Active Clamp Synchronous Controllers for Forward Converters with 6.5V to 100V+ Inputs

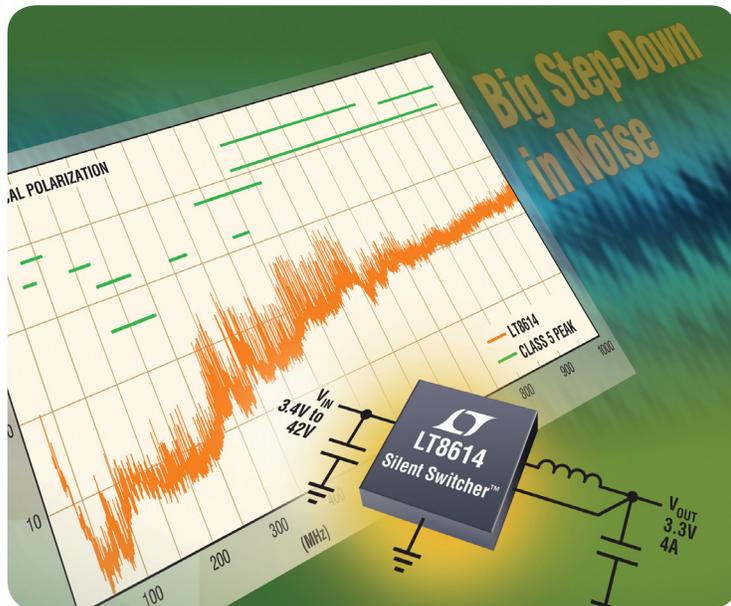Wei Gu, Randyco Prasetyo and Fei Guo

The LT3752, LT3752-1 and LT3753 are highly integrated, high performance active clamp forward controllers that minimize external component count, solution size and cost. Two of these controllers, the LT3752 and LT3753, are designed for inputs up to 100V, while the LT3752-1 is designed for applications with input voltages greater than 100V—suitable for HV car battery and offline isolated power supplies, industrial, automotive and military systems. All produce compact, versatile and efficient solutions for single-IC output power levels up to 400W. Higher power levels are supported by stacking converter outputs in series. See Table 1 (on page 4) for a feature comparison of these devices.

NO-OPTO MODE OPERATION REGULATES WITH ACCURATE PROGRAMMABLE VOLT-SECOND CLAMP

Figure 1 shows a complete 150W forward converter that requires no opto-couplers thanks to the LT®3752's accurate, programmable volt-second clamp. For a forward converter operating in continuous conduction mode, the output voltage is $v_{OUT} = v_{IN} \bullet N \bullet D$, where v_{IN} is the input voltage, N is the secondary to primary turns ratio and D is the duty cycle. The duty cycle clamp on the OUT pin of the LT3752, LT3752-1 and LT3753 inversely tracks v_{IN} to maintain constant v_{OUT} over the input voltage range.

The LT8614 Silent Switcher™ selected for *EDN* & *EE Times* ACE Award (page 3)

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LINEAR TECHNOLOGY

In this issue...

Linear in the News

NEW LINEAR VIDEO PRESENTATIONS

Two new videos at www.linear.com from Linear Chief Technical Officer Bob Dobkin cover the new family of LDO+™ linear regulators, which add monitoring and control functions to the usual regulation features. Here are summaries of those and two other recently released videos:

2.1A LDO+ Regulator Features Cable Drop Compensation and Monitors Current & Temperature

Bob Dobkin, Vice President Engineering & CTO—In addition to the usual LDO regulatory functions, the LT3086 LDO+ can monitor and externally limit both temperature and output current, has an accurate power good output and can compensate for wire drops between the regulator and the load. www.linear.com/solutions/4522.

1.5A LDO+ Regulator Monitors Current & Temperature

Bob Dobkin, Vice President Engineering & CTO—The LT3081 LDO+ features a wide safe area, allowing operation with high currents at high input-output differentials. The LT3081's output voltage is adjustable from 0V to 37V and it withstands reverse voltage. It includes a current monitor and temperature monitor outputs. The LT3081 is stable with no output or input capacitor, a feature unique to this device. www.linear.com/solutions/4521

Single-Ended to Differential Conversion Using Differential Op Amps

Kris Lokere, Applications Manager, Signal Chain Products—Differential op amps are important building blocks in modern analog and mixed signal circuits. For instance, many modern ADCs require differential signals at the inputs, and differential analog signals are used to drive signals over a cable. This video shows how to connect differential op amps to convert a single-ended input signal to a differential output, how common mode level shifting works and how to use differential op amps to build active filters. www.linear.com/solutions/4524

Wireless Power Receiver Enables Compact and Efficient Contactless Battery Charging

Trevor Barcelo, Product Line Manager, Battery Charger Products—Wireless battery charging enables applications where it is difficult or impossible to use a wired connector. Examples include products that need to operate in harsh environments or need to be cleaned or sterilized, as well as products that are simply too small for a connector. This video shows the LTC®4120 400mA wireless power receiver buck battery charger with a wireless power transmitter to charge a 3.5V to 11V battery with a constant-current/constant-voltage charge algorithm. It enables high efficiency charging without any of the thermal or overvoltage problems typical of wireless power systems. www.linear.com/solutions/4469

STANFORD SOLAR CAR RACES, POWERED BY LINEAR BATTERY MANAGEMENT SYSTEM

The Stanford Solar Car Project is an entirely student-run, nonprofit organization at Stanford University that builds solar powered cars to race in the 2000-mile World Solar Challenge in the Australian Outback. It provides an opportunity for students to gain valuable hands-on engineering experience while raising awareness of clean energy vehicles. The team finished 4th overall in the 2013 Bridgestone World Solar Challenge, and was the fastest undergraduate solar car in the grueling five-day race in Australia last October. They experienced no mechanical failures and did not burn a single drop of gasoline.

The Stanford solar car uses numerous Linear Technology products, including the LTC6803 and LTC6804 multicell battery stack monitors. Other Linear products in the Luminos solar car include Hot Swap™ controllers, precision references and amplifiers, LED drivers, micropower step-down regulators, micropower low dropout regulators and synchronous step-down switching regulators.

LINEAR PRODUCT AWARDS
EDN & EE Times ACE Awards

Winner, Ultimate Products: Power—
The LT8614 Silent Switcher™ regulator is a 4A, 42V input capable synchronous step-down switching regulator. It reduces EMI/EMC emissions by more than 20dB. Even with switching frequencies in excess of 2MHz, synchronous rectification delivers efficiency as high as 96% while Burst Mode® operation keeps quiescent current under 2.5µA in no-load standby conditions. Its 3.4V to 42V input voltage range is ideal for automotive and industrial applications.

Finalist, Ultimate Products: Analog ICs—
The LTC2378-20 20-bit, 1Msps, low power, no latency SAR ADC leads the industry with 0.5ppm integral nonlinearity
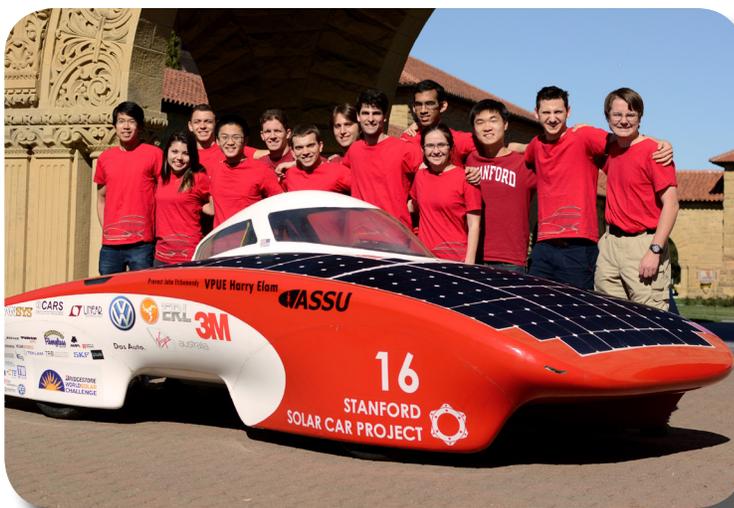
error (INL), making it a true 20-bit ADC, able to resolve down to 5µV of resolution on a 5V differential input span. Its 104dB SNR is the industry's highest for any 1Msps no latency ADC, providing higher dynamic range compared to fast delta-sigma ADCs that also have latency. Applications include seismic monitoring, energy exploration, airflow sensing, silicon wafer fabrication, medical devices, data acquisition systems, automatic test equipment, compact instrumentation and industrial process control systems.

Finalist, Ultimate Products: Wireless/RF—
The LTC5551 downconverting mixer's +36dBm IIP3 (input third-order intercept) and 2.4dB conversion gain are unparalleled. Other passive mixers claiming similar IIP3 performance typically have 7dB to 9dB of conversion loss. The LTC5551's 2.4dB of conversion gain substantially improves receiver dynamic range. The mixer can be used over a broad RF frequency range, from 300MHz to 3.5GHz. The LTC5551 features an integrated LO buffer on chip, requiring only 0dBm drive level, eliminating the need for a high power buffer amplifier stage, often requiring power levels of +17dBm or higher. By eliminating such a high power LO signal in the user's receiver, overall cost is lowered, and a potential source of undesirable radiation is removed, thus simplifying

filtering and RF shielding requirements. The superior performance of this mixer is ideal for applications in multicarrier GSM, 4G LTE and LTE-advanced multimode base stations, point-to-point backhauls, military communications, wireless repeaters, public safety radios, VHF/UHF/white-space broadcast receivers, radar and avionics.

CONFERENCES & EVENTS

Advanced Automotive Battery Conference, International Conference Center, Kyoto, Japan, May 19-23, Booth 40—Linear will exhibit power management and battery monitoring systems. More info at www.advanced-autobat.com/conferences/automotive-battery-conference-Asia-2014/index.html

Wireless Japan 2014, Tokyo Bigsight, Tokyo, Japan, May 28-30, West Hall 3, Booth W118—Presenting Linear's Dust Networks® wireless sensor network solutions. More info at www8.ric.co.jp/expo/wj/

Sensors Expo/Energy Harvesting Pavilion, Donald E. Stephens Convention Center, Rosemont, Illinois, June 24-26, Booth 920—Linear will showcase energy harvesting and wireless sensor network solutions. Presentations: "Energy Harvesting for Battery-Operated Applications" by Sam Nork; "Reliable, Low-Power Wireless Sensor Networks for the Industrial Internet of Things" by Joy Weiss. More info at www.sensorsmag.com/sensors-expo

The Stanford solar car uses numerous Linear Technology products. including the LTC6803 and LTC6804 multicell battery stack monitors.

Table 1. Feature comparison of LT3752, LT3752-1 and LT3753

PART	INPUT RANGE	ACTIVE CLAMP DRIVER	HOUSEKEEPING FLYBACK CONTROLLER
LT3753	8.5V–100V	Lo-Side	No
LT3752	6.5V–100V	Lo-Side	Yes
LT3752-1	100V–400V+	Hi-Side	Yes

(LT375x) continued from page 1

In an active volt-second clamp scheme, the accuracy of v_{OUT} depends heavily on the accuracy of the volt-second clamp. Competing volt-clamp solutions use an external RC network connected from the system input to trip an internal comparator threshold. Accuracy of the RC method suffers from external capacitor error, part-to-part mismatch between the RC time constant and the IC's switching period, the error of the internal comparator threshold and the nonlinearity of charging at low input voltages.

To ensure accurate regulation part to part, the LT3752, LT3752-1 and LT3753 feature trimmed timing capacitor and comparator thresholds. Figure 2 shows v_{OUT} versus load current for various input voltages.

If the resistor that programs the duty cycle clamp goes open circuit, the part immediately stops switching, preventing the device from running without the volt-second clamp in place.

## INTEGRATED HOUSEKEEPING FLYBACK CONTROLLER

The LT3752/LT3752-1 includes an internal constant frequency flyback controller for generating a housekeeping supply. The housekeeping supply can efficiently provide bias for both primary and secondary ICs, eliminating the need to generate bias supplies from auxiliary windings in the main forward transformer, significantly reducing transformer complexity, size and cost.

The housekeeping supply can be used to overdrive the INTV$_{CC}$ pin to take power outside of the part, improve efficiency, provide additional drive current and optimize the INTV$_{CC}$ level. The housekeeping supply also allows bias to any secondary side IC before the main forward converter starts switching. This removes the need for external start-up circuitry on the secondary side.

PRECISION UNDERVOLTAGE LOCKOUT AND SOFT-START

The precision LT3752/LT3752-1 undervoltage lockout (UVLO) feature can be used for supply sequencing or start-up overcurrent protection—simply apply a resistor divider to the UVLO pin from the v_{IN} supply.

Figure 1. 150W forward converter in No-Opto mode
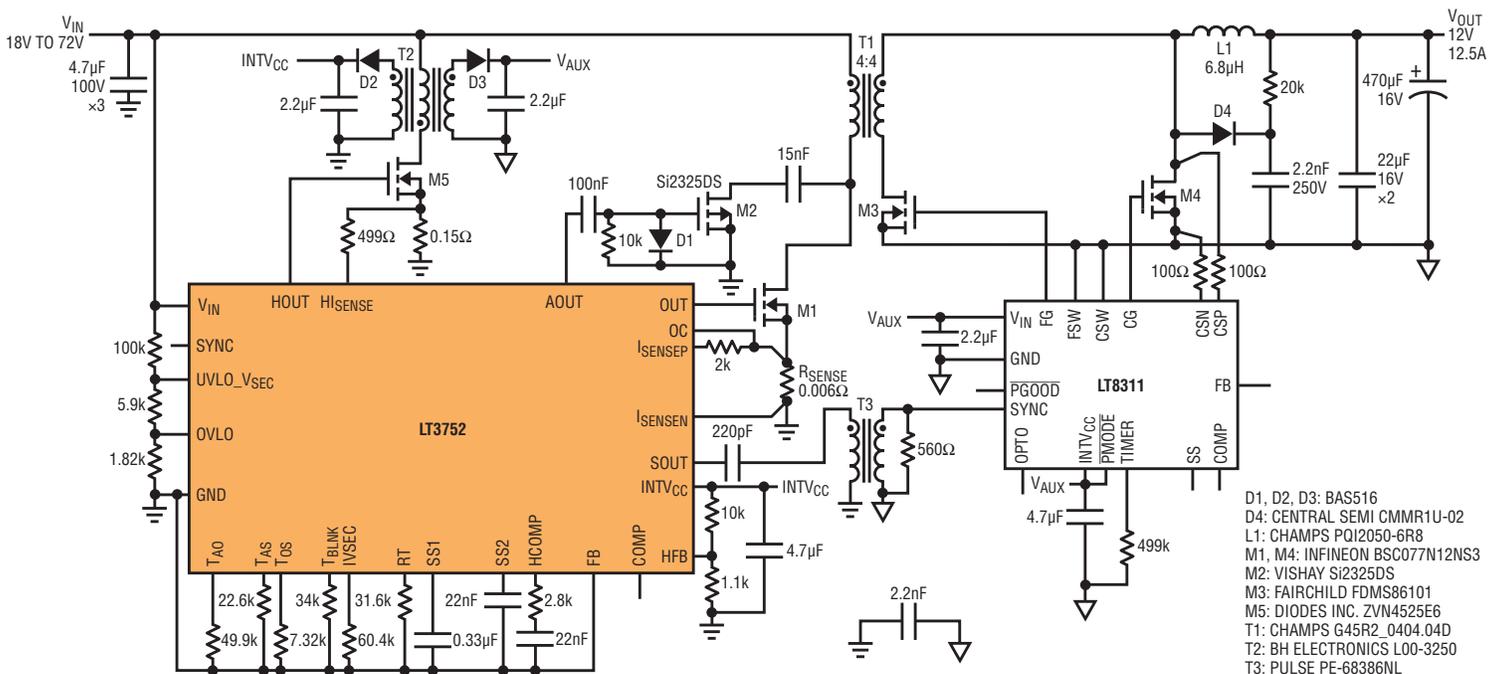
In an active volt-second clamp scheme, the accuracy of V_{OUT} depends heavily on the accuracy of the volt-second clamp. Competing volt-clamp solutions use an external RC network which suffers from a number of error sources. To ensure accurate regulation part to part, the LT3752, LT3752-1 and LT3753 feature trimmed timing capacitor and comparator thresholds.

The UVLO pin features adjustable input hysteresis, allowing the IC to resist input supply droop before engaging soft-stop. During soft-stop the converter continues to switch as it folds back the switching frequency, volt-second clamp and COMP pin voltage. The LT3752, LT3752-1 and LT3753 have a micropower shutdown threshold of approximately 400mV at the UVLO pin—v_{IN} quiescent current drops to 40µA, or lower.

Adding capacitors to the soft-start pins, (SS1 and SS2) implements the soft-start feature, which reduces the peak input current and prevents output voltage overshoot during start-up or recovery from a fault condition. The SS1/2 pins reduce the inrush current by lowering the current limit and reducing the switching frequency, allowing the output capacitor to gradually charge toward its final value.

