV voltage variation on the output across temperature.

For relatively high voltage outputs, say 12V and 24V, the output diode temperature coefficient has a negligible effect on the output voltage regulation. But for lower voltage outputs, such as 3.3V and 5V, the output diode temperature coefficient contributes an additional 2% to 5% output voltage regulation.

For designs requiring tight output voltage regulation across temperature, a micropower low dropout linear regulator can be added to post-regulate the LT8300 output. The LT8300 should be programmed slightly higher than the sum of the regulation voltage and the LDO's dropout voltage.

Figure 8 shows the LT8300 combined with a LT3009-3.3 post-regulator to generate a 3.3V/20mA isolated output from an 18V-to-32V input. The no-load input standby current is less than 250µA as shown in Figure 9, which conforms to DEF-STAN61-5.

The LT8300 greatly simplifies the design of isolated flyback converters, improves light load efficiency and reduces no-load input standby current when compared to traditional schemes.

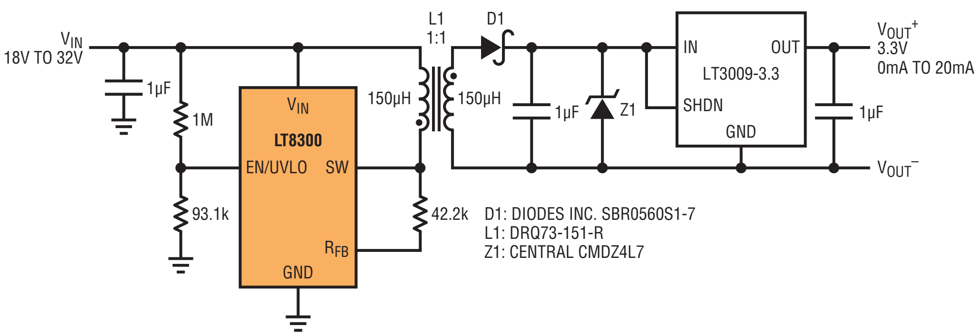


Figure 8. A 3.3V/20mA micropower isolated converter from an 18V-to-32V input conforming to DEF-STAN61-5

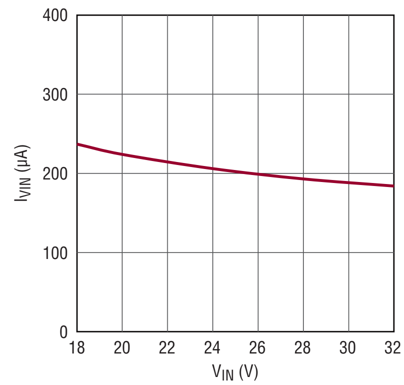


Figure 9. No-load input standby current of the 3.3V application in Figure 8

VARIOUS INPUT-REFERRED POWER SUPPLIES

In addition to isolated power supplies, the LT8300 can be used in various nonisolated applications. Two interesting applications are input-referred positive and negative power supplies often used for special gate drivers. Figure 10 shows a simple V_{IN} to (V_{IN} + 10V) micropower converter, and Figure 11 shows a simple V_{IN} to (V_{IN} – 10V) micropower converter. In both of these converters, the LT8300's unique feedback sensing scheme is used to easily develop an output voltage that tracks V_{IN}.

CONCLUSION

The LT8300 greatly simplifies the design of isolated flyback converters, improves light load efficiency and reduces no-load input standby current when compared to traditional schemes. The high level of integration and the use of boundary and low ripple burst modes results in a simple to use, low component count, and high efficiency solution for isolated power supplies, as well as various special nonisolated power supplies. ■

Figure 10. A V_{IN} to (V_{IN} + 10V) micropower converter

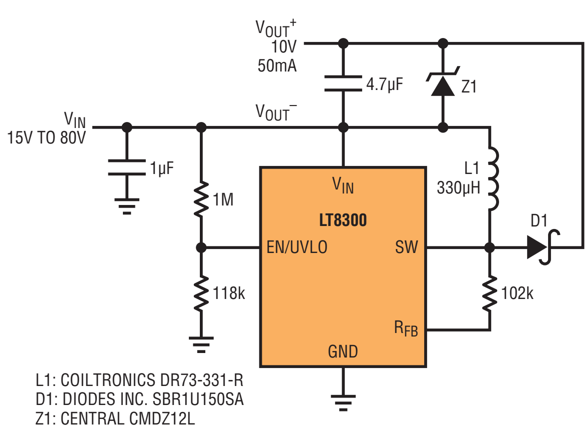
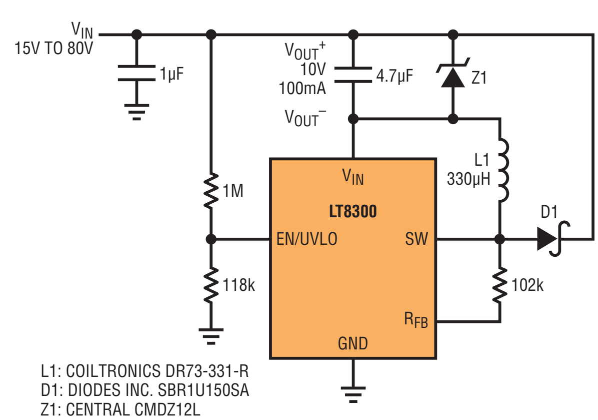


Figure 11. A V_{IN} to (V_{IN} – 10V) micropower converter



What's New with LTspice IV?

Gabino Alonso

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

NEW DEMO CIRCUITS

Overvoltage Protection and Pushbutton Controllers

- **LT4363-2:** Overvoltage regulator with 250V surge protection (5.5V–250V to 16V clamped output) www.linear.com/LT4363
- **LTC2955:** Pushbutton on/off control with auto turn-on at 12V (12V or battery backup to 3.3V at 20mA) www.linear.com/LTC2955

Step-Down Regulators

- **LT3988:** Dual 60V step-down regulator (7V–60V to 5V at 1A and 3.3V at 1A) www.linear.com/LT3988
- **LT3992:** FMEA fault tolerant dual converter (7V–60V to 5V at 2A and 3.3V at 2A) www.linear.com/LT3992
- **LT8611:** µPower synchronous step-down regulator with current sense (3.8V–42V to 3.3V at 2.5A) www.linear.com/LT8611
- **LTM4620:** High efficiency 8-phase 100A step-down regulator (4.5V–16V to 1V at 100A) www.linear.com/LTM4620
- **LTM8026:** Two 2.5V series supercapacitor charger (7V–36V to 5V at 5.6A) www.linear.com/LTM8026

Battery Chargers, Bipolar Supplies and LED Drivers

- **LT3796:** Boost LED driver with short-circuit protection and current monitor (9V–60V to 85V LED string at 400mA) www.linear.com/LT3796
- **LTC3260:** Low noise ±12V power supply from a single 15V Input (15V to ±12V at 50mA) www.linear.com/LTC3260
- **LTM8062A:** 2A, 4-cell Li-ion battery charger (18V–32V to 16.4V at 2A) www.linear.com/LTM8062

Currrent Sense Amplifiers

- **LT1787:** Bidirectional current sense amplifier with offset bipolar output www.linear.com/LT1787
- **LT6105:** Unidirectional current sense amplifier for negative supplies www.linear.com/LT6105
- **LT6106:** Single supply, unidirectional current sense amplifier www.linear.com/LT6106

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.

