

IN THIS ISSUE

dual input/output 3A monolithic buck with 3V–36V input range 10

how to drive low power, 1MSPS, 16-bit, differential input ADC from single-ended signals 30

maximize output power from current-limited USB and PCMCIA sources 38

dual output step-down controller converts 60V directly to 3.3V 40

Harvest Energy from a Single Photovoltaic Cell

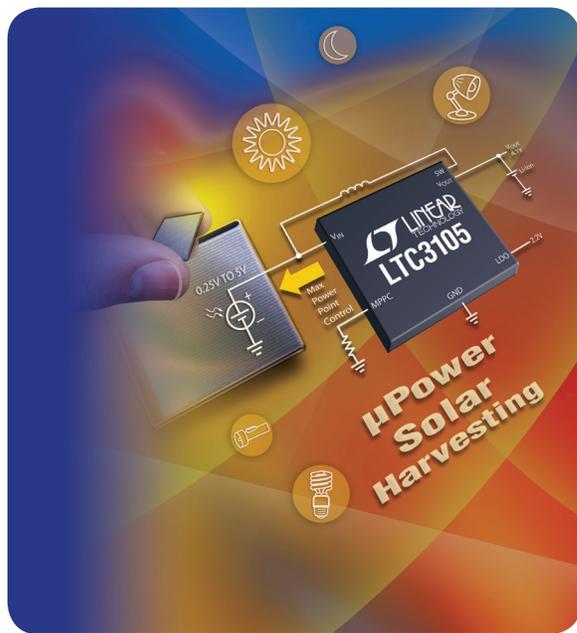
Nathan Bourgoine

To simplify the distribution of wireless communications for instrumentation, monitoring and control applications, power supply designers strive for device grid-independence. Batteries, the immediately obvious solution, offer the illusion of grid independence, but require replacement or recharging, which means eventual connection to the grid and expensive human intervention and maintenance. Enter energy harvesting, where energy is collected from the instrument's immediate environment, offering perpetual operation with no connection to the grid and minimal or no maintenance requirements.

A variety of ambient energy sources can be harvested to produce electrical power, including mechanical vibration, temperature differential and incident light. Linear Technology produces power management solutions that solve the problems specific to harvesting ambient low energy sources, including the LTC[®]3588 for vibration sources, the LTC3108/LTC3109 for thermal, and now the LTC3105 for photovoltaic energy harvesting applications. Photovoltaic energy harvesting is widely applicable, given that light is almost universally available, photovoltaic (PV) cells are relatively low cost and they produce relatively high power compared to other ambient energy harvesting solutions. Because of its relatively high energy output, photovoltaic energy harvesting can be used to power wireless sensor nodes, as well as higher power battery charging applications to extend battery life, in some cases eliminating tethered charging altogether.

While high voltage stacks of series-connected photovoltaic cells are prolific, single PV-cell solutions are rare, due to the difficulty of generating useful power rails from the low voltage produced by a single PV cell under load. Few boost converters can produce outputs from a low voltage, relatively

(continued on page 2)



In this issue...

COVER STORY

Harvest Energy from a Single Photovoltaic Cell
Nathan Bourgoine 1

DESIGN FEATURES

Protect Mobile Devices from Hot Plug Transients (to 85V) and from Users Who Use the Wrong Power Adapter
Kevin Wong 7

Monolithic, Dual 3A Input/Output Buck with 3V–36V Operating Range Simplifies and Shrinks DC/DC Converters in Automotive, Industrial and Distributed Power Applications
Jonathan Paolucci 10

3A Output, 96% Efficient Buck-Boost DC/DC Converter Sets the Standard for Power Density and Noise Performance
Richard Cook 19

Intermediate Bus Buck Regulator Maintains 5V Gate Drive During Automobile Cold Crank Conditions
Theo Phillips and Tick Houk 22

Low I_Q , Triple Output Boost/Buck/Buck Synchronous Controller Keeps Electronics Running Through Battery Transients in Automotive Start-Stop and Always-On Systems
Joe Panganiban and Jason Leonard 26

DESIGN IDEAS

How to Drive Low Power, 1Msps, $\pm 2.5V$ Differential-Input, 16-Bit ADC with a Variety of Single-Ended Signals
Guy Hoover 30

Easy, Isolated Low Power Telecom Supply: No Opto-Isolator Required
Mayur Kenia 32

4mm \times 5mm, Dual Input/Output, Synchronous Monolithic Buck Regulator Converts 12V to 1.2V at 4MHz
Phil Juang 34

Isolated Flyback Converters Eliminate Opto-Coupler
Yat Tam 36

Buck-Boost Converter with Accurate Input Current Limit Maximizes Power Utilization from USB and PCMCIA Sources
Michael Munroe 38

Low I_Q , Dual Output Step-Down Controller Converts 60V Directly to 3.3V
Jason Leonard and Joe Panganiban 40

product briefs 43

back page circuits 44

The LTC3105 enables autonomous remote sensor nodes, data collection systems and other applications that require grid independence and minimal maintenance.