SHUTDOWN WITH SOFT-STOP

In a reversal of soft-start start-up, the LT3752/LT3752-1 and LT3753 can gradually discharge the SS1 pin (soft-stop) during shutdown. Figure 3 shows shutdown waveforms of the converter shown in Figure 5. Without soft-stop, the self-driven synchronous rectifier feedback transfers capacitor energy to the primary, potentially causing shutdown oscillation and damaging components on the primary side.

Figure 4 shows shutdown waveforms with soft-stop. The converter continues to switch as it folds back switching frequency, volt-second clamp and COMP pin voltage, resulting in clean shutdown.

CURRENT MODE CONTROL

The LT3752/LT3752-1 and LT3753 use a current mode control architecture to increase supply bandwidth and response to line and load transients over voltage mode controllers. Current mode control requires

fewer compensation components than voltage mode control architectures, making it much easier to compensate a broad range of operating conditions. For operation in continuous mode and above 50% duty cycle, required slope compensation can be programmed by a single resistor.

PROGRAMMABLE FEATURES SIMPLIFY OPTIMIZATION

The LT3752/LT3752-1 and LT3753 include a number of programmable features that allow the designer to optimize them for a particular application. For instance, programmable delays between various gate signals can be used to prevent cross-conduction and to optimize efficiency. Each delay can be set with a single resistor.

Programmable turn-on current spike blanking (adaptive leading edge blanking plus programmable extended blanking) of the main MOSFET greatly improves the converter's noise immunity. During gate rise time, and sometime thereafter,

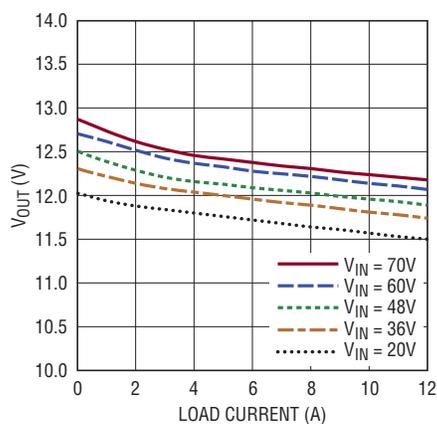Figure 2. Output voltage vs load current at various input voltages

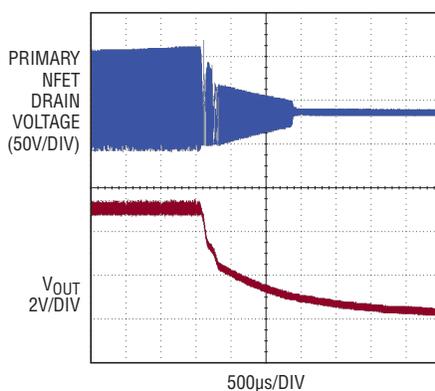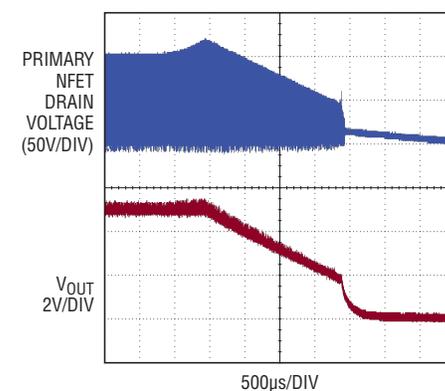Figure 3. Shutdown waveforms of circuit in Figure 5 without soft-stop show oscillations.

Figure 4. Shutdown waveforms of circuit in Figure 5 showing soft-stop in action

The LT3752/LT3752-1 and LT3753 include a number of programmable features that enable optimization for particular applications. For instance, programmable delays between various gate signals can be used to prevent cross-conduction and to optimize efficiency.
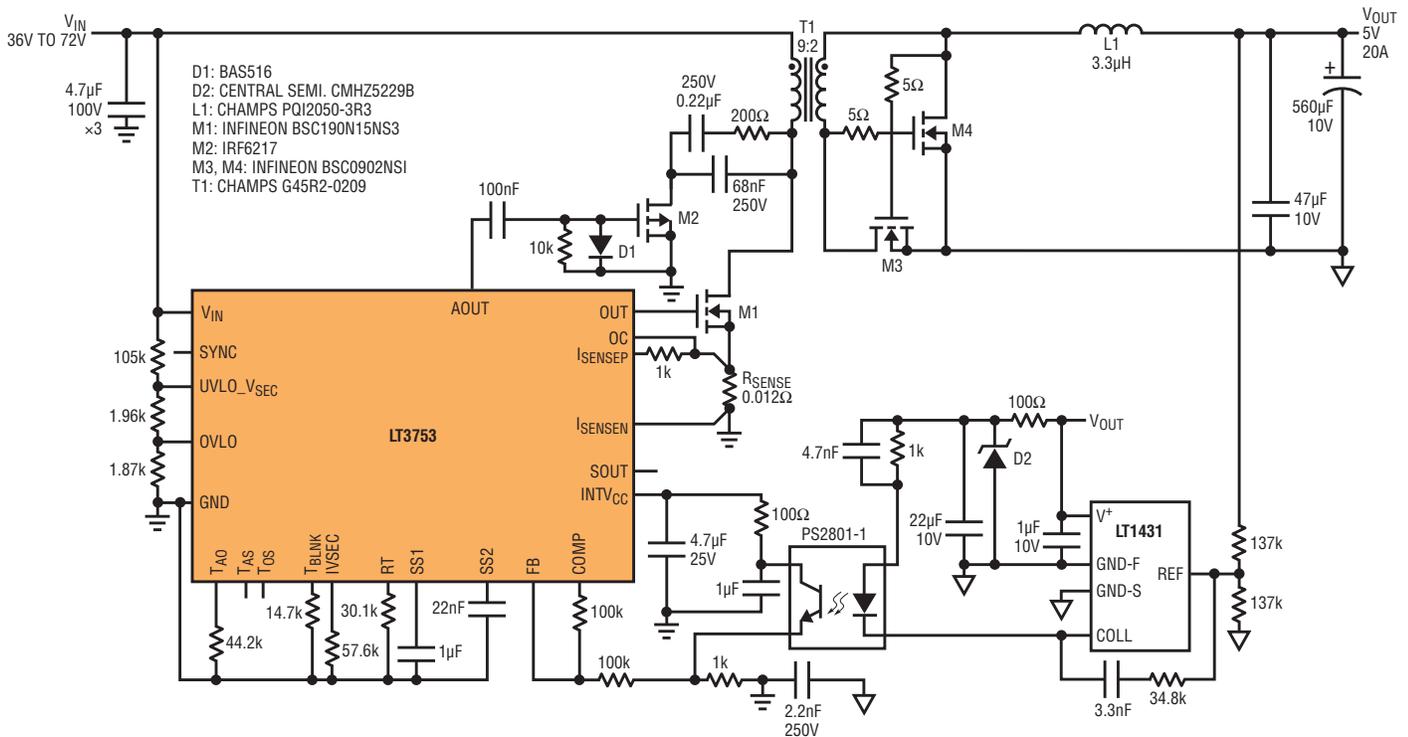

**Figure 5. 5V at 20A forward converter that takes an input of 36V to 72V**

noise can be generated in the current sensing resistor connected to the source of the MOSFET. This noise can false trip the sensing comparators, resulting in early switch turnoff. One solution to this problem is to use an oversized RC filter to prevent false trips, but programmable turn-on spike blanking can eliminate the need for additional RC filtering.

The operating frequency can be programmed from 100kHz to 500kHz range with a single resistor from the RT pin to ground, or synchronized to an external clock via the SYNC pin. The adjustable operating frequency allows it to be set outside certain frequency bands to fit applications that are sensitive to spectral noise.

36V–72V INPUT, 5V/20A FORWARD CONVERTER

Figure 5 shows a 5V, 20A output converter that takes a 36V–72V input. The

Figure 6. Efficiency of the converter in Figure 5
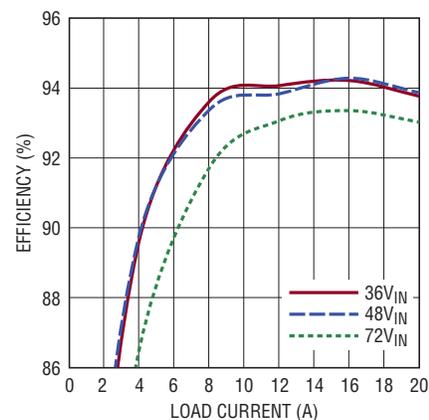
active reset circuit consists of a small P-channel MOSFET M2 and a reset capacitor. The MOSFET M2 is used to connect the reset capacitor across the transformer T1 primary winding during the reset period when M1 MOSFET is off. The voltage across the reset capacitor automatically adjusts with the duty cycle to provide complete transformer reset under all operating conditions.

Also the active reset circuit shapes the reset voltage into a square waveform that is suitable for driving the secondary synchronous MOSFET rectifier M4. The MOSFETs are on the secondary side and are driven by the secondary winding voltage. Figure 6 shows the efficiency for this converter.

The LT3752/LT3752-1 and LT3753 use a current mode control architecture to increase supply bandwidth and response to line and load transients when compared to voltage mode controllers. Current mode control requires fewer compensation components than voltage mode control architectures, making it easier to compensate a broad range of operating conditions.
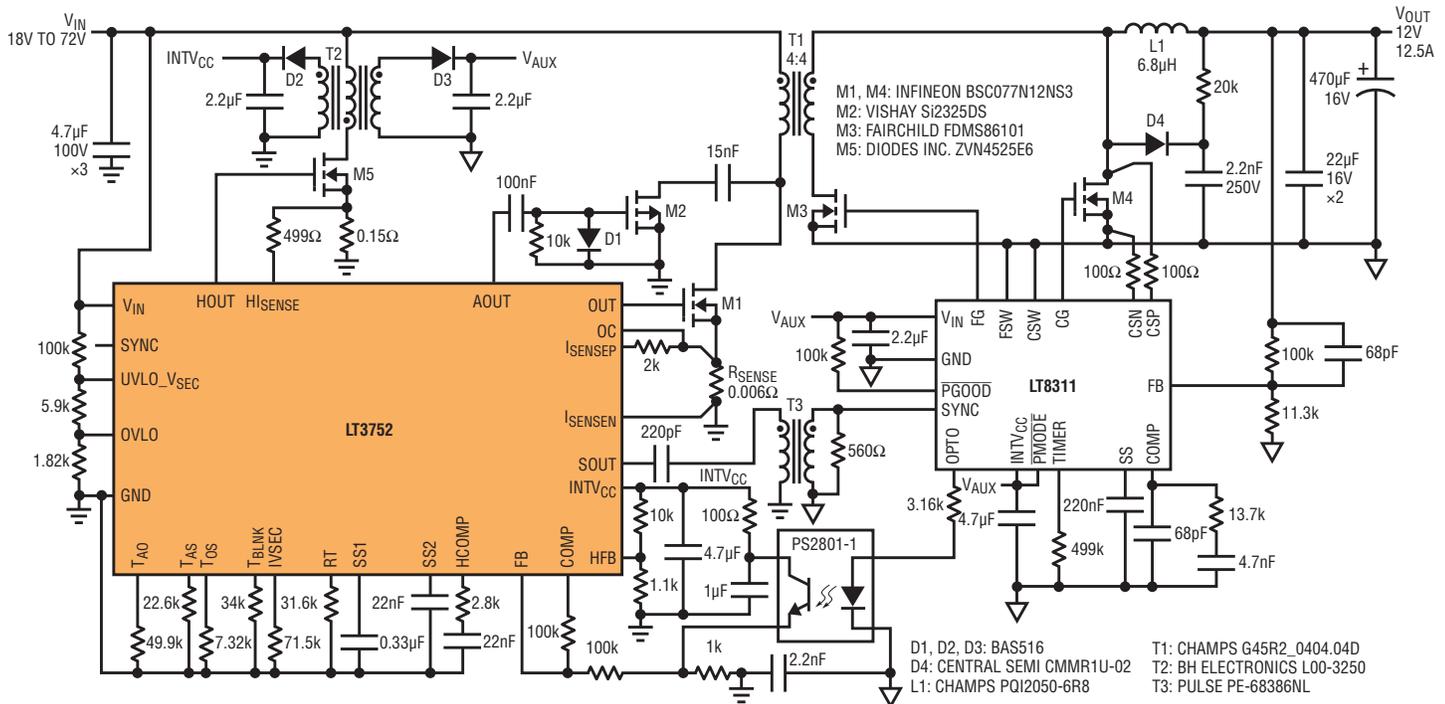

**Figure 7. 18V–72V input, 12V at 12.5A output forward converter**

18V–72V INPUT, 12V/12.5A FORWARD CONVERTER

Figure 7 shows an 18V–72V input, 12V/12.5A output forward converter. The LT8311 is used on the secondary side of forward converters to provide synchronous MOSFET control and output voltage feedback through an opto-coupler. A pulse transformer (see T3 in Figure 7) is required to allow the LT8311 to receive synchronization control signals from the primary-side IC. These control signals are interpreted digitally (high or low) by the LT8311 to turn on/off the catch and forward MOSFETs. Figure 8 shows the efficiency for this converter.

150V–400V INPUT, 12V/16.7A FORWARD CONVERTER

Figure 9 shows a 150V–400V input, 12V/16.7A output isolated flyback converter. For high input voltage applications, the voltage rating of the available P-channel MOSFETs may not be high enough to be used as the active clamp switch in the low side active clamp topology. An N-channel approach using the high side active clamp topology should be used. This topology requires a high side gate driver or a gate transformer to drive the N-channel MOSFET to switch in the active clamp capacitor. Figure 10 shows the efficiency for this converter.

Figure 8. Efficiency for the converter in Figure 7
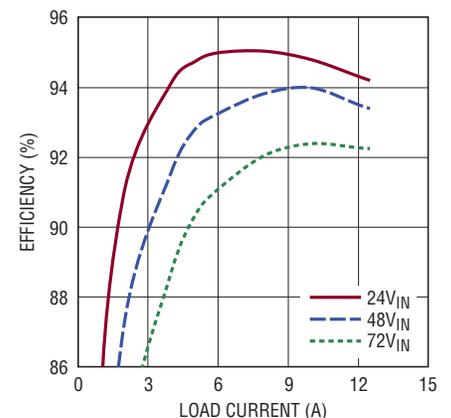
The LT3752/LT3752-1 includes an internal constant frequency flyback controller for generating a housekeeping supply. The housekeeping supply can efficiently provide bias for both primary and secondary ICs, eliminating the need to generate bias supplies from auxiliary windings in the main forward transformer, significantly reducing transformer complexity, size and cost.
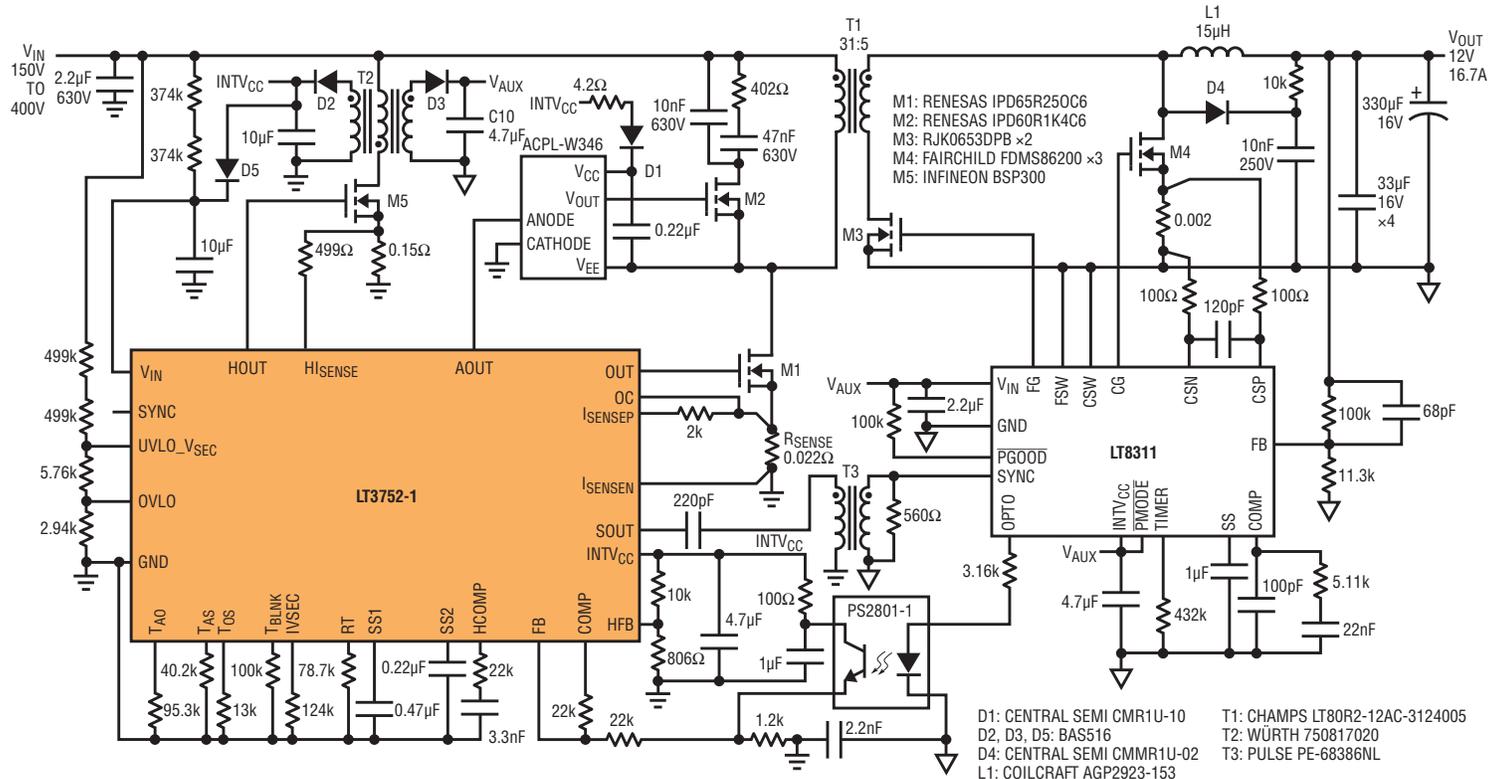
Figure 9. 150V–400V input, 12V/16.7A output isolated forward converter