NEW MODELS

High Speed Amplifiers and Resistor Networks

- **LT5400:** Quad matched resistor network www.linear.com/LT5400
- **LTC6417:** 1.6GHz low noise high linearity differential buffer/16-bit ADC driver www.linear.com/LTC6417

Energy Harvesting

- **LTC3109:** Auto-polarity, ultralow voltage step-up converter and power manager www.linear.com/LTC3109
- **LTC3588-2:** Piezoelectric energy harvesting power supply with 14V minimum V_{IN} www.linear.com/LTC3588-2

Step-Down Regulators

- **LT3975:** 42V, 2.5A, 2MHz step-down switching regulator with 2.7µA quiescent current www.linear.com/LT3975
- **LT3976:** 40V, 5A, 2MHz step-down switching regulator with 3.3µA quiescent current www.linear.com/LT3976
- **LTC3605A:** 20V, 5A synchronous step-down regulator www.linear.com/LTC3605A
- **LTC3626:** 20V, 2.5A synchronous monolithic step-down regulator with current and temperature monitoring www.linear.com/LTC3626
- **LTM4620:** Dual 13A or single 26A DC/DC µModule regulator www.linear.com/LTC4260

Multi-Topology Regulators

- **LT3758A:** HV, boost, flyback, SEPIC and inverting controller with improved transient www.linear.com/LT3758

Power User Tip

PIECEWISE LINEAR FUNCTION FOR VOLTAGE OR CURRENT SOURCES

Piecewise linear (PWL) functions are used to construct a waveform from a series of straight line segments connecting points defined by the user. Since PWL functions are useful in creating custom waveforms, they are typically used in defining voltage or current sources.

To add a PWL function to a voltage or current source:

1. Right-click on the symbol in the schematic editor
2. Click Advanced
3. Select either PWL(t1, v1, t2, v2…) or PWL File:
4. Depending on your choice in step 3, either enter the PWL values or choose a file.

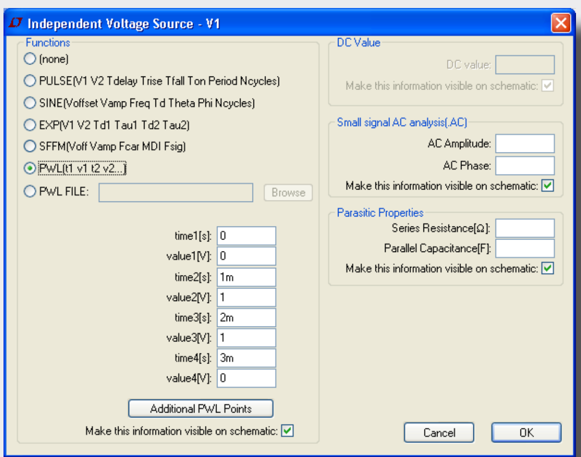
If you choose to enter the values directly, the PWL statement will be built from your values. The syntax of a PWL statement is a list of two-dimensional points that represent time and value data pairs where the time value is in ascending order:

```
PWL (0 0 1m 1 2m 1 3m 0)
```

Time values can also be defined relative to the previous time value by prefixing the time value with a + sign:

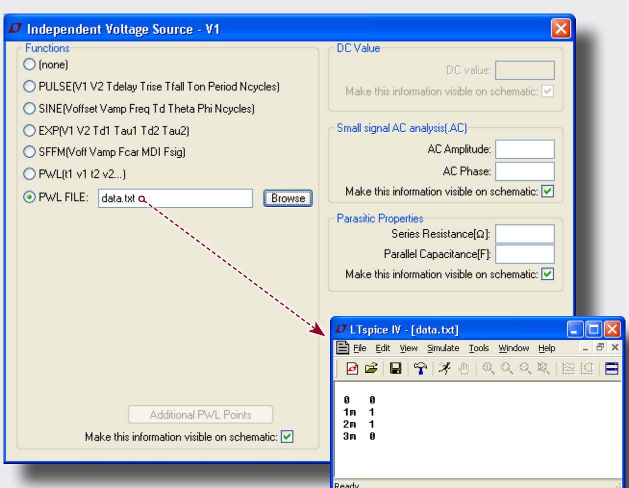
```
PWL (0 0 +1m 1 +1m 1 +1m 0)
```

Here's an example of the nonrelative value pairs in the dialog:



The list of two-dimensional points that represent time and value data pairs can be encapsulated in a file and used in a PWL statement:

```
PWL (file=data.txt)
```



Other Forms of PWL Statement

LTspice IV supports many other forms of PWL statement. To explore these you will have to directly edit your statement by right-clicking on the text line with the PWL statement (not the component symbol), in the schematic editor. Some examples of alternate PWL forms:

- Repeating data pairs a specified number of cycles, or forever:

```
PWL REPEAT FOR 5 (0 0 1m 1 2m 1 3m 0) ENDREPEAT
PWL REPEAT FOREVER (0 0 1m 1 2m 1 3m 0) ENDREPEAT
```

- A trigger expression that turns the source on as long as the expression is true:

```
PWL (0 0 1m 1 2m 1 3m 0) TRIGGER V(n003)>1
```

- Scaled time or source values:

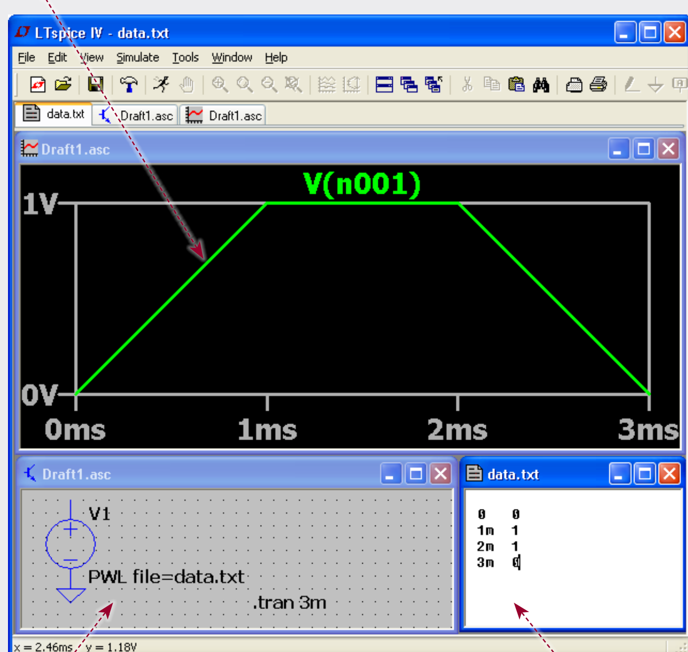
```
PWL TIME_SCALE_FACTOR=0.5 VALUE_SCALE_FACTOR=2 (0 0 1m 1 2m 1 3m 0)
```

Try using one of these forms of PWL expressions in your next simulation.

Happy simulations!

PWL functions are an easy way to create a custom waveform, typically used to define values for a voltage or current source

WAVEFORM PRODUCED BY THE PWL STATEMENT



SCHEMATIC EDITOR SHOWS COMPONENT WITH ATTACHED PWL STATEMENT

FILE WITH PWL DATA

100V Surge Stopper Protects Components from 300V Transients

Hamza Salman Afzal

High voltage transients in automotive and industrial systems are common and can last from microseconds to hundreds of milliseconds, sending significant energy downsteam. Transient causes include automotive load dumps, and spikes caused by load steps and parasitic inductance. To avoid the risk of failure, all electronics in these systems must either be robust enough to directly withstand the transient energy spikes, or they must be protected from them.

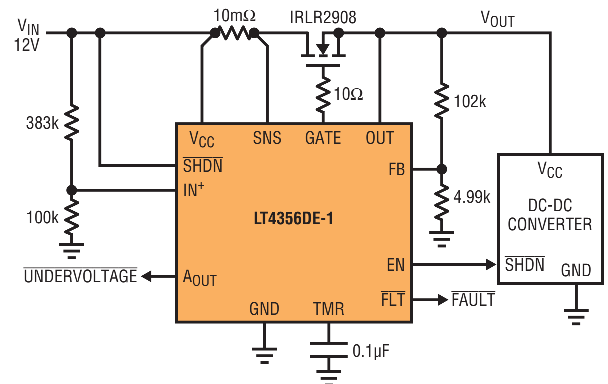


Figure 1. 12V overvoltage regulator

The LT4356 surge stopper is a dramatic performance upgrade over traditional, passive clamp protection techniques. It actively protects downstream components from overvoltage by regulating the gate of a pass MOSFET and it limits current with the help of a standard sense resistor. Figure 1 shows a typical 12V application.

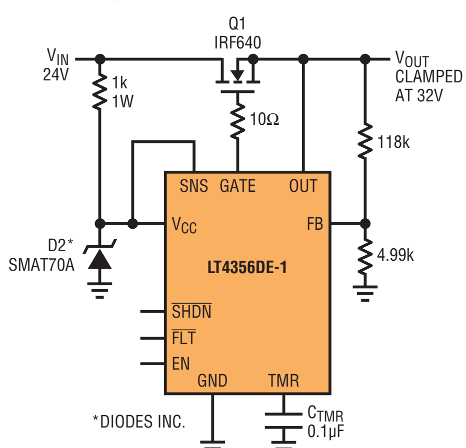
The LT4356 has a rated maximum of 100V with an operating voltage range of 4V to 80V, making it ideal for protecting downstream electronics in a wide variety of industrial and automotive applications. Nevertheless, some circuits require protection against transients as high as 200V to 300V.

Figure 2 shows one way that the LT4356 can be made to suppress such high voltages, but at the cost of the current limiting feature. In Figure 2 the V_{CC} and SNS pins are decoupled from the raw input voltage and separately clamped to a safe value below 100V. Since the V_{CC} and SNS pins are of necessity disconnected from the input path, current sensing is not possible and the circuit serves only as a voltage clamp.

It is possible to overcome this limitation by cascading a second pre-regulating MOSFET, Q2, as shown in Figure 3. Q2 clamps the V_{CC} and SNS pins to a safe level, restores the current limit feature and as an added benefit, shares SOA (safe operating area) stress with Q1.

When power is first applied, R3 and D1 pull up on the gate of Q2, which in turn passes power through to the LT4356. The GATE pin then pumps up the gates of Q1 and Q2, fully enhancing both MOSFETs

Figure 2. 24V application circuit capable of withstanding 150V



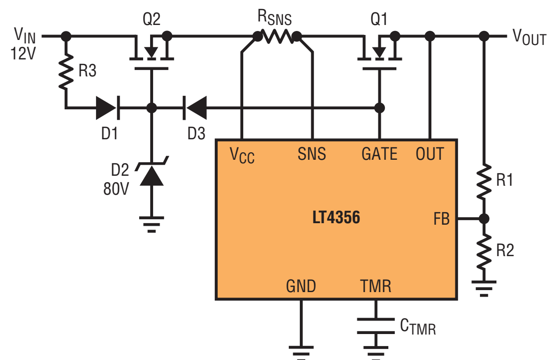
and sending power through to the output. Thus R3 and D1 are critical to start-up. Under normal operating conditions the GATE pin limits itself to about 12.5V above the output, so with 12V at the input, Q1's gate is biased to 24.5V and Q2's gate is biased slightly lower, about 24V.

When the input is subjected to a high voltage transient, R3 and D1 pull up on the gate of Q2, which in turn is clamped by D2 to approximately 80V. Acting as a source follower, Q2's source rises no further than about 75V, keeping V_{CC} and SNS safely below their 100V maximum rating. Unlike the shunt clamped application shown in Figure 2, the series clamped topology of Figure 3 permits full use of the LT4356's current limiting feature. Q1 regulates in the normal way, limiting the output voltage as prescribed by R1 and R2.

An added benefit of the topology shown in Figure 3 is that Q2 shares SOA stress with Q1. For inputs in the range of 150V to 200V, the SOA stress is shared equally between Q1 and Q2. In certain applications this allows two inexpensive

The LT4356 has a rated maximum of 100V with an operating voltage range of 4V to 80V, but a little extra circuitry enables it to protect against transients as high as 300V.

