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IN THIS ISSUE

60V and 100V, Low I_Q Boost/SEPIC/Inverting Converters for Compact, Efficient, Low EMI Power Supplies

Joey Yurgelon , Jesus Rosales and Mark Marosek

Automotive and industrial markets demand cool running power supplies that fit tight spaces and meet low EMI standards. The LT8362, LT8364 and LT8361 switching regulators meet these demands in boost, SEPIC or inverting topologies. Each supports a wide 2.8V to 60V input range, for industrial or automotive environments, low I_Q Burst Mode capability and optional SSFM for reduced EMI. With built-in rugged power switches of 60V/2A, 60V/4A and 100V/2A, including efficient operation up to 2MHz, these devices can deliver high power in small spaces while meeting stringent thermal and EMI requirements.

With 10,000:1 dimming, the LT3932 buck LED driver makes cutting edge applications possible. (See page 20.)

AUTOMOTIVE INPUT TRANSIENTS AND PRE-BOOST

With the dramatic increase of electronic content in today's automobiles, the number of power supplies has multiplied, with many required to directly convert a wide-ranging battery voltage to a usable, regulated output. With a minimum input voltage of 2.8V, all members of the LT836x family can operate during cold crank or stop-start events; the maximum input voltage

(continued on page 4)

AHEAD OF WHAT'S POSSIBLE™

In this issue...

Open Circuit

POWER DEMOS SHOWN AT APEC 2018

The ADI Power by Linear™ group was at APEC 2018 (Applied Power Electronics Conference in San Antonio, Texas in March) with a team of power experts to showcase innovative power technologies. The demonstrations presented at APEC included:

- High power isolated gate driver board for Microsemi half-bridge SiC power module
- Hot Swap and power management
- Power over Ethernet
- Power system management (see Spotlight below)
- Wireless power for industrial and medical handheld devices and hearing aids (see Spotlight below)
- USB-C power delivery battery charger featuring the LTC4162
- Power µModule® solutions are simple & done
- Low electromagnetic emissions benefits of Silent Switchers

SPOTLIGHT ON APEC 2018: PSM & WIRELESS POWER

Power System Management (PSM), Hot Swap & LTpowerPlay

Mike Jones' demonstration at APEC provided a live, interactive experience of the Total Managed Power demo board (DC2578A) and the LTpowerPlay software.

Power System Management ICs give designers vast digital control of system power rails. LTpowerPlay is a PC-based graphical interface that allows designers to monitor and program the complete power system, from Hot Swap, through intermediate buses, to point-of-load controllers.

The PSM family provides extremely accurate configurable power regulation, configurable safety limits, coordinated fault responses, a full suite of live telemetry, a rich set of configuration and control encapsulated in EEPROM memory, and a comprehensive software tool that brings together all of these features and ICs. PSM solutions provide:

- Extreme accuracy
- High reliability and safety
- Autonomous operation
- Complete telemetry and status information
- High system configurability across any number of supply rails

The Power by Linear group presented a variety of industry-specific power solutions at APEC 2018

Wireless Battery Chargers for Hearing Aid and Handheld Applications

Brian Shaffer (Applications Engineering Manager for Analog Devices Power Business) demonstrated wireless battery charging solutions for hearing aids and handheld applications.

25mA Wireless NiMH Charger for Hearing Aid Applications—On display was the LTC4123, a complete 1.5V, 25mA, NiMH wireless battery charger. The LTC4123 features a temperature-compensated charge voltage, an integrated rectifier with overvoltage limit, zinc-air primary battery detection and reverse polarity protection. A complete solution comprising the 2mm × 2mm LTC4126 and four additional components fits on a PCB with less than 6mm diameter, ideal for hearing aid applications.

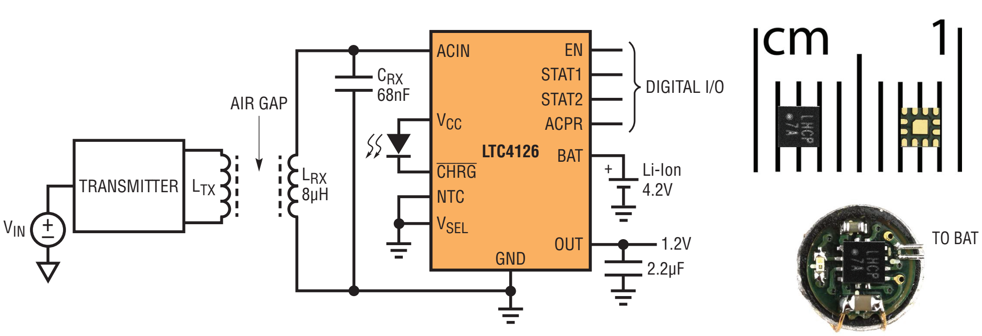
Hearing Aid Wireless Charging and DC/DC Power: 7.5mA Wireless Li-Ion Charger & 1.2V/60mA DC/DC—Shaffer also demonstrated the LTC4126 wireless 7.5mA Li-ion battery charger with integrated high efficiency 1.2V, 60mA multimode DC/DC charge pump. The LTC4126 is perfectly suited for hearing aid applications because of its extremely small solution size and numerous protection features, such as:

- Integrated rectifier with overvoltage limit
- Pin-selectable charge voltages of 4.2V or 4.35V
- 3V low battery disconnect
- NTC pin for temperature qualified charging
- 6-hour termination timer

The LTC4126 is offered in a thermally enhanced 2mm × 2mm LQFN package. The charge pump output is designed to duplicate the load profile of a NiMH battery so that existing hearing aid ASICS can be powered directly, without additional conversion.

Battery Charger Receiver and Transmitter Combination for Higher Power Industrial Handheld Solutions—For industrial handheld applications, Brian demonstrated the LTC4120 battery charger receiver and the LTC4125 transmitter combination. The LTC4120 is a wireless power receiver and 400mA buck battery charger with dynamic harmonization control, which optimizes wireless charging over a wide coupling gap. It can charge single or multiple series lithium-ion batteries and is offered in a thermally enhanced, 16-lead 3mm × 3mm QFN package.

The LTC4125, 5W AutoResonant™ wireless power transmitter works seamlessly with the LTC4120. The LTC4125's switching frequency adjusts to changes in resonant capacitance and transmit coil inductance. The LTC4125 reduces power dissipation by automatically adjusting its transmit power to the receiver load. It has multiple foreign object detection methods, programmable average input current limit and an NTC input for system component temperature-qualified power transfer. ■



The LTC4126 for hearing aid applicatins was demonnstrated at APEC 2018

To meet the demand for compact power supplies, DC/DC converters use high switching frequencies to minimize component size and cost. Furthermore, the requirements for operation above the AM band in automotive applications has driven frequencies to 2MHz.

(LT836x family, continued from page 1)

capability of up to 60V handles high input voltage transients such as load dump.

This wide input voltage range makes the LT836x family ideal for automotive pre-boost applications. Automotive buck regulators require a pre-boost stage in applications where battery input voltage can drop below the buck output voltage. The LT8361, LT8362 and LT8364 provide the necessary boosting during low battery levels, and turn off with minimal power consumption during normal or load dump battery voltages.

RUGGED POWER SWITCHES

A key requirement for any switching regulator is to provide enough power for a given application over the entire input voltage range while also guaranteeing reliability. Rugged power switches with voltage/peak current offerings of 60V/2A (LT8362), 60V/4A (LT8364) and 100V/2A (LT8361) enable a wide range of applications. The high power switch voltage ratings of the LT836x family extend output voltage capability in addition to extending the input voltage range for SEPICs and inverting converters.

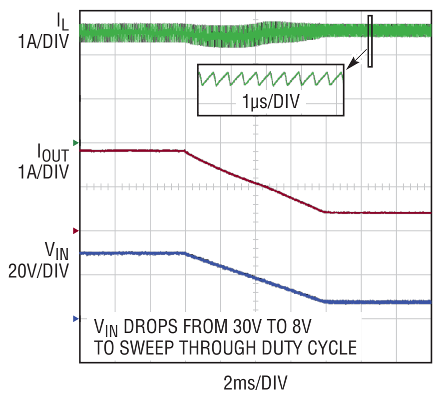


Figure 1. LT836x converters provide the full slope compensation necessary for proper operation at peak switch current limit, without the DC reduction of peak switch current limit versus duty cycle.

MAXIMIZING POWER DELIVERY: FLAT CURRENT LIMIT VS DUTY CYCLE

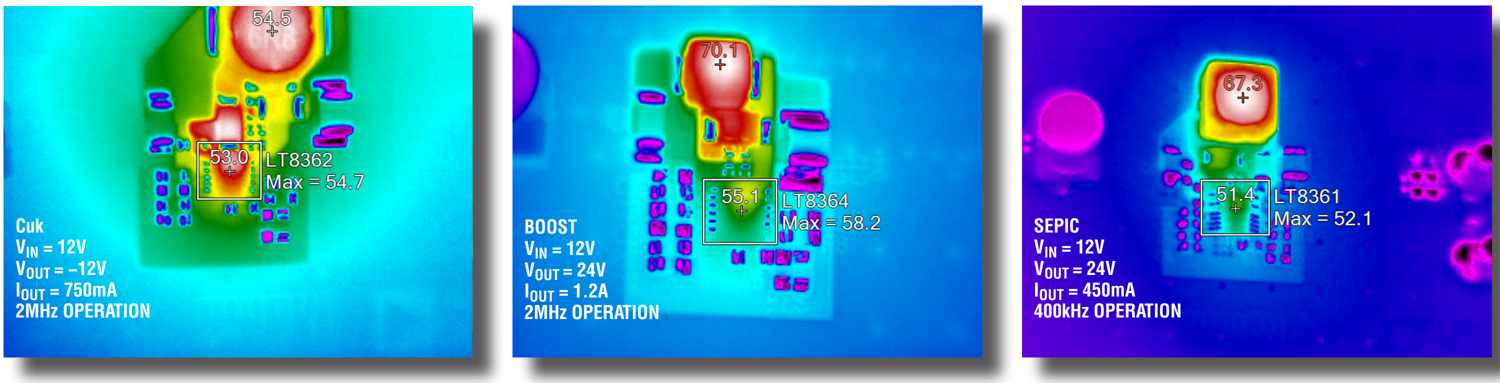
To maximize power delivery over the entire input voltage range, the power switches of the LT836x family maintain their peak switch current limit over the entire duty cycle range. The advertised current of the switch is available, without compromise. This is a significant advantage over converters that may exhibit a fall of 30% or more in peak switch current limit at high duty cycles.

Current mode DC/DC converters typically add slope compensation to their peak switch current limit to avoid subharmonic oscillations when that peak switch current limit is met. The drawback is a reduction of peak switch current limit as duty cycle increases (as input voltage lowers). The LT836x family provides the full slope compensation necessary for proper operation at peak switch current

Table 1. Low I_Q boost/SEPIC/inverting converters. Devices described in this article are highlighted.

	LT8362	LT8364	LT8361	LT8330	LT8331	LT8335
Burst Mode I_Q	9µA	9µA	9µA	6µA	6µA	6µA
Input voltage range	2.8V–60V	2.8V–60V	2.8V–60V	3V–40V	4.5V–100V	3V–25V
Programmable, fixed switching frequency	300kHz–2MHz	300kHz–2MHz	300kHz–2MHz	2MHz	100kHz–500kHz	2MHz
Spread spectrum frequency modulation for Low EMI						
Power switch voltage/current	60V/2A	60V/4A	100V/2A	60V/1A	140V/0.5A	28V/2A
Package	3mm × 3mm DFN, MSE- 16(12)	4mm × 3mm DFN, MSE- 16(12)	MSE- 16(12)	3mm × 2mm DFN,TSOT- 23	MSE- 16(12)	3mm × 2mm DFN
Temperature grades	E,I,H	E,I,H	E,I,H	E,I,H	E,I,H	E,I,H

Traditionally, high switching frequencies result in increased switching losses and limited duty cycle range. The LT836x family minimizes AC switching losses using fast power switch drivers and features low minimum on- and off-times, enabling support of a wide conversion range even at 2MHz.



(a) LT8362 DC2517A inverting converter

(b) LT8364 DC2716A boost converter

(c) LT8361 DC2599A SEPIC converter

Figure 2. Thermal performance of LT8362 Cuk inverting, LT8364 boost and LT8361 SEPIC solutions.

limit, without the DC reduction of peak switch current limit versus duty cycle.

2MHz OPERATION: COMPACT POWER SUPPLIES, ABOVE AM BAND

To meet the demand for compact power supplies, DC/DC converters use high switching frequencies to minimize component size and cost. Furthermore, the requirements for operation above the AM band in automotive applications has driven frequencies to 2MHz.

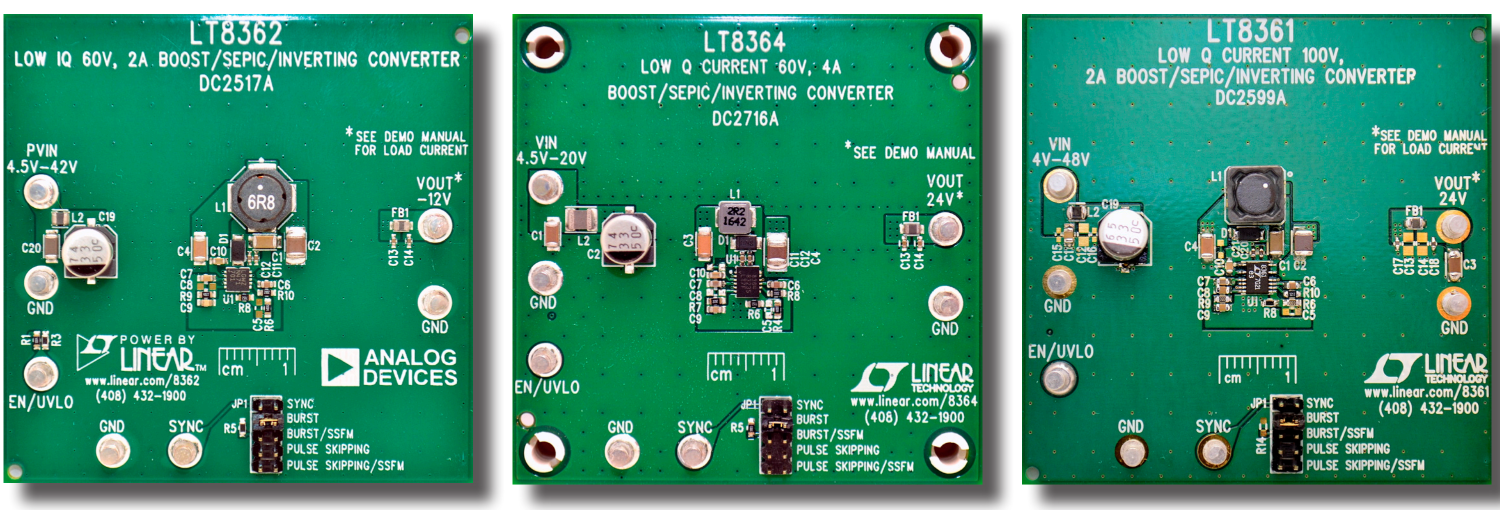
Traditionally, high switching frequencies result in increased switching losses and limited duty cycle range. The LT836x family minimizes AC switching losses using fast power switch drivers and features low minimum on- and off-times, enabling support of a wide conversion range even at 2MHz. For instance, the LT836x family can achieve lower losses and a higher duty cycle range than many applications that would traditionally run at 400kHz to maximize efficiency. Thermal performance for each of the covered topologies—boost, SEPIC and inverting—is shown in Figure 2.