CONCLUSION

The LT3752, LT3752-1 and LT3753 simplify the design and improve performance to isolated power supplies with a volt-second clamp architecture that produces accurate regulation. An integrated flyback controller can be used to produce a housekeeping supply, simplifying the magnetics. Current mode control improves bandwidth and allows compensation for a broad range of operating conditions. Soft-stop features protect the supply and other components from potentially damaging voltage and current spikes. ∎

Figure 10. Efficiency for the converter in Figure 9
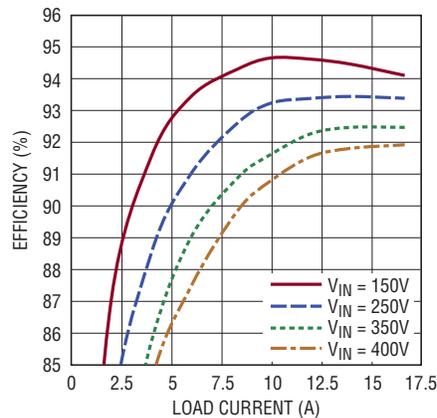
RS485/RS422 Transceivers Operate from 3V to 5.5V Supplies and Withstand ±60V Faults

Ciaran Brennan

The LTC2862–LTC2865 are robust RS485/RS422 transceivers that feature ±60V overvoltage and ±15kV ESD tolerance to reduce failures caused by electrical overstress. These transceivers introduce several new capabilities for high voltage tolerant RS485 transceivers: operation from 3V to 5.5V supply voltages, up to 20Mbps data rate, ±25V common mode voltage range, selectable slew rate, interface to low voltage logic, and availability in 3mm × 3mm DFN packages.

The venerable RS485 serial bus forms the backbone of many commercial and industrial data communications systems. RS485-based networks are used in a wide variety of applications, including industrial control systems, supervisory control and data acquisition systems, building automation and security, theatre and performance venue lighting control, commercial aircraft and ground vehicle busses, and other custom networked systems. Robustness to electrical overstress is an important attribute for RS485 transceivers used in these applications, with risk of wiring faults, ground voltage faults and lightning induced surge voltages.

Figure 1. This family of robust high voltage tolerant transceivers includes features typically only found only in less robust ICs
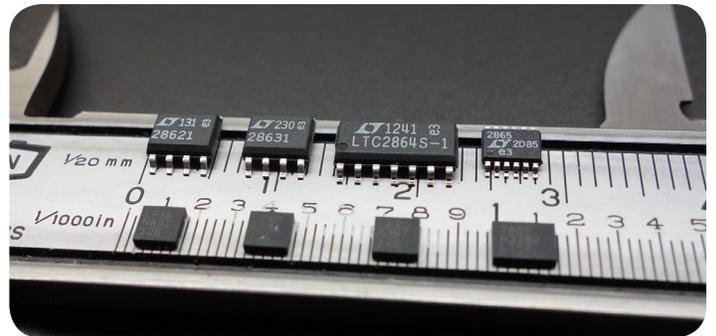
However, most high voltage tolerant RS485 transceivers lack the performance and features of the latest non high voltage tolerant RS485 transceivers. The LTC2862–LTC2865 transceivers fill this gap by combining fault tolerance with the expanded capabilities demanded in the specifications for contemporary network applications.

3V TO 5.5V OPERATION

High voltage tolerant RS485 transceivers typically operate from 5V supplies, but the 5V supply is fast becoming an anachronism, rarely used in modern digital circuits. In some cases, a fault-tolerant RS485 transceiver is the only 5V component in the system, incurring the cost of a dedicated supply.

In contrast to some high voltage tolerant transceivers, the LTC2862–LTC2865 maintain full compliance to RS485 and RS422 standards when operating from a 3.3V supply. Competing parts sometimes drive a reduced VOD when powered by 3.3V. The LTC2862–LTC2865 transceivers are fully interoperable with 5V-powered transceivers on the same bus when operating from either a 3.3V or 5V supply.

LOW VOLTAGE LOGIC INTERFACE

Many microcontroller systems operate at voltages lower than 3.3V. The LTC2865 provides the means to interface to logic operating as low as 1.65V. A v_L supply pin and built in level shifters translate the I/O signals from the lower voltage v_L logic supply to the higher voltage v_{CC} supply used to power the RS485 receiver and transmitter. This eliminates the need for external level shifters in mixed-voltage RS485 systems. The two supplies may be powered up and powered down independently of each other.

20Mbps OR 250kbps DATA RATE

Modern RS485 systems can operate at data rates that exceed the capabilities of most high voltage tolerant transceivers. For example, the highly popular LT1785/LT1791 transceivers operate at a maximum of 250kbps. The LTC2862–LTC2865 offer similar high voltage tolerance, but can communicate 160 times faster at up to 20Mbps.

Not all systems require a high data rate. In applications where 250kbps suffices, the system designer may prefer an RS485 driver with low EMI slew-controlled

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transitions. The LTC2862–LTC2865 satisfy this need. These parts come in two versions: the high speed 20Mbps LTC2862-1, LTC2863-1, LTC2864-1; and the slew-limited 250kbps LTC2862-2, LTC2863-2, LTC2864-2. The LTC2865 supports both the high speed and the slew-limited transmit modes and provides an additional input pin to select between the two modes.

±25V COMMON MODE VOLTAGE RANGE

Standard RS485 transceivers operate over a limited common mode voltage range that extends from −7V to 12V. In a commercial or industrial environment, ground faults, noise, and other electrical interference can induce common mode voltages that exceed these limits. An ideal RS485 transceiver would not only survive large common mode voltages but would continue to send and receive data without disruption.

The receivers in the LTC2862–LTC2865 operate over an expanded ±25V common

PART NUMBER	DUPLEX	ENABLES	V_L PIN	SLEW LIMIT PIN	PACKAGES
LTC2862-1, -2	HALF	YES	NO	NO	S8: 8-LEAD SO DD: 8-LEAD DFN
LTC2863-1, -2	FULL	NO	NO	NO	S8: 8-LEAD SO DD: 8-LEAD DFN
LTC2864-1, -2	FULL	YES	NO	NO	S: 14-LEAD SO DD: 10-LEAD DFN
LTC2865	FULL	YES	YES	YES	MSE: 12-LEAD MSOP DE: 12-LEAD DFN

Table 1. LTC2862–LTC2865 pinouts and packages

mode voltage range. The receivers use low offset bipolar differential inputs, combined with high precision resistor dividers to maintain precise receiver thresholds over the wide common mode voltage range. The transmitters operate up to the absolute maximum voltages of ±60V, and will sink or source current up to the limits imposed by their current limit circuitry.

The LTC2862–LTC2865 excel in rejecting large amplitude, high frequency and high slew rate common mode perturbations. Figure 2 shows the LTC2865 receiving 10Mbps data with a ±200mV differential signal superimposed on a 50VP-P 1MHz common mode signal, while Figure 3 shows the LTC2865 receiving 20Mbps data with a ±200mV differential signal superimposed on a −12V step in the common mode voltage with a 36ns 10%–90% fall time. In a noisy electrical environment this exceptional common mode rejection can greatly improve the reliability of data communications.

Both the high speed 20Mbps and the slew-limited 250kbps version of the LTC2862–LTC2865 contain receivers with the full 20Mbps bandwidth. A fast common mode transient such as the one illustrated in Figure 3 can produce a differential voltage as it propagates along the cable if the capacitive loads on the two lines are not well matched. If the resulting differential voltage exceeds the receiver
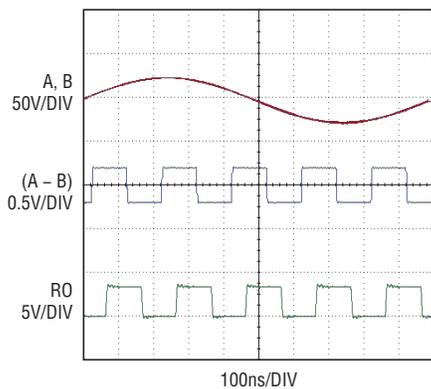

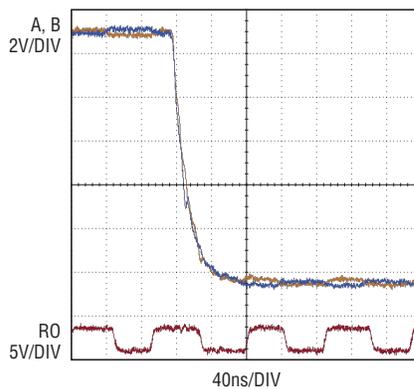**Figure 2. LTC2865 receiving 10Mbps ±200mV differential signal with 1MHz 50VP-P common mode sweep**

Figure 3. LTC2865 receiving 20Mbps ±200mV differential signal with −12V 36ns fall time common mode step

These devices have a failsafe feature that guarantees the receiver output is in a logic 1 state (the idle state) when the inputs are shorted, left open, or terminated but not driven, for more than about 3µs. The delay allows normal data signals to transition through the threshold region without being interpreted as a failsafe condition. This failsafe feature is guaranteed to work for inputs spanning the entire common mode range of –25V to 25V.

threshold it may trigger a state change in the receiver. In systems where the data rate is ≤ 250kbps, the noise immunity of the receivers may be increased by adding a 100pF–1nF capacitor across the receiver pins to filter the high frequency differential noise generated by common mode noise acting on mismatched capacitive loads.

FULL FAILSAFE OPERATION WITH SYMMETRICAL RECEIVER THRESHOLDS

These devices have a failsafe feature that guarantees the receiver output is in a logic 1 state (the idle state) when the inputs are shorted, left open, or terminated but not driven, for more than about 3µs. The delay allows normal data signals to transition through the threshold region without being interpreted as a failsafe condition. This failsafe feature is guaranteed to work for inputs spanning the entire common mode range of –25V to 25V.

The LTC2862–LTC2865 implement the failsafe function with a window comparator (Figure 4). The comparator has fully symmetric positive and negative signal threshold voltages (typically ±75mV). The voltage difference between the two signal threshold voltages constitutes the signal hysteresis (typically 150mV). In addition the failsafe threshold voltage lies between the negative signal threshold voltage and 0V with a typical value of –50mV. The difference between the negative signal threshold voltage and the failsafe threshold voltage is the failsafe hysteresis, typically 25mV.
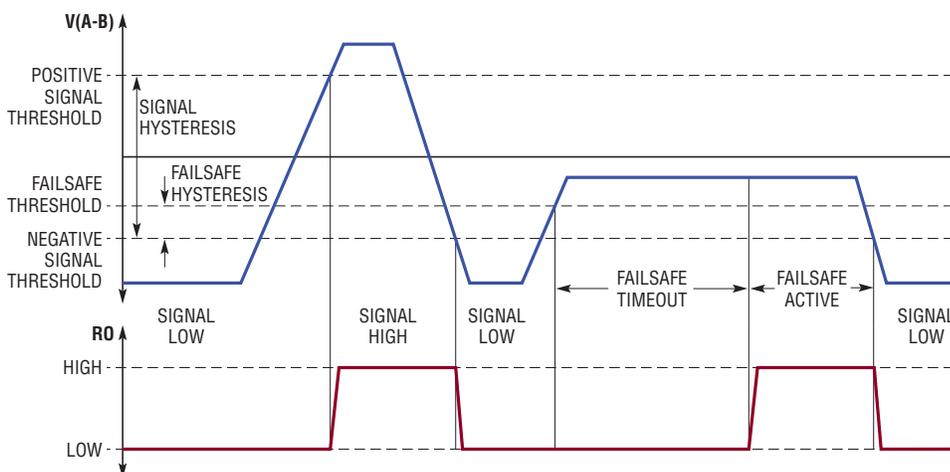

Figure 4. Failsafe window comparator operation

A normal data signal produces a high on the receiver output RO when the differential input voltage goes above the positive signal threshold voltage and a low on RO when the differential input voltage goes below the negative signal threshold voltage. The failsafe function is triggered when the differential input voltage goes above the failsafe threshold voltage but stays below the positive signal threshold for longer than the

failsafe timeout time. When the failsafe timer times out, the failsafe is active and RO is forced high. It stays high until the differential input voltage goes below the negative signal threshold voltage.

Many RS485 transceivers have asymmetrical receiver thresholds that employ only the negative signal threshold and the failsafe threshold voltages. This provides effective failsafe detection but causes
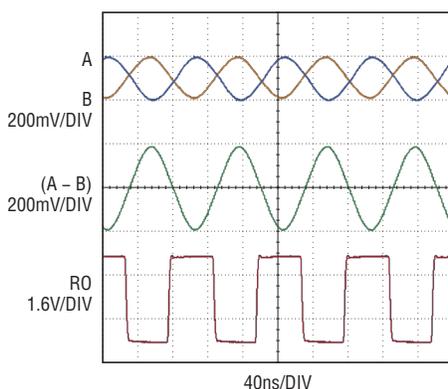

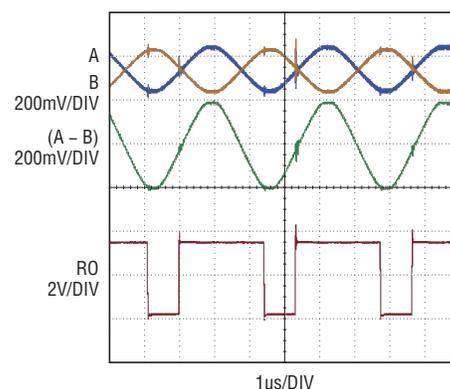Figure 5. Duty cycle of LTC2865 symmetrical receiver with ±200mV 20Mbps input signal

Figure 6. Duty cycle of competitor asymmetrical receiver with ±200mV 600kbps input signal

distortions in the duty cycle of the receiver output RO in the case of attenuated signals with slow edges. The symmetrical thresholds used in the LTC2862–LTC2865 maintain the proper duty cycle in the RO output even with highly attenuated signals (Figure 5), while a transceiver with asymmetric thresholds introduces substantial duty cycle distortion (Figure 6).

In addition, the 150mV (typical) signal hysteresis of the LTC2862–LTC2865 receivers provides superior noise immunity compared to receivers with asymmetrical receiver thresholds. Noise transients that momentarily go above the failsafe threshold but return below the negative signal threshold will trigger an erroneous high RO output in an asymmetric receiver (Figure 8) but are filtered out by the failsafe timer in the symmetric LTC2862–LTC2865 receivers (Figure 7).

HOT PLUGGING, HOT SWAPPING, AND GLITCH-FREE POWER-UP AND POWER-DOWN

The LTC2862–LTC2865 feature glitch-free power-up and power-down protection to meet hot plugging (Hot Swap) requirements. These transceivers do not produce a differential disturbance on the bus when they are connected to the bus while unpowered, or while powered but disabled. Similarly, these transceivers do not produce a differential disturbance on the bus when they are powered up in the disabled state while already connected to the bus. In these cases the receiver output RO remains off with a high impedance output.
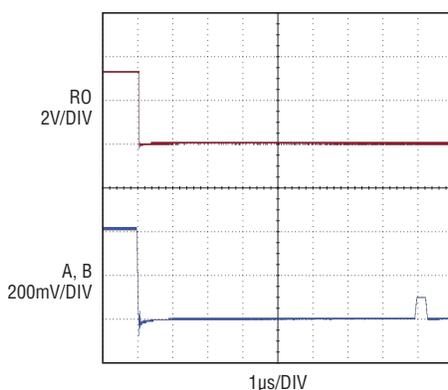

Figure 7. LTC2862 symmetrical receiver rejecting +100mV noise pulse on –200mV differential input

If the driver or receiver inputs are in an enabled state during power-up or power-down, the outputs make a glitch-free transition to the proper state as the supply passes through the transceiver's internal supply undervoltage detector threshold. The LTC2863 has no means to disable the receiver or driver, so it always powers up with a glitch-free transition to the fully enabled state.