Figure 3. Pre-regulator topology extends protection range of the LT4356. Figure 4 shows the complete circuit.



MOSFETs to replace a single, and much more costly, special high SOA device. As the peak input voltage requirement rises above 200V, the SOA becomes increasingly concentrated in Q2 and the series connection offers no substantial relief.

Figure 4 shows a complete circuit based on the new topology, designed to withstand up to 300V peak input. As previously described, Q2's gate is clamped at 80V so that with a 300V input, Q2 drops 225V, while Q1 sees no more than 75V total. For this reason a 250V device is specified for Q2, and a 100V device suffices for Q1. It is possible to withstand even higher input voltages by appropriate selection of Q2.

When designing circuits to withstand such high input voltages, it is important to recognize the potential for high dV/dt at the input and resulting consequences. Until the circuit can respond, current arising from an instantaneously applied high input voltage is limited only by the parasitic inductance and the path resistance to the output capacitor. While most test waveforms specify some sufferable rise time, an infinite input slew rate is not inconceivable, such as might arise during bench testing. Q3 is added to give the LT4356's current limit loop a head start under these conditions.

Figure 5 shows the results of the circuit subjected to a 300V spike. C_{TMR} is sized to ride through such excursions, but longer duration surges will be interrupted, thereby protecting the MOSFETs from certain destruction. ■

Figure 4. 16V overvoltage regulator capable of blocking 300V transients

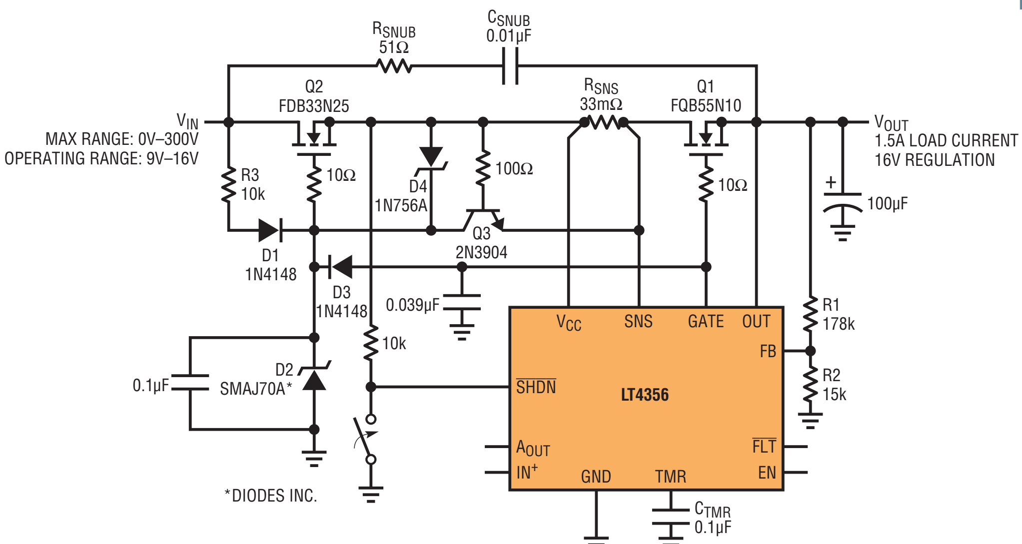
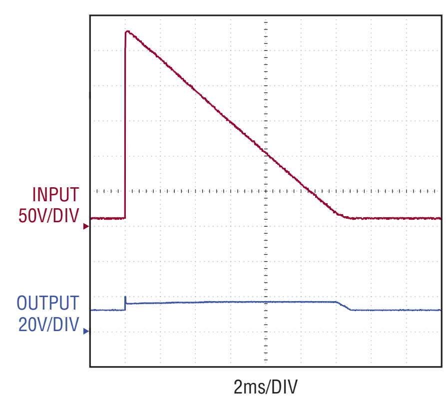


Figure 5. Results of 300V spike on input of circuit in Figure 4



Accurate PWM LED Dimming without External Signal Generators, Clocks or µControllers

Keith Szolusha

LEDs can be dimmed in two ways: analog and pulse-width modulation (PWM) dimming. Analog dimming changes LED light output by simply adjusting the DC current in the string, while PWM dimming acheives the same effect by varying the duty cycle of a constant current in the string to effectively change the *average* current in the string. Despite its attractive simplicity, analog dimming is inappropriate for many applications because it loses dimming accuracy by about 25%+ at only 10:1 brightness levels, and it skews the color of the LEDs. In contrast, PWM dimming can produce 3000:1 and higher dimming ratios (at 100Hz) without any significant loss of accuracy, and no change in LED color.

The LT3761 combines the simplicity of analog dimming with the accuracy of PWM dimming by generating its own PWM signal. High dimming ratios are possible by adjusting a simple DC signal at its dimming input—no additional PWM-generating microcontrollers, oscillators or signal generators are required. The LT3761's internal PWM signal can produce 25:1 dimming, while it can still deliver up to 3000:1 dimming with an external PWM signal.

HIGH POWER LED DRIVER

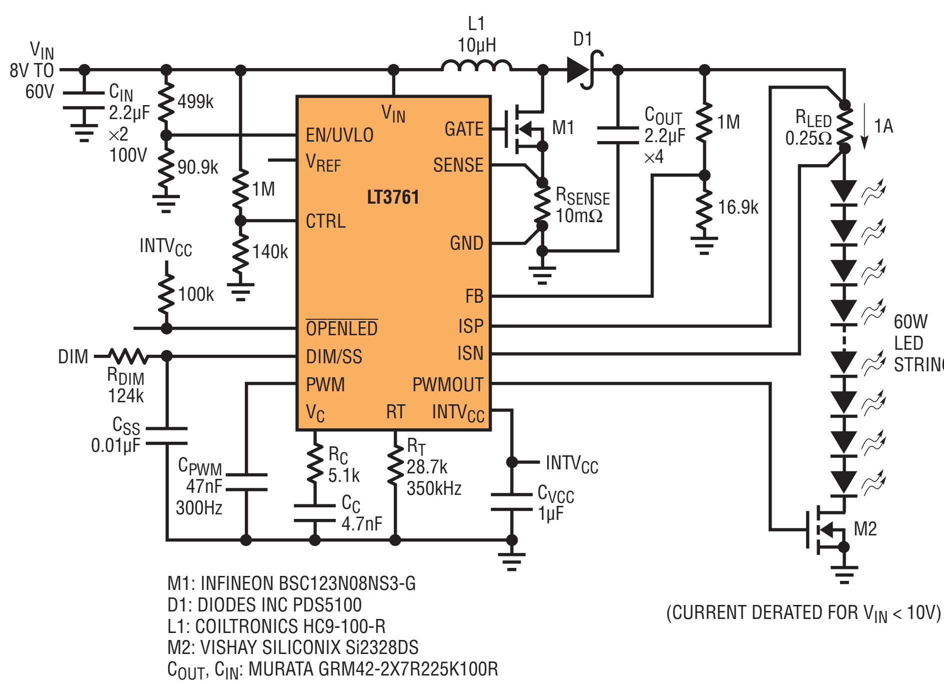
The LT3761 is a high power LED driver similar to the LT3755-2 and LT3756-2 family. It is a 4.5V-to-60V input to 0V-to-80V output single-switch controller IC that can be configured as a boost, SEPIC, buck-boost mode or buck mode LED driver. It has a 100kHz to 1MHz switching frequency range, open LED protection, extra internal logic to provide short-circuit protection, and can be operated as a constant voltage regulator with current limit or as a constant-current SLA battery or supercap charger.