Figure 3. Compact, EMI friendly converter solutions

(a) LT8362 low EMI inverting converter

(b) LT8364 low EMI boost converter

(c) LT8361 low EMI SEPIC converter



SYNC/MODE PIN INPUT	CAPABLE MODES OF OPERATION
(1) GND or < 0.14V	Burst Mode operation
(2) External clock	Pulse-skipping/sync
(3) 100k resistor to GND	Burst/SSFM
(4) Float (pin open)	Pulse-skipping
(5) $INTV_{CC}$ or > 1.7V	Pulse-skipping/SSFM

Table 2. LT836x family capable modes of operation

BURST MODE OPERATION: HIGH EFFICIENCY AT LIGHT LOAD

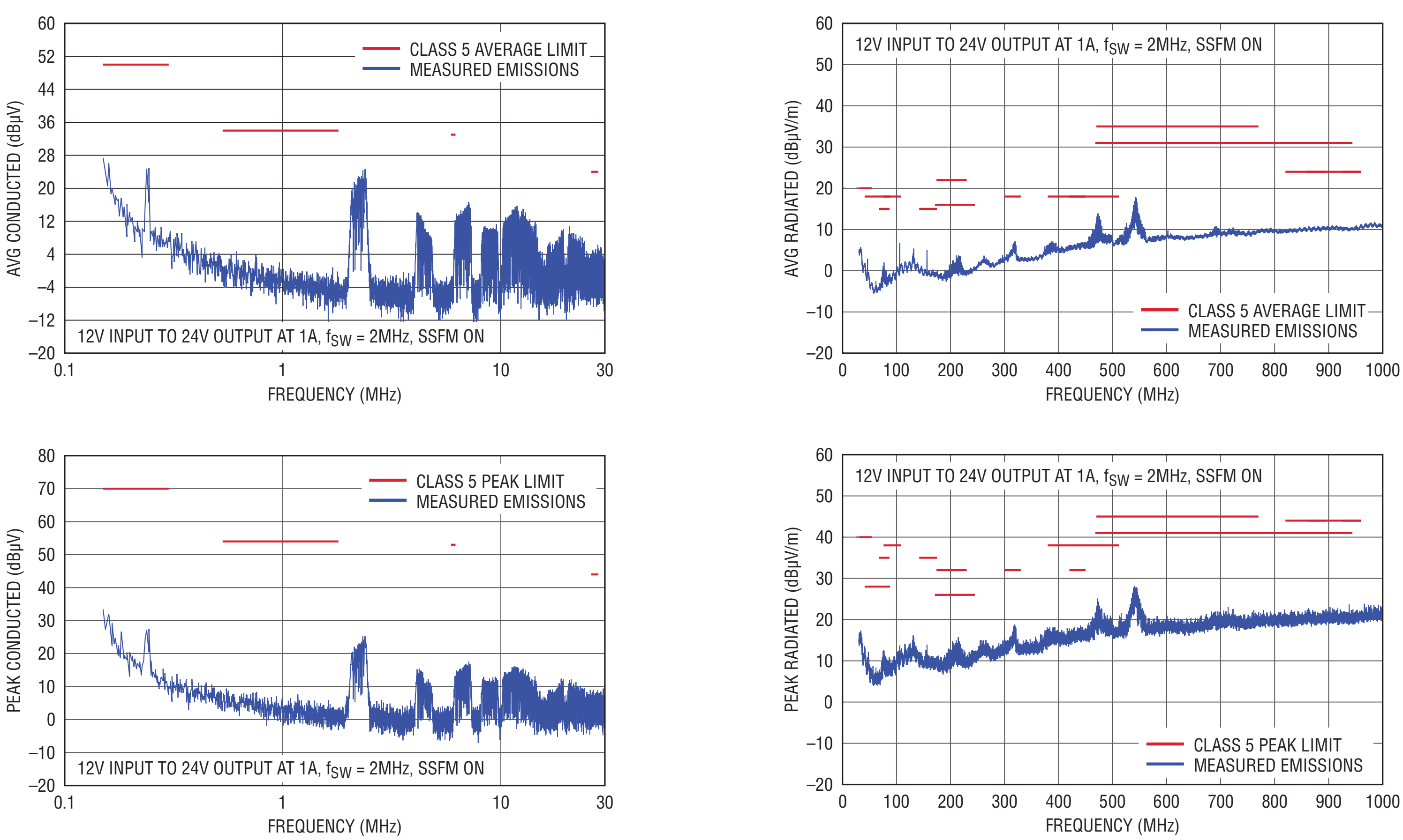
High efficiency at light loads is a critical feature in automotive environments where extending battery life is of utmost importance. The LT836x family offers high efficiency at light loads with optional Burst Mode® operation—selectable using the SYNC/MODE pin (see Table 2.). Burst Mode operation uses single-switch pulses spaced evenly at a lower switching frequency to reduce switching losses, while minimizing output voltage ripple. The LT836x family can draw as little as 9μA from the input pin when in deep sleep or in pass through mode in a pre-boost application.

SSFM MODE: THREE TOPOLOGIES PASSING CISPR 25 CLASS 5

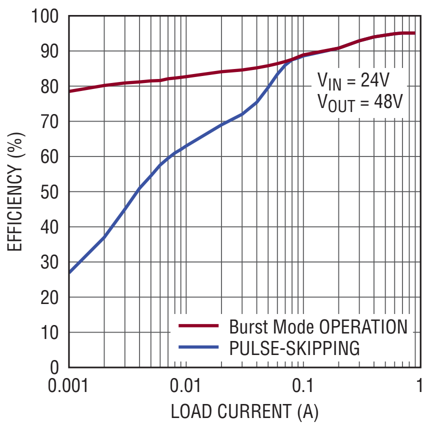
The LT836x family is capable of meeting CISPR 25 Class 5 standards using spread spectrum frequency modulation (SSFM) mode and proper board layout with some filtering.

Designers have traditionally avoided using switching regulators throughout EMI sensitive environments. A switcher's large capacitors and troublesome hot loops elevate the importance of PCB layout to achieve good EMI performance and small solution size, placing a burden on board design and manufacture. The available factory demonstration circuits for the LT8362, LT8364 and LT8361 include the requisite input/output filters and feature exemplary PCB layout to meet CISPR 25 Class 5 standards (as tested) when SSFM

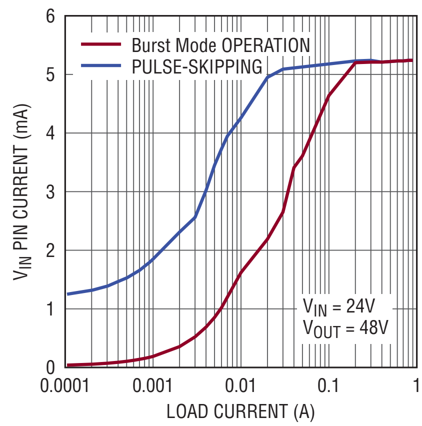
Figure 4. EMI test results for LT8364 boost solution



Until recently, selecting SSFM mode for low EMI meant using the less efficient pulse-skipping mode at light load. The LT836x family does not require this trade-off.



(a) Pulse-skipping and Burst Mode operation light load efficiency



(b) Pulse-skipping and Burst Mode operation light load V_{IN} pin current

Figure 5. Pulse-skipping vs Burst Mode operation for LT8362 boost solution (24V input to 48V output)

mode is selected (see Table 2). By essentially removing the converter from the EMI equation, application development time and cost are reduced. Figure 4 shows EMI test results for a boost solution.

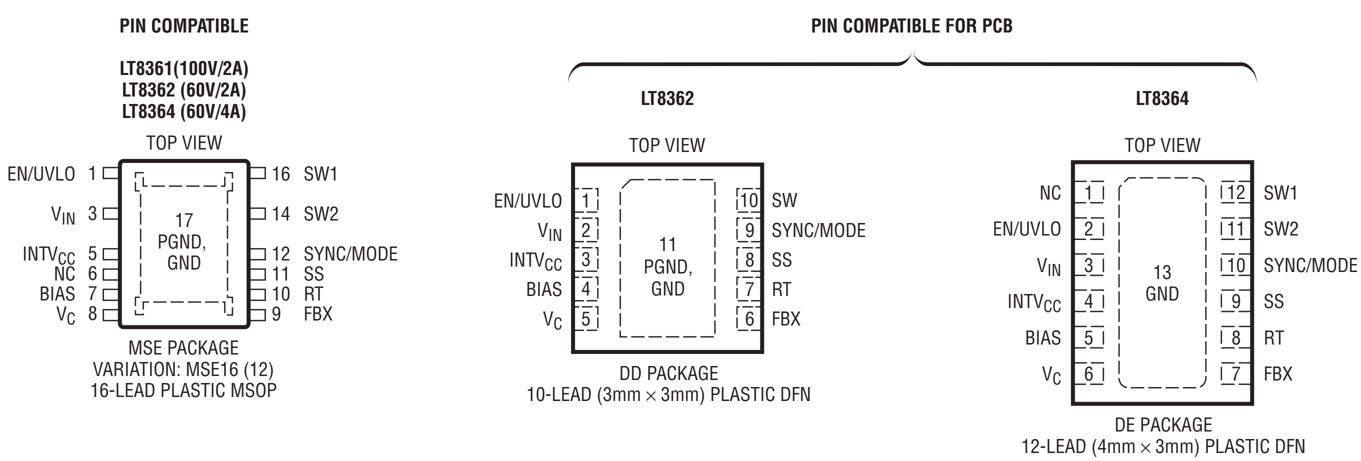
BEST OF BOTH: BURST MODE OPERATION & SSFM

Until recently, selecting SSFM mode for low EMI meant having to use the less efficient pulse-skipping mode at light load, but the LT836x family does not require this trade-off. By simply adding a 100k resistor from SYNC/MODE pin to ground (see Table 2), the LT836x family seamlessly transitions from SSFM mode to Burst Mode operation when loads become light. The result is low EMI and high efficiency over all loads.

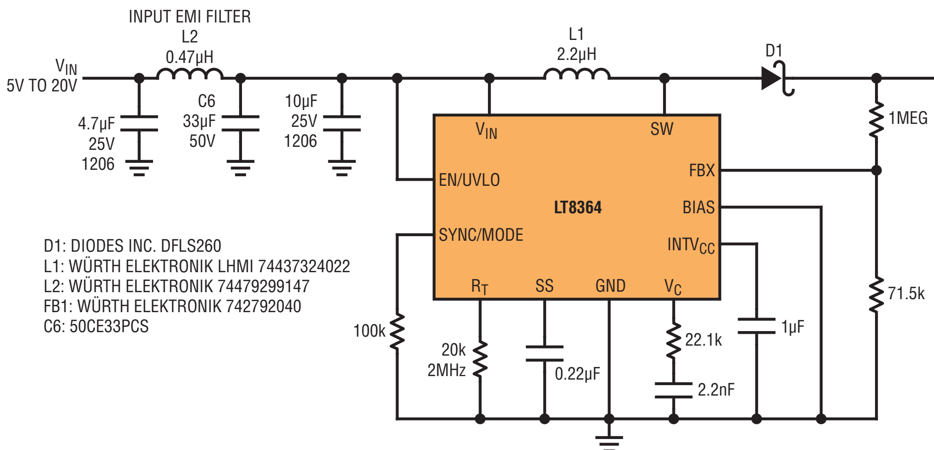
PACKAGES, PIN COMPATIBILITY AND TEMPERATURE GRADES

For customers who prefer leaded packages, each part is offered in a pin-compatible MSE16(12) TSSOP with four pins removed for HV pin spacing. For a smaller solution size, the LT8362 and LT8364 are also offered in DFN packages. The LT8362 (3mm × 3mm) DFN(10) is pin compatible with the LT8364 by placing it onto the (4mm × 3mm) LT8364 DFN(12) PCB space (see Figure 6). All packages include a thermally enhanced exposed ground pad and are offered in E, I and H temperature grades.

Figure 6. Pin compatiblity of packages for the LT8361, LT8362 and LT8364



By offering a single FBX pin that allows for both positive and negative output voltages, all topologies are within reach. An inverting application is just as accessible as that of a boost or SEPIC, reducing design time and effort.



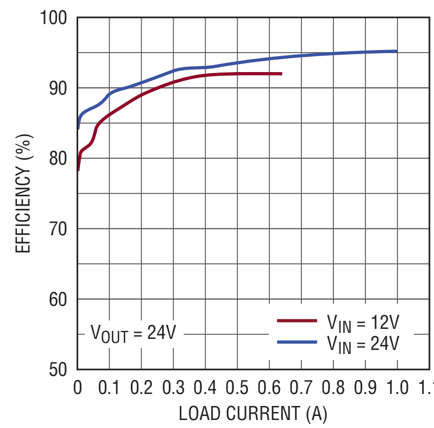
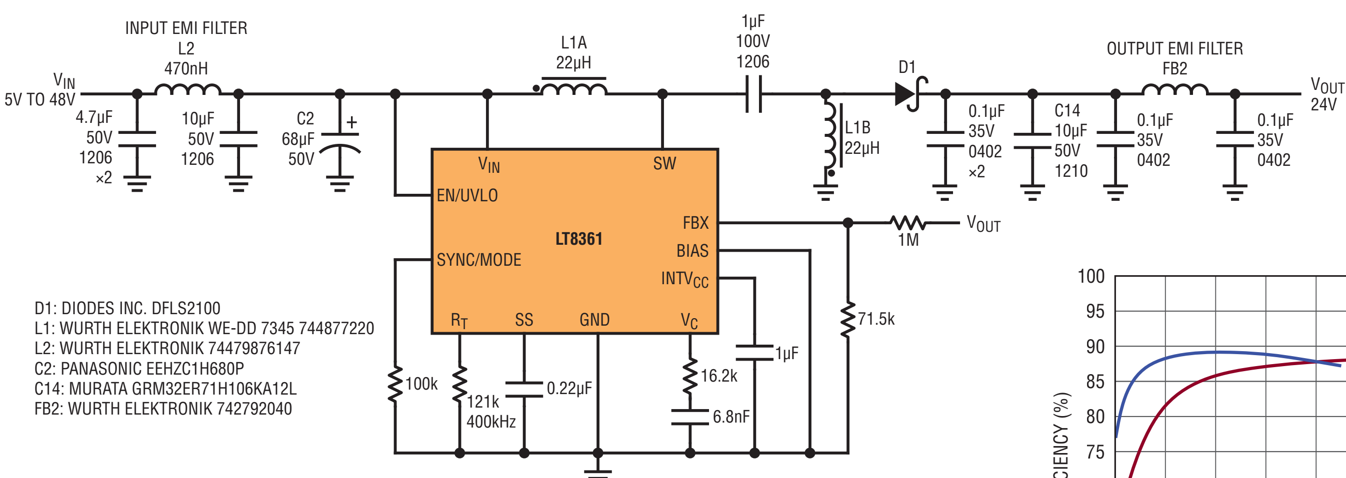


Figure 7. LT8364, 2MHz, 24V output boost converter passes CISPR 25 Class 5 EMI (see Figure 4).



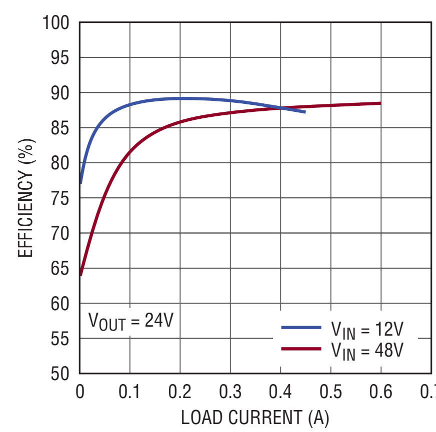


Figure 8. LT8361, 400kHz, 24V output SEPIC converter passes CISPR 25 Class 5 EMI

For applications requiring output voltages greater than the input, the LT836x family is ideal for many boost converter applications given the 2.8V-to-60V input capability and range of power switch ratings. For large conversion ratio designs, operating in discontinuous conduction mode (DCM) might be the best solution; continuous conduction mode (CCM) can deliver higher output power.

BOOST/SEPIC/INVERTING: FBX PIN FOR POSITIVE OR NEGATIVE OUTPUTS

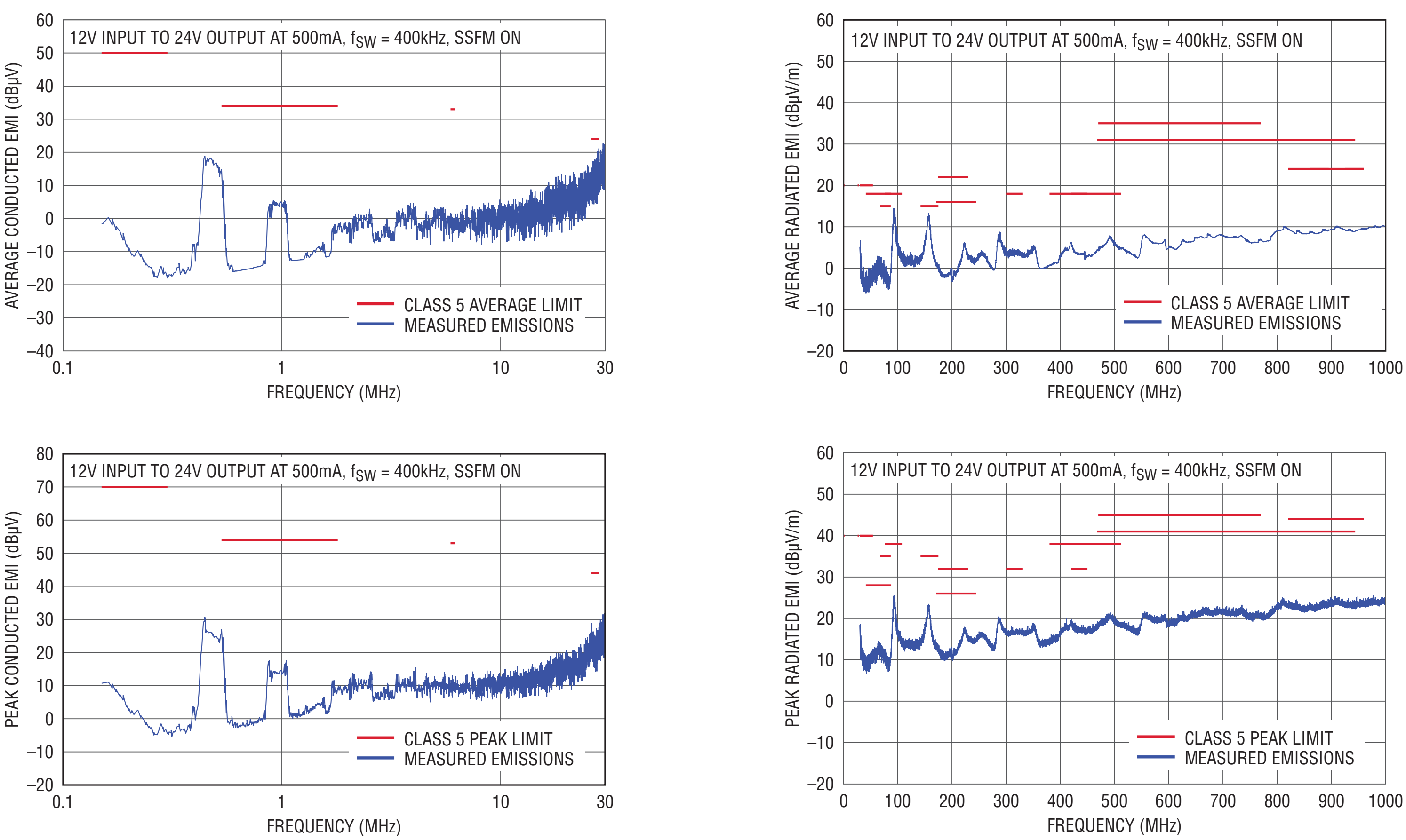
By offering a single FBX pin that allows for both positive and negative output voltages, all topologies are within reach. An inverting application is just as accessible as that of a boost or SEPIC, reducing design time and effort.

Boost Converters

For applications requiring output voltages greater than the input, the LT836x family is ideal for many boost converter applications given the 2.8V-to-60V input capability and range of power switch ratings. For large conversion ratio designs, operating in discontinuous conduction mode (DCM) might be the best solution; continuous conduction mode (CCM) can deliver higher output power.