PACKAGES AND PINOUTS

The LTC2862–LTC2865 offer four pin configurations to meet a wide range of application requirements, with each pinout offered in leaded and leadless packages.

LTC2862: The half-duplex LTC2862 with shared receive and transmit pins is the most commonly used version. It comes in an 8-pin leaded SO package and a small 3mm × 3mm 8-pin leadless DFN package. The LTC2862 in the SO package is socket compatible with its predecessor, the LT1785.
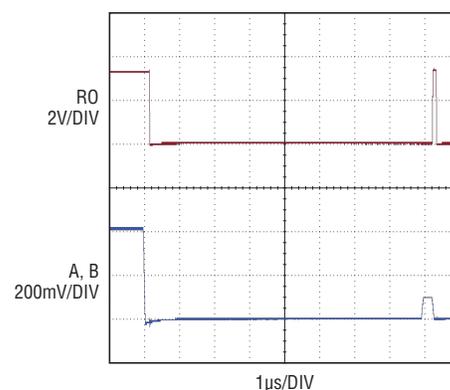
Figure 8. Competitor asymmetrical receiver responding to +100mV noise pulse on –200mV differential input

LTC2863: The LTC2863 is a full-duplex transceiver with separate receive and transmit pins that omits the receiver and driver enable pins in order to fit in an 8-pin package. As a consequence, both the driver and receiver are always enabled and the part has no shutdown mode. Like the LTC2862, it is available in an 8-pin leaded SO package and a small 3mm × 3mm 8-pin leadless DFN package.

LTC2864: The LTC2864 is a full-duplex transceiver with enable pins. It is available in a 14-pin leaded SO package for socket compatibility with the LT1791 as well as a 10-lead 3mm × 3mm DFN package.

LTC2865: The LTC2865 includes the superset of the functionality available in the rest of the family. Like the LTC2864, it offers a full-duplex pinout and adds two additional pins: a VL pin for a logic interface supply voltage and an SLO input pin to select the high speed or slew-limited transmitter mode.

The handling of exposed wires and screw terminals by service personnel introduces the risk of ESD damage, while the possibility of wiring the cables to the wrong screw terminals introduces the risk of overvoltage damage. The high fault voltage and ESD tolerance make the LTC2862–LTC2865 exceptionally resistant to damage from these hazards.

±60V FAULT AND ±15kV ESD TOLERANCE

RS485 wiring connections are often made by connecting the bare twisted wire to screw terminal blocks. The apparatus containing the RS485 interface may house circuits powered by 24V AC/DC or other voltages that are also connected with screw terminals. The handling of exposed wires and screw terminals by service personnel introduces the risk of ESD damage, while the possibility of wiring the cables to the wrong screw terminals introduces the risk of overvoltage damage. The high fault voltage and ESD tolerance make the LTC2862–LTC2865 exceptionally resistant to damage from these hazards.

The ±60V fault protection of the LTC2862–LTC2865 is achieved by using a high voltage BiCMOS integrated circuit technology. The naturally high breakdown voltage of this technology provides protection in powered-off and high impedance conditions. The driver outputs use a progressive foldback current limit design to protect against overvoltage faults while allowing high current output drive. The LTC2862–LTC2865 are protected from ±60V faults even with GND open, or VCC open or grounded.

The LTC2862–LTC2865 are protected from electrostatic discharge from personnel or equipment up to ±15kV (HBM) to the A, B, Y and Z pins with respect to GND. On-chip protection devices start to conduct at voltages greater than approximately ±78V and conduct the discharge current safely to the GND pin. Furthermore, these
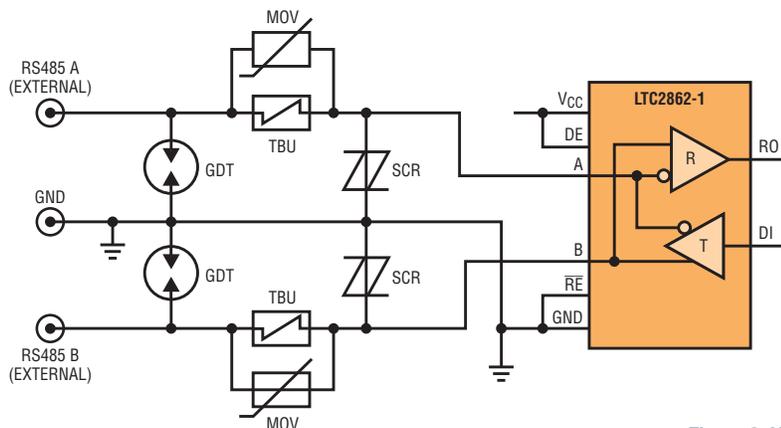
GDT: BOURNS 2031-42T-SM; 420V GAS DISCHARGE TUBE
TBU: BOURNS TBU-CA085-300-WH; 850V TRANSIENT BLOCKING UNIT
MOV: BOURNS MOV-7D391K; 390V 25J METAL OXIDE VARISTOR
SCR: BOURNS TISP4P035L1NR-S; 35V BIDIRECTIONAL THYRISTOR

Figure 9. Network for IEC Level 4 protection against surge, EFT and ESD plus ±360V overvoltage protection

devices withstand up to ±15kV discharges even when the part is powered up and operating without latching up. All the other pins are protected to ±8kV (HBM).

EXTENDED PROTECTION AGAINST IEC SURGE, EFT, ESD AND OVERVOLTAGE FAULTS

An RS485 transceiver used in an industrial environment can be exposed to extremely high levels of electrical overstress due to lightning surge, electrical fast transients (EFT) from switching high current inductive loads, and electrostatic discharge (ESD) from electrically charged personnel or equipment. (Test methods for ESD, EFT, and surge are defined in the IEC standards 61000-4-2, 61000-4-4, and 61000-4-5, respectively.)

The transients produced by the surge tests in particular contain much more energy than can be absorbed by the on-chip ESD protection devices of the LTC2862–LTC2865. Therefore, a properly designed

external protection network is necessary to achieve a high level of surge protection. An external network can also extend the ESD, EFT and overvoltage performance of the LTC2862–LTC2865 to extremely high levels.

The protection network shown in Figure 9 demonstrates how the high breakdown voltage of the LTC2862–LTC2865 is used to advantage in a protection circuit that meets the highest defined IEC protection levels (Level 4) for surge, EFT and ESD, while extending the overvoltage fault tolerance to ±360V. This protection circuit maintains the ±25V common mode voltage range and adds only ~8pF of capacitance per line (line to GND), thereby providing an extremely high level of protection without impacting the performance of the LTC2862–LTC2865 transceivers.

The gas discharge tubes (GDTs) provide the primary protection against electrical surges. These devices provide a very low impedance and high current

Figure 10. LTC2862-1 PROFIBUS compatible line interface

V_{CC} (4.75V TO 5.25V)

LTC2862-1

RO

$\overline{RE}$

DI

DE

GND

A*   8.2Ω   B WIRE

B*   8.2Ω   A WIRE

V_{CC} 390Ω

220Ω

390Ω

100m

5.5Ω/WIRE

V_{CC} 390Ω

220Ω V_{OD}

390Ω

B WIRE

A WIRE

$4V_{P-P} \leq V_{OD} \leq 7V_{P-P}$ AT 12Mbps

* THE POLARITY OF A AND B IN THIS DATA SHEET IS OPPOSITE THE POLARITY DEFINED BY PROFIBUS.

carrying capability when they fire, safely discharging the surge current to GND.

The transient blocking units (TBUs) are solid-state devices that switch from a low impedance pass-through state to a high impedance current limiting state when a specified current level is reached. These devices limit the current and power that can pass through to the secondary protection.

The secondary protection consists of a bidirectional thyristor that triggers above 35V to protect the bus pins of the LTC2862–LTC2865 transceiver. The high trigger voltage of the secondary protection maintains the full ±25V common mode voltage range of the receivers.

The final component of the network is the metal oxide varistor (MOV) that clamps the voltage across the TBUs to protect them against fast ESD and EFT transients that exceed the turn-on time of the GDT. The high performance of this network is attributable to the low capacitance of the GDT and thyristor primary and secondary protection

devices. The 130pF MOV capacitance floats on the line and is shunted by the TBU, so it contributes no appreciable capacitive load on the signal.

The high breakdown voltage and robustness of the LTC2862–LTC2865 is an essential element of this protection circuit. The ±35V SCR devices used to maintain the common mode voltage range would not protect transceivers with breakdown voltages below ±35V. Furthermore, connecting the MOVs in parallel with the TBUs prevents the MOV capacitance from loading the RS485 bus, but it has the disadvantage of shunting ESD and EFT current through the SCR devices. The resulting voltage drop across the SCR is placed on the bus pins of the transceiver. This unique low capacitance topology can only be used with a robust high voltage transceiver.

USING THE LTC2862 IN PROFIBUS APPLICATIONS

PROFIBUS is an RS485-based field bus with additional requirements for cables, interconnects, line termination, and signal levels. Figure 10 shows the LTC2862-1 in a PROFIBUS network. The

following considerations must be followed for full PROFIBUS compliance:

1. Each end of the PROFIBUS line must be terminated with a 220Ω resistor between B and A, a 390Ω pullup resistor between B and V_{CC}, and a 390Ω pulldown resistor between A and GND.

2. 8.2Ω resistors in series with the LTC2862-1 A and B pins are necessary to reduce the peak to peak differential voltage V_{OD} received at the end of a 100m terminated cable to less than 7V per the PROFIBUS standard.

3. The polarity of the PROFIBUS signal is opposite to the polarity convention used in most RS485 transceiver data sheets. Connect pin A to the PROFIBUS B wire (through an 8.2Ω series resistor) and connect pin B to the PROFIBUS A wire (through an 8.2Ω series resistor).

4. Power the LTC2862-1 transceiver with a 5% tolerance 5V supply (4.75V to 5.25V) to ensure that the PROFIBUS VOD tolerances are met.

CONCLUSION

System designers are no longer required to choose between robust fault tolerance or high performance in a RS485 and RS422 t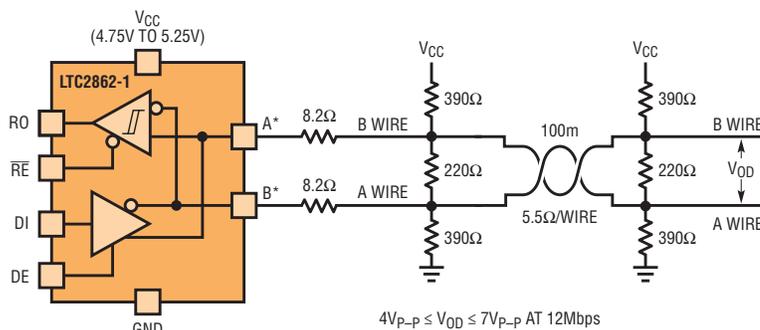ransceivers—the LTC2862–LTC2865 transceivers offer both. These transceivers feature ±60V overvoltage and ±15kV ESD tolerance, but also include: operation over 3V to 5.5V supply voltages, up to 20Mbps data rate, ±25V common mode voltage range; selectable slew rate, interface to low voltage logic; and availability in 3mm × 3mm DFN packages. ∎

High Voltage Surge Stoppers Ease MIL-STD-1275D Compliance by Replacing Bulky Passive Components

Dan Eddleman

Electronics in a military vehicle face a unique set of challenges, chief among them operation from a perverse power supply. Recognizing the difficult power supply fluctuations that occur in the field, the US Department of Defense created MIL-STD-1275D to set down the requirements of electrical systems powered from a military vehicle's 28V supply. Designing systems to withstand MIL-STD-1275D's surge and related transients traditionally requires large and expensive passive components. Linear Technology's surge stopper product line is well suited to protecting systems from this type of surge while reducing the cost and solution size.

MIL-STD-1275D REQUIREMENTS

MIL-STD-1275D defines a variety of conditions, most importantly those of steady state operation, starting disturbances, spikes, surges, and ripple. MIL-STD-1275D lays down requirements for each of these conditions in three separate "modes of operation": starting mode, normal operating mode, and generator-only mode.

Before describing the specifics of spikes, surges, ripple, and other requirements, let's first look at the modes of operation. Not surprisingly, "starting mode" describes the conditions that occur when the engine is started; "normal mode" describes the conditions when the system is operating without any faults; and "generator-only" mode describes a particularly vicious circumstance where the battery has been disconnected and the generator is directly powering the electronics.

Generator-only mode is a challenging situation. Normally, a battery conceals the erratic nature of the generator by maintaining a relatively constant voltage despite the generator's power fluctuations. Predictably, the limits set down for generator-only mode are worse than normal operating mode. For the most part, if the system operates through the generator-only mode conditions, it will have no difficulty with normal mode. (The one possible exception is that generator-only mode's 500mΩ source impedance during a surge can ease the burden when compared with the 20mΩ source impedance in the normal operating mode.)

Steady-State

As with any standard, MIL-STD-1275D spells out conditions and requirements in detail. The purpose of this article is to present these requirements, and a proposed solution, in a more digestible form. It is recommended to refer to MIL-STD-1275D for more precise definitions and requirements.

MIL-STD-1275D defines *steady-state* as, "The condition in which circuit values remain essentially constant, occurring after all initial transients or fluctuating conditions have subsided. It is also definitive of the condition where, during normal system operation, only inherent or natural changes occur; (i.e., no malfunctions occur and no unanticipated changes are made to any part of the system)."

More simply, in steady-state the input voltage remains relatively constant.

As shown in Table 1, the steady-state input voltage range during normal operating mode ranges from 25V to 30V. During generator-only mode (the condition where the battery is disconnected), the steady-state voltage range is somewhat wider at 23V to 33V.

Table 1. Selected MIL-STD-1275D specifications in normal operating mode and generator-only mode

SPECIFICATION	NORMAL OPERATING MODE	GENERATOR-ONLY MODE
Steady State	$25V < V_{IN} < 30V$	$23V < V_{IN} < 33V$
Spikes	250V, Max Energy=15mJ	Same as Normal Operating Mode
Surges	40V Max, ~500ms, R_{IN} = 20mΩ	100V Max, ~500ms, R_{IN} = 500mΩ
Ripple	Magnitude ±2V	Magnitude ±7V

Linear Technology's surge stopper products provide a compelling solution to MIL-STD-1275D compliance. Alternative designs typically use shunt clamps at the input, which can result in damage or blown fuses during sustained overvoltage conditions.
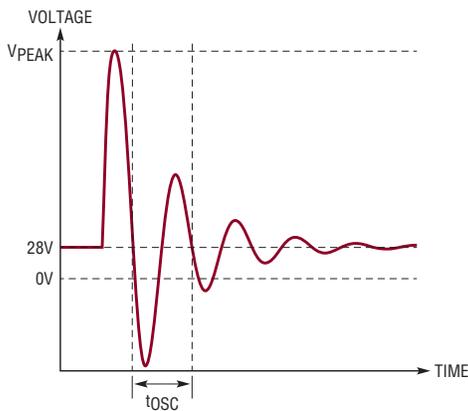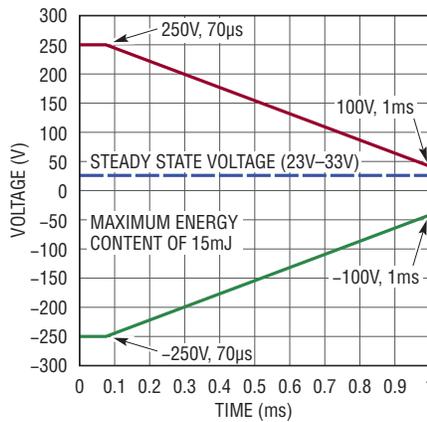

Figure 1. MIL-STD-1275D spike

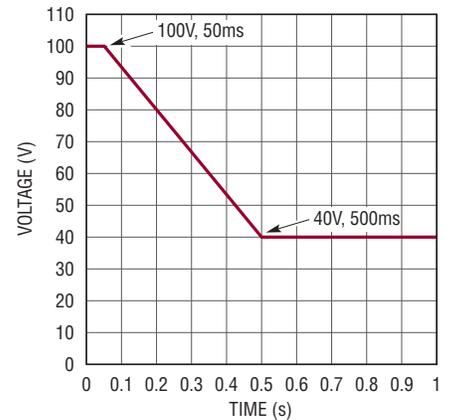Figure 2. Envelope of spike in generator-only mode

Figure 3. Generator-only mode surge envelope

Spikes

Rather than quote the definition of a *spike* from MIL-STD-1275D, let's instead look at the example in Figure 1. A spike is generally oscillatory (it rings) and decays to the steady-state voltage within 1ms. MIL-STD-1275D states that these spikes occur when reactive loads are switched, and may occur during events such as sounding the horn, operating the bilge pumps, starting and stopping the engine, or rotating the turret.