(LTC3105, continued from page 1)

high impedance single PV cell. The LTC3105, however, is designed specifically to meet these challenges. Its ultralow 250mV start-up voltage and programmable maximum power point control allow it to generate the typical voltage rails (1.8V–5V) required for most applications from challenging PV sources.

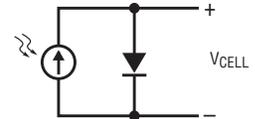


Figure 1. Simple photovoltaic cell model

UNDERSTANDING PHOTOVOLTAIC CELL SOURCES

Photovoltaic sources can be electrically modeled by a current source connected in parallel with a diode as shown in Figure 1. More complex models show secondary effects, but for our purposes this model is sufficient.

Two common parameters that characterize a PV cell are the open circuit voltage and the short-circuit current. Typical curves for PV cell current and voltage are shown in Figure 2. Note that the short-circuit current is the output of the model's current generator while the open circuit voltage is the forward voltage of the model's diode. As light levels increase, the current from the generator increases and the IV curves move up.

To extract maximum power from the PV cell, the input resistance of the power converter must be matched to the output resistance of the cell, resulting in operation at the maximum power point. Figure 3 shows the power curve for a typical single photovoltaic cell. To ensure maximum power extraction, the output voltage of the PV cell should be operated at the peak of the power curve. The LTC3105 adjusts the output current delivered to the load in order to maintain the PV cell

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Figure 2. Typical photovoltaic cell IV curve

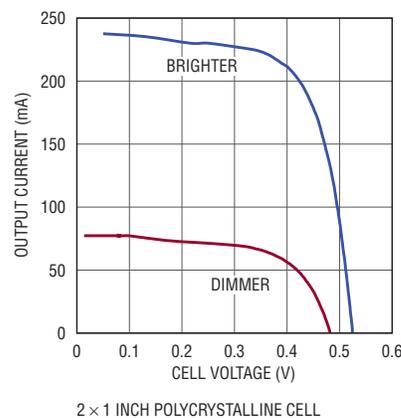
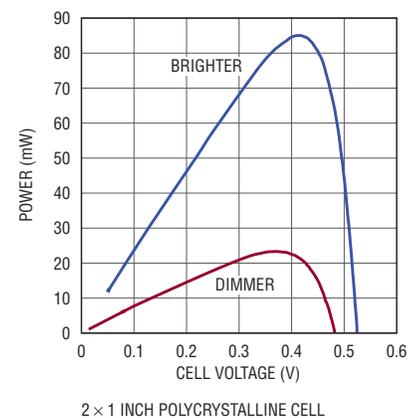


Figure 3. Typical photovoltaic cell power curve



Linear in the News

JAPAN PRESS CONFERENCE

On December 17, Linear Technology held a major press conference in Japan to give 27 assembled members of the press an overview of Linear's strategy. At the meeting, Executive Chairman Bob Swanson presented an overview of the company's repositioning to focus primarily on three major market segments—industrial (including medical, security, factory automation, instrumentation and industrial control), communications infrastructure (including cellular base stations to support worldwide growth in wireless networks, as well as networking), and automotive electronics (including battery stack monitors for hybrid/electric vehicles and LED lighting systems). CEO Lothar Maier further elaborated on Linear's strategy and product focus in Japan and globally.

The press conference was covered by several major Japanese publications, including *Dempa Shimbun*, *EDN Japan*, *EE Times Japan*, *Electronic Journal* and *Nikkei Electronics*, among others.

LINEAR RECEIVES PRODUCT AWARDS

Linear continues to receive numerous awards for its innovative, high performance products. The awards are determined by independent groups of technical editors, representing various print and online publications around the globe. Following are a few recent award highlights:

EDN Innovation Award Finalists. *EDN* magazine has announced finalists for their annual Innovation Awards, to be presented on May 2. Linear finalists include:

- Innovator of the Year: Robert Dobkin and Tom Hack for the LT[®]4180 Virtual Remote Sense™ Controller.
- Power ICs: LT4180 Virtual Remote Sense Controller
- Analog ICs: TimerBlox[®] IC family

You can read more about the finalists at innovation.edn.com/finalists.