The converter in Figure 7 shows an LT8364 low I_Q, low EMI, 2MHz, 24V boost converter with SSFM that passes CISPR 25 Class 5 radiated and conducted EMI (Figure 4). With an input of 12V, this application easily reaches a peak efficiency of 94%.

Figure 9. EMI test results for LT8361 SEPIC solution



For applications where the DC/DC converter is required to both step-up and step-down its input, a SEPIC topology is often the solution. SEPICs support applications that require output disconnect, ensuring no output voltage during shutdown and tolerating output short-circuit faults since there is no DC path from input to output.

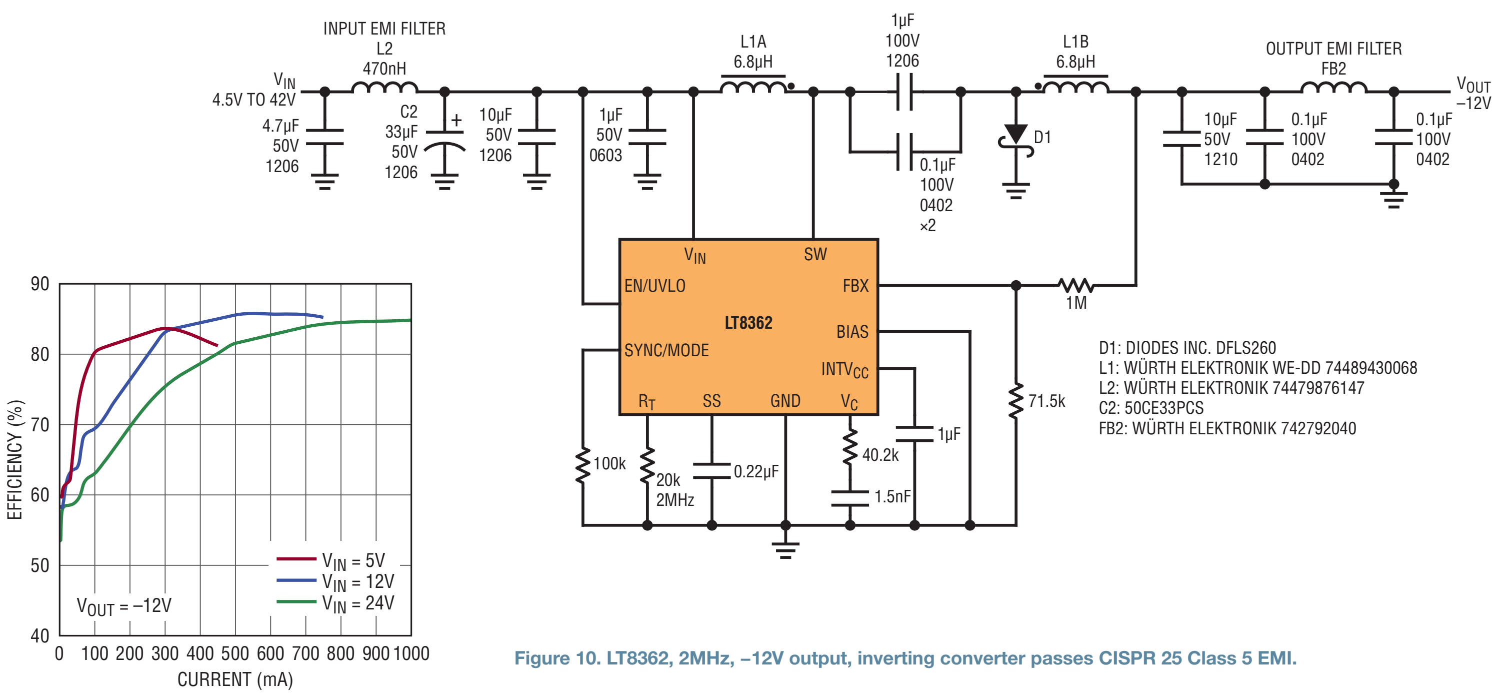


Figure 10. LT8362, 2MHz, –12V output, inverting converter passes CISPR 25 Class 5 EMI.

SEPIC Converters

Automotive and industrial applications often operate from input voltages that can be above and below the required output voltage. For applications where the DC/DC converter is required to both step-up and step-down its input, a SEPIC topology is often the solution. SEPICs support applications that require output disconnect, ensuring no output voltage during shutdown and tolerating output short-circuit faults since there is no DC path from input to output. With switch ratings of 60V/100V, and low minimum on- and off-times, wide input voltage ranges are achievable. The LT836x family offers an optional BIAS pin which serves as a second input supply for the $INTV_{CC}$ regulator for improved efficiency.

The SEPIC converter in Figure 8 uses the LT8361 to showcase the versatility of a 100V rated switch. The switch voltage rating must be greater than the addition of maximum input and output voltages. With a 48V input to 24V output, the switch can easily handle the required 72V. With use cases where the input is greater than the output, the BIAS pin can offer improved efficiency when connected to V_{OUT}. Operating with SSFM, this application passes CISPR 25 Class 5 radiated and conducted EMI (Figure 9). Peak efficiency with a 12V input is 88%.

Inverting Converters

Negative supplies are commonly used in today's electronics. However, many applications only have a positive input voltage from which to operate. The LT836x family, when configured in the inverting topology, can regulate from a positive input voltage that is above or below the magnitude of the negative output voltage. As with the SEPIC topology, the high 60V/100 switch ratings and low minimum on- and off-times allow wide input voltage ranges.

Operating at 2MHz, the LT8362 offers an easy way to create a negative voltage from a positive input supply, as shown in Figure 10—a low I_Q, low EMI, 2MHz, –12V inverting converter with SSFM. With the rugged 60V switch, this

To satisfy the automotive and industrial market demand for compact, efficient, low EMI power supplies, the LT836x family provides the rugged LT8362 (60V/2A), LT8364 (60V/4A) and LT8361 (100V/2A) switching regulators for boost, SEPIC and inverting topologies.

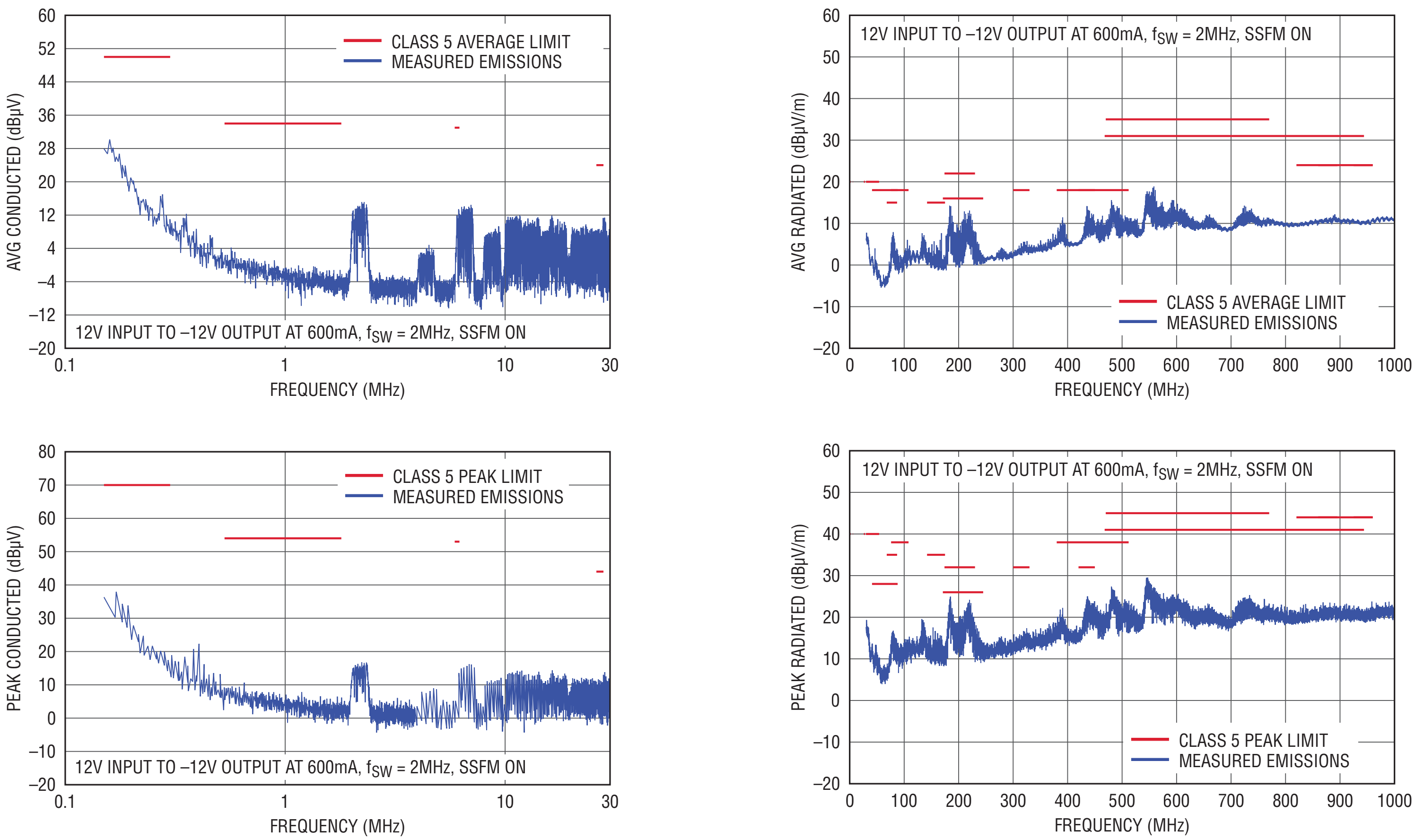


Figure 11. EMI test results for LT8362 inverting solution

application can operate with inputs up to 42V ($|V_{OUT}| + V_{IN} < 60V$). With a V_{IN} of 12V, a peak efficiency of 85% can be achieved. Operating with SSFM, this application passes CISPR 25 Class 5 radiated and conducted EMI (Figure 11).

CONCLUSION

To satisfy the automotive and industrial market demand for compact, efficient, low EMI power supplies, the LT836x family provides the rugged LT8362 (60V/2A), LT8364 (60V/4A) and LT8361 (100V/2A) switching regulators for boost, SEPIC and inverting topologies. These devices are a significant improvement over alternatives due to low I_Q Burst Mode operation, flat switch current limit over duty cycle, low loss switching for 2MHz operation and a wide 2.8V to 60V input range.

Low EMI performance is achieved through proper demo board layout and filter design with SSFM mode to meet CISPR 25 Class 5 EMI standards.

Design development is simplified with MSE16(12) pin compatibility for all parts and footprint compatibility for LT8362 (3mm × 3mm DFN(10)) and LT8364 (4mm × 3mm DFN(12)). All members of the LT836x family are available in E, I, and H temperature grades. ■

Automotive USB Type-C Power Solution: 45W, 2MHz Buck-Boost Controller in 1-Inch Square

Kyle Lawrence

USB Type-C is a relatively new, high power USB peripheral standard used in computer and portable electronic devices. The USB Type-C standard has driven changes in the USB power delivery specification, allowing for increased bus voltages (up to 20V) and current delivery capability (up to 5A) from the long-standing 5V USB standard. Connected USB-C devices can recognize each other and negotiate a bus voltage—from the default 5V USB output to several higher preset voltage steps—for faster battery charging and higher power delivery where needed, up to 100W.

Figure 1. Efficient, low EMI USB Type-C power solution fits 1-inch square.

The simple, compact buck regulators and linear regulators used in battery chargers that require only USB 5V at 500mA–2A do not sufficiently cover the full range of Type-C USB power. The increased voltage range, 5V–20V, of Type-C USB power delivery requires more than just step-down voltage conversion from 9V–36V (or 60V) automotive batteries, or other charging sources. An adjustable buck-boost converter is needed with the ability to both step-up and step-down the input-to-output voltage.

Additionally, for high power automotive USB chargers, a buck-boost converter should support a 10A or higher peak switch current rating and offer low EMI performance. The ability to set the switching frequency outside the AM radio band and maintain a small solution size are sought-after features. High voltage monolithic converters (with onboard switches) are not capable of sustaining such high peak switch currents without burning up.

The LT8390A is a unique 2MHz synchronous 4-switch buck-boost controller. At 2MHz switching frequency, it can deliver output voltages between 5V and 15V (up to 45W at 3A), to provide power to a connected USB-C device from a car battery.

This high controller switching frequency keeps the solution size small, the bandwidth high, and the EMI outside of the AM radio band. Both spread spectrum frequency modulation and low EMI current-sense architecture help LT8390A applications pass the rigors of the CISPR 25 Class 5 automotive EMI standard.

Portable and automotive battery-powered USB-C charger devices require a wide V_{IN}/V_{OUT} buck-boost regulator to deliver a bus voltage above or below the input voltage. The LT8390A provides up to 45W of output power in a small footprint, made possible by its 2MHz switching frequency.

HIGH POWER DENSITY CONVERSION: SIZE (AND POWER), EFFICIENCY, HEAT

The design of a voltage regulator system operating in an automotive or portable electronics environment is constrained by the space required for the circuit as well as heat it generates during operation. These two factors impose an upper bound of achievable power levels while operating within the given design constraints.

Increasing the switching frequency of a design allows for the use of smaller inductors, which is often the largest footprint component in wide input voltage 4-switch buck-boost voltage regulator designs. The LT8390A's 2MHz switching frequency capability enables the use of a much smaller inductor size than a 150kHz or 400kHz design. A complete design is shown in Figure 1. Along with a smaller inductor, this LT8390A solution uses only ceramic output capacitors, eliminating the need for bulky electrolytic capacitors. All the components necessary for this design, including the IC, are contained within a small 1 inch square footprint, as shown in Figure 1.

Figure 2 shows a 45W LT8390A solution using AEC qualified components. This design experiences a maximum temperature increase of 65°C from ambient, as shown in Figure 3. Even with the small solution size, the LT8390A system boasts a peak efficiency of 94% while delivering a 45W output, and deviates in efficiency by less than 10% over the input range for each output voltage created, shown in the graphs in Figure 4.

LOW EMI FOR AUTOMOTIVE APPLICATIONS

The LT8390A has several unique EMI mitigating features that enable high power conversion with low noise performance, simplifying its implementation

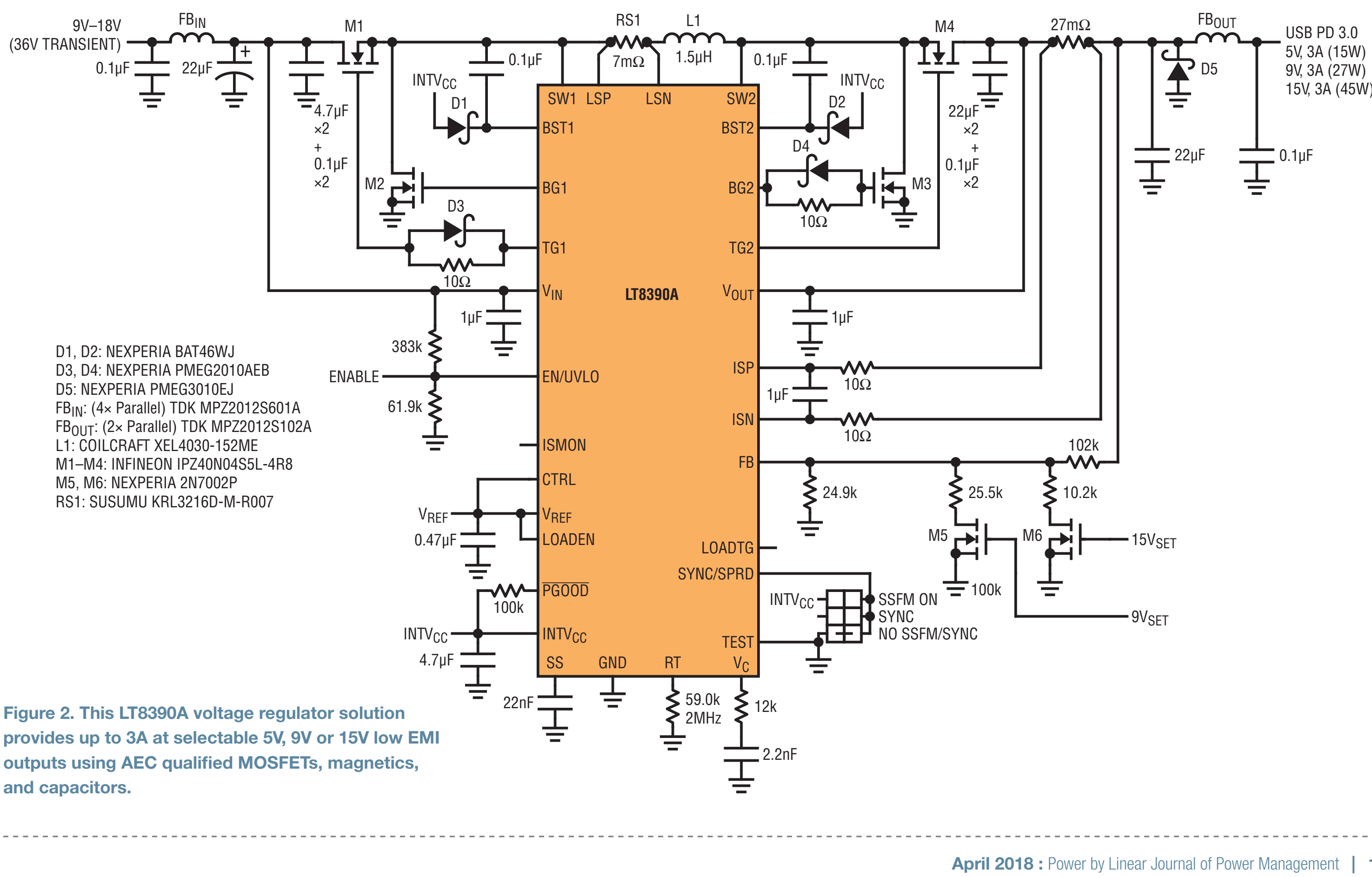


Figure 2. This LT8390A voltage regulator solution provides up to 3A at selectable 5V, 9V or 15V low EMI outputs using AEC qualified MOSFETs, magnetics, and capacitors.