While that description is useful in understanding a spike, the actual requirements are defined by Figure 2 (for generator-only mode). Additionally, in subsection 5.3.2.3, "Voltage Spikes Imported into EDUT," MIL-STD-1275D describes a recommended test setup as well as the required risetime and frequency of oscillation. An important fact to note is that the maximum energy is limited to 15mJ. The spike requirement for normal operating mode is similar to generator-only mode except that rather

than a 100V limit at 1ms, the normal operating mode limit is 40V at 1ms.

Surges

Spikes are transients that last less than 1ms; *surges* are transients that last longer. Figure 3 shows the limitations for generator-only mode. Note that the recommended test in MIL-STD-1275D specifies that five 100V pulses of 50ms duration should be applied at the system input with a 1s repeat time. Interestingly, the envelope of the surge condition shown in Figure 3 is more difficult to satisfy, as it does not return to 40V for a full 500ms. The solution shown in this article satisfies both of these conditions. Once again, the requirements for normal operating mode are easier; the surge envelope looks similar, except that it has a 40V maximum instead of 100V. The reader should refer to the actual specification for details not covered here.

Figure 4. Starting disturbances
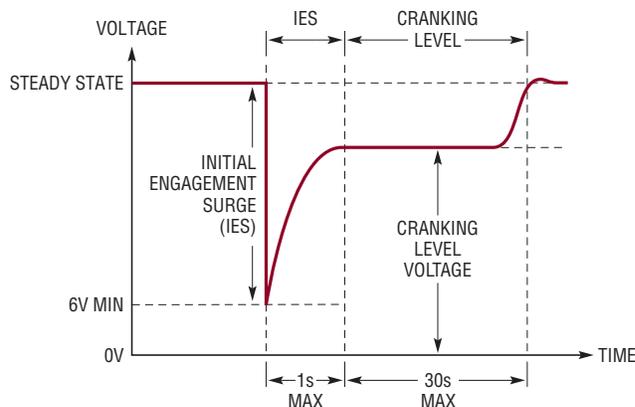
Rather than shunt high energy levels to ground using bulky passive components, high voltage surge stoppers such as the LTC4366 and LT4363 limit the output voltage using series MOSFETs when faced with input voltage spikes and surges.

Figure 5. 4A/28V MIL-STD-1275D solution provides uninterrupted power to 4A loads while limiting the output voltage to 44V during MIL-STD-1275D 100V/500ms surges and ±250V spikes; powers 2.8A loads during ±7V ripple.

C1–C12: TDK CKG57NX7S2A226M500JH
C25: TDK C5750X7R2E105K230KA
D1: VISHAY FEP30GP-E3/45
D2: DIODES INC. BAT54-7-F
D3, D4: DIODES INC. MMBD3004S-7-F
D5: DIODES INC. BAS21W-7-F
M1: IXYS IXTQ88N30P
M2: IXYS IXTQ170N10P
R$_{SENSE}$: IRC LRC-LRF-1206LF-01-R010
R$_{THERM}$: EPCOS B59901D100A40
Q1, Q2: DIODES INC. MMDT5551-7-F
TVS (OPTIONAL): VISHAY P6SMB150CA-E3/5B
HS1, HS2, HS3 (HEATSINKS): ASSMANN WSW COMPONENTS V8813X

UNLESS OTHERWISE NOTED, COMPONENT PACKAGE SIZES ARE 0805 AND CAPACITOR RATINGS ARE 100V

Ripple

Ripple is the term used to refer to variations of the input voltage about the steady state DC voltage. It may be composed of frequencies from 50Hz to 200kHz. In generator-only mode, the ripple is as large as ±7V about the DC steady state voltage. In normal mode, it is somewhat lower, ±2V around the steady state DC voltage. The MIL-STD-1275D specification provides explicit test conditions and recommends a set of frequencies for testing.

Starting Mode

In addition to normal mode and generator-only mode, MIL-STD-1275D defines starting mode, which describes the voltage variations caused by the engine starter and cranking. Figure 4 appears in the MIL-STD-1275D specification. It begins at the steady-state DC voltage and then drops as low as 6V during the "Initial Engagement Surge." Within one second it rises to the "Cranking Level" which has a 16V minimum voltage. It returns again to the steady state DC voltage within 30 seconds.

Other Requirements

MIL-STD-1275D stipulates that the system withstand polarity reversal without harm. Such a condition can occur during a jump start, if the jumper cables are connected backwards.

MIL-STD-1275D in turn refers to another standard, MIL-STD-461—regarding electromagnetic compatibility requirements—which is beyond the scope of this article.

During normal operation, the MOSFET is fully enhanced to minimize the power dissipated in the MOSFET. When the input voltage rises during a surge or spike, a surge stopper regulates the output voltage to provide safe, uninterrupted power to the load. Current limit and timer features protect the external MOSFETs from more severe conditions.

SURGE STOPPER SOLUTION FOR MIL-STD-1275D COMPLIANCE

Linear Technology's surge stopper products provide a compelling solution to MIL-STD-1275D compliance. Alternative designs typically use shunt clamps at the input, which can result in damage or blown fuses during sustained overvoltage conditions.

Rather than shunt high energy levels to ground using bulky passive components, high voltage surge stoppers such as the LTC4366 and LT4363 limit the output voltage using series MOSFETs when faced with input voltage spikes and surges. During normal operation, the MOSFET is fully enhanced to minimize the power dissipated in the MOSFET. When the input voltage rises during a surge or spike, a surge stopper regulates the output voltage to provide safe, uninterrupted power to the load. Current limit and timer features protect the external MOSFETs from more severe conditions.

Surge

In MIL-STD-1275D, the worst-case MOSFET power dissipation condition occurs during the 100V input surge. The circuit shown in Figure 5 regulates the output voltage to 44V. As a result, the circuit must drop 56V from the 100V input to the 44V output. In this MIL-STD-1275D solution, to increase power available at the output, two series MOSFETs are used. The first MOSFET's source is regulated to 66V by the LTC4366, while the second MOSFET's source is regulated to 44V by the LT4363. This reduces the power that must be dissipated in either MOSFET.
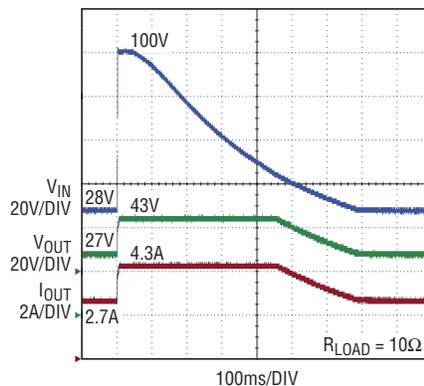

Figure 6. MIL-STD-1275D 100V/500ms surge test

Figures 6 and 7 show the results measured during surge testing. The oscilloscope waveform in Figure 6 shows this circuit operating through the full 100V/500ms MIL-STD-1275D surge requirement described earlier. Figure 7 shows this circuit operating through the less stringent 100V/50ms pulses described in MIL-STD-1275D's recommended tests.

Spike

The +250V spike condition is handled by MOSFET M1, which is rated to withstand over 300V from drain to source. MIL-STD-1275D specifies that the input energy is limited to 15mJ, well within the capabilities of this MOSFET. Figure 8 shows that a +250V spike at the input is blocked from the output.

Similarly, the −250V spike test result is shown in Figure 9. In this condition, diode D1 is reverse biased during the −250V spike, blocking the spike from M2 and the output. D1 also provides reverse polarity protection, preventing negative
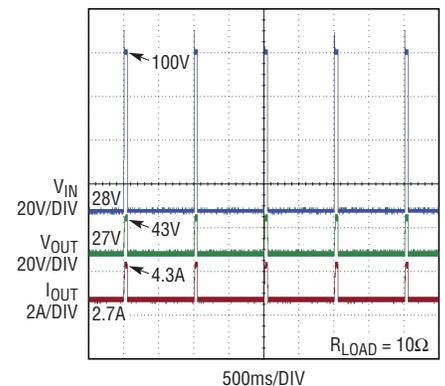

Figure 7. MIL-STD-1275D 100V/50ms surge repeated five times

input voltages from appearing at the output. (The LTC4366 surge stopper in front of D1 is capable of withstanding reverse voltages and the −250V spike without additional protection.)

An optional bidirectional transient voltage suppressor (TVS) is present at the input to provide extra protection. Its 150V breakdown voltage does not affect circuit operation below 100V. For applications where a TVS is not desirable at the input, this optional component can be removed. Note that in Figures 8 and 9, the output voltage trace (v_{OUT}) during the MIL-STD-1275D spike shows high frequency ringing, which is a measurement artifact of the large currents that flow in supply and ground traces when a 0.1μF test capacitor is discharged directly at the circuit input with all resistances and inductances minimized.

Even when the maximum transient power dissipation (such as during a high voltage surge) exceeds the capability of a single MOSFET, multiple series MOSFETs can be used to support higher power levels.
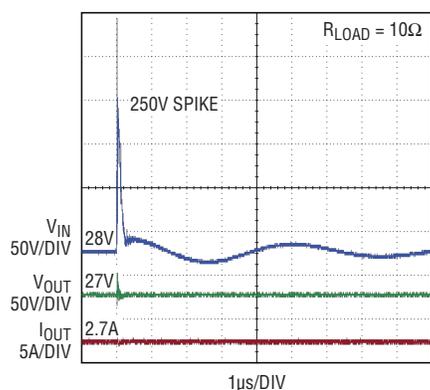

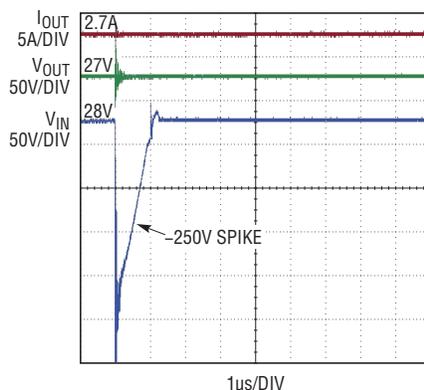
Figure 8. Positive input spike
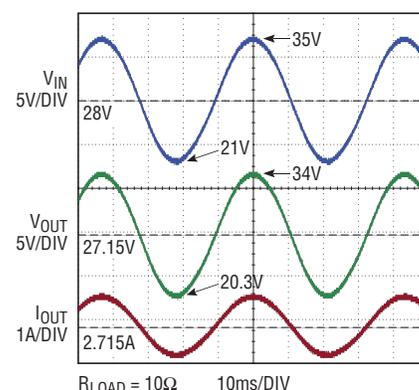

Figure 9. Negative input spike

Figure 10. 14V_{P-P} input ripple condition

Ripple

Satisfying the ripple specification of MIL-STD-1275D requires a few more components. Diode D1 in combination with capacitors C1–C12 form an AC rectifier. This rectified signal appears at the DRAIN2 node.

The LT4363 in combination with sense resistor R_{SENSE} limits the maximum current to 5A (typical). If the rising edge of the input ripple waveform attempts to pull up the output capacitor with more than 5A, the LT4363 momentarily limits the current by pulling down on M2's gate.

To quickly restore the gate voltage, the small charge pump formed by components D3–D4, C13–C15 supplements the LT4363's internal charge pump to quickly pull up MOSFET M2's gate. Even so, the available load current must be reduced to 2.8A during this ripple condition. Figure 10 shows that the output remains powered during ripple testing.

Thermal

Finally, thermal protection is implemented by components Q1, Q2, R1–R4 and thermistor R_{THERM}. If the temperature at M2's heat sink (HS3) exceeds 105°C, the LT4363's UV pin is pulled down by Q2A to force off MOSFET M2 and limit its maximum temperature.

It should be noted that with the specified components, this circuit is only guaranteed to work down to a minimum of 8V during the starting mode initial engagement surge rather than the minimum 6V specified in MIL-STD-1275D.

Typically, an EMI filter is placed at the input of MIL-STD-1275D compliant systems—while surge stoppers do not eliminate the need for filtering, their linear mode operation introduces no additional noise.

CONCLUSION

Linear Technology's surge stopper products simplify MIL-STD-1275D compliance by using MOSFETs to block high voltage input surges and spikes while providing uninterrupted power to downstream circuitry. Blocking the voltage with series components avoids the blown fuses and damage that can occur when circuits attempt to shunt high energy to ground with bulky passive components. Additionally, this article has shown that even when the maximum transient power dissipation (such as during a high voltage surge) exceeds the capability of a single MOSFET, multiple series MOSFETs can be used to support higher power levels. ∎

What's New with LTspice IV?

Gabino Alonso

LTspice IV WORLD CIRCUIT SEMINAR TAKES WORLD TOUR

Mike Engelhardt, the creator of LTspice, is embarking on a world tour to teach the ins and outs of LTspice in a series of free half-day seminars. Each seminar will cover how to quickly simulate switch mode power supplies, compute efficiencies and observe power supply start-up behavior and transient response. You will also learn how to use LTspice as a general-purpose SPICE simulator for AC analysis, noise analysis and circuit simulations. The presentation includes perspectives on the inner workings of LTspice IV and its capabilities.

For more information on these upcoming seminars, please visit www.linear.com/LTspiceEvents.

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.

BLOG BY ENGINEERS, FOR ENGINEERS

Check out the LTspice blog (www.linear.com/solutions/LTspice) for tech news, insider tips and interesting points of view regarding LTspice.

New Video on the Blog: "AC Analysis" — the latest video topic is available at www.linear.com/solutions/4581.

Sometimes the frequency response of a circuit is more important than looking at the individual voltages or currents at a specific part of the schematic. LTspice can help you achieve this with its AC analysis function. This video shows how to perform a basic AC analysis in LTspice as well as pointing out some new capabilities.

SELECTED DEMO CIRCUITS

For a complete list of example simulations utilizing Linear Technology's devices, please visit www.linear.com/democircuits.

Step-Down Regulators

- **LT8610AB:** 5V 2MHz µPower step-down converter with light load efficiency (5.5V–42V to 5V at 3.5A) www.linear.com/LT8610A

- **LTM®4624:** 4A step-down µModule® regulator (4V–14V to 1.5V at 4A) www.linear.com/LTM4624

- **LTM4644:** Quad 4A step-down µModule regulator (4V–14V to 3.3V, 2.5V, 1.5V and 1.2V at 4A) www.linear.com/LTM4644

- **LTM4649:** 10A step-down µModule regulator (4.5V–16V to 1.5V at 10A) www.linear.com/LTM4649

Isolated Controller

- **LTC3765 & LTC3766:** 120W isolated forward converter with synchronous rectification (9V–36V to 12V at 10A) www.linear.com/LTC3765

Boost Regulators

- **LT3905:** Adjustable APD bias supply (2.7V–12V to 54V at 1mA) www.linear.com/LT3905

- **LTC3862-1:** High power, high voltage, 4-phase boost converter (6V–36V to 50V at 10A) www.linear.com/LTC3862-1

Inverting Regulators

- **LTC3805-5 & LT1797:** Positive-to-negative Cuk converter (8V–16V to –12V at 3A) www.linear.com/LTC3805-5

- **LTC3863:** Low I_Q inverting DC/DC converter (4.5V–16V to –12V at 1A) www.linear.com/LTC3863

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- **LT3795:** Short-circuit robust boost LED driver with spread spectrum frequency modulation (8V–60V to 87V LED string at 400mA) www.linear.com/LT3795

- **LTC4000-1 & LT3845A:** Battery charger for three LiFePO4 cells with a solar panel input (20V–60V to 10.8V float at 10A max) www.linear.com/LTC4000-1

Overvoltage and Overcurrent Protection

- **LTC4366-2:** Surge protected automotive 12V supply (9V–100V to 18V clamp at 4A) www.linear.com/LTC4366

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- **LT6105:** Current sense monitor for +15V and –15V supplies (0A to 2A) and www.linear.com/LT6105

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SELECT MODELS

Linear Regulators

- **LT3086:** 40V, 2.1A low dropout adjustable linear regulator with monitoring and cable drop compensation www.linear.com/LT3086

Buck Regulators

- **LTC3875:** Dual, 2-phase, synchronous controller with low value DCR sensing and temperature compensation www.linear.com/LTC3875

- **LTM4633:** Triple 10A step-down DC/DC µModule regulator www.linear.com/LTM4633

Constant Current/Constant Voltage Regulators

- **LT3797:** Triple output LED driver controller www.linear.com/LT3797

- **LTC4020:** 55V buck-boost multi-chemistry battery charger www.linear.com/LTC4020

Wireless Power Transfer

- **LTC4120:** Wireless power receiver and 400mA buck battery charger www.linear.com/LTC4120

Energy Harvesting

- **LTC3330:** µPower buck-boost DC/DC with energy harvesting battery life extender www.linear.com/LTC3330

Overvoltage & Overcurrent Protection

- **LTC4365-1:** Overvoltage, undervoltage and reverse supply protection controller www.linear.com/LTC4365

Transceivers

- **LTC2862, LTC2863, LTC2864 & LTC2865:** ±60V fault protected 3V to 5.5V RS485/RS422 transceivers www.linear.com/LTC2865

Operational Amplifiers

- **LT6238:** Rail-to-rail output 215MHz, 1.1nV/$\sqrt{\text{Hz}}$ op-amp/SAR-ADC driver www.linear.com/LT6238 ∎

SIMULATING TRANSFORMERS

Here is the simple approach to simulate a transformer in LTspice:

1. Draft an inductor for each transformer winding

2. Couple them using a single mutual inductance (K) statement via a SPICE directive:

```
K1 L1 L2 L3 1
```

The last entry in the K statement is the coupling coefficient, which can vary between 0 and 1, where 1 represents no leakage inductance. For practical circuits, it is recommended you start with a coupling coefficient of 1.