Energy Harvesting Product Awards. Two UK publications presented Linear Technology with awards for energy harvesting products. *Electronics Weekly* featured the LTC3109 auto-polarity energy harvesting power supply as winner of the Renewable Energy Design Award in their coverage of the Elektra 2010 Awards. In addition, *Electronic Product Design* featured the LTC3109 as winner of the Alternative Energy Award in their 2010 e-Legacy Awards.

EN-Genius Network Awards. Online publication, *En-Genius Network* presented 2010 Product of the Year Awards to:

- Best RF Detector: LTC5583 Dual RMS RF Detector
- Best Advance in Remote Load Power Sensing: LT4180 Virtual Remote Sense Controller
- Best Ultralow Input Voltage DC/DC Power Module: LTM[®]4611 1.5V Input 15A μ Module[®] Controller

EDN Hot 100 Products. *EDN* magazine highlighted the Hot 100 Products of 2010, including:

- LT6656 low power voltage reference
- LT4180 Virtual Remote Sense Controller
- LTC3108 energy harvesting boost regulator

CONFERENCES & EVENTS

EDN Designing with LEDs Conference & Workshop, San Jose Marriott Hotel, San Jose, California, May 4. Linear will showcase LED driver solutions at the booth and Design Manager Bryan Legates will conduct a workshop on LED drivers. Info at ubmelectronicvirtualconferences.businesscatalyst.com/LED/index.html

Energy Efficiency & Technology Conference, Marriott Santa Clara, Santa Clara, California, May 6. Linear will highlight its energy harvesting solutions at the booth, and provide a speaker at the conference. Info: eetweb.com/sponsor/energy-efficiency-technology/

Electronic Sourcing Live Exhibition, Regency Park Hotel, Newbury, UK, May 12. Linear will have a booth promoting μ Module power solutions and Linear Express[®] product fulfillment. Info: www.es-live.co.uk/index.html

Sensors Expo, Donald E. Stephens Convention Center, Rosemont, Illinois, June 6-8. Linear will showcase energy harvesting solutions at its booth, and designer Jim Noon will give a presentation on energy harvesting. Info: www.sensorsmag.com/sensors-expo ■

While high voltage stacks of series-connected photovoltaic cells are prolific, single PV-cell solutions are rare, due to the difficulty of generating useful power rails from the low voltage produced by a single PV cell under load.

(LTC3105, continued from page 2)

voltage at the voltage set by the maximum power point control pin. Therefore, a single programming resistor establishes the maximum power point and ensures maximum power extraction from the PV cell and peak output charging current.

HOW MUCH POWER IS AVAILABLE?

The amount of power that can be generated using a photovoltaic cell depends on a number of factors. The output power of the cell is proportional to the brightness of the light landing on the cell, the total area of the cell, and the efficiency of the cell.

Most PV cells are rated for use under full direct sunlight ($1000\text{W}/\text{m}^2$), but such ideal conditions are unlikely to occur in most applications. For devices operating from sunlight, the peak power available from the cell can easily change by a factor of ten from day to day due to weather, season, haze, dust, and incident angle of the sunlight. Typical output power for a crystalline cell in full sunlight is about 40mW per square inch depending on cell characteristics. A PV cell with an area of a few square

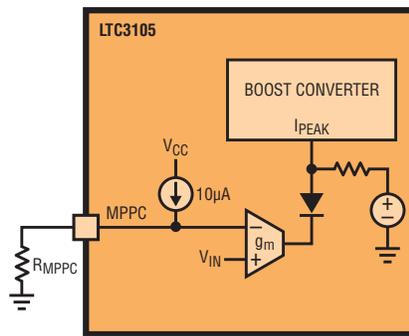


Figure 4. Maximum power point control mechanism

inches is sufficient to run many remote sensors and to trickle charge a battery.