Figure 1 shows a 94% high efficiency 60V, 1A (60W) 350kHz automotive headlamp application with PWM dimming. The LT3761 uses the same high performance PWM dimming scheme as the LT3755/LT3756 family, but with the additional feature of the internally generated PWM dimming signal and no additional pins.

INTERNAL PWM DIMMING GENERATOR

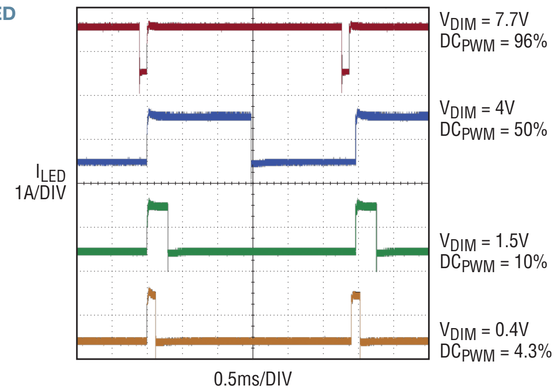
Unlike other high power LED drivers, the LT3761 can generate its own PWM dimming signal to produce up to 25:1 dimming. This enables it to produce accurate PWM dimming without the need for external PWM-generating components. The

Figure 1. 94% efficient boost LED driver for automotive headlamp with 25:1 internal PWM dimming



The LT3761 generates its own PWM signal to achieve accurate PWM dimming, but with the simple control of analog dimming. High dimming ratios are possible by adjusting a simple DC signal at its dimming input—no additional PWM-generating microcontrollers, oscillators or signal generators are required.

Figure 2. Internally generated PWM signal and LED current for the application in Figure 1



LT3761 requires only an external DC voltage, much like analog dimming control, for high performance PWM dimming at a chosen frequency. It can still receive a PWM input signal to drive the LED string with that signal in standard fashion.

The internal PWM dimming signal generator features programmable frequency and duty cycle. The frequency of the square wave signal at PWMOUT is set by a capacitor C_{PWM} from the PWM pin to GND according to the equation: $f_{PWM} = 14kHz \bullet nF/C_{PWM}$. The duty cycle of the signal at PWMOUT is set by a µA-scale current into the DIM/SS pin as shown in Figure 3. Internally generated pull-up and pull-down currents on the PWM pin are used to charge and discharge its capacitor between the high and low thresholds to generate the duty cycle signal. These current signals on the PWM pin are small enough so they can be easily overdriven by a digital signal from a microcontroller to obtain very high dimming performance. The practical minimum duty cycle using the internal signal generator is about 4% if the DIM/SS pin is used to adjust the dimming ratio. For 100% duty cycle operation, the PWM pin can be tied to $INTV_{CC}$.

CONCLUSION

The high power and high performance LT3761 LED driver has its own onboard PWM dimming signal generator that is both accurate and easy to use. ■

Figure 3. Setting the duty cycle at the DIM/SS pin takes a µA-scale signal. This pin can also be used with an external PWM signal for very high dimming ratios.

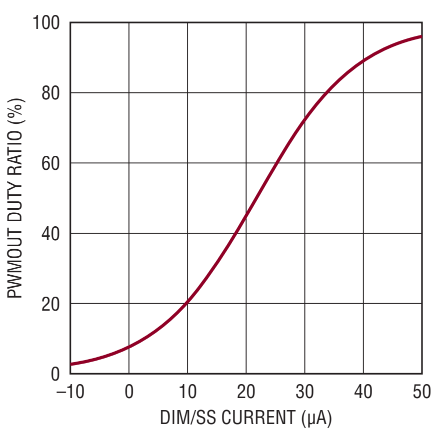
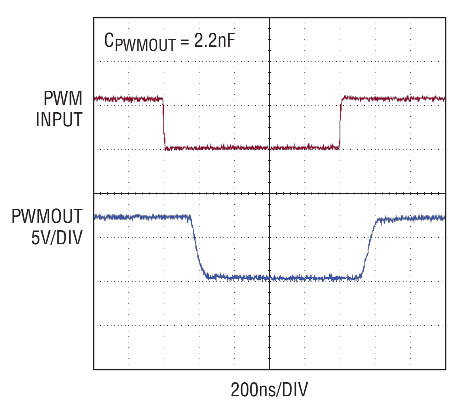


Figure 4. Given a high speed PWM input signal, the LT3761 still provides a high speed PWMOUT signal.



Eliminate Opto-Isolators and Isolated Power Supply from Power over Ethernet Power Sourcing Equipment

Heath Stewart

Power over Ethernet (PoE), is defined by the IEEE 802.3at specification to safely deliver application power over existing Ethernet cabling. Implementation of Power over Ethernet requires careful architecture and component selection to minimize system cost, while maximizing performance and reliability. A successful design must adhere to IEEE isolation requirements, protect the Hot Swap™ FET during short-circuit and overcurrent events, and otherwise comply with the IEEE specification.

The IEEE standard also defines PoE terminology. A device that provides power to the network is known as power sourcing equipment (PSE), while a device that draws power from the network is known as a powered device (PD).

The LTC4290/LTC4271 PSE controller chipset revolutionizes PSE architecture by deleting the customary digital isolation and removing an entire isolated power supply. Instead, the chipset employs a proprietary isolation protocol using a low cost Ethernet transformer pair, leading to a significant reduction in bill of materials cost.

The LTC4290/LTC4271 fourth generation PSE controller supports fully compliant IEEE 802.3at operation, while minimizing heat dissipation through the use of low $R_{DS(ON)}$ external MOSFETs and 0.25Ω sense resistors.