Only a single K statement is needed per transformer; LTspice applies a single coupling coefficient to all inductors within a transformer. The following is an equivalent to the statement above:
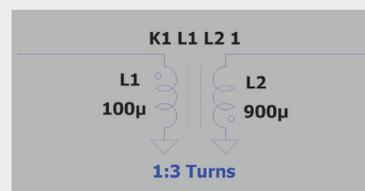
```
K1 L1 L2 1
K2 L2 L3 1
K3 L1 L3 1
```

3. Adjust the inductor positions to match the transformer polarity by using move (F7), rotate (Ctrl + R) and mirror (Ctrl + E) commands. Adding the K statement displays the phasing dot of the included inductors.

4. LTspice simulates the transformer using individual component values, in this case, the inductance of the individual inductors, not the turns ratio of the transformer. The inductance ratio corresponds to the turns ratio as follows:

$$\frac{L_{PRIMARY}}{L_{SECONDARY}} = \left(\frac{N_{PRIMARY}}{N_{SECONDARY}}\right)^2$$

For example, for a 1:3 turns ratio, enter inductance values to produce a one to nine ratio:

K1 L1 L2 1

L1	**L2**
100µ	**900µ**

1:3 Turns

For more information on how to simulate a transformer see the video at www.linear.com/solutions/1079

Happy simulations!

Power User Tip

Boost-then-Buck LED Drivers Enable Wide PWM Dimming Range with Wide-Ranging Input Voltages

Keith Szolusha and Taffy Wong

Multichannel LED drivers are primarily designed to power multiple LEDs or multiple LED strings, sometimes of different colors or lengths, from a single IC. These drivers, however, include a number of features that allow for other compelling uses. The LT3797 3-channel LED driver, for instance, can be configured to produce boost-then-buck capability with one channel as a boost voltage preregulator while the other two channels are configured as buck mode LED drivers.

When the input voltage source is wide-ranging and can be both above and below the LED string rating, a buck-boost or SEPIC topology is commonly used. These topologies have some disadvantages when compared to buck-only or boost-only regulators: namely, lower efficiency and bandwidth (reduced PWM dimming capability) compared to buck-only converters, and lower efficiency and higher conducted EMI compared to boost-only regulators.

One way to avoid these problems is to boost a wide-ranging input with a voltage preregulator and use that as the input to a buck-only LED driver. This has the advantages of step-up and step-down, high PWM dimming bandwidth, and lower conducted EMI. Since the LT3797 has three channels that can be used for either voltage regulation or driving LEDs, one channel can be used to boost the input voltage to a higher voltage,

Figure 1. LT3797 triple LED driver configured as 3 × 50V 1A boost LED drive
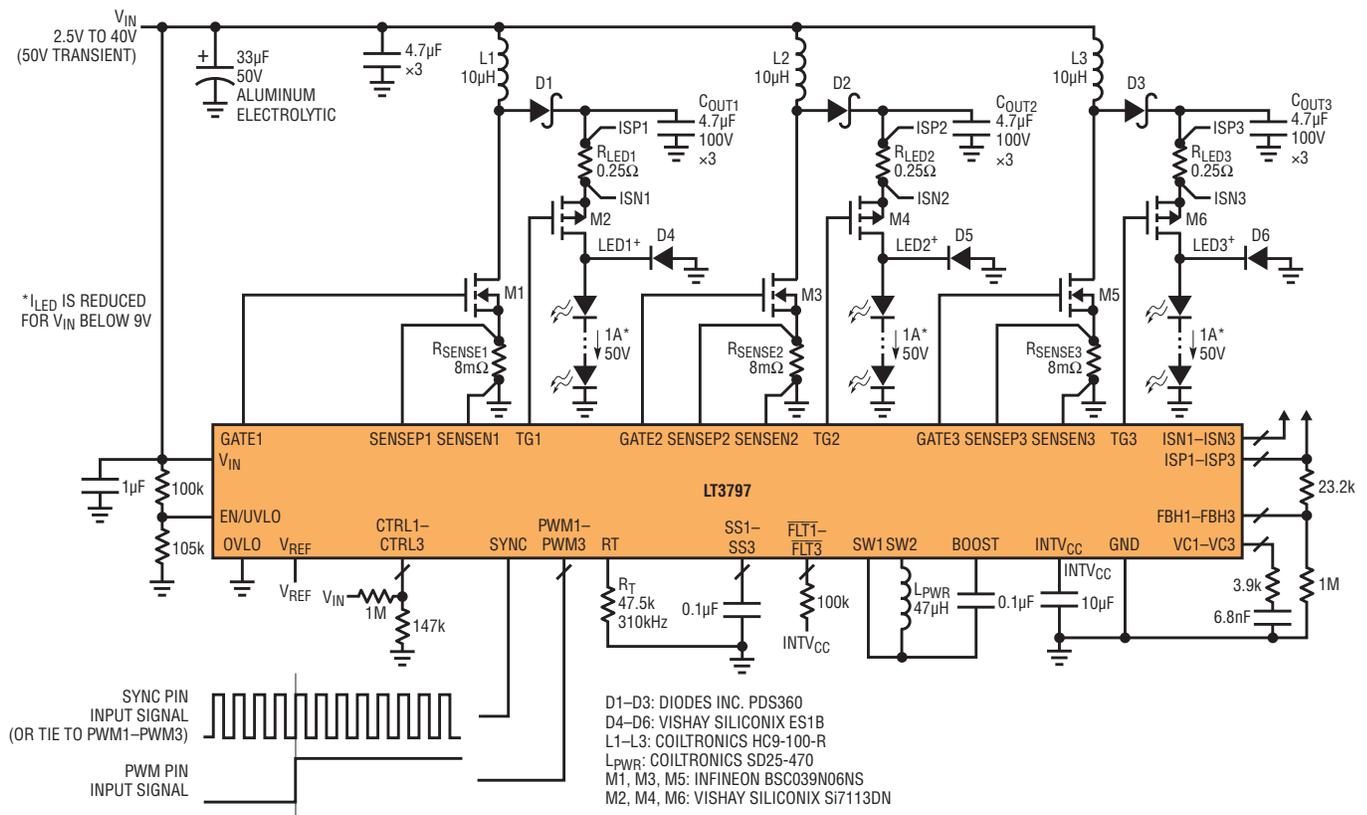
Higher PWM dimming ratios can be achieved by a buck LED driver than by a boost mode driver. To achieve high LED dimming ratios from a wide-ranging input, low input voltages can be boosted to an intermediate voltage with a preregulator. The intermediate, boosted output serves as input to buck-mode LED drivers. Figure 2 shows a boost-then-buck scheme achieved using a single LT3797.

which can then be used to power two high bandwidth buck mode LED drivers produced using the other two channels.

TRIPLE LED DRIVER (MULTI-TOPOLOGY, HIGH EFFICIENCY)

The LT3797 is a triple LED driver controller IC that can be used to power three strings of LED current in several topologies, including boost, buck mode, buck-boost mode, and SEPIC. Each channel runs
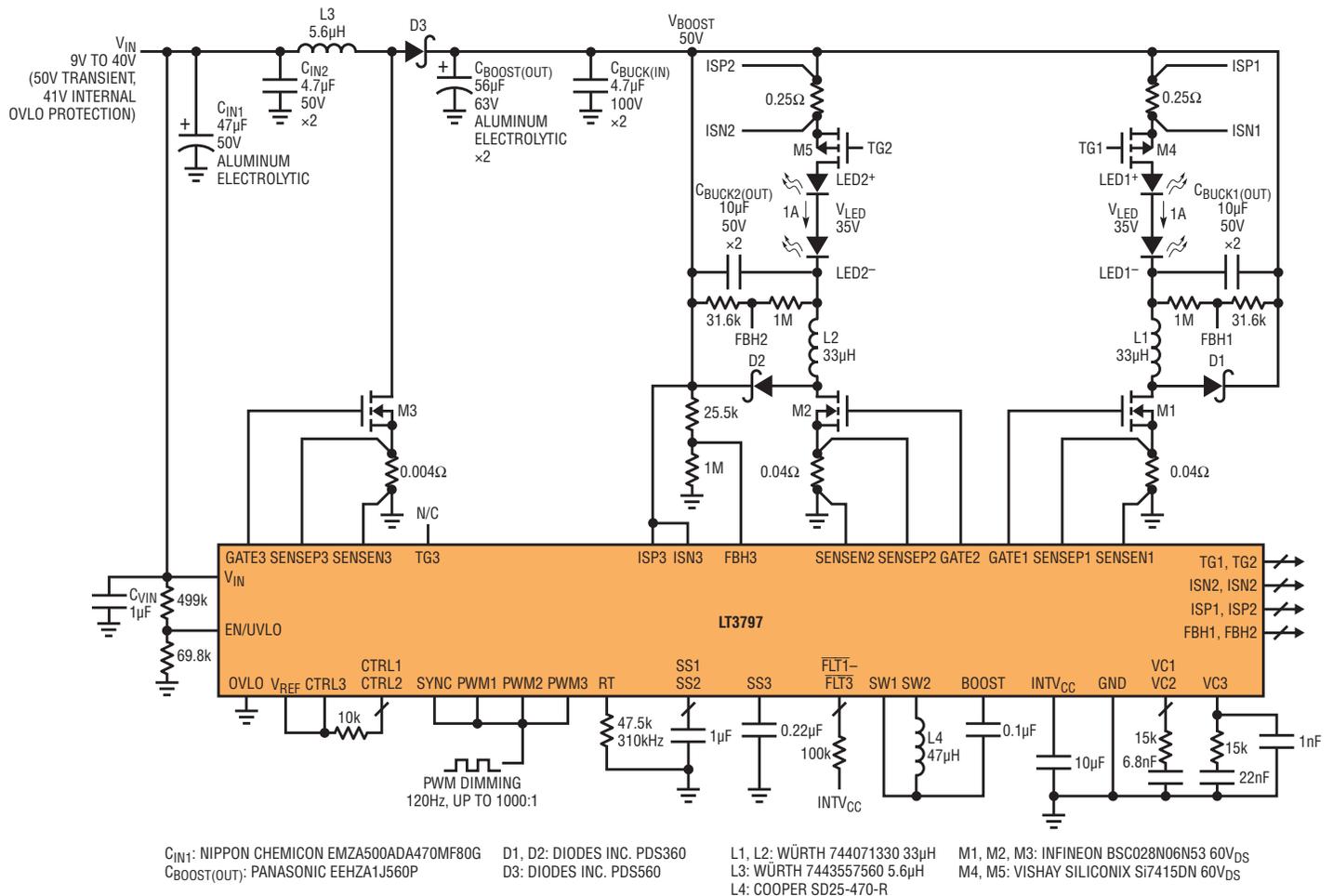
independently of the other channels, but they share clock phase. LED current, open LED protection, analog and PWM dimming control can be controlled independently.

The high side feedback pin, FBH, provides versatile overvoltage protection in both buck mode and buck-boost mode when the LED string does not return to GND, eliminating the need for a level-shifting feedback transistor. The

2.5V–40V V_{IN} range and 100V output range give the LED driver high voltage and power capability. It can be used in automotive and industrial applications as well as battery-powered devices.

Figure 1 shows a 93%-efficient triple boost LED driver powering three 50W (50V, 1A) LED strings from an automotive input. It features 250:1 PWM dimming at 120Hz and short-circuit protection. An internal

Figure 2. LT3797 double boost-then-buck LED driver with 1000:1 PWM dimming ratio

CIN1: NIPPON CHEMICON EMZA500ADA470MF80G
CBOOST(OUT): PANASONIC EEHZA1J560P

D1, D2: DIODES INC. PDS360
D3: DIODES INC. PDS560

L1, L2: WÜRTH 744071330 33μH
L3: WÜRTH 7443557560 5.6μH
L4: COOPER SD25-470-R

M1, M2, M3: INFINEON BSC028N06N53 60V$_{DS}$
M4, M5: VISHAY SILICONIX Si7415DN 60V$_{DS}$

An extra benefit of the boost-then-buck mode driver is the reduced conducted EMI versus a similarly rated buck-boost regulator. Boost converters typically have lower conducted EMI around the AM band than buck converters due to the location of the main inductor in series with the input. In a boost-then-buck scheme, the inductor is in series with the input, versus a buck-boost single inductor between the buck and boost stages.
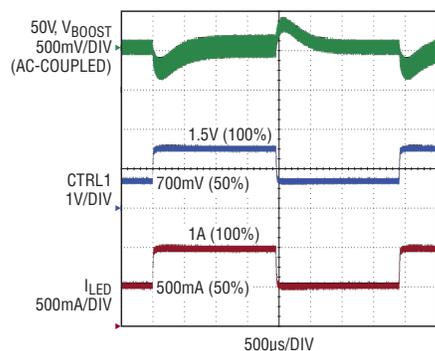

Figure 3. Analog dimming transient from 50% (500mA) to 100% (1A) full-scale current shows high bandwidth of buck mode, even as the boost stage recovers at its own, regular speed.

buck-boost $INTV_{CC}$ supply delivers 7.8V of gate charge to the power switches, even when v_{IN} drops down to 2.5V, making this a very wide input range converter.

DUAL BOOST-THEN-BUCK MODE LED DRIVER

The highest PWM dimming ratios can be achieved by a buck LED driver, which offers the highest operating bandwidth. To achieve high LED dimming ratios from a wide-ranging automotive input voltage, the automotive voltage must first be boosted with a preregulator. The boosted output voltage can then be applied as input to buck-mode LED drivers. Figure 2 shows how this can be achieved with a single IC by using one of the channels of the LT3797 as the boost preregulator with the other two channels acting as buck mode LED drivers.

Besides reduced component count and cost, the advantage of this single-IC scheme

over adding a separate boost IC as a pre-regulator, is that the PWM pin of the boost regulator can be used to both disable switching and freeze the state of the control loop during PWM off-time. This allows the boost converter to quickly return to its previous PWM on state without its output collapsing when the buck mode LED drivers are turned back on. If PWM of the boost is not turned off during PWM off-time, or if a separate boost IC is used, then the bandwidth of the boost converter can limit the maximum PWM dimming ratio.

An extra benefit of the boost-then-buck mode driver is the reduced conducted EMI versus a similarly rated buck-boost regulator. Boost converters typically have lower conducted EMI around the AM band than buck converters due to the location of the main inductor in series with the input. In a boost-then-buck scheme, the inductor is in series with the input, versus a buck-boost single inductor between the buck and boost stages. Although the basic buck-boost topology requires only a single inductor, a second input filter inductor is

often required to reduce conducted EMI in high-powered LED driver applications.

The LT3797 dual boost-then-buck LED driver shown in Figure 2 powers two 35W (35V, 1A) LED strings directly from an automotive input. It features 1000:1 PWM dimming ratio at 120Hz. It also includes short-circuit protection and open LED protection. All three PWM dimming input pins are tied to the same PWM dimming input in order to maximize the PWM dimming ratio and freeze the state of the control loops of all three channels when PWM is off. The output of the boost channel is a regulated 50V. A higher boost output voltage would yield even higher PWM dimming ratios, but at the cost of requiring higher-voltage-rated power components and reduced efficiency. The two buck mode LED driver channels power the two 1A, 35V LED strings from 50V input with high efficiency. Total converter efficiency is 87%.

HIGH PWM DIMMING RATIO

As mentioned above, buck and buck mode LED drivers offer higher bandwidth than boost topology drivers (including

The LT3797 dual boost-then-buck LED driver shown in Figure 2 powers two 35W (35V, 1A) LED strings directly from an automotive input. It features 1000:1 PWM dimming ratio at 120Hz. It also includes short-circuit protection and open LED protection. All three PWM dimming input pins are tied to the same PWM dimming input in order to maximize the PWM dimming ratio and freeze the state of the control loops of all three channels when PWM is off.
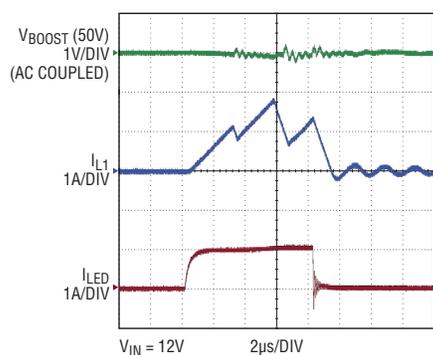

Figure 4. Dual boost-then-buck mode LED driver PWM dimming waveform. 1000:1 dimming at 120Hz.

buck-boost and SEPIC converters), and therefore a higher possible PWM dimming ratio. Unlike boost topologies, where the output temporarily receives less energy as duty cycle is increased in order to raise inductor current during a transient, buck topologies continue to deliver increased energy to the output when duty cycle is increased. The control loop of the buck converter can be optimized at a higher bandwidth for this reason, separate from the boost.