In contrast, devices operating from indoor lighting have far less energy available to them. Common indoor lighting is roughly 0.25% as strong as full sunlight (the huge difference in intensity between indoor lighting and sunlight is hard to perceive due to the human eye's ability to adjust to a wide range of illumination levels). The dramatically lower light levels available to indoor applications

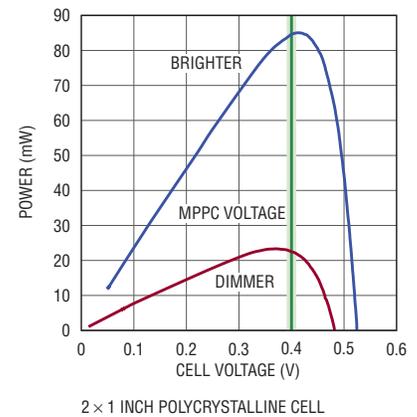


Figure 5. Err on the side of a lower voltage when choosing a maximum power point voltage to avoid the steep drop-off

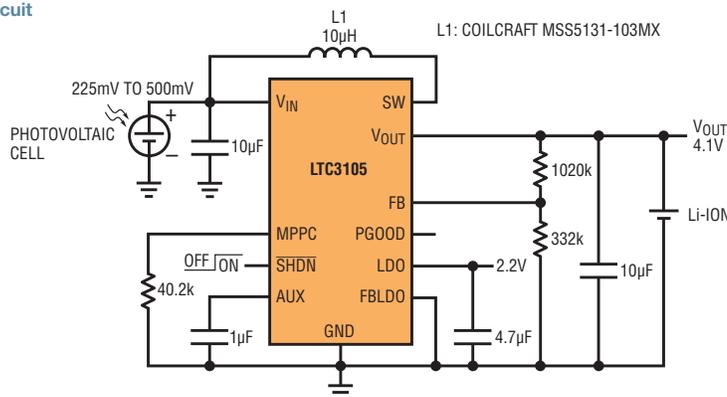
presents design challenges. Even a large high efficiency crystalline cell with an area of four square inches generates only $860\mu\text{W}$ in typical office lighting.

CHOOSING THE MAXIMUM POWER POINT CONTROL VOLTAGE

Figure 4 shows a model of the maximum power point control mechanism used by the LTC3105. Figure 3 shows the power curve for a PV cell. Note that PV cell power declines sharply from its peak as the cell voltage rises away from peak power. It is thus generally more desirable to err on the side of a lower-than-ideal control voltage, rather than a higher voltage, because the power curve rolls off more sharply on the high side.

When selecting the MPPC tracking voltage, various operating conditions must be considered. Typically, the maximum power point does not move substantially with changes in illumination. As a result, it is

Figure 6. Li-ion charging circuit



The LTC3105's integrated maximum power point control and low voltage start-up functionality enable direct operation from a single PV cell and ensure optimal energy extraction. The LTC3105 can be used to directly power circuitry or for charging energy storage devices to allow operation through dark or low light periods.

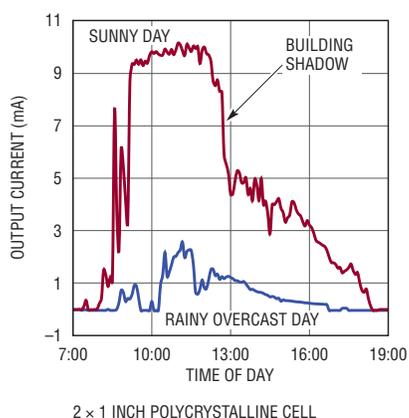


Figure 7. Charging profiles for two square inch photovoltaic cell

possible to choose a single tracking voltage that provides operation near the maximum power point for a wide range of illumination levels. Even though the operating point will not be precisely at the maximum power point at extreme levels of illumination, the reduction in output power from the ideal is usually only 5%–10%.

For the power curve shown in Figure 5, an MPPC voltage of 0.4V yields performance near the maximum power point at either illumination extreme. The voltage difference from the maximum power point is approximately 20mV in both cases, resulting in a power loss of less than 3%.

As a rule of thumb, the maximum power point control voltage should be around 75%–80% of the open circuit voltage for the PV cell. Tracking the cell to this voltage results in a cell output current that is 75%–80% of the short-circuit current.

LI-ION BATTERY CHARGING IN OUTDOOR LIGHTING

One of the challenges faced by applications using a photovoltaic source is the lack of input power during darkness and low light conditions. For most applications this necessitates use of energy storage elements such as a supercapacitor or rechargeable battery that is large enough to provide power throughout the longest expected dark period.