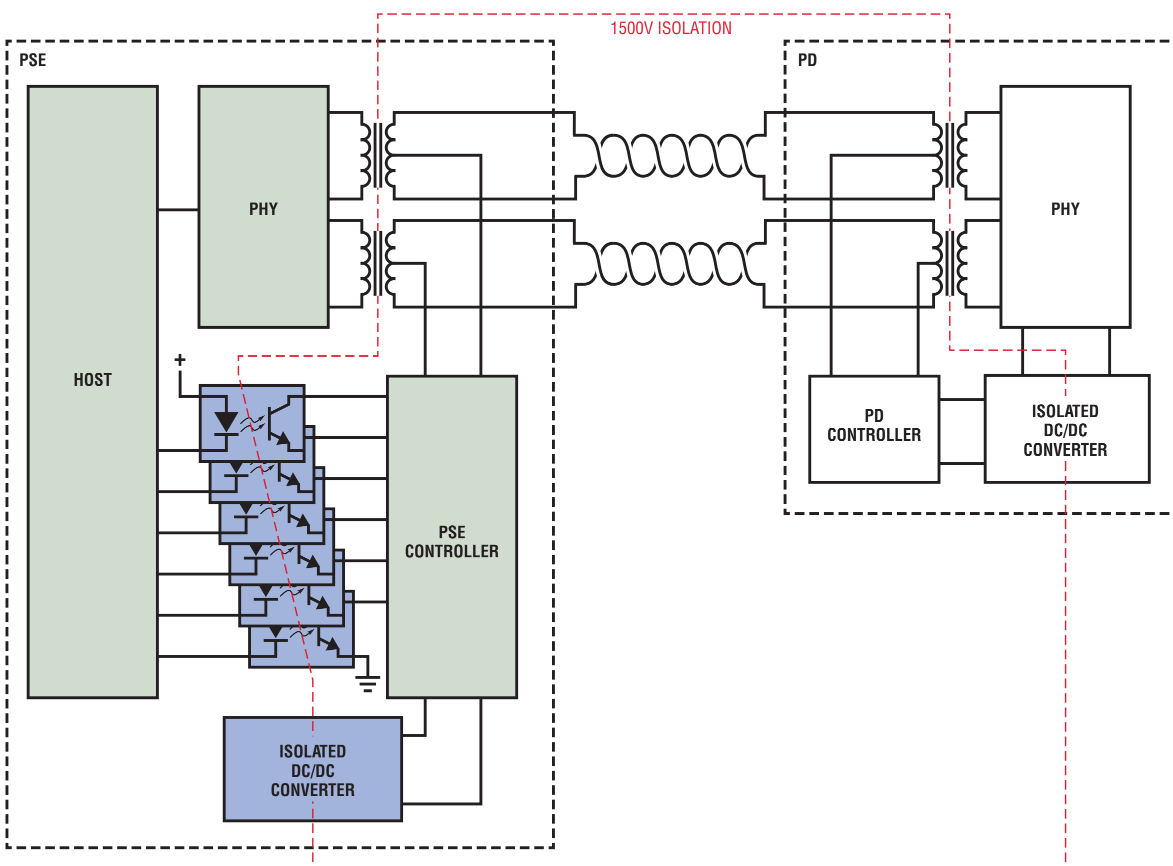


Figure 1. Traditional PSE isolation schemes require a number of opto-isolators and a cumbersome, and costly isolated DC/DC converter. The LT4271-LT4290 solution shown in Figure 2 eliminates these components.

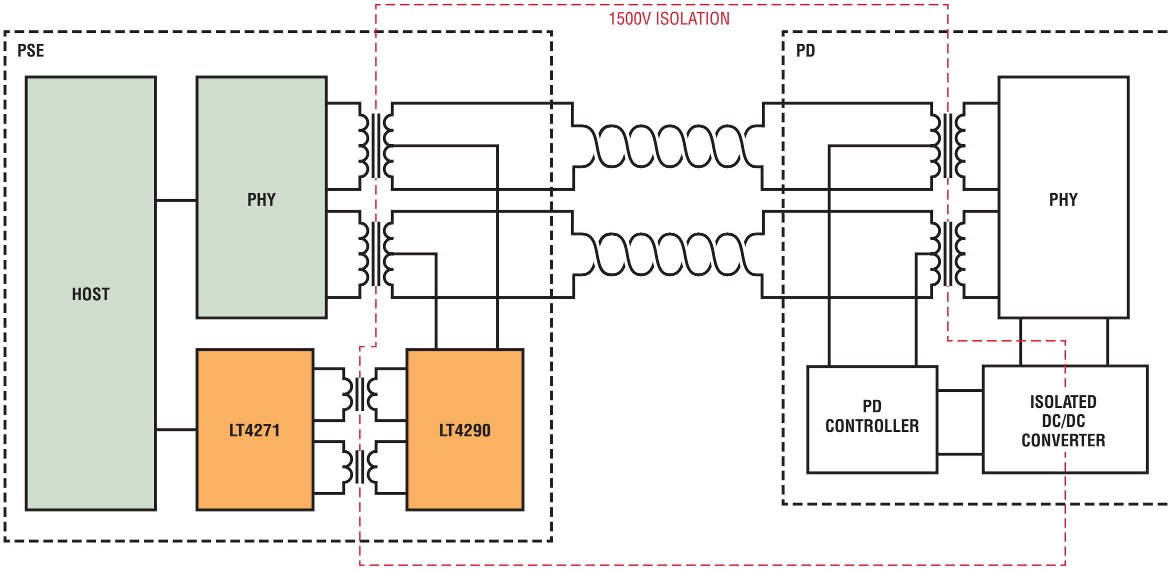


Figure 2. In contrast to the traditional scheme shown in Figure 1, a cleaner PSE architecture incorporates the LTC4290/LTC4271 chipset, achieving isolation without any opto-isolators and eliminatinating the need for a dedicated isolated DC/DC converter.

SYSTEM ISOLATION REQUIREMENTS

The PoE specification clearly lays out isolation requirements, guaranteeing ground loops are broken, maintaining Ethernet data integrity and minimizing noise in the PD application circuit.

Traditional PSE isolation architectures isolate the digital interface and power at the host-to-PSE controller interface. Digital isolation elements such as opto-couplers are inherently expensive and unreliable. ICs capable of performing the isolation function are cost-prohibitive or do not support fast I²C transfer rates. In addition, isolated DC/DC converters needed to power the PSE logic increase board space and system cost.