Additionally, during PWM dimming, at the beginning of each cycle, inductor current in a buck regulator does not need to ramp up as far as it must for a boost regulator, since its current is approximately equal to the LED current and not higher. This gives buck converters an advantage over boost converters in both transient response and PWM dimming ratio. As long as the boost preregulator does not lose its output charge during transients, a boost-then-buck mode converter can mimic the high bandwidth of the buck converter.

SHORT AND OPEN LED PROTECTION

The LT3797 LED drivers shown in Figures 1 and 2 are short-circuit proof. The high-side PMOS disconnects are not only used for PWM dimming, but also for short-circuit protection when an LED+ terminal is shorted to ground. Unique internal circuitry monitors when the output current is too high, and turns off the disconnect PMOS on that channel and reports a fault. Similarly, if an LED string is removed or opened, the IC limits its maximum output voltage on that channel and reports a fault.

CONCLUSION

The LT3797 is a 2.5V–40V input and up to 100V output triple LED driver that can be used in many topologies. When step-up and step-down is needed, for the highest PWM dimming ratio of 1000:1 or higher, one channel can be used as a voltage boost preregulator and the other two channels can be used as buck mode LED drivers. Short-circuit protection is available in all topologies, making this IC a robust and powerful solution for driving LEDs in many applications. ■

Low Cost isoSPI Coupling Circuitry for High Voltage High Capacity Battery Systems

Jon Munson

The isoSPI™ feature built into the LTC6804 battery stack monitor, when combined with an LTC6820 isoSPI communications interface, enables safe and robust information transfer across a high voltage barrier. isoSPI is particularly useful in energy storage systems that produce hundreds of volts via series-connected cells, which require full dielectric isolation to minimize hazards to personnel.

In a typical isoSPI application (Figure 1) pulse transformers provide the dielectric isolation and reject common-mode interference that can be impressed on the wiring. The isoSPI function operates with readily available and inexpensive Ethernet LAN magnetics, which typically include a common-mode-choke section (as shown in Figure 1) to improve common-mode line noise, along with the usual 100Ω line termination resistors and common-mode decoupling capacitors.

Ordinary signal transformers, including Ethernet and gate-driver types, are wound with enameled wire that can have pin-hole sized insulation defects, which expose the copper to the atmosphere, inherently limiting the inter-winding bias that for which such transformers are certified. Such units are tested in production with high potential (called hi-pot screening) to identify gross insulation problems, typically with 1.5kV. This is established as a safe design margin for long-term bias of 60V, since the tiny corrosion sites tend to require more than 60V to form conductive paths between windings.

PROBLEM: HIGH VOLTAGE = HIGH COST

For battery-stack voltages in the 400V range, good design practice is to specify transformers with reinforced (double) insulation and hi-pot testing to 3750V or higher. Such transformers are difficult to find as small parts due to the creepage (surface distance) and clearance (air spacing) dimensions required, and they are relatively expensive. isoSPI is applied in battery systems up to 1kV, which requires transformers with hi-pot testing to 5kV for conservative design margin. At this level, isolation components can become bulky, costly, and compromise pulse fidelity.

SOLUTION: DIVIDE AND CONQUER

One alternative to using reinforced transformers is to separate the bias requirement from the magnetics by moving the extra insulation to coupling capacitors instead. While capacitors alone could provide a seemingly complete isolation option, they offer neither common-mode rejection nor the shock-resistant isolation characteristics that transformers offer, so an L-C approach is actually optimal. In this way capacitors charge to the nominal DC bias and leave the transformer to handle transients, for which even ordinary units are well suited.

The coupling capacitors are biased by high value resistors, generally tied to the transformer center-tap connection, as shown in Figure 2. As a bonus, if the DC current of the biasing resistors is monitored, then any dielectric breakdown becomes a detectable fault. The resistance is chosen to be a high value, like 10MΩ,

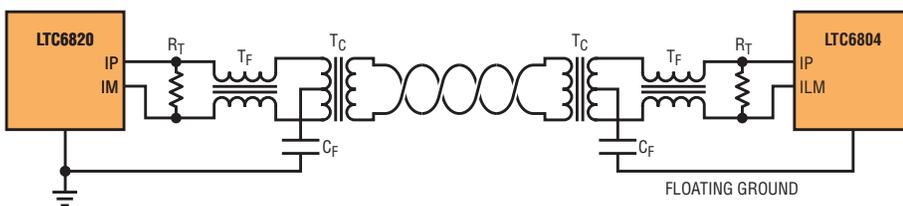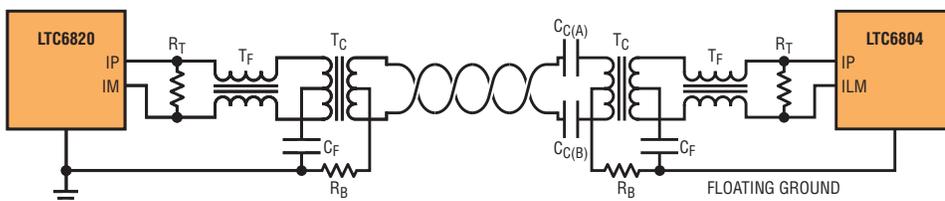Figure 1. Generalized isoSPI point-to-point link

Figure 2. AC-coupled isoSPI point-to-point link for increased voltages
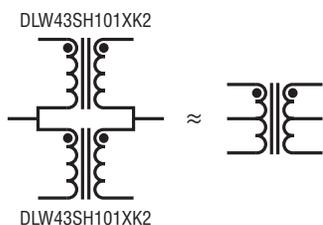
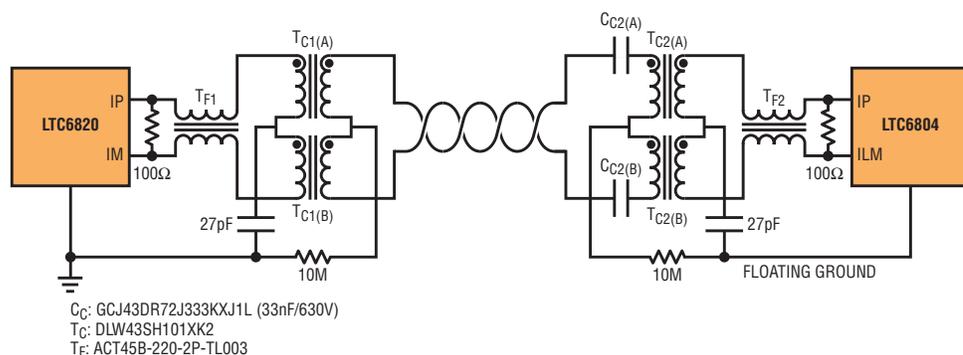Figure 3. Using two common-mode-chokes as a center-tapped isoSPI transformer

Figure 4. Complete high voltage isoSPI point-to-point link

so that fault currents are within the fine wire rating of the transformers and the shock hazard to personnel is minimal.

Eliminating the high voltage requirement from the transformer magnetic design enables a number of relatively low cost options. One is to simply use appropriately approved Ethernet transformers. Another is to use other off-the-shelf low profile magnetics to reduce component height and part mass (reducing solder fatigue issues). These can be installed via surface-mount automated assembly methods like any other part, reducing production costs. A good candidate with

these features is the discrete common-mode-choke (CMC), a transformer structure that is ordinarily used as a filtering element. Such parts are available up to 100μH and carry approvals for use with automotive systems, making them desirable for isoSPI configurations as well.

Suitable CMCs are inexpensive. They can be quickly and easily produced as a machine-wound wire pair on a chip-sized ferrite form. Although isoSPI designs require somewhat higher inductance to effectively pass the longer pulse waveforms, adequate inductance can be achieved by using two of the chokes with windings in series to

produce 200μH. This has the additional benefit of forming virtual center-tap connections, which are useful for common-mode biasing and decoupling functions.

Figure 3 shows an equivalent transformer model realized with two CMCs. The chokes indicated have an 1812 SMT footprint and bifilar windings (wires paired in construction), so primary and secondary are intimately matched—minimizing the leakage inductance and thus preserving high frequency performance. Types with physically separated windings have poor pulse fidelity due to excessive leakage inductance. The units shown have a 50V DC continuous rating.

COMPLETE THE PICTURE

Figure 4 shows the complete circuit when using the L-C solution with CMCs as the transformers. Since the usual isoSPI application includes beneficial CMC filtering sections (integrated in the case of standard LAN parts), this circuit includes a recommended discrete part to retain that function. The coupling capacitors are high quality 10nF–33nF parts with an 1812 footprint (630V or 1kV rating). Here, we assume that the LTC6820 is operating at chassis ground potential, so that biasing of the twisted pair is at a safe level.

In situations where both ends of the pair are at floating potentials, as in links between daisy-chained LTC6804-1 modules, then capacitors can be used at both ends of the link and the pair itself can be biased to "earth" potential with high value resistors to each line as shown in Figure 5. Since the capacitors are in

Figure 5. High voltage daisy-chain isoSPI link with isolated wiring
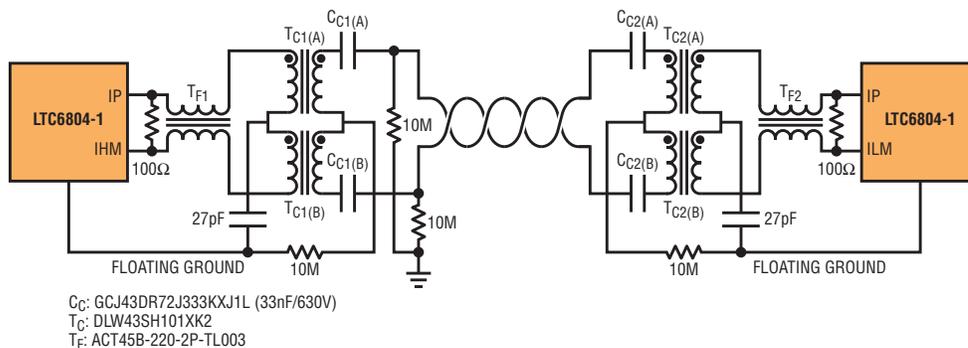
Use an AC-coupling method to mitigate the cost impact of high voltage isoSPI systems, eliminating the double insulation requirement on magnetics. Cost can be further reduced by replacing specialty toroidal transformer magnetics with inexpensive bobbin-wound common-mode-choke (CMC) components. Both the capacitors and CMCs are relatively low profile surface-mount chip components.
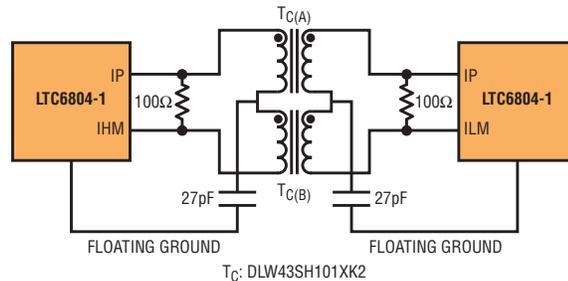

Figure 6. Daisy-chain isoSPI link for same-board interconnections

series in this situation, at least 22nF is recommended (33nF/630V type shown).

Links between daisy-chained LTC6804-1s on the same board do not need any capacitor couplings since the potential is ordinarily < 50V, usually requiring only a single transformer section as well (Figure 6) since the noise ingress without a cable is far smaller.

HIGH VOLTAGE LAYOUT

The printed circuit layout should include wide isolation spacing across the main dielectric barrier, namely, the capacitors. Figure 7 shows a placement example that provides good high voltage performance, with the blue regions representing frame ground (left side, with twisted-pair connector) and IC common (right side).

Note that the transformers must withstand HV transient potentials, so clearance is maintained there as well by using a 1206 size-biasing resistor. The HF decoupling capacitor and impedance termination resistor can be small parts (0602 size depicted).

Another good practice to avoid leakage current across the HV barrier is to suppress soldermask in the area of the HV components (parts over the "gap"

between grounds). This facilitates effective rinsing of flux residue under the parts, and avoids moisture retention in the porous soldermask layer.

SPECIAL CONSIDERATIONS FOR AN isoSPI BUS

The previous circuits apply to point-to-point isoSPI links, but one of the important cases for providing a high voltage solution is the bus-connected addressable LTC6804-2 with the twisted-pair link passing through each "tap" connection, as shown in Figure 8. The bus application places a high voltage requirement on every transformer since the same

Figure 7. Suggested printed-circuit layout for high voltage performance at an isoSPI interface
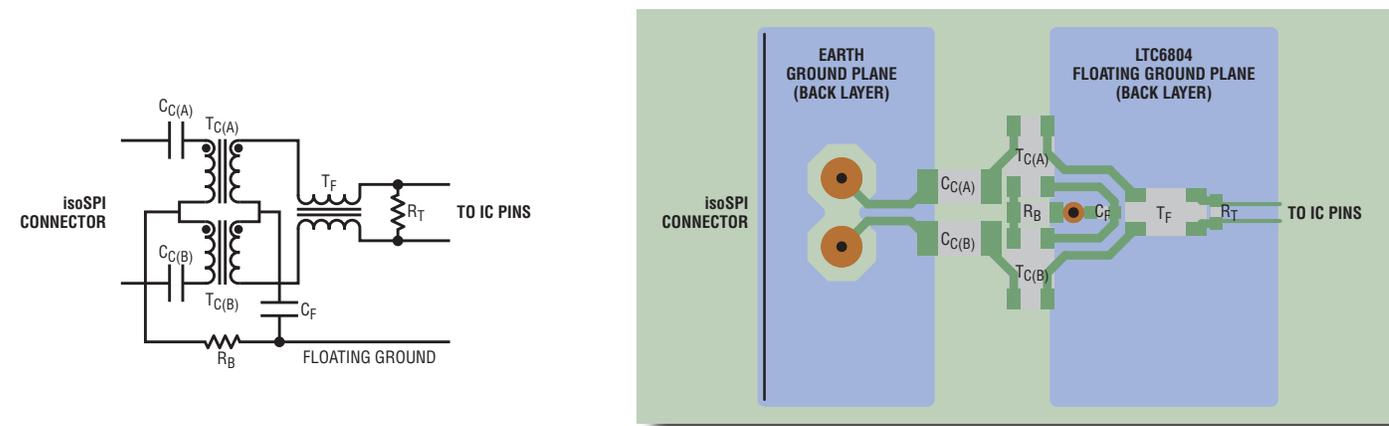
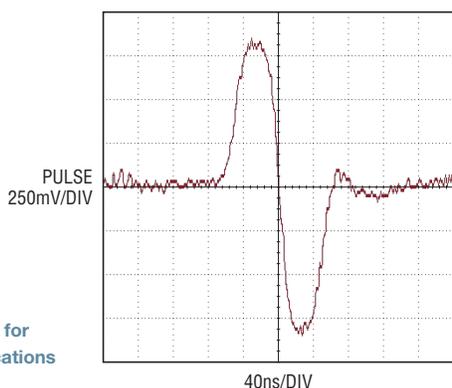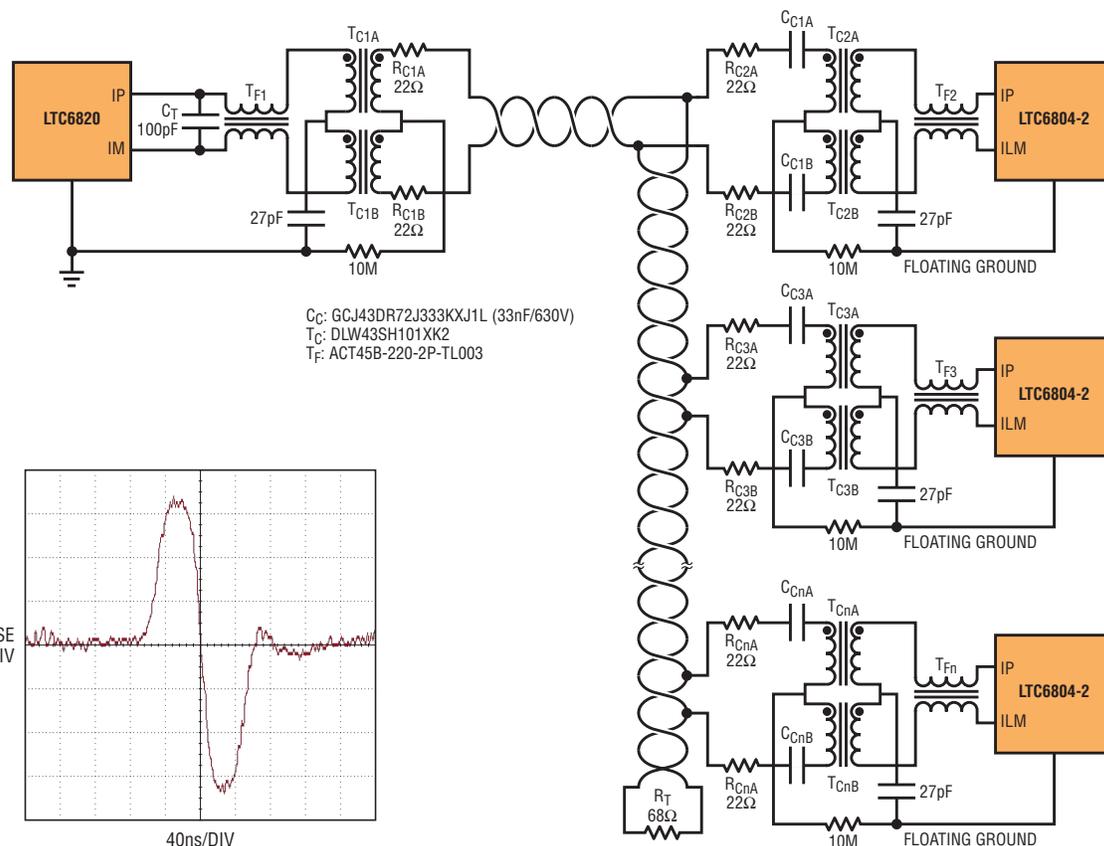**Figure 8. Complete high voltage isoSPI bus with echo control**

C$_C$: GCJ43DR72J333KXJ1L (33nF/630V)
T$_C$: DLW43SH101XK2
T$_F$: ACT45B-220-2P-TL003

PULSE
250mV/DIV

Figure 9. Modified pulse shaping for echo control in isoSPI bus applications

40ns/DIV

twisted-pair potential must interface with any voltage on the floating cell-stack.