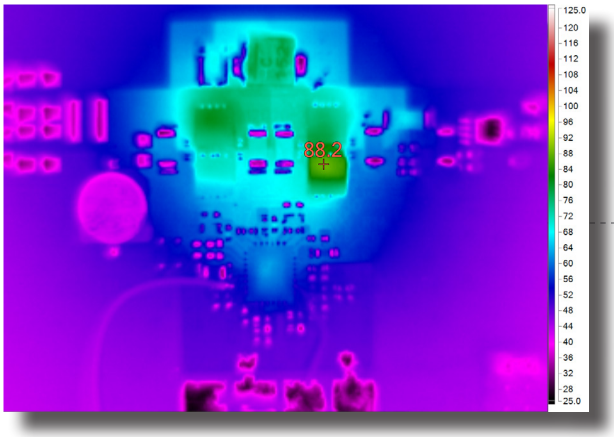


Figure 3. While generating 45W of output power, this small circuit's greatest temperature rise is only 65°C above ambient.

in automotive systems. A notable difference between LT8390A and alternative 4-switch controllers is the placement of the inductor current sensing resistor. Most 4-switch buck-boost controllers tend to use a ground-referred current sensing scheme to obtain switch current information, whereas the LT8390A places its current sense resistor in-line with the inductor. By placing the sensing resistor in-line with the inductor, it is effectively removed from both the buck and boost hot loops, shrinking the loops in size and improving the EMI performance.

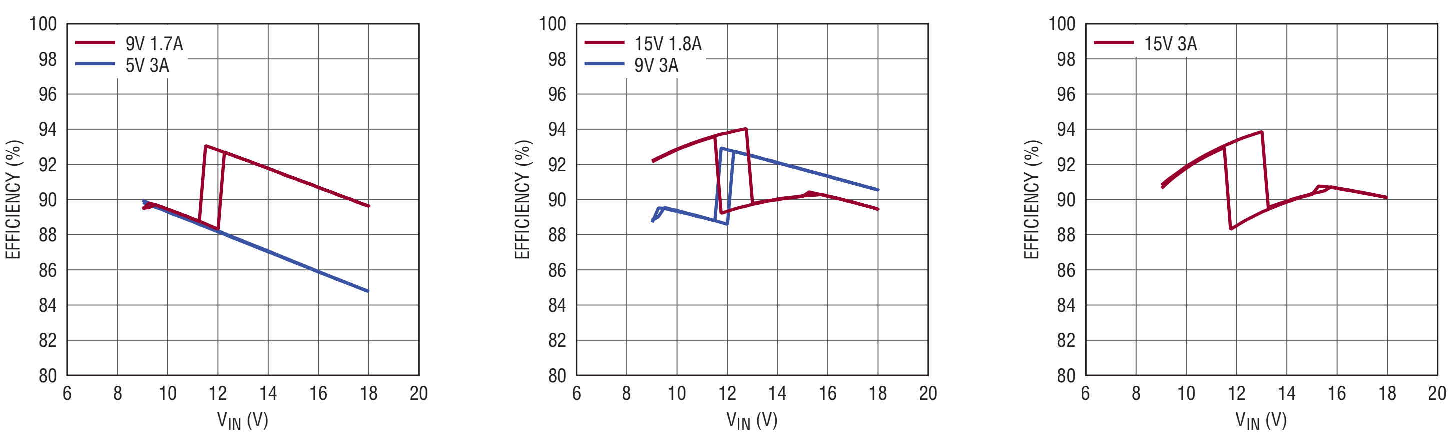
Along with the architectural advantage of the inductor sensing resistor placement, the LT8390A has built-in spread spectrum frequency modulation to further reduce EMI generated by the controller. Furthermore, switching edge rate is controlled on both the buck and boost power switches using only a few discrete components to slow the turn-on of the MOSFETs, ensuring the proper balance of high frequency EMI reduction and temperature rise in the power switches. With these EMI-reducing features, the only filtering needed to meet CISPR 25 compliance is taken care of by small ferrite filters on the input and output rather than large ferrite cases and bulky LC filters. The solution shown in Figure 1 was designed using only AEC-Q100 components.

SEAMLESS OUTPUT VOLTAGE TRANSITIONS

The LT8390A's output voltage can be adjusted without shutting down the converter, using logic level signals to drive MOSFETs that adjust the resistor divider off the output to change the set voltage. A USB PD source controller device with GPIO pins can be used in conjunction with the LT8390A system to facilitate the negotiation process between host and USB-connected device and to set the desired bus voltage.

Figure 5 demonstrates how smoothly the output of the LT8390A system transitions from one output voltage to another. When powered from a 12V input source, each transition to an increased output voltage takes at most 150μs to settle, as measured from the rising edge of the digital control signal. During these changes in the output voltage, the buck-boost controller goes through mode transitions—between buck, boost, and buck-boost operation—depending on the relation of input

Figure 4. The LT8390A voltage regulator system remains in the 94%–84% efficiency range across all output voltages generated when powered from an automotive SLA battery.



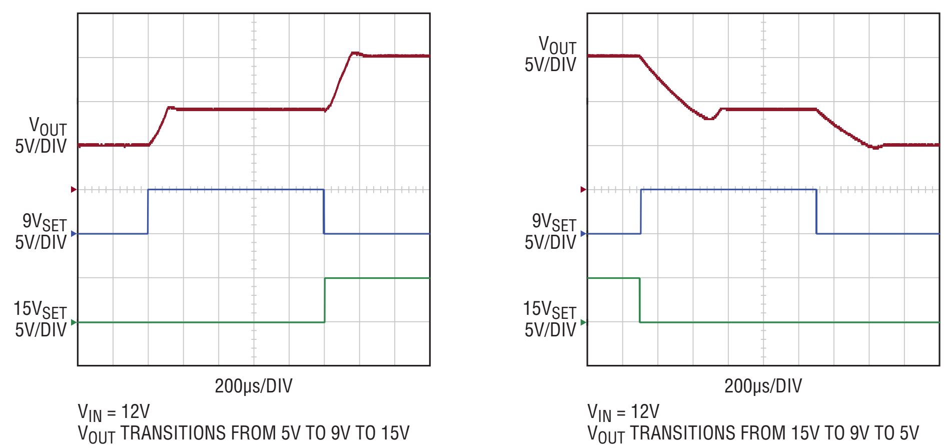
One of the most notable differences between LT8390A and alternative 4-switch controllers is the placement of the inductor current sensing resistor. Most 4-switch buck-boost controllers tend to use a ground-referred current sensing scheme to obtain switch current information, whereas the LT8390A places its current sense resistor in-line with the inductor.

to output voltages. These mode transitions are performed in a controlled manner, preventing excessive overshoot or sagging of the output voltage.

EXPANDING BEYOND 45W

To push the output power level beyond 45W requires operating at a lower switching frequency to reduce switching losses, which might otherwise thermally stress the MOSFETs at this power level. As an alternative to the LT8390A, the LT8390 operates between 150kHz and 600kHz with the same feature set as LT8390A, allowing low EMI, high power buck-boost designs. A 400kHz LT8390 system, utilizing a larger inductor and output capacitor, easily achieves 100W of output power from an automotive battery input with acceptable temperature rise. Figure 6 illustrates the power capabilities of the LT8390A and LT8390 product line from various battery powered inputs.

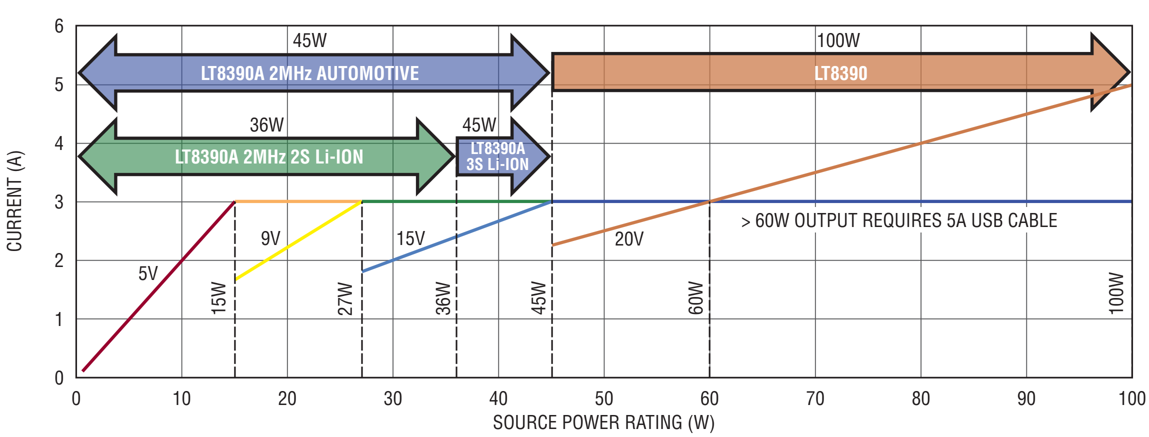
Figure 5. The output of the LT8390A system smoothly transitions between 5V, 9V, and 15V outputs while maintaining continuous power deliver to the output.



CONCLUSION

The new USB standard for voltage regulators powering connected devices permits higher power transfer by increasing the output voltage range and current delivery that regulators can provide. Portable and automotive battery-powered USB-C charger devices require a wide V_{IN}/V_{OUT} buck-boost regulator to deliver a bus voltage above or below the input voltage. The LT8390A provides up to 45W of output power in a small footprint, made possible by its 2MHz switching frequency. For power levels exceeding 45W, the LT8390 can be used with a slightly larger solution size and lower switching frequency. ■

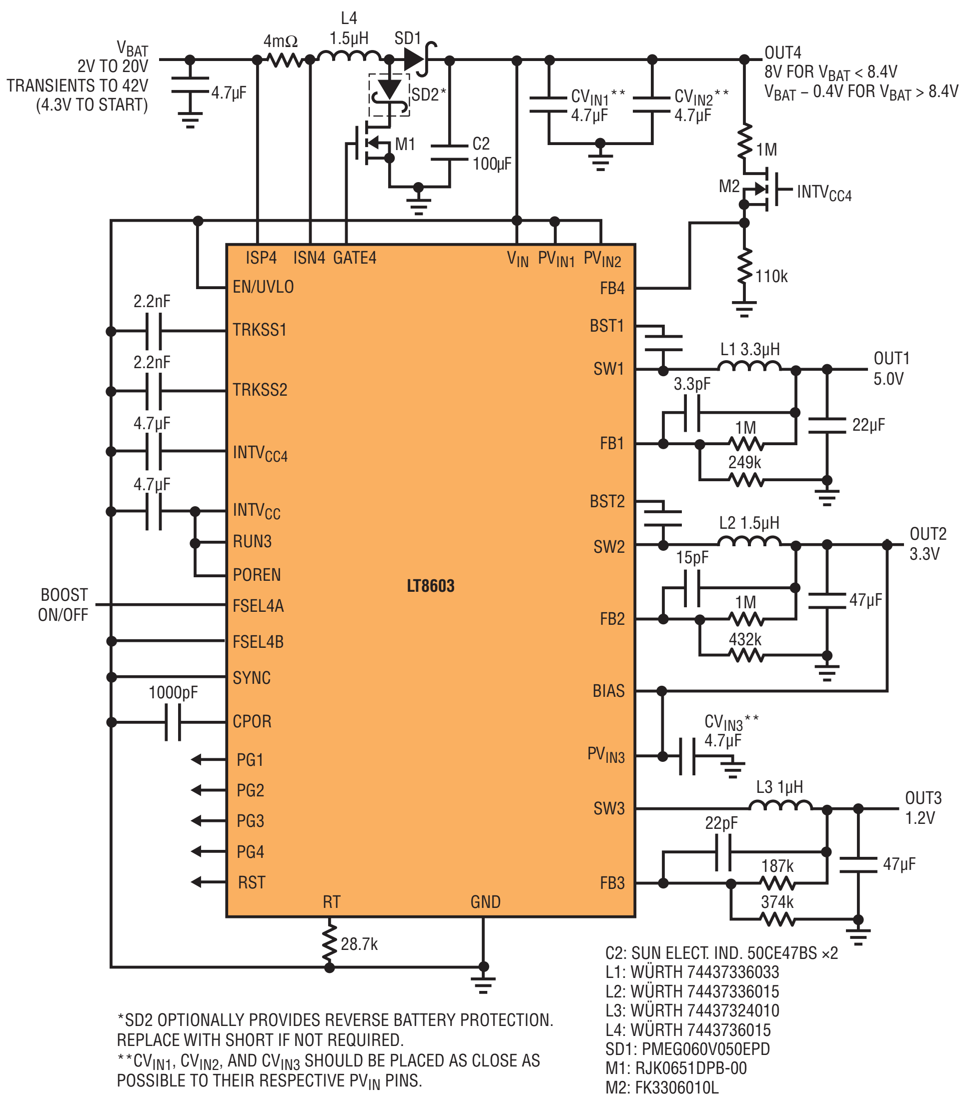
Figure 6. The LT8390A and LT8390 cover a wide range of output power levels for USB power delivery.



Triple Bucks Plus a Boost Controller to Meet Tough Requirements of Wide Range V_{IN} Automotive Applications

Zhongming Ye

Automobiles present space-constrained harsh environments, demanding reliable and compact power supplies for increasingly complex electronics systems. The LT8603 compact regulator is a robust solution that combines two high voltage 2.5A and 1.5A buck regulators, a low voltage 1.8A buck regulator and a boost controller in a compact 6mm × 6mm QFN package. The boost controller simplifies the design of wide-input multiple-output supplies, for instance, when used in the following solutions:



- Cold crank tolerant automotive supply with three regulated outputs
- Four regulated outputs with fourth rail as SEPIC
- Boost powered from one of the bucks.

COLD CRANK TOLERANT AUTOMOTIVE SUPPLY WITH THREE REGULATED OUTPUTS

In automobile applications, regulated 5V, 3.3V, and sub-2V rails are required to power various analog and digital ICs that may require different rails for content, processor I/O and core. These rails are generated from the nominal 12V automotive battery voltage, V_{BAT}, which typically ranges from 8V to 16V. High efficiency step-down buck regulators cover most

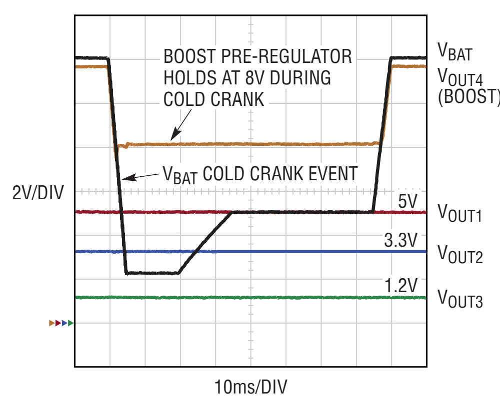
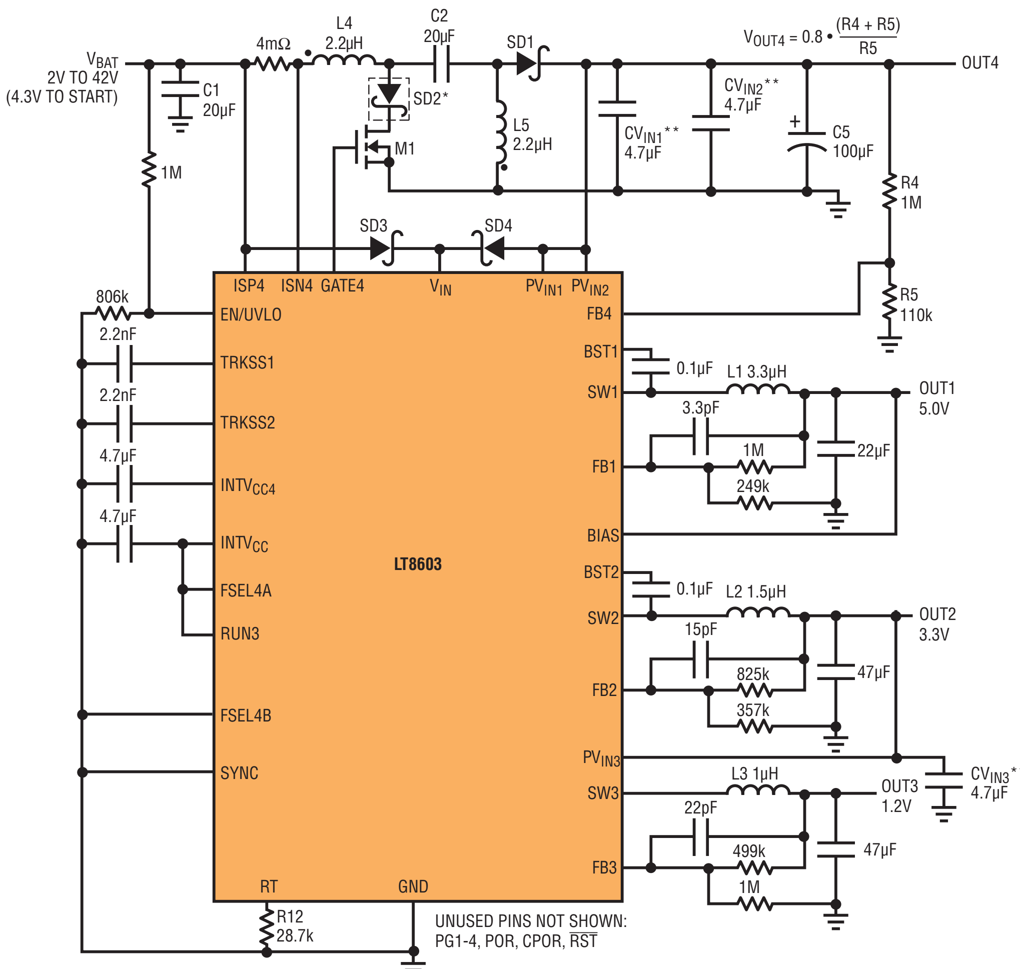


Figure 1. Cold crank tolerant automotive supply with three regulated outputs. Three bucks are powered with a boost pre-regulator (V_{OUT4}), yielding precise regulation for all three outputs through a V_{BAT} cold crank event, also shown.