ISOLATION MADE EASY

The LTC4290/LTC4271 chipset takes a different approach to PSE isolation (Figure 2) by moving all digital functions to the host side of the isolation barrier. This significantly reduces the cost and complexity of required components. There is no longer the need for a separate, isolated DC/DC power supply; the LTC4271 digital controller can use the host's logic supply. The LTC4271 controls the LTC4290 using a transformer-isolated communication scheme. An inexpensive and ubiquitous Ethernet transformer pair replaces six opto-couplers. Intra-IC communication including port management, reset and fast port shutdown are encoded in a protocol designed to minimize radiated energy and provide 1500V of isolation.

ADVANCED FOURTH GENERATION FEATURES

Linear's PSE family incorporates a wealth of PoE experience and expertise backed by well over 100 million shipped ports. This latest PSE generation adds features to a proven, field-tested product line. New features include field-upgradable firmware, future-proofing platforms that incorporate the LTC4290/LTC4271. Also new is optional 1-second current averaging, which simplifies host power management. The highest grade LTC4290A analog controller enables delivered PD power of up to 90W using the new LTPoE++™ physical classification scheme.

As with previous generations, a key benefit of the LTC4290/LTC4271 chipset architecture is the lowest-in-industry power dissipation, making thermal design significantly easier than designing with PSEs that integrate more fragile and higher $R_{DS(ON)}$ MOSFETs. System designers will appreciate the robustness provided by 80V-tolerant port pins. PD discovery is accomplished using a proprietary dual-mode, 4-point detection mechanism that ensures immunity from false PD detection.

Advanced power management includes prioritized fast shutdown, 12-bit per-port voltage and current read back, 8-bit programmable current limits and 7-bit programmable overload current thresholds.

A 1MHz I²C interface allows a host controller to digitally configure the IC or query port readings. "C" libraries are available to reduce engineering costs and improve time to market.

CONCLUSION

The LTC4290/LTC4271 builds on an established, robust lineup of Linear PSE solutions by slashing BOM costs while providing an overall best-in-field solution. ■

Product Briefs

NANO-CURRENT HIGH VOLTAGE MONITOR

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. Status indicators RST and OUT are available with 36V open-drains or low voltage active pull-ups.

External resistive dividers configure monitor thresholds for each of the two comparator inputs. The LTC2960 monitors the ADJ input and pulls RST output low when the voltage at the comparator input drops below the comparator threshold. RST remains low until the ADJ input rises 2.5% above the threshold. A reset timeout period delays the return of the RST output to a high state to allow voltage settling, initialization time and/or a microprocessor reset function. An additional comparator with inverting or noninverting input includes 5% hysteresis and is indicated on the OUT pin.

A manual reset (MR) input enables external activation of the RST output. Other options include a selectable 15ms or 200ms reset timeout periods. A logic supply pin, DVCC, provides a power input for the active pull-up circuits. The LTC2960 is available in 8-lead 2mm × 2mm DFN and TSOT-23 packages. Electrical specifications are guaranteed from –45°C to 125°C.

MULTIPHASE STEP-UP DC/DC PROVIDES 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 LTC3862-2 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 a 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 allows for 2-, 3-, 4-, 6-, or 12-phase operation.

Like the LTC3861-1, the LTC3862-2's internal LDO regulates to 10V, optimizing gate drive for most automotive and industrial grade power MOSFETs. But unlike the LTC3861-1, the LTC3862-2's 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. This allows thermal dissipation to be shared more evenly between phases.

FULLY DIFFERENTIAL AMPLIFIER DRIVES 18-BIT ADCs & CONSUMES ONLY 5mW

Linear Technology announces the LTC6362, a low power fully differential amplifier that can drive high precision 16- and 18-bit SAR ADCs at only 1mA supply current. With 200µV max input offset voltage and 3.9nV/$\sqrt{Hz}$ input-referred noise, it is well suited for precision industrial and data acquisition applications.

The LTC6362 has an output common-mode pin with a 0.5V to 4.5V range, and 18-bit settling time of 550ns with an $8V_{P-P}$ output step, making it ideal for driving ADCs such as the LTC2379-18 in multiplexed input and control loop applications. This 18-bit SAR ADC features digital gain compression, which sets its full scale input range at 10% to 90% of the reference voltage. Together with the rail-to-rail output stage of the LTC6362, this feature eliminates the need for a negative supply rail, simplifying the circuit and minimizing power consumption.

The flexible architecture of the LTC6362 can convert single-ended DC-coupled, ground-referenced signals to differential, or DC level shift differential input signals. The low input bias current, low offset voltage and rail-to-rail inputs of the LTC6362 enable its use in a high impedance configuration to interface directly to sensors early in the signal chain.

The LTC6362 is available in MSOP-8 and 3mm × 3mm DFN packages, with fully guaranteed specifications over the 0°C to 70°C, –40°C to 85°C and –40°C to 125°C temperature ranges.

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

60V SYNCHRONOUS BUCK-BOOST LED DRIVER DELIVERS OVER 100W OF LED POWER

The LT3791 is a synchronous buck-boost DC/DC LED driver and voltage controller, which can deliver over 100W of LED power. Its 4.7V to 60V input voltage range makes it ideal for a wide variety of applications, including automotive, industrial and architectural lighting. Similarly, its output voltage can be set from 0V to 60V, enabling the LT3791 to drive a wide range of LEDs in a single string. Its internal 4-switch buck-boost controller operates from input voltages above, below or equal to the output voltage, ideal for applications such as automotive, where the input voltage can vary dramatically during stop/start, cold crank and load dump scenarios. Transitions between buck, pass-through and boost operating modes are seamless, offering a well regulated output even with wide variations of supply voltage. The LT3791's unique design utilizes three control loops to monitor input current, LED current and output voltage to deliver optimal performance and reliability.

The LT3791 uses four external switching MOSFETs and delivers from 5W to over 100W of continuous LED power with efficiencies up to 98.5%. LED current accuracy of +6% ensures constant lighting while ±2% output voltage accuracy enables the converter to operate as a constant voltage source. The LT3791 utilizes either analog or PWM dimming as required by the application. Furthermore, its switching frequency can be programmed between 200kHz and 700kHz or synchronized to an external clock. Additional features include output disconnect, input and output current monitors, open and shorted LED detection and integrated fault protection. The LT3791EFE is available in 38-lead thermally enhanced TSSOP package.