The use of the CMC and AC-coupling capacitors for added insulation is the same as previously described, but we suggest slightly different coupling circuitry to damp the multitude of reflections and provide a consistent wave shape for communicating devices irrespective of their physical position in the network. There are three differences:

- The LTC6820 termination is changed to a 100pF capacitor (C$_T$).

- Far-end termination is only applied to the live bus (R$_T$) and set to 68Ω (no termination at any of the LTC6804-2s).

- 22Ω coupling resistors (R$_C$) are used for all bus connections to decouple stray capacitive loading.

These are shown in the Figure 8 circuit, which again assumes the LTC6820 is operating at a safe "earth" potential. The modified waveforms are band-limited to control distortion from reflections, so the received pulses at the IC pins appear more rounded as in Figure 9, but the isoSPI pulse discriminator circuit works fine with this filtered shaping and supports a full sixteen address bus. Depending on actual losses encountered in a given system, it may be necessary to lower the pulse-detection thresholds for optimal operation (configure thresholds to be 40%–50% of the differential signal peak).

Note that for networks of five or less addresses, the reflections are generally not a significant problem, so standard resistive end-terminations can be retained (namely 100Ω at the C$_{TERM}$ and R$_{TERM}$ positions of Figure 8, with the R$_C$s omitted).

CONCLUSION

Use an AC-coupling method to mitigate the cost impact of high voltage isoSPI systems, eliminating the double insulation requirement on magnetics. Cost can be further reduced by replacing specialty toroidal transformer magnetics with inexpensive bobbin-wound common-mode-choke (CMC) components. Both the capacitors and CMCs are relatively low profile surface-mount chip components that are competitively priced and available with automotive approvals for high reliability. The biasing resistors for the AC coupling offer a useful means of monitoring the dielectric integrity of the system. ■

Ideal Diode Combines 200V Busses

Mitchell Lee

As the power consumption of individual cards increases in rack-mounted systems, current consumption necessarily follows suit. A point is reached where the current delivered by the backplane becomes untenable, and the only solution is to increase the bus voltage. This point has been reached in even some 48V systems, leading to the use of bus voltages exceeding 100V.

The LTC4359 ideal diode controller is used in 12V, 28V and 48V battery, vehicular, line operated and solar power systems as a blocking diode and diode OR, achieving substantially lower power and voltage loss than is possible with a conventional diode. Its 100V absolute maximum rating would seemingly preclude use in higher voltage applications, but with the addition of a simple source follower clamp, this limitation is easily overcome.

Figure 1 shows a 200V, 7A ideal diode realized with the LTC4359. Two or more of these circuits are used to OR multiple busses. Q1 serves as the pass element. At 7A load current, Q1's dissipation is 1W; this beats a conventional rectifier by a factor of 5 to 10 and results in a substantial savings in board area. The LTC4359 is powered by a shunt regulator comprising D1, R1A and R1B. The use of large value resistors is made possible by the LTC4359's low, 200µA maximum supply current. With the values shown, the control circuit operates down to 50V input, and consumes about 200mW with a 200V input. If low voltage operation is not important, R1A and R1B can be increased to 200kΩ, reducing the total control circuit dissipation to 100mW, or about 10% of the circuit's total dissipation when operating with a 7A load.

When power is first applied, Q1's body diode passes current to the output. Q3, a 600V depletion mode device, turns on and connects the output voltage directly to the LTC4359's OUT pin. The IN and OUT pins sense v_{SD} across Q1 and drive the GATE pin in an attempt to hold the MOSFET's "forward" drop to 30mV. This condition is maintained up to about 1.5A, beyond

which Q1 is driven fully on and the voltage drop is dictated by its 20mΩ $R_{DS(ON)}$.

If v_{SD} is less than 30mV, such as might be the case if the output is pulled up by a second, higher supply, the LTC4359's GATE pin turns the MOSFET off and blocks reverse current flow. If the input voltage drops significantly below the output, Q3's source-follower action protects the

Figure 1. An LTC4359-based ideal diode for 200V busses
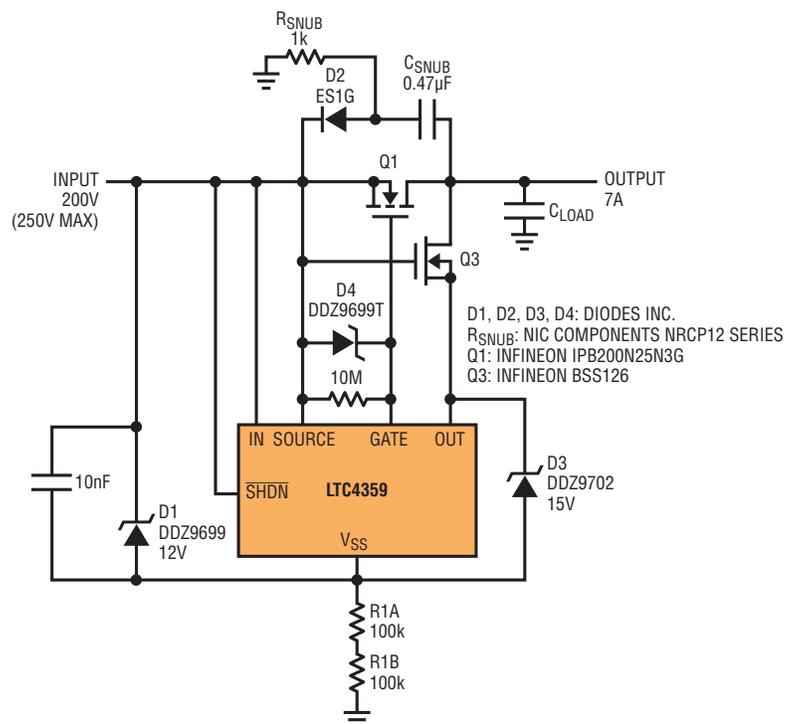
New Product Briefs

16A µMODULE REGULATOR CONFIGURABLE AS QUAD, TRIPLE, DUAL OR SINGLE OUTPUT POWERS FPGAs, ASICs & MICROPROCESSORS

The LTM4644 quad output step-down µModule® regulator is configurable as a single (16A), dual (12A, 4A or 8A, 8A), triple (8A, 4A, 4A) or quad (4A each) output regulator. This flexibility enables system designers to rely on a single compact µModule regulator for the variety of voltage and load current requirements of FPGAs, ASICs and micro-processors and other board circuitry.

The DC/DC controllers, power switches, inductors and compensation components are incorporated into the 9mm × 15mm × 5.01mm BGA package. Eight external ceramic capacitors (1206 or smaller case sizes) and four feedback resistors (0603 case size) complete four inde-pendently adjustable outputs between 0.6V to 5.5V. Separate input pins allow the four channels to be powered from different supply rails from 4V to 14V.

At an ambient temperature of 55°C, the LTM4644 delivers up to 13A at 1.5V from a 12V input or up to 14A with 200LFM air-flow. The four channels operate at 90° out-of-phase to minimize input ripple whether at the 1MHz default switching frequency or synchronized to an external clock between 700kHz and 1.3MHz. With the addition of an external bias supply above 4V, the LTM4644 can regulate from an input supply voltage as low as 2.375V.

QUAD PHY INTERFACE ENABLES RUGGED MULTIPORT IO-LINK MASTERS

The LTC2874 IO-Link master IC provides the power and communications interface to four remote IO-Link devices (slaves). A rugged interface and rich feature set make the LTC2874 ideal for larger systems implementing IO-Link (IEC61131-9) in harsh, industrial environments. Managing four slaves per master IC, the LTC2874 reduces board space, design complexity and costs while increasing reliability.

Unique features of the LTC2874 include automatic wake-up request (WURQ) generation and an output supply current-boosting capability for slave start-up. The WURQ generator produces self-timed wake-up pulses of correct polarity, reduc-ing demands on the microcontroller. Safety mechanisms manage multiport and repeat WURQs to prevent thermal overload and maintain error-free com-munication. The current-boosting pulse generator fully implements the start-up current pulse requirements added to the IO-Link v1.1.1 specification.

The onboard Hot Swap controller and external N-channel MOSFET in the power interface protect connected devices from inrush currents during start-up and fault conditions. Integrated ±50V block-ing diodes in the data line interface protect against faults and high volt-age excursions, making the LTC2874 well suited for the harsh PLC environ-ment driving cables up to 20m long. ■

LTC4359's OUT pin by keeping it within a few volts of the IN pin. Thus, it is Q3, with help from the floating supply archi-tecture of D1 and R1A/B, that permits the 100V LTC4359 to operate comfort-ably at 200V. D3 is included to protect against brief, dynamic conditions that could otherwise damage Q3's gate pin.
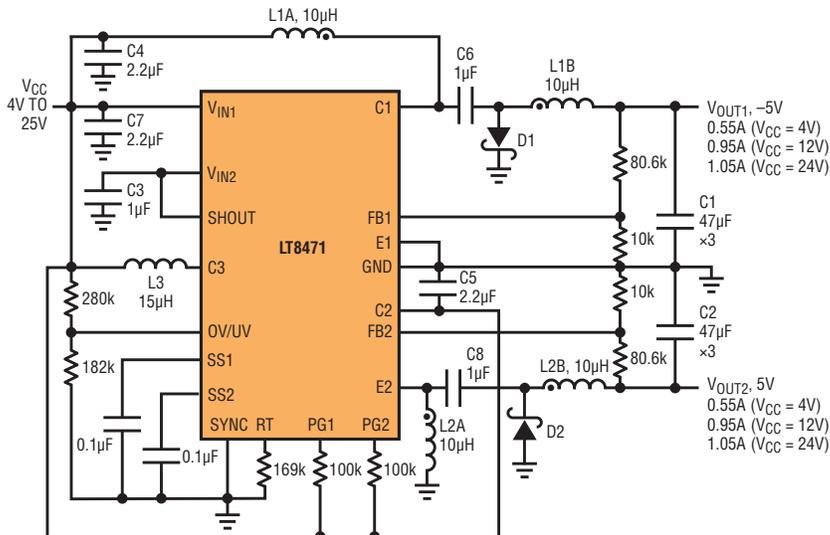
Q1, a 250V-rated component, is chosen for its exceptional on-resistance of just 20mΩ. Another feature of this device is

its advantageous c_{GS}/c_{RSS} ratio, which simplifies the gate drive requirements and precludes self-enhancement during Hot Swap events. Because Q1 is operated in triode, it is possible to parallel multiple devices for higher power applications.

Commutation spikes are clamped with a simple diode reset snubber. Q1 is gener-ously rated at 320mJ avalanche energy, but the recommended peak avalanche current is only 47A. This figure is easily

exceeded in high voltage systems where circuit faults may impress the full sup-ply across small, parasitic inductances. Commutation spike energy is diverted away from Q1 and stored in CSNUB, then slowly dissipated by RSNUB.

Maximum operating voltage is lim-ited by Q1 to 250V. Q3 is rated to 600V. Replacing Q1 with a suitable higher volt-age unit and scaling R1A and R1B accord-ingly permits operation up to 600V. ■

LT8471 500kHz ZETA AND 2L INVERTING CONVERTERS GENERATES ±5V OUTPUTS WITH LOW OUTPUT RIPPLE

The LT®8471 is a dual PWM DC/DC converter containing two internal 2A, 50V switches and an additional 500mA switch to facilitate step-down and inverting conversion. Each 2A channel can be independently configured as a buck, boost, SEPIC, flyback or inverting converter. Capable of generating positive and negative outputs from a single input rail, the LT8471 is ideal for many local power supply designs.

www.linear.com/solutions/4711

C1, C2: 10V, X7R, 1210
C3, C4, C5, C7: 35V, X74, 1206
C6, C8: 50V, X7R, 1206
D1, D2: MICROSEMI UPS140
L1, L2: COOPER BUSSMANN DRQ74-100-R
L3: WÜRTH 744025 150

LT3048-15 2.7V TO 4.8V V_IN, 15V V_OUT, 40mA LOW NOISE BIAS GENERATOR IN 2mm × 2mm DFN

The LT3048-15 generates a low noise, low ripple bias supply from an input voltage of 2.7V to 4.8V. The LT3048-15 includes a boost regulator and a linear regulator. The boost regulator provides power to the linear regulator. The boost regulator output voltage is regulated to 1.1V above the LDO output, optimizing LDO ripple rejection and transient response. Fixed frequency operation and current mode control allow the use of very small inductors and results in low, predictable output ripple. The linear regulator in the LT3048-15 generates a fixed 15V output. High power supply ripple rejection, combined with a low noise internal reference, results in less than 500µV_P-P output ripple and noise.

http://www.linear.com/solutions/4547

V_IN (V)	I_OUT (mA)
2.7	19
3.3	22
3.6	24
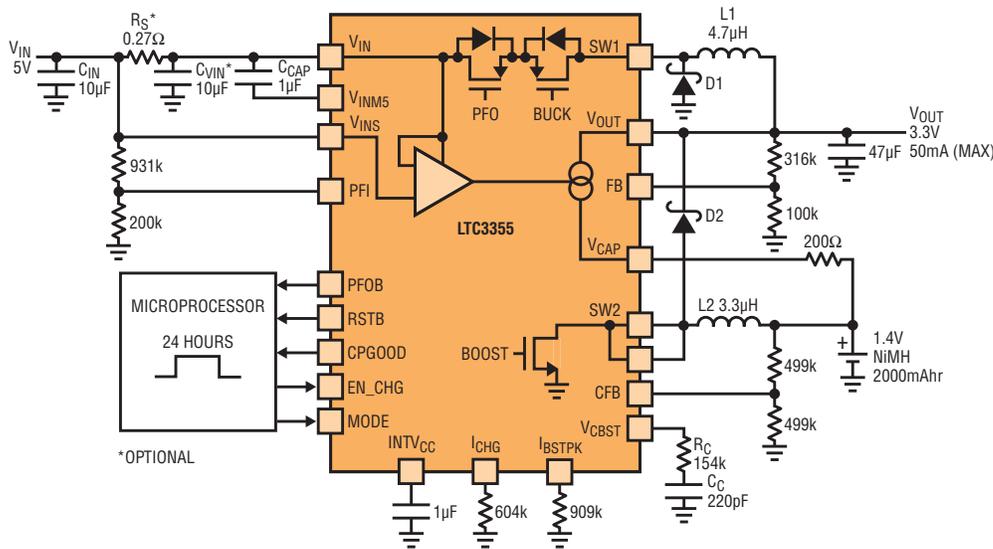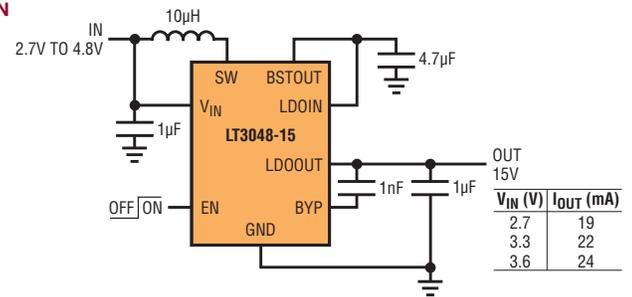
LTC3355 NiMH TRICKLE CHARGER AND RIDE-THROUGH BACKUP SUPPLY

The LTC®3355 is a complete input power interrupt ride-through DC/DC system. The part charges a supercapacitor while delivering load current to V_OUT, and uses energy from the supercapacitor to provide continuous V_OUT backup power when V_IN power is lost. The LTC3355 contains a nonsynchronous constant frequency current mode monolithic 1A buck switching regulator to provide a 2.7V to 5V regulated output voltage from an input supply of up to 20V.

www.linear.com/solutions/4814

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