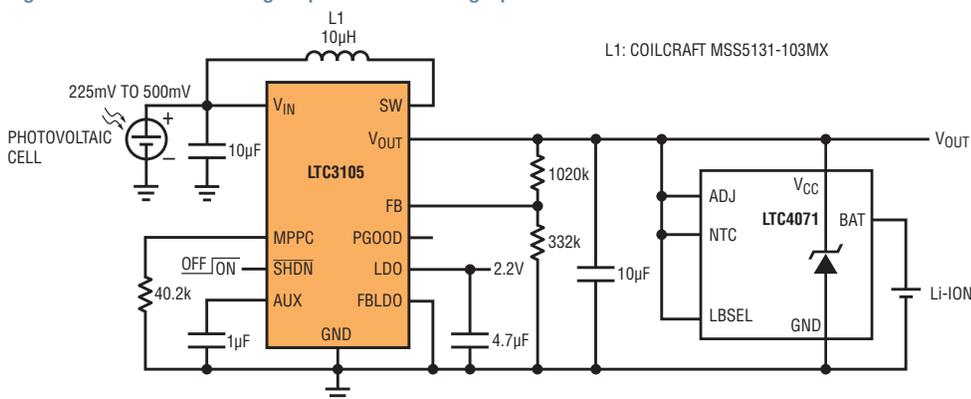
Figure 7 shows the measured charging current profile using a 2" × 1" polycrystalline PV cell to charge a Li-ion battery using the LTC3105 circuit shown in Figure 6. The upper curve of Figure 7 shows the charging current on a typical clear day with full sun. The lower curve shows the charging current observed over the course of a heavily overcast day. Even under these low light conditions a charging current of 250 μ A or more was maintained throughout the day totaling 6mAh of charge delivered to the battery.

CHOOSING THE RIGHT ENERGY STORAGE DEVICE

There are many alternatives for storing harvested energy, including a wide variety of rechargeable battery technologies and high energy density capacitors. No one technology is perfect for all applications. When selecting the storage element for your application, consider a number of factors, including the self-discharge rate, maximum charge and discharge current, voltage sensitivity, and cycle lifetime.

The self-discharge rate is particularly important in photovoltaic applications. Given the limited amount of charging current available in most photovoltaic power applications, a high self-discharge rate may consume a large portion of the available energy from the PV source. Some energy storage elements, such as large supercapacitors, may have self-discharge current in excess of 100 μ A, which could dramatically reduce the net charge accumulated over a daily charge cycle.

Figure 8. A Li-ion trickle charger operates from a single photovoltaic cell



The LTC3105 is a complete single-chip solution for energy harvesting from low cost, single photovoltaic cells.

Another key consideration is the rate at which the energy storage device can be charged. For example, a lithium coin cell with a maximum charging current of 300µA requires a large resistor between it and the output of the LTC3105 in order to prevent overcurrent conditions. This can put a limit on the amount of energy harvested, decreasing the amount of energy available to the application.

In many cases the charge rate is proportional to another important factor, cycle lifetime. The cycle life of a storage element determines how long it can operate in the field without maintenance. Generally, faster charging and discharging reduces the operational life of the element. Supercapacitors offer very good cycle life, while batteries charged with relatively high currents (charge > 1C) have degraded lifetimes. In addition to the charge and discharge rate, the depth

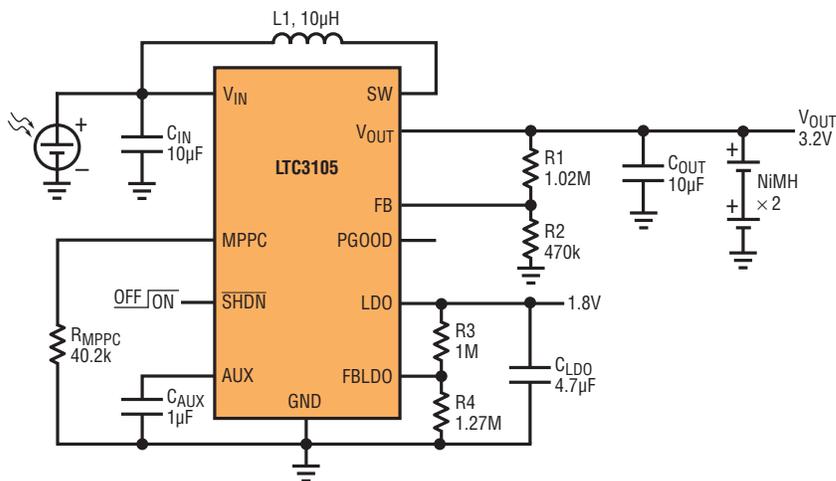


Figure 9. Single-cell photovoltaic NiMH trickle charger

of each charge/discharge cycle can affect the lifetime of batteries, with deeper cycles leading to shorter life times.