30MHz TO 1.4GHz WIDEBAND I/Q DEMODULATOR WITH IIP2 OPTIMIZATION & DC OFFSET CANCELLATION IMPROVES ZERO-IF RECEIVER PERFORMANCE

The LTC5584 is an ultrawide bandwidth direct conversion I/Q demodulator with outstanding linearity of 31dBm IIP3 and 70dBm IIP2. The device offers best-in-class demodulation bandwidth of over 530MHz, supporting the latest generation of LTE multimode, LTE Advanced receivers, as well as digital predistortion (DPD) receivers. The I/Q demodulator operates over a wide frequency range from 30MHz to 1.4GHz, covering a broad range of VHF and UHF radios and the 450MHz/700MHz LTE frequency bands. Unique to the LTC5584 are two built-in calibration features. One is advanced circuitry that enables the system designer to optimize the receiver's IIP2 performance, increasing from a nominal 70dBm to an unprecedented 80dBm or higher. The other is on-chip circuitry to null out the DC offset voltages at the I and Q outputs. Combined with a 9.9dB noise figure, these features enhance the dynamic range performance in receivers. Moreover, the device exacts P1dB of 12.6dBm, along with its 13.6dB noise figure under a 0dBm in-band blocker, ensuring robust receiver performance in the presence of interference.

To enhance its flexibility for use in low IF receiver applications, the LTC5584 exhibits very low I/Q amplitude and phase mismatch. The amplitude mismatch is typically 0.02dB, while the phase error is typically 0.25 degree, both specified at 450MHz. This combination produces receiver image rejection of 52dB.

With its wide bandwidth capability, the LTC5584 is ideal for multimode LTE and CDMA DPD receivers as well as other wideband receiver applications. Particularly suited for DPD, these latest generation base stations are pushing demodulation bandwidth of over 300MHz. The LTC5584 exceeds these bandwidth requirements while delivering better than ±0.5dB conversion gain flatness. Beyond wireless infrastructure applications, the LTC5584 is ideal for military receivers, broadband communications, point-to-point microwave data links, image-reject receivers and long-range RFID readers.

The LTC5584 is offered in a 24-lead 4mm × 4mm QFN package. The device is specified for case operating temperature from –40°C to 105°C. Powered from a single 5V supply, the LTC5584 draws a total supply current of 200mA. The device provides a digital input to enable or disable the chip. When disabled, the IC draws 11µA of leakage current typical. The demodulator's fast turn-on time of 200ns and turn-off time of 800ns enables it to be used in burst-mode receivers. ■

–3.3V NEGATIVE CONVERTER WITH 1A OUTPUT CURRENT LIMIT

The LT8611 is a compact, high efficiency, high speed synchronous monolithic step-down switching regulator that consumes only 2.5µA of quiescent current. Top and bottom power switches are included with all necessary circuitry to minimize the need for external components. The built-in current sense amplifier with monitor and control pins allows accurate input or output current regulation and limiting. Low ripple Burst Mode® operation enables high efficiency down to very low output currents while keeping the output ripple below 10mV$_{P-P}$.

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LTspice IV
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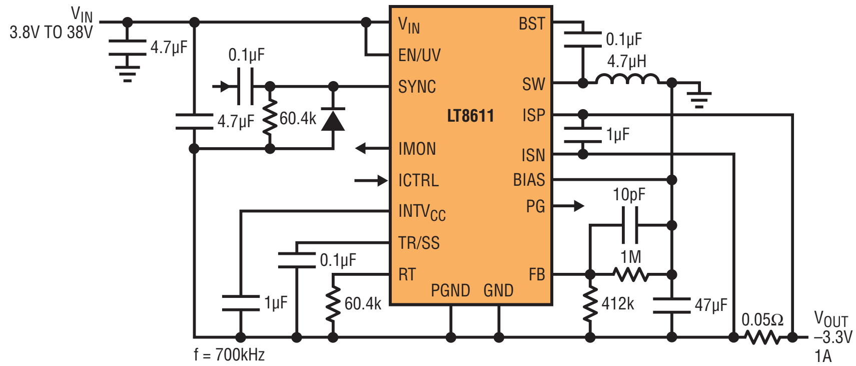

2A, 4-CELL LI-ION BATTERY CHARGER WITH C/10 TERMINATION

The LTM8062/LTM8062A are complete 32V V_{IN}, 2A µModule power tracking battery chargers. The LTM8062/ LTM8062A provide a constant-current/constant-voltage charge characteristic, a 2A maximum charge current, and employ a 3.3V float voltage feedback reference, so any desired battery float voltage up to 14.4V for the LTM8062 and up to 18.8V for the LTM8062A can be programmed with a resistor divider.

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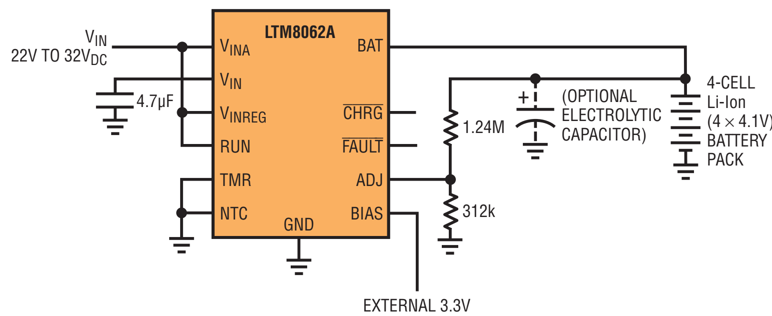

4.3V TO 42V INPUT, 3.3V, 5A OUTPUT STEP-DOWN CONVERTER

The LT3976 is an adjustable frequency monolithic buck switching regulator that accepts a wide input voltage range up to 40V. Low quiescent current design consumes only 3.3µA of supply current while regulating with no load. Low ripple Burst Mode operation maintains high efficiency at low output currents while keeping the output ripple below 15mV in a typical application.

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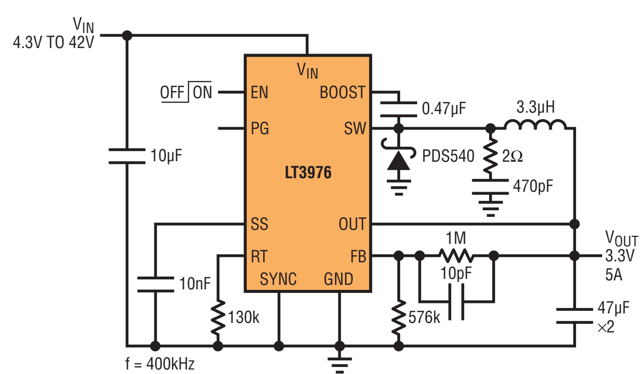

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