In automobile applications, regulated 5V, 3.3V, and sub-2V rails are required to power various analog ICs and digital ICs that may require different rails for content, processor I/O and core. These rails are generated from the nominal 12V automotive battery voltage, V_{BAT}, which typically ranges from 8V to 16V.

situations, but V_{BAT} can drop to 2V for tens of ms during a cold crank situation, where pure buck regulators would lose regulation if powered directly from V_{BAT}.

The LT8603 boost controller operates down to 2V, making it ideal as a pre-regulator to power the buck regulators. When V_{BAT} drops below 8.5V, the boost controller output (OUT4) is regulated to 8V. The two high voltage bucks can ride through the cold crank condition, while providing constant 5V and 3.3V outputs, as shown in Figure 1. Once V_{BAT} recovers to above 8V from the cold crank, the boost



*SD2 OPTIONALLY PROVIDES REVERSE BATTERY PROTECTION. REPLACE WITH SHORT IF NOT REQUIRED.
SD3 ENSURES START-UP.
SD4 MAINTAINS V_{IN} AT V_{BAT} < 4V.
**CV_{IN1}, CV_{IN2}, AND CV_{IN3} SHOULD BE PLACED AS CLOSE AS POSSIBLE TO THEIR RESPECTIVE PV_{IN} PINS.

C1, C2: MURATA GRM31CR61H106KA12L ×2
L1: WÜRTH 74437336033
L2: WÜRTH 74437336015
L3: WÜRTH 74437324010
L4, L5: WÜRTH 74485540220
SD1 PMEG060V050EPD
M1 BSZ067N06LS3

Figure 2. High voltage bucks optimized for efficiency; powered by a SEPIC

The LT8603 uses a 2-phase clock. Channel 1 operates 180° from channel 2, reducing the peak input current of the bucks and helping reduce EMI. The high density of electronic components requires careful balancing of thermal and EMI performance. The LT8603 demo circuit DC2114A exemplifies a layout optimized for low EMI, passing CISPR 25 Class 5 peak limits.

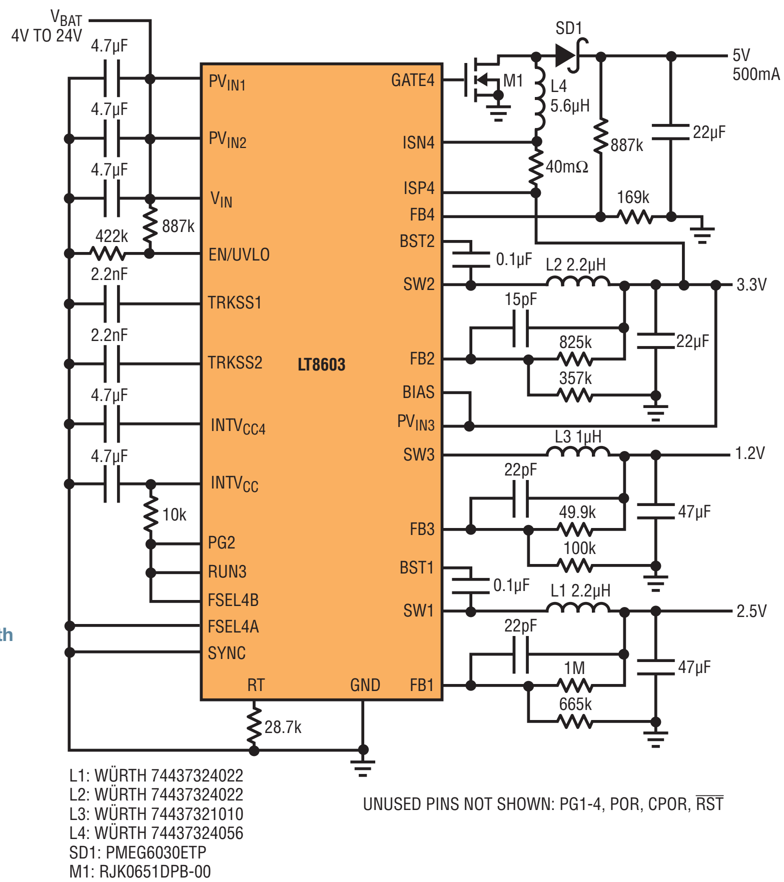


Figure 3. Four regulated outputs with the boost converter is powered from the channel 3 buck regulator.

controller simply works as diode through. The high voltage bucks can handle V_{BAT} up to 42V. In Figure 1, the low voltage buck is powered from OUT2, providing 1.2V through the cold crank event.

FOUR REGULATED OUTPUTS WITH FOURTH RAIL AS SEPIC

V_{BAT} can remain high for an extended period of time, such as during a double battery jump-start or in a 24V system. This has no effect on the boost regulator in Figure 1—V_{BAT} passes through when V_{BAT} is higher than 8V—but the current output capacities of the two high voltage buck regulators are typically thermally limited at higher V_{BAT} due to increased switching losses, especially at 2MHz switching frequency that is often used in automotive applications.

The temperature rise can be controlled by either reducing the switching frequency or reducing the operating voltage of the buck regulators. In Figure 2, the fourth channel is set up as a SEPIC to power the high voltage bucks, with its output regulated at 12V, optimal for the buck regulator efficiency. By running the bucks at optimal efficiency, the temperature rise is well controlled. Figure 2 shows an easy way to generate four accurately regulated outputs. At light load this circuit maintains regulations with input down to 2V.

BOOST POWERED FROM ONE OF THE BUCKS

Some automotive applications require a regulated high voltage, such as 54V. One way to produce this regulated high voltage rail is to drive the boost regulator from the output of one of the high voltage buck regulators, as shown in Figure 3. All four outputs are regulated as long as V_{BAT} is higher than the minimum input voltage of the high voltage bucks. The buck regulator limits the maximum current of the boost converter, protecting the boost against short circuits and limiting cycle-by-cycle current.

ADDITIONAL REGULATED VOLTAGE WITH CHARGE PUMP

A charge pump circuit can be added to a SEPIC circuit as shown in Figure 4, to provide another regulated output. The regulation curves are shown in Figure 4 for different input voltages. Similarly a negative output charge pump can be implemented to generate a negative rail.

EMI PERFORMANCE

The LT8603 uses a 2-phase clock. Channel 1 operates 180° from channel 2, reducing the peak input current of the bucks and helping reduce EMI. The high density of electronic components requires carefully balancing of thermal and EMI performance. The LT8603 demo circuit DC2114A exemplifies a layout optimized

The LT8603 offers versatile and compact power supply solutions by combining three buck regulators and a boost controller into a tiny 6mm × 6mm QFN package. Each of the buck regulators has internal power switches, cycle-by-cycle current limiting and track/soft-start control.

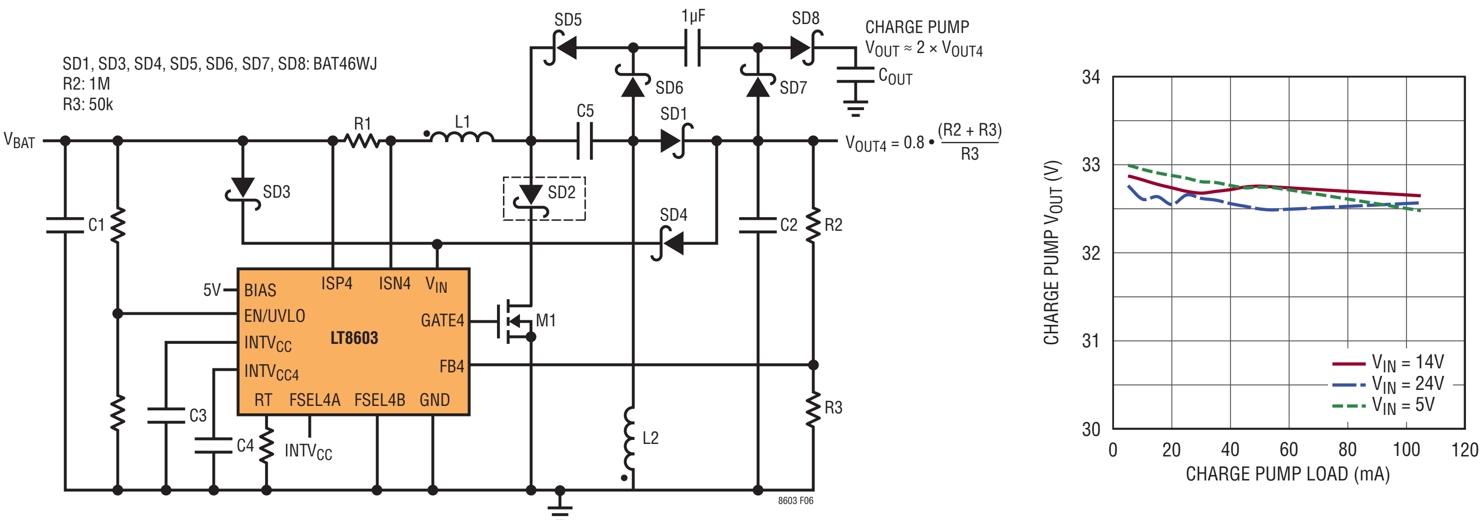


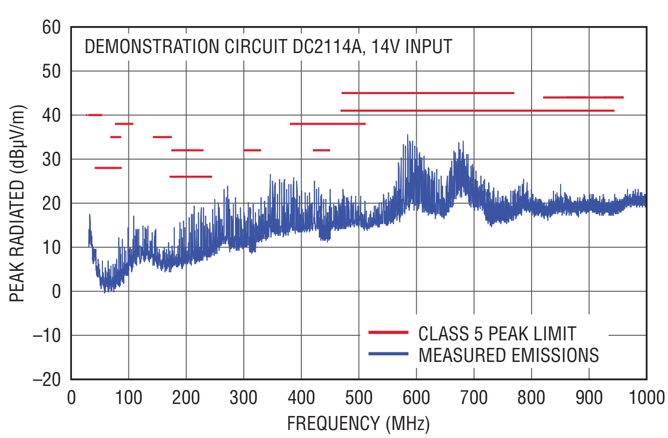
Figure 4. A charge pump circuit provides an additional high voltage output.

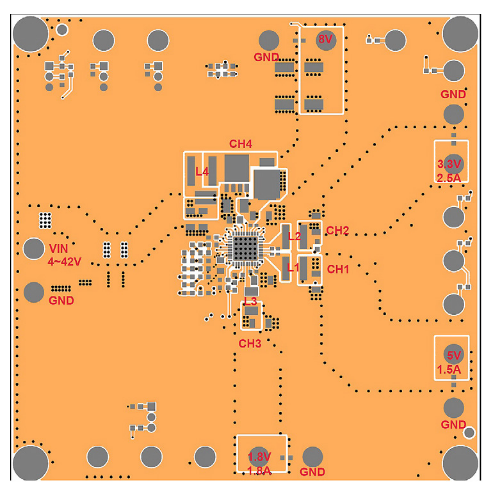
for low EMI, passing CISPR 25 Class 5 peak limits. Figure 5 shows the radiated EMI results with vertical polarization in the range of 30MHz to 1000MHz. Input is 14V with 1A load in each of the outputs.

CONCLUSION

The LT8603 offers versatile and compact power supply solutions by combining three buck regulators and a boost controller into a tiny 6mm × 6mm QFN package. Each of the buck regulators has internal power switches, cycle-by-cycle current limiting and track/soft-start control. Its synchronous rectification topology delivers up to 94% efficiency. Burst Mode® operation keeps quiescent current under 30μA (all channels on), ideal for always-on systems. The wide input range, from 2V to 42V, and versatile functions make the LT8603 a good fit for automotive and other demanding applications. ■

Figure 5. LT8603 DC2114A CISPR 25 Class 5 radiated EMI, 30MHz to 1GHz





LED Driver for High Power Machine Vision Flash

Kyle Lawrence and Keith Szolusha

Machine vision systems use very short flashes of intense light to produce high speed images used in a wide variety of data processing applications. For instance, fast moving conveyer belts are run through machine vision systems for quick label and defect inspections. IR and laser LED flashes are commonly used for proximity and motion-sensing machine vision. Security systems send out high speed, hard-to-detect LED flashes to sense motion and capture and store security footage.

One challenge in all of these systems is creating the very high current and short-term (microseconds) LED camera flash waveforms, which can be spread out over long periods of time, such as 100ms to over 1s. Creating short, square LED flash waveforms separated by long periods of time is nontrivial. As the drive currents for the LEDs (or strings of LEDs) rise above 1A and the LED on-times shrink to microseconds, the challenge increases. Many LED drivers with high speed PWM capabilities may not efficiently handle long off-times and high currents for short amounts of time without degradation of the square-type waveform needed for proper high speed image processing.

PROPRIETARY LED FLASH

Fortunately, the LT3932 high speed LED driver can provide machine vision camera flash for up to 2A LED strings, even with long off-times of 1 second, 1 hour, 1 day, and longer. The LT3932's special camera flash feature allows it to maintain the output capacitor and

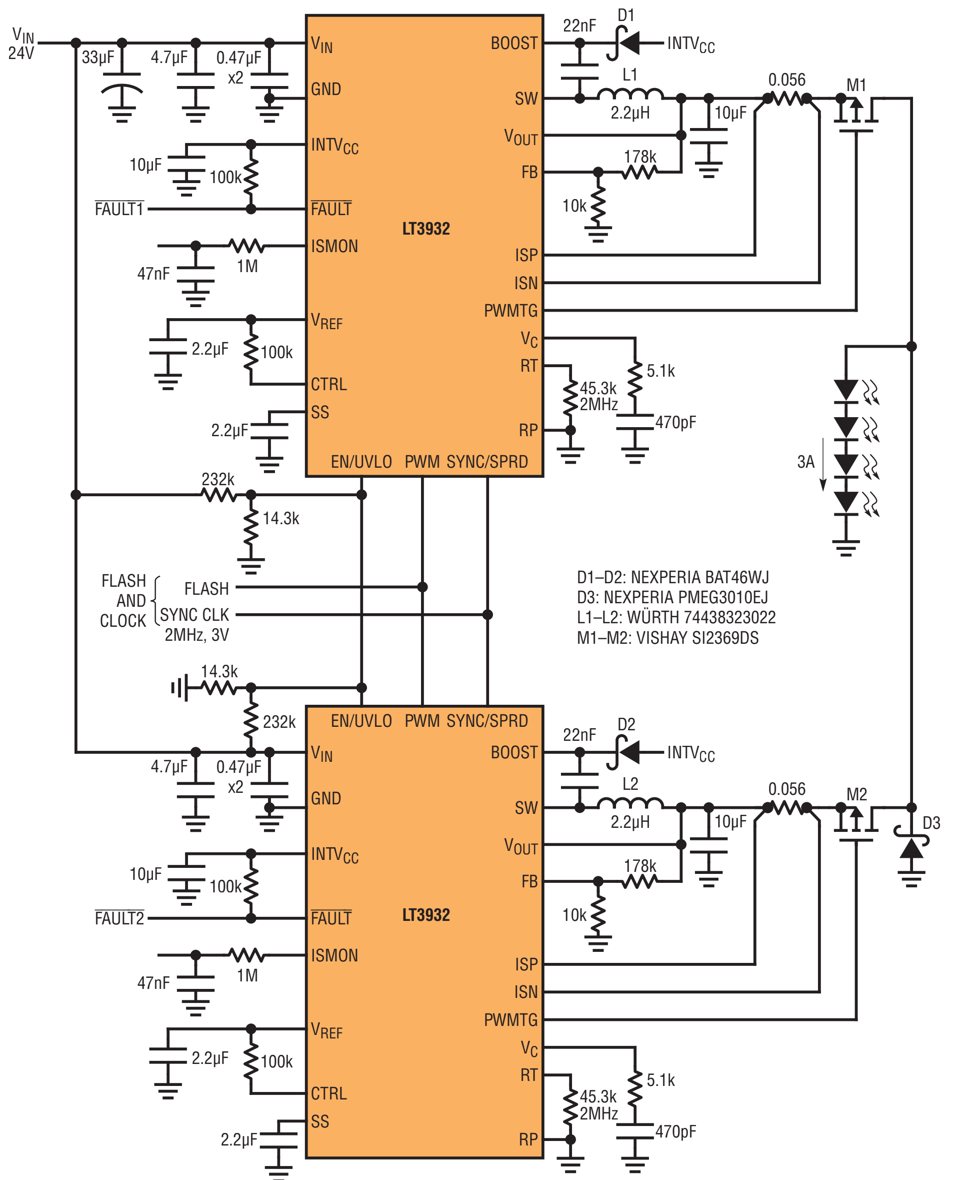


Figure 1. Parallel LT3932 1.5A LED drivers yield 3A machine vision LED pulses with long off-times relative to standard PWM dimming frequencies

LED drivers act as current sources, regulating the current sent out through the light emitting diodes. Since current only flows in a single direction to the output, multiple LED drivers can be placed in parallel and their currents sum through the load. Current sources do not need to be protected against current running backward through one converter or having mismatched outputs.

control loop charge state, even during long off-times. After sampling the state of the output and control loop capacitors, the LT3932 continues to trickle-charge these components during long off-times to compensate for typical leakage currents, not accounted for by other LED drivers.

The proprietary flash technology of the LT3932 scales up when drivers are paralleled for increased LED flash current. The desired flash shape and integrity are maintained. Figure 1 shows how easy it is to parallel two drivers for a 3A camera flash—designs up to 4A are possible.