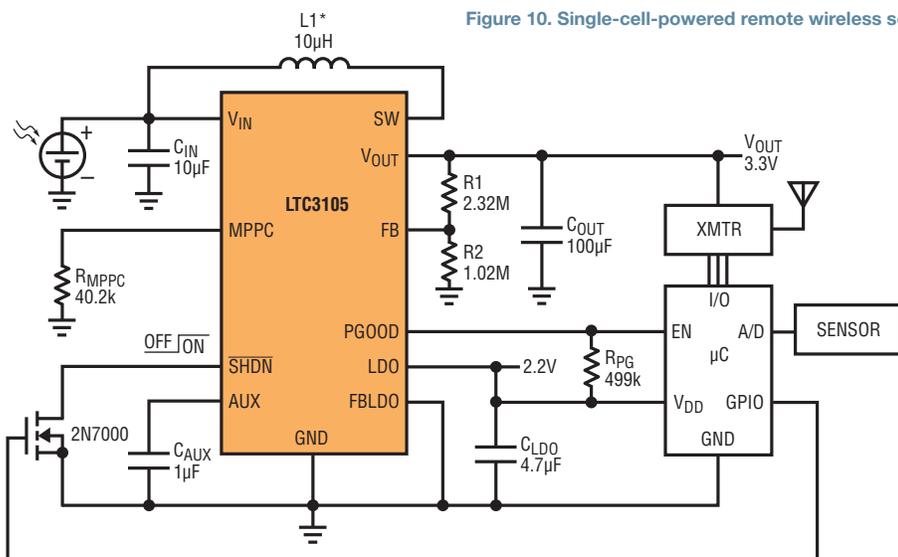
With several battery types, notably lithium and thin film, the maximum and minimum voltage must be carefully controlled. The

maximum charge voltage is well controlled in LTC3105 applications since the converter terminates charging when the output comes into regulation. To prevent over-discharge, the LTC3105 can be used in conjunction with the LTC4071 shunt battery charger as shown in Figure 8.

CONCLUSION

The LTC3105 is a complete single chip solution for energy harvesting from low cost, single photovoltaic cells. Its integrated maximum power point control and low voltage start-up functionality enable direct operation from a single pv cell and ensure optimal energy extraction. The LTC3105 can be used to directly power circuitry or for charging energy storage devices to allow operation through dark or low light periods. The LTC3105 makes it possible to produce autonomous remote sensor nodes, data collection systems and other applications that require grid independence and minimal maintenance. ■

Figure 10. Single-cell-powered remote wireless sensor



* COILCRAFT MSS5131-103MX

Protect Mobile Devices from Hot Plug Transients (to 85V) and from Users Who Use the Wrong Power Adapter

Kevin Wong

Battery powered mobile gadgets like smart phones, tablets and digital cameras have become integral parts of the modern lifestyle. More and more functionality is squeezed into increasingly small form factors in the endless quest for more mobility. The proliferation of mobile devices has spawned a corresponding number of power adapters to charge batteries and power the devices: from AC wall outlets, car battery adapters, USB ports and even mobile solar panels. Although many adapters use similar plugs, their electrical specifications can be very different. Product designers are thus forced to employ protection circuitry to protect the low voltage rated electronics from transient and steady state overvoltages.

Failures or faults in the power adapters can cause an overvoltage event. So can hot-plugging an adapter into the power input of the mobile device (see Linear Technology Application Note 88). With the prevalence of universal connectors, a user can also unknowingly plug in the wrong adapter, damaging the device with a high or even negative power supply voltage. The LTC4360, LTC4361 and LTC4362 can protect against the above mentioned fault situations with minimal components. See Table 1 for a comparison of these devices.

The LTC4360 and LTC4361 protect low voltage electronics from overvoltage conditions by controlling a low cost external N-channel MOSFET configured as a pass transistor. The LTC4362 achieves an even smaller PCB footprint by incorporating an internal 28V, 71mΩ $R_{DS(ON)}$ MOSFET and a 31mΩ sense resistor.