LED flash requirements for machine vision systems are far more demanding than a standard PWM dimming driver can meet. That is, most high end LED drivers are designed to produce PWM dimming brightness control at a PWM frequency of at least 100Hz. This is because lower frequencies can be perceived by the human eye as annoying flicker or strobing, even if the LED waveforms are square and repeatable. At 100Hz, the theoretical maximum off-time is about 10ms. During the 10ms off-time, if designed correctly, an LED driver loses minimal output capacitor charge, allowing it to start its control loop in the approximately the same state in which it ended the last PWM ON pulse. A quick response and ramp-up of the inductor current and the next LED PWM ON pulse can be quick and repeatable, with minimized start-up time. Longer off-times (for frequencies below 100Hz) risk output capacitor charge loss due to leakage, preventing a quick response when the LED is turned back on.

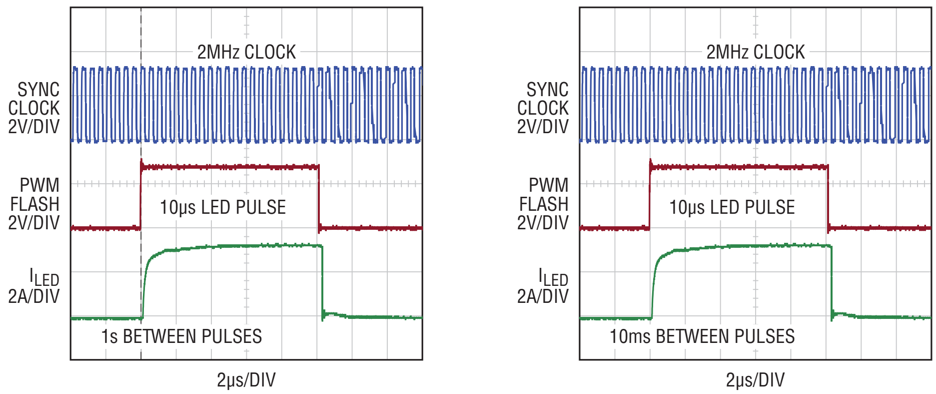


Figure 2. 3A camera flash waveform of Figure 1 parallel LED drivers looks the same regardless of the amount of PWM off-time. Waveforms show that a 10µs pulse looks the same after one second or 10ms. The LT3932 LED flash also looks the same after a day or longer of PWM off-time.

PARALLEL LED DRIVERS FOR HIGHER CURRENT

LED drivers act as current sources, regulating the current sent out through the light emitting diodes. Since current only flows in a single direction to the output, multiple LED drivers can be placed in parallel and their currents sum through the load. Current sources do not need to be protected against current running backward through one converter or having mismatched outputs. Voltage regulators, on the other hand, are not inherently good at current sharing. If they are all trying to regulate the output voltage to a single point, and there are slight differences in their feedback networks, a regulator may draw reverse current.

An LED driver maintains its output current, regardless of other drivers that may supply additional current summed at the output load. This makes paralleling LED drivers quite simple. For example, the LED flash system of two parallel LT3932 LED drivers shown in Figure 1 efficiently drives 4 LEDs at 3A with short 10µs pulses spread out by long periods of time—defined by the machine vision system. Each LT3932 converter sources half of the total string current during PWM on-time and turns off and saves its output state during PWM off-times. The off-time can be short or long, with no effect on the flash waveform repeatability.

Parallel camera flash applications share nearly the same simplicity as single converters during long off-times. The converters observe the shared output voltage at the end of the last PWM on pulse, and keep the output capacitor charged to that state, even during long off-times. Each converter disconnects its PWM MOSFET from the shared load and keeps its output capacitor charged to approximately the last voltage state by sourcing current to that capacitor as it leaks energy. Any leakage experienced by these capacitors over long

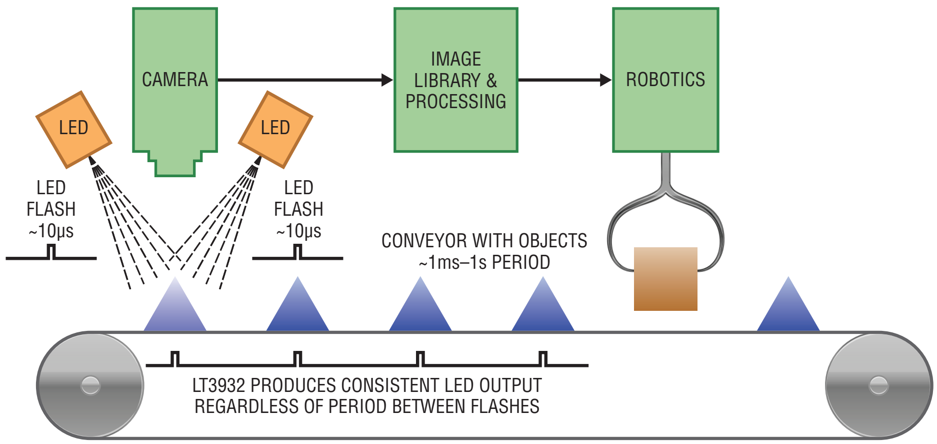


Figure 3. An example of machine vision on an industrial conveyor belt. Inspection systems move at many different speeds, yet the flash technology must be fast and crisp.

off-times is overcome by the small amount of maintenance current. When the next PWM on pulse starts, the PWM MOSFETs of each converter are turned on and the output capacitors start up in approximately same state as the last pulse, whether 10ms has passed or a full day.

Figures 2(a) and 2(b) demonstrate the LT3932 parallel LED drivers driving 4 LEDs at 3A with a 10µs machine vision camera pulse. The LED pulse is sharp and fast, regardless if there is a 10ms PWM off-time (100Hz) or a 1s PWM off-time (1Hz), ideal for machine vision systems.

EVEN HIGHER CURRENT IS POSSIBLE

Parallel LED drivers are not limited to two converters. Three or more converters can be paralleled to create even higher current waveforms with sharp edges. Since this system does not have a master or slave device, all of the converters source the same amount of current and share the load equally. It is recommended that all of the parallel LED driver converters share the same synchronized clock and remain in-phase. This ensures that all converters have approximately the same phasing on the ripple of their output capacitors so that ripple currents do not flow backward or between the different converters. It is important for the PWM pulse waveform to remain in-phase with the 2MHz synchronization clock. This ensures that the LED flash waveform remains square and without jitter, producing the best image-processing results.

The LT3932 demonstration circuit (DC2286A) is designed to drive 1A of LED current through one or two LEDs as a step-down LED driver. It can easily be altered and paralleled as shown in Figure 1 for higher current, higher voltage or parallel operation. Figure 4 demonstrates how two of these circuits are easily connected together to drive 10µs, 3A pulses through 4 LEDs from 24V input. For testing purposes, a pulse generator can be used for the synchronized clock signal, as shown in Figure 4. In a production machine vision system, a clock chip can be used to generate the synchronized SYNC and PWM pulses. For higher current pulses, add more demonstration circuit DC2286A converters using the same parallel scheme.

CONCLUSION

Machine vision systems can use parallel LED drivers to create the fast, square, high current waveforms required for automated image processing. The LT3932 LED driver's proprietary camera flash technology can be extended to higher currents by connecting parallel converters. 3A and higher pulses on the order of microseconds are possible with parallel LT3932 converters, even with long off-times. LED camera flash waveforms remain square and without jitter, no matter how long the off-time between LED flashes may be. ■

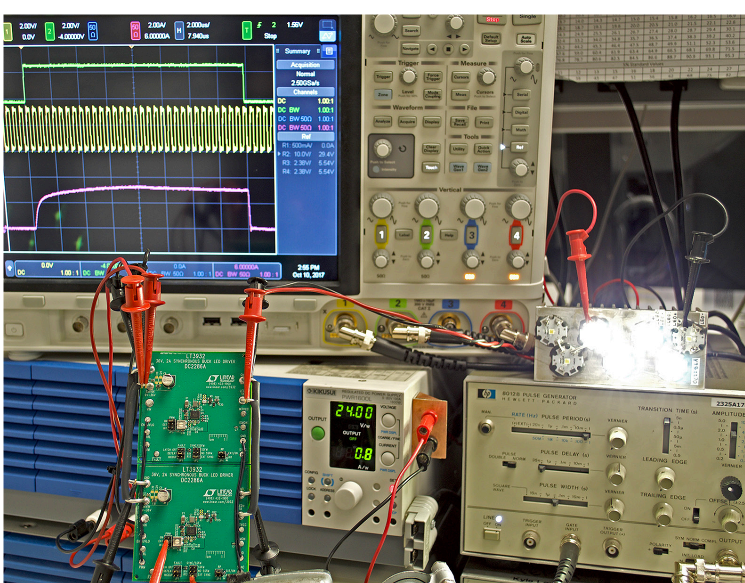


Figure 4. Two DC2286A LT3932 demo circuits are easily connected in parallel to create the 3A (to 4A) machine vision LED flash application shown in Figure 1.

1000V Output, No-Opto Isolated Flyback Converter

George Qian and Michael Wu

Isolated flyback converters are used in automotive, industrial, medical and telecom applications where the power supply must be reliable, easy-to-use, high voltage and isolated, and must provide excellent regulation over load, line and temperature. LT8304-1 is an isolated no-opto flyback converter optimized for high output voltage applications—providing outputs up to 1000V.

Traditionally, the regulation feedback loop requires a bulky high voltage divider to directly sense the high output voltage, along with opto-couplers to convey feedback information back through the isolation barrier. The bulky resistor solution results because a 1206 resistor can handle 200V maximum. So to sense 1000V, at least six 1206 resistors are required, plus a small bottom resistor.

1000V/15mA OUTPUT, FROM A 4V–28V INPUT

An LT8304-1 flyback converter design features a low component count. Figure 1 shows a complete 4V–28V input to 1000V output solution capable of supporting 15mA loads. The output current capability increases with input voltage, reaching 13mA when the input voltage is greater than 24V. The LT8304-1's ability to sense the output voltage through the primary-side waveform eliminates the need for a bulky high voltage divider, and no opto-coupler is required.

The guidelines for calculating voltage and current stress on the components surrounding the LT8304-1 are detailed in the LT8304-1 data sheet. Notably, this 1000V solution uses a transformer with three split-output windings on the secondary side. The primary side to secondary side turns ratio is 1:10:10:10,

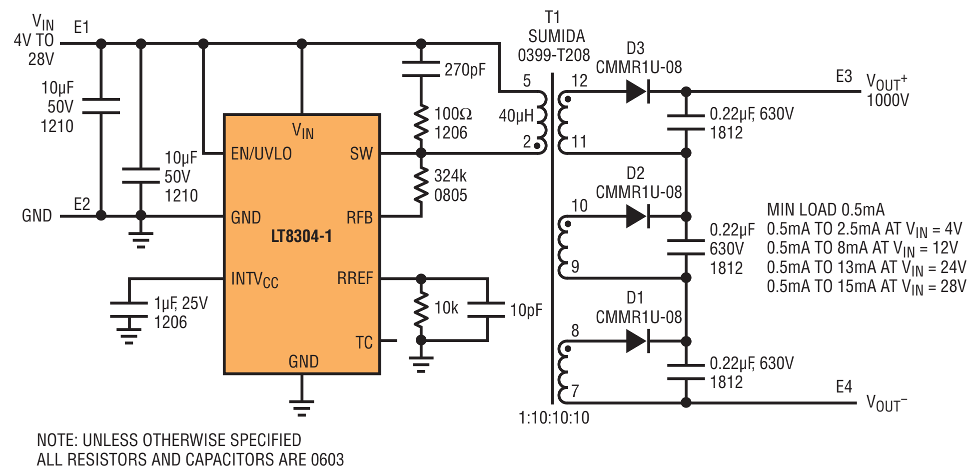


Figure 1. A complete 1000V/15mA isolated flyback converter from a 4V–28V input

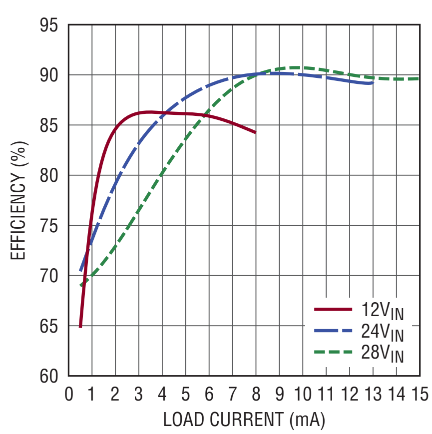


Figure 2. Efficiency of Figure 1 at various input voltages

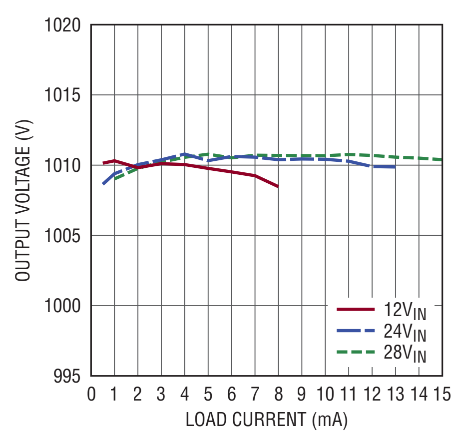


Figure 3. Load regulation of Figure 1 at various input voltages

The LT8304-1 is an easy-to-use monolithic micropower isolated flyback converter optimized for high output voltage applications. By sampling the isolated output voltage directly from the primary-side flyback waveform, complete solutions maintain tight regulation—requiring neither output voltage divider nor opto-isolator.

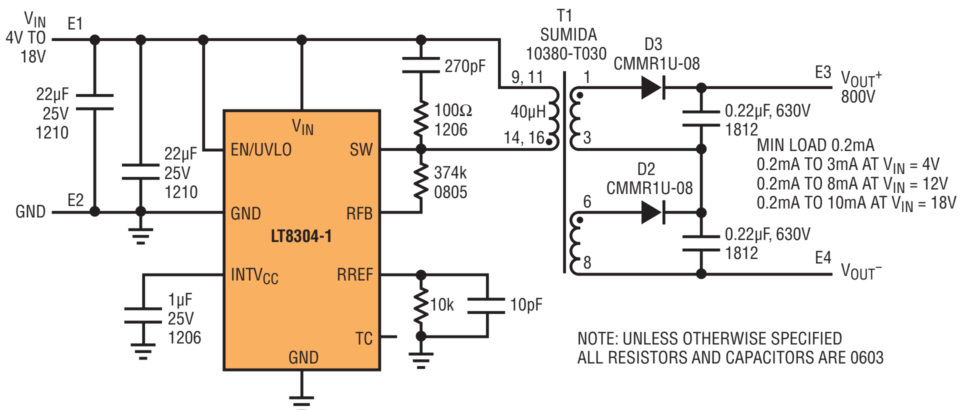


Figure 4. A complete 800V/10mA isolated flyback converter from a 4V–18V input

instead of a single-secondary-winding 1:30 transformer. The 1:10:10:10 transformer enables the output voltage stress to be split among three high voltage output diodes and three high voltage output capacitors. Individual component voltage ratings need only be one-third of the total voltage, facilitating more options for output diode and output capacitor selection.

Figure 2 shows this flyback converter reaching 90.5% peak efficiency. Even with no opto-coupler, load regulation at various input voltages remains tight, typically 2% to 3%, as shown in Figure 3.

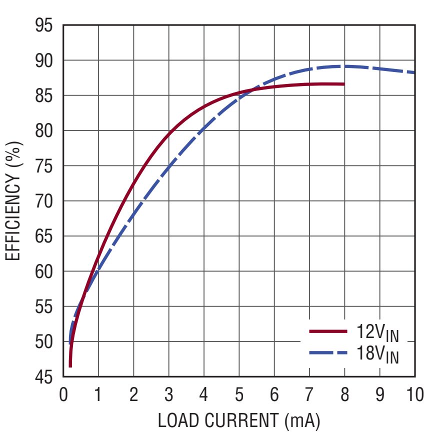


Figure 5. Efficiency of the solution in Figure 4 at various input voltages

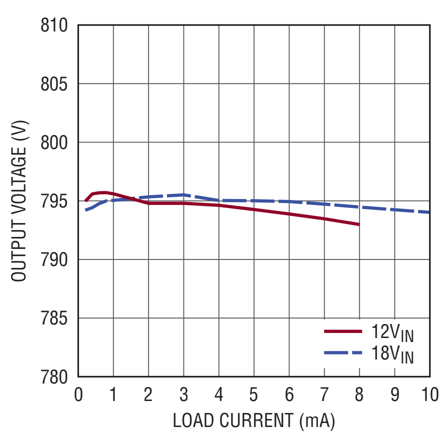


Figure 6. Load regulation of the solution in Figure 4 at various input voltages

800V/10mA OUTPUT, FROM 4V–18V INPUT

Figure 4 shows a complete 4V–18V input to 800V output solution capable of providing up to 10mA output current. This flyback converter achieves 88.2% peak efficiency when the input is 18V and the load current is 10mA. Figure 5 shows the efficiency curve at various input voltages; Figure 6 shows the excellent load regulation. This solution also features a low component count.

CONCLUSION

The LT8304-1 is an easy-to-use monolithic micropower isolated flyback converter optimized for high output voltage applications. By sampling the isolated output voltage directly from the primary-side flyback waveform, complete solutions maintain tight regulation—requiring neither output voltage divider nor opto-isolator.

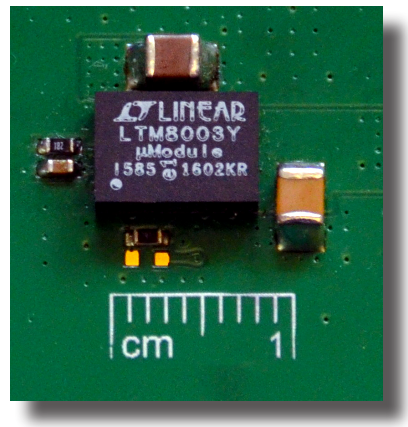
The output voltage is simply programmed with two external resistors and a third optional temperature compensation resistor. Boundary mode operation enables a small magnetic solution with excellent load regulation. A 2A, 150V DMOS power switch is integrated, along with all the high voltage circuitry and control logic, in a thermally enhanced 8-lead SO package. The LT8304-1 operates at an input voltage range of 3V to 100V, and delivers up to 24W of isolated output power. ■

40V Input, 3.5A Silent Switcher µModule Regulator for Automotive and Industrial Applications

Zhongming Ye

The LTM8003 is a wide input and output range step-down µModule® regulator featuring the Silent Switcher® architecture. Inputs from 3.4V to 40V can produce outputs from 0.97V to 18V, eliminating the need for intermediate regulation from batteries or industrial supplies. The pinout is specifically designed to be FMEA compliant, so the output stays at or below the regulation voltage during adjacent pin shorts, single pin shorts to ground or pins left floating. Redundant pins enhance electrical connections in the event a solder joint weakens or opens due to vibration, aging or wide temperature variations, such as in automotive and transportation applications.

Figure 1. A complete step-down solution is barely larger than the 6.25mm × 9mm footprint of the LTM8003 µModule regulator



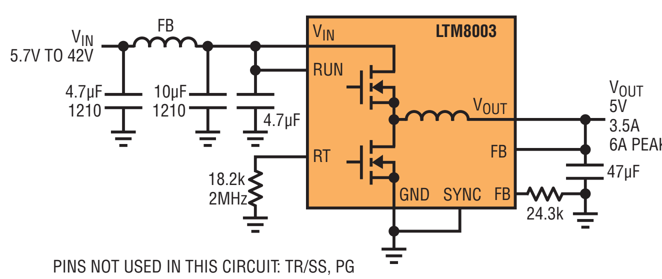
A complete solution fits a compact space not much larger than the 6.25mm × 9mm footprint of the LTM8003, including the input and output capacitors. The quiescent current of typical 25µA, and wide temperature operation from –40°C to 150°C (H-grade) make it ideal for applications in automotive, transportation and industrial, where space is tight, the operational environment is harsh, and low quiescent current and high reliability are mandatory.

LOW NOISE SILENT SWITCHER ARCHITECTURE SIMPLIFIES EMI DESIGN

Automotive, transportation and industrial applications are noise-sensitive, and demand low EMI power solutions. Traditional approaches control EMI with slowed-down switching edges or lower switching frequency. Both have undesired effects, such as reduced efficiency, increased minimum on- and off-times, and a large solution. Alternative solutions such as an EMI filter or metal shielding add significant costs in required board space, components and assembly, while complicating thermal management and testing.

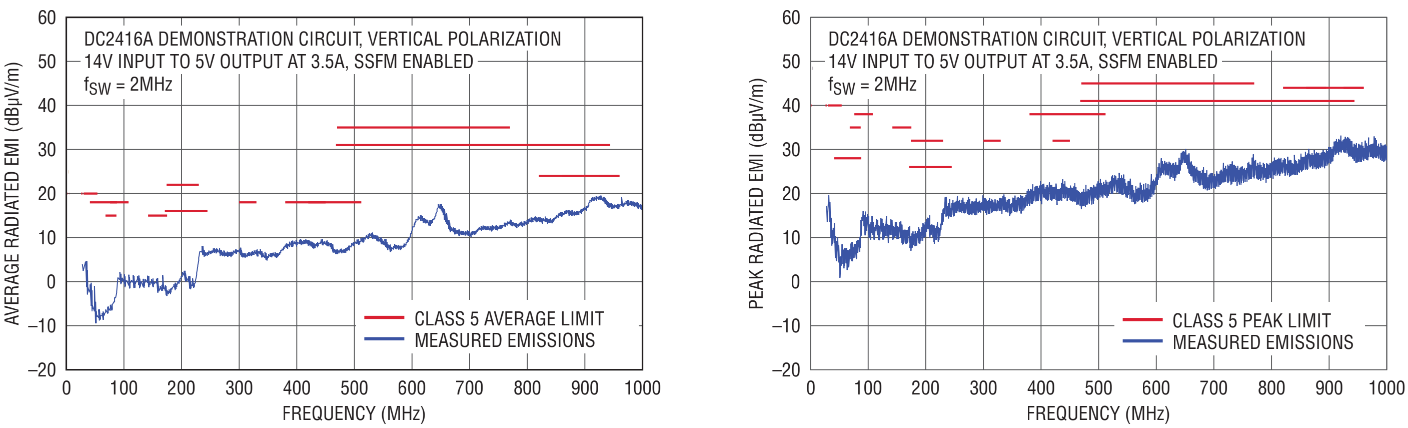
Our low noise µModule offers a breakthrough in switching regulator design. The regulator within the µModule package uses a proprietary Silent Switcher architecture to minimize EMI emissions while delivering high efficiency at high switching frequencies. The architecture of the regulator and the internal layout of the µModule are designed so that the input loop of the regulator is minimized. This significantly reduces the switching node ringing and the associated energy stored in the hot loop, even with very fast switching edges. This quiet switching offers excellent EMI performance, while minimizing the AC switching losses, allowing the regulator

Figure 2. A 5V converter with a simple EMI filter at the input passes CISPR 25 Class 5



The internal regulator is capable of safely delivering up to 6A of peak output current, and no extra thermal management—airflow or heat sink—is required for the LTM8003 to continuously support a 3.5A load at 3.3V or 5V from a nominal 12V input. This meets the needs of the battery powered applications in industrial robotics, factory automation and automotive systems.

Figure 3. DC2416A demonstration circuit passes radiated EMI spectrum CISPR 25 Class 5.



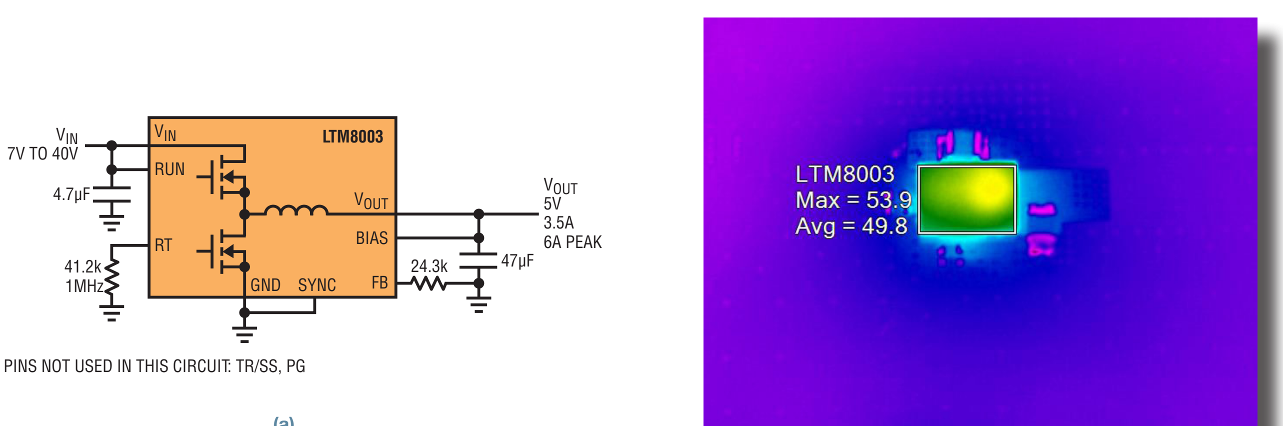
to operate at high switching frequencies without significant efficiency loss.

This architecture, combined with spread spectrum frequency operation, greatly simplify the EMI filter design and layout, ideal for noise-sensitive environments. Figure 2 shows a simple EMI filter on the input side, enabling the demo circuit to pass CISPR 25 Class 5 with plenty of margin, as shown in Figure 3.

CONTINUOUS 3.5A WITH PEAK CURRENT CAPABILITY 6A

The internal regulator is capable of safely delivering up to 6A of peak output current, and no extra thermal management—airflow or heat sink—is required for the LTM8003 to continuously support a 3.5A load at 3.3V or 5V from a nominal 12V input. This meets the needs of the battery powered applications in industrial robotics, factory automation and automotive systems.

Figure 4. A 5V, 3.5A solution for 7V to 40V inputs using the H-grade version. Thermal imaging shows no need for bulky heat mitigation components.



(a)

(b)

The LTM8003 is a 40V, 3.5A step-down µModule featuring wide input and output ranges, an FMEA compliant pinout and low noise Silent Switcher architecture. It is packaged in a compact overmolded ball grid array (BGA) 6.25mm × 9mm × 3.32mm package for ease of manufacturing.

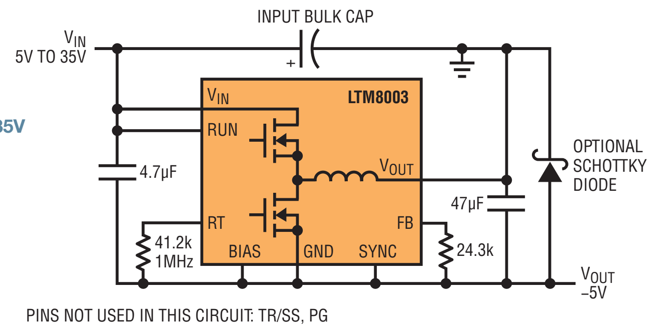
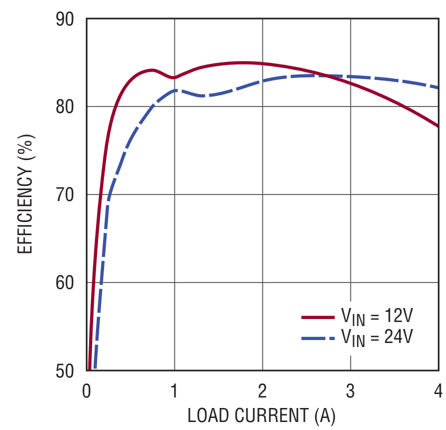


Figure 5. A –5V supply from a 5V to 35V input delivers current up to 4A.



WIDE OPERATION TEMPERATURE RANGE FROM –40°C TO 150°C

Automotive, industrial and military applications require power supply circuits to operate continuously and safely in ambient temperatures over 105°C or require significant headroom for a thermal rise. The LTM8003H is designed to meet specifications over –40°C to 150°C internal operating temperature range. The internal overtemperature protection (OTP) monitors the junction temperature, and stops switching when the junction temperature is too hot.

Figure 4a shows a 3.5A, 5V solution that operates from a wide-ranging 7V to 40V input. The thermal performance at a nominal 12V input is shown in Figure 4b. Typical efficiency is above 92% with a 12V input and 2A load.

NEGATIVE OUTPUT –5V FROM 3.5V TO 35V INPUT

Figure 5 shows a solution for a –5V, 4A output from a nominal 12V input, with a maximum of 35V input. The BIAS pin is should be connected to GND.

CONCLUSION

The LTM8003 is a 40V, 3.5A step-down µModule featuring wide input and output ranges, an FMEA compliant pinout and low noise Silent Switcher architecture. It is packaged in a compact overmolded ball grid array (BGA) 6.25mm × 9mm × 3.32mm package for simplified manufacturing. Minimal design effort is required to meet the stringent standards posed by harsh operating environments such as industrial robotics, factory automation, avionics and automotive systems. ■

Dual Channel 42V, 4A Monolithic Synchronous Step-Down Silent Switcher 2 with 6.2µA Quiescent Current

Hua (Walker) Bai

The LT8650S 42V, dual channel, 4A, synchronous Silent Switcher®2 regulator features a wide input voltage range of 3V to 42V, ideal for automotive, industrial and other step-down applications. Its quiescent current is only 6.2µA, with the outputs in regulation—a critical feature in automotive environments, where always-on systems can drain the battery even when the car is not running. In many switching regulator designs, EMI can be a problem if board layout does not adhere to stringent layout standards. Not so with a Silent Switcher 2 design, where automotive EMI standards are easily passed with minimal layout concerns.

7.5V/4A AND 3.3V/4A OUTPUTS HAVE FAST TRANSIENT RESPONSE

Figure 1 shows a dual output regulator designed to optimize transient response. Although the LT8650S includes internal compensation, external compensation is used to minimize transient response time and output voltage excursions. Switching is at 2MHz, allowing higher loop bandwidth and faster transient response.

Figure 2 shows the output response to a 0A to 4A load step, where V_{OUT} drops less than 100mV for both the 3.3V and 7.5V outputs. This response is combined with high initial accuracy for a solution that meets tight V_{OUT} tolerances.

PARALLELED OUTPUTS DELIVER 9V/8A FROM 24V WHILE REMAINING COOL

The LT8650S packs two synchronous step-down regulators into a 4mm × 6mm package. The two outputs can be easily paralleled for high current as shown by the 72W output, 24V input design in Figure 3. Efficiency at full load is 95%, with the thermal performance of the board shown in Figure 4. Running at room temperature, the hottest part of the IC reaches about 75°C without active cooling.

The temperature and efficiency are even better for a 12V input. When paralleling,

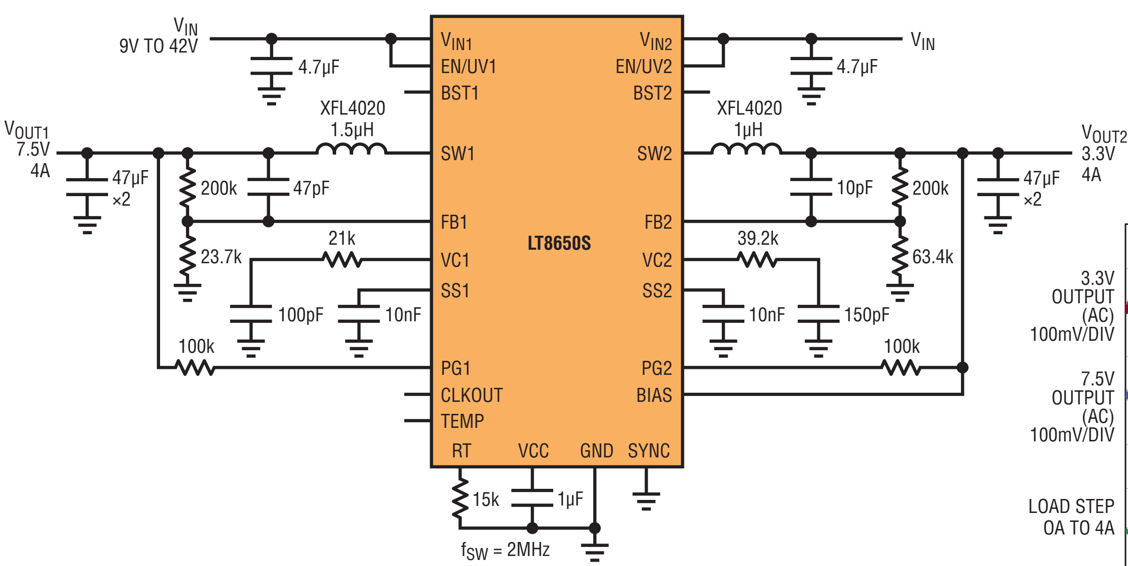


Figure 1. 7.5V/4A and 3.3V/4A outputs feature fast transient response.

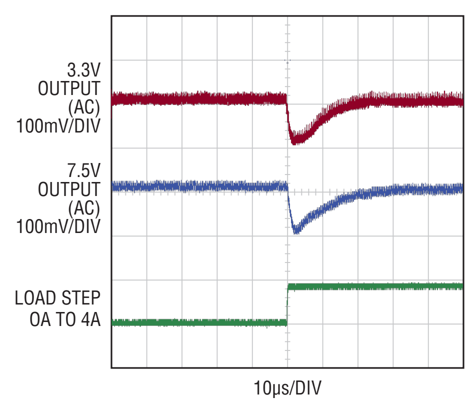


Figure 2. 0A to 4A transient responses of the circuit in Figure 1 (Burst Mode® operation)

The LT8650S packs two synchronous step-down regulators into a 4mm × 6mm package. The two outputs can be easily paralleled for high current.

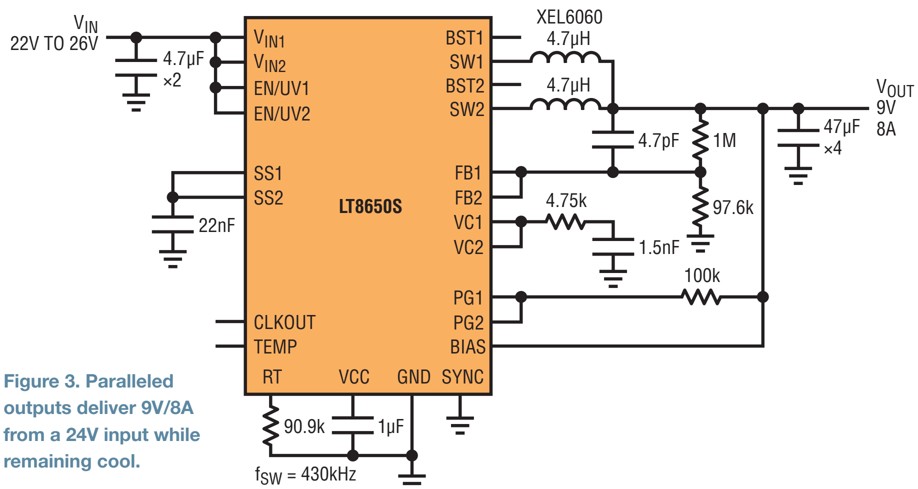


Figure 3. Paralleled outputs deliver 9V/8A from a 24V input while remaining cool.

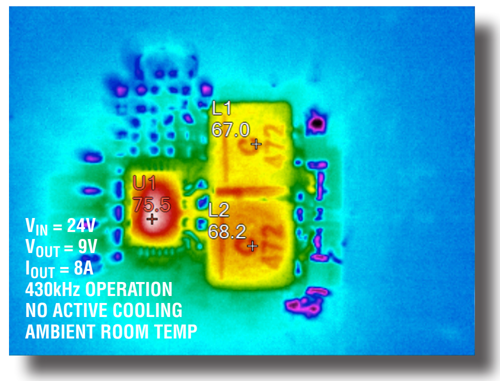


Figure 4. Thermal performance of the circuit in Figure 3

it is important to balance the current between the outputs by tying the outputs of error amplifiers together. This can be achieved by connecting VC1 and VC2 together and using external compensation. For applications that require a larger thermal budget, the LT8650H operates with a 150°C junction temperature.