The LTC4360 and LTC4361 can withstand up to 85V at IN, SENSE and GATEP. For all three parts, there is no requirement for a high voltage bypass capacitor at IN, eliminating a potential point of failure. The low voltage capacitor required at

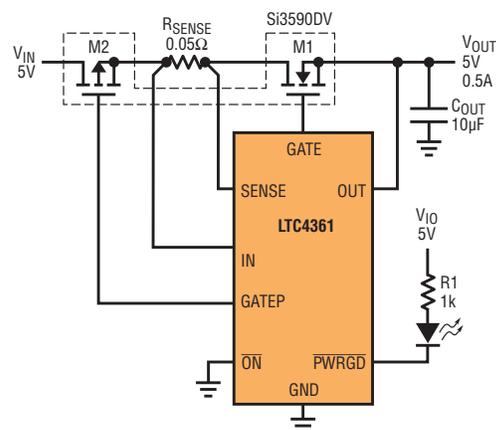


Figure 1. A 5V system protected from $\pm 24V$ power supplies and overcurrent

OUT is also the bypass capacitor to the downstream circuits. It helps to slow down the dV/dt at OUT during a fast overvoltage, allowing time for the protection part to shut off the MOSFET before V_{OUT} overshoots to a dangerous voltage. These features make the parts versatile building blocks for some very robust yet simple overvoltage protection circuits.

OPERATION

When power is first applied or the part is activated by pulling \overline{ON} low, a 130ms delay cycle starts. Any undervoltage or overvoltage event at IN ($V_{IN} < 2.1V$ or $V_{IN} >$

Table 1. Comparison of overvoltage protection parts

PART	FEATURES	PACKAGE
LTC4360	85V Rated Input, 5.8V Overvoltage Threshold	SC70
LTC4361	85V Rated Input, 5.8V Overvoltage Threshold, 50mV Electronic Circuit Breaker Threshold	SOT23, DFN (2mm x 2mm)
LTC4362	28V Rated Input, Internal 40mΩ N-Channel MOSFET and 31mΩ R_{SENSE} , 5.8V Overvoltage Threshold, 1.5A Overcurrent Threshold	DFN (2mm x 3mm)

With the prevalence of universal connectors for mobile devices, users can easily plug in the wrong adapter, damaging the device with a high or even negative power supply voltage. The LTC4360, LTC4361 and LTC4362, along with a few components, protect valuable downstream devices against this and other fault situations.

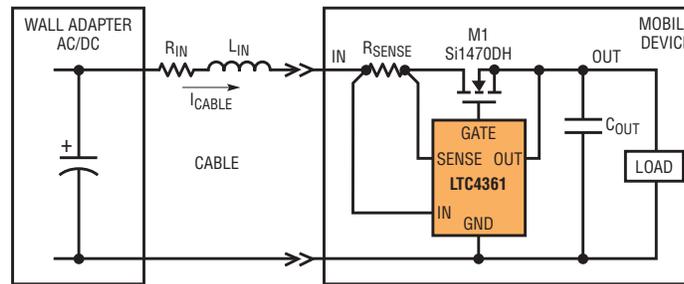


Figure 2. Typical circuit of voltage adapter charging a mobile device

5.7V) restarts the delay cycle. This allows the MOSFET to isolate the output from any input transients that occur at start-up. When the delay cycle completes, the MOSFET is turned on by a controlled 3V/ms gate ramp. The voltage ramp of the output capacitor follows the slope of the gate ramp and sets the supply inrush current at:

$$I_{INRUSH} = C_{OUT} \cdot 3 \text{ [mA/}\mu\text{F]}$$

As GATE ramps higher, it trips an internal gate high threshold (7.2V for $V_{IN} = 5V$) to start a 65ms delay cycle. After the delay, \overline{PWRGD} asserts low to signal that the MOSFET has fully enhanced. An internal circuit clamps GATE at 6V above OUT to protect the MOSFET gate.

When V_{IN} rises above the 2% accurate overvoltage threshold of 5.8V, a 30mA fast pull-down on the GATE pin is activated within 1 μ s and the \overline{PWRGD} pull-down is released. After an overvoltage condition, the MOSFET is held off until V_{IN} once again remains below 5.7V for 130ms.

In addition to overvoltage protection, the LTC4361 and LTC4362 have overcurrent protection to protect the pass MOSFET from

excessive current. The LTC4361 implements a 10% accurate 50mV electronic circuit breaker threshold with a 10 μ s glitch filter. A 50m Ω R_{SENSE} connected between IN and SENSE implements a 1A overcurrent threshold as shown in Figure 1. The LTC4362 implements internal current sensing and has a 20% accurate 1.5A overcurrent threshold with a 10 μ s glitch filter. As in an overvoltage, an overcurrent activates a 30mA fast pull-down on GATE and releases the \overline{PWRGD} pull-down. After an overcurrent

fault, the LTC4361-1 and LTC4362-1 latch off while the LTC4361-2 and LTC4362-2 automatically restart after a 130ms delay.