3.3V/3A AND 1V/5A RUNNING AT 2MHz FOR AN SoC APPLICATION

Many System on Chip (SoC) applications require 3.3V for peripherals and 1V for the core. Figure 5 shows the LT8650S used in a cascade topology, where the input for the 1V converter is powered by the 3.3V output. There are a number of benefits of a cascade configuration over powering V_{IN2} from the main supply, including reduced solution size and constant 2MHz operation.

The 4A current rating per channel of the LT8650S is based on thermal limitations, but each channel can electrically deliver 6A if temperature rise is managed with additional cooling. In the solution of Figure 5, the output power of the 1V channel 2 is low, so it can deliver 5A.

CONCLUSION

The LT8650S features a wide input range, low quiescent current and its Silent Switcher 2 design. Packing two 4A synchronous step-down regulators in a 4mm × 6mm package reduces part count and solution size while allowing design flexibility for a broad range of applications. ■

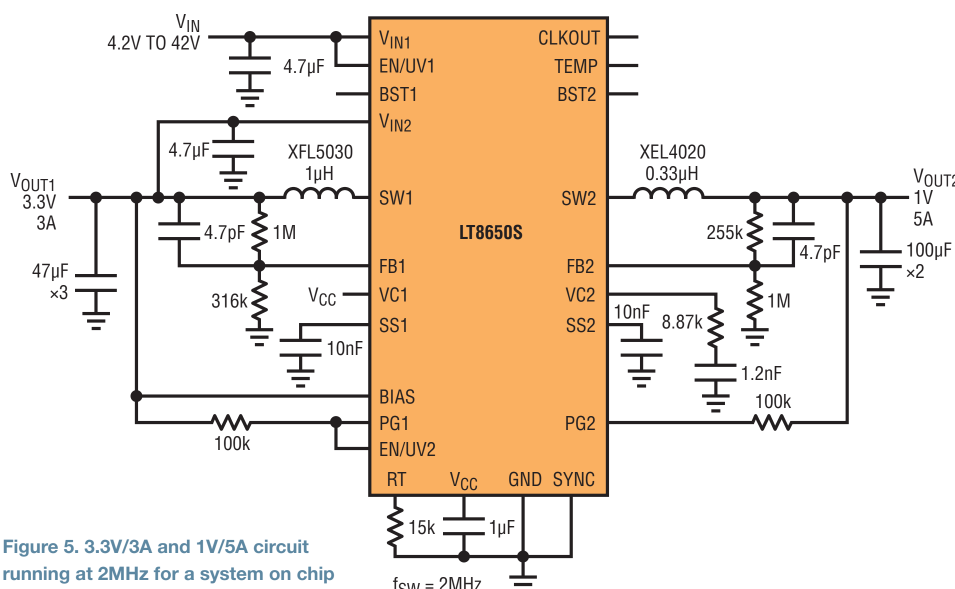


Figure 5. 3.3V/3A and 1V/5A circuit running at 2MHz for a system on chip (SoC) application

Active Rectifier Controller with Ultrafast Transient Response and Low Power Dissipation

Bin Wu

The LT8672 is an active rectifier controller that (along with a MOSFET) provides reverse current protection and rectification for power supplies in automotive environments. The LT8672's active protection has a number of advantages over Schottky diode designs:

- Minimal power dissipation
- Small, predictable, regulated 20mV voltage drop

The LT8672 also includes features to satisfy supply rail requirements in automotive environments:

- Reverse input protection to –40V
- Wide input operation range: 3V to 42V
- Ultrafast transient response
- Rectifies $6V_{P-P}$ up to 50kHz; rectifies $2V_{P-P}$ up to 100kHz
- Integrated boost regulator for the FET driver outperforms charge pump devices

Figure 1 shows a complete protection solution.

FAST RESPONSE FOR INPUT RIPPLE RECTIFICATION

Automotive standards—ISO 16750 or LV124—specify that automotive electronic control units (ECUs) may face a supply with a superimposed AC ripple of up to $6V_{P-P}$ at up to 30kHz. The LT8672's gate driver that controls the external MOSFET is strong enough to handle ripple frequencies of up to 100kHz, which minimizes reverse current. An example of such an AC ripple rectification is shown in Figure 2.

LOW POWER DISSIPATION COMPARED WITH A SCHOTTKY DIODE

The performance of the LT8672 (using the IPD100N06S4-03 as external MOSFET) can be compared to a Schottky diode (CSHD10-45L) with the setup shown in Figure 3. Here, a 12V power supply at the input emulates the automotive voltage supply, and the output is loaded with a constant current of 10A. Thermal performance for both solutions at steady state is shown in Figure 4. Without cooling, the thermal performance of the LT8672 solution is far superior, reaching a peak temperature of only 36°C, while the Schottky diode solution reaches a much higher 95.1°C.

EXTRA LOW INPUT VOLTAGE OPERATION CAPABILITY

Automotive mission critical circuitry must be able to operate during cold crank conditions, when the car battery voltage can collapse to 3.2V. With this in mind, many automotive grade electronics are designed to operate down to 3V input. A Schottky's variable forward voltage drop can present a problem during cold crank, where this drop produces a downstream voltage of 2.5V to 3V, too low for some systems to operate. In contrast, a LT8672 solution guarantees the required 3V due to its regulated 20mV voltage drop, allowing easier circuit design and improved system robustness.

Figure 1. LT8672 active rectification/reverse protection solution

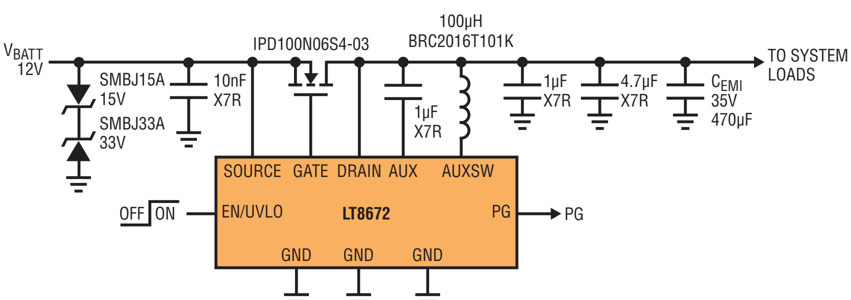
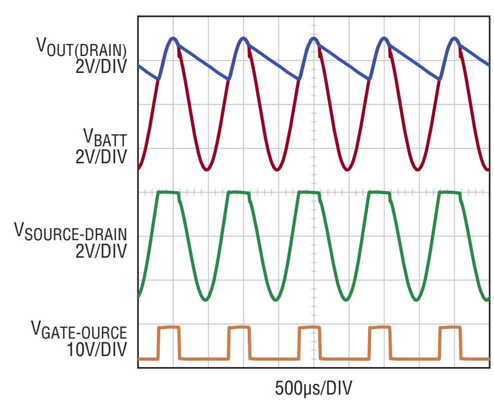


Figure 2. Rectification of input ripple



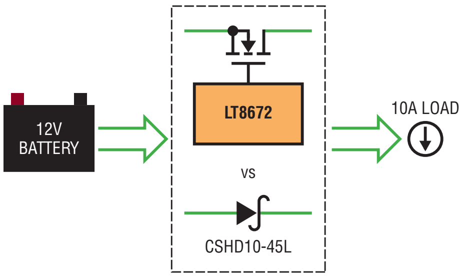
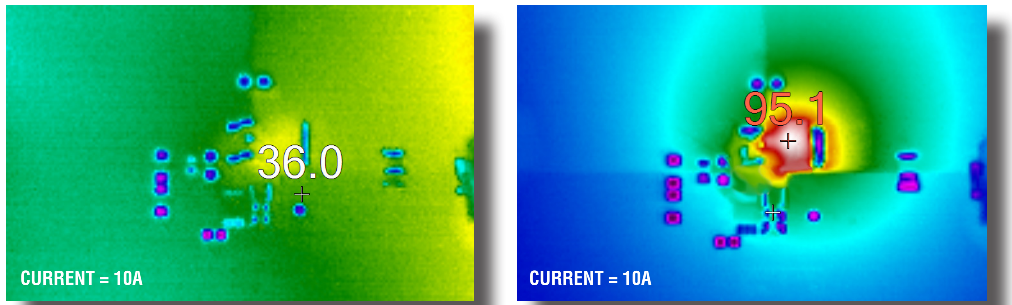


Figure 3. System configuration for thermal performance comparison



(a) LT8672 controlled system

(b) Schottky diode system

Figure 4. Thermal performance comparison: The LT8672 controlled system (a) tops out at a cool 36°C, while the Schottky diode system (b) reaches 95.1°C, causing significant heating over the entire board.

Figure 5 shows a comparative cold crank test setup using an LT8650S step-down converter as the downstream test system. The LT8650S output is set to 1.8V at a constant load of 4A, and its minimum input operating requirement is 3V. The results are shown in Figure 6.

When V_{BATT} drops to 3.2V, the LT8672 controlled system (a) maintains $V_{IN} > 3V$, allowing the LT8650S to keep its output V_{SYS} stable at 1.8V, while in the Schottky diode system (b) the input voltage V_{IN} of the LT8650S drops below its minimum operating voltage, preventing it from maintaining 1.8V at its output V_{SYS}.

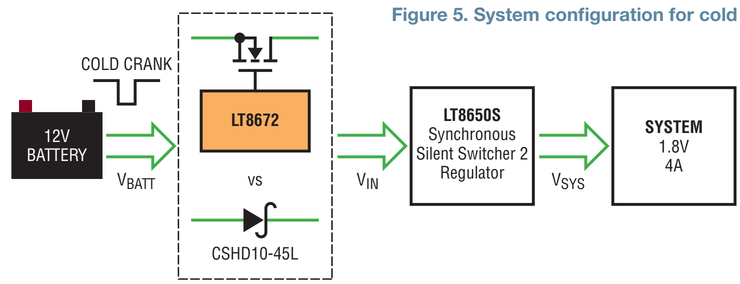
INTEGRATED BOOST REGULATOR

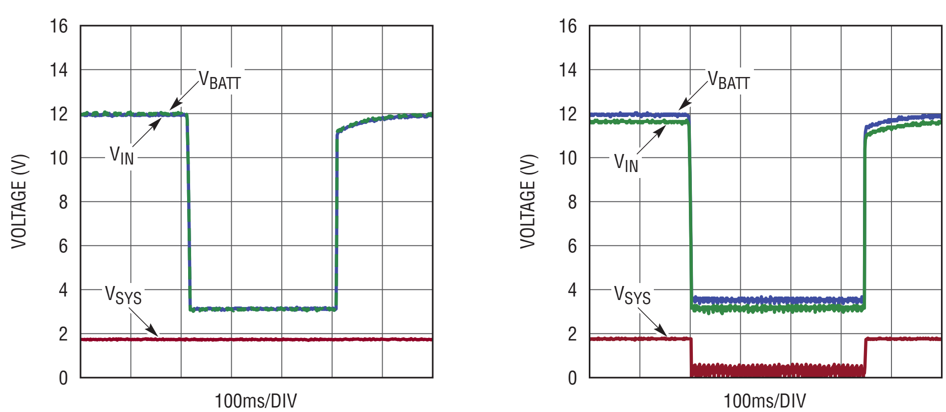
Many alternative active rectifier controllers use a charge pump to power the gate driver. These solutions often cannot provide strong gate charging current and a regulated output voltage, limiting the frequency range and performance of continuous rectification. The LT8672's integrated boost regulator provides a tightly regulated gate driver voltage with strong gate driver current.

CONCLUSION

The LT8672 is able to rectify high frequency AC ripple on automotive supplies. It uses an integrated boost regulator to drive a MOSFET for ultrafast response during continuous rectification, an improvement over charge pump solutions. It provides rectification and reverse input protection with low power dissipation and an ultrawide operational range (desirable for cold crank) in a tiny 10-lead MSOP package. ■

Figure 5. System configuration for cold crank test





(a) LT8672 controlled system

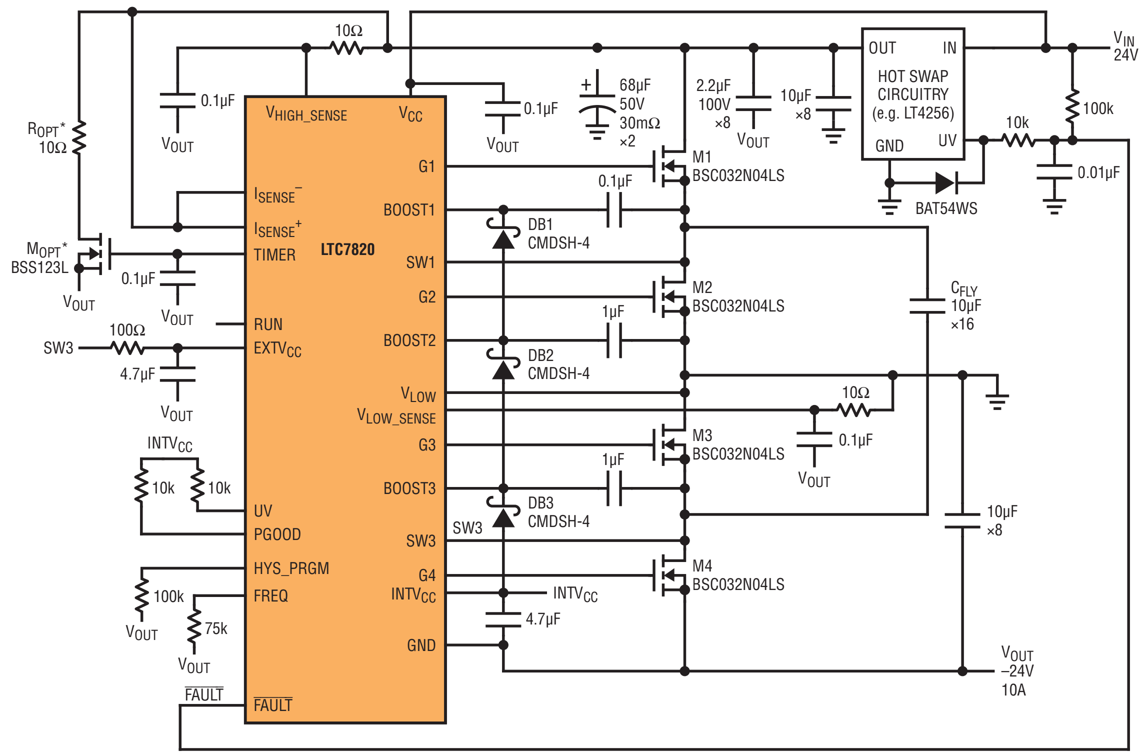
(b) Schottky diode system

Figure 6. System voltage comparison under cold crank

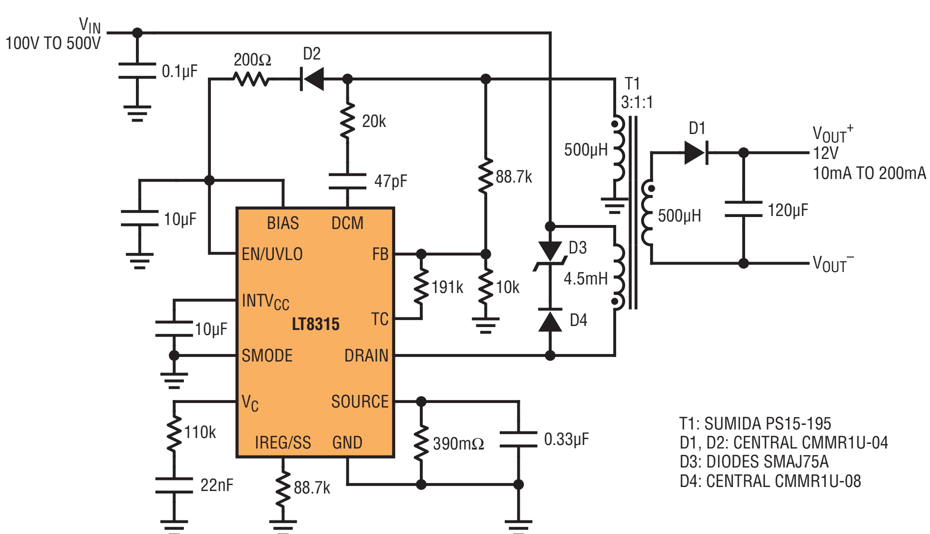
LTC7820 HIGH EFFICIENCY 24V TO –24V, 10A VOLTAGE INVERTER WITH HOT SWAP AT INPUT

The LTC7820 is a fixed ratio high voltage high power switched capacitor/charge pump controller. The device includes four N-channel MOSFET gate drivers to drive external power MOSFETs in voltage divider, doubler or inverter configurations. The device achieves a 2:1 stepdown ratio from an input voltage as high as 72V, a 1:2 step-up ratio from an input voltage as high as 36V, or a 1:1 inverting ratio from an input voltage up to 36V. Each power MOSFET is switched with 50% duty cycle at a constant preprogrammed switching frequency. System efficiency can be optimized to over 99%. The LTC7820 provides a small, cost-effective solution for high power, nonisolated intermediate bus applications with fault protection.

www.linear.com/solutions/7941



*OPTIONAL DISCHARGING COMPONENTS FOR FAST START-UP.



T1: SUMIDA PS15-195
D1, D2: CENTRAL CMMR1U-04
D3: DIODES SMAJ75A
D4: CENTRAL CMMR1U-08

LT8315 12V HIGH INPUT VOLTAGE ISOLATED FLYBACK CONVERTER

The LT8315 is a high voltage flyback converter with integrated 630V/300mA switch. No opto-isolator is needed for regulation. The device samples the output voltage from the isolated flyback waveform appearing across a third winding on the transformer. Quasi-resonant boundary mode operation improves load regulation, reduces transformer size, and maintains high efficiency.

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