An optional p-channel MOSFET driven by the GATEP pin as shown in Figure 1 provides low loss negative input voltage protection down to the BV_{DSS} of the MOSFET. An internal IN to GATEP Zener protects the MOSFET gate by clamping its V_{GS} to 5.8V when V_{IN} goes high.

Another feature is the CMOS-compatible, active low enable input \overline{ON} . With

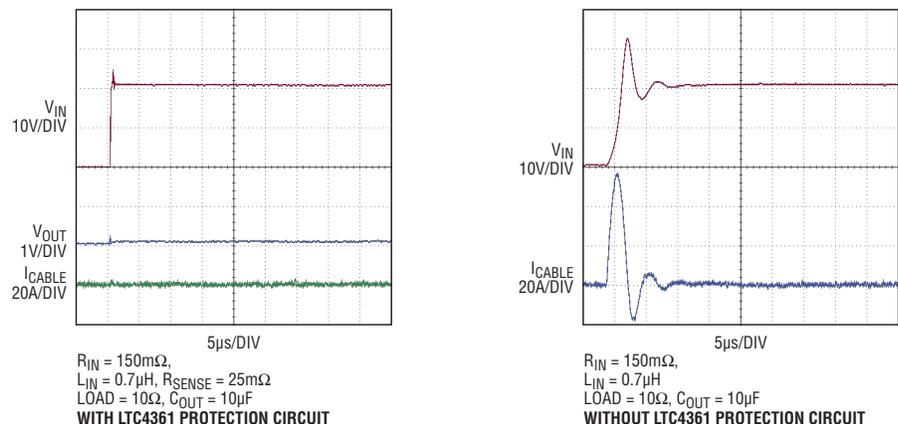


Figure 3. Hot-plug waveform with and without the protection of the LTC4361

The LTC4360 and LTC4361 overvoltage protection controllers use small footprint and low cost external N-channel MOSFETs while the LTC4362 incorporates the MOSFET into a 2mm × 3mm DFN package. Although these overvoltage protection circuits occupy very little PCB space, they are rich in features like an 85V rating at the input side and fast response in the event of overvoltage or overcurrent.

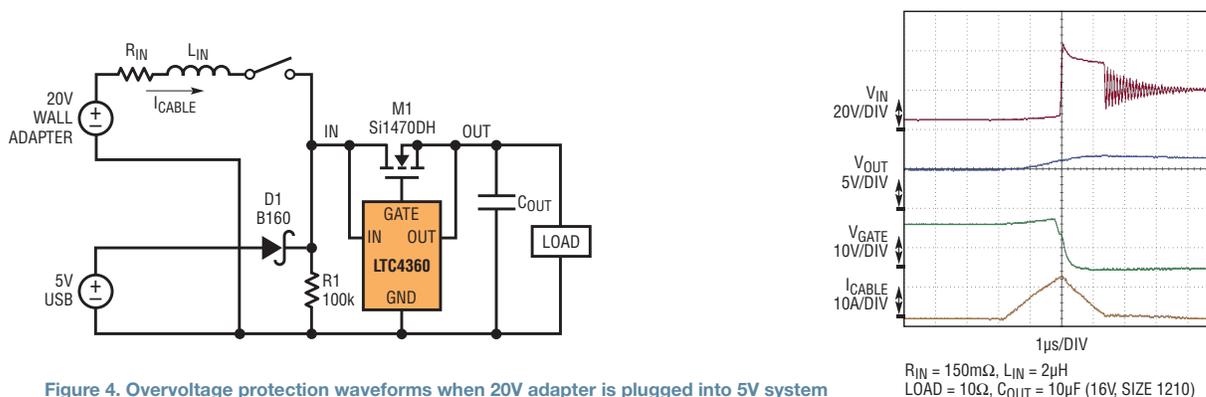


Figure 4. Overvoltage protection waveforms when 20V adapter is plugged into 5V system

$\overline{\text{ON}}$ actively pulled to ground or left open to pull low with its internal 5 μ A pull-down, the device operates normally. If $\overline{\text{ON}}$ is driven high while the MOSFET is turned on, GATE is pulled low with a weak pull-down current (40 μ A) to turn off the MOSFET gradually, minimizing input voltage transients. The part then goes into a low current sleep mode and draws only 1.5 μ A at IN.

INPUT TRANSIENTS

Figure 2 shows the circuit of a LTC4361 protecting the power input of a mobile device. L_{IN} and R_{IN} model the accumulated parasitic inductance and resistance in the wall adapter, adapter cable and the connector. A 20V wall adapter's output is hot-plugged into the device to simulate an accidental plug-in with the wrong adapter. To do a before and after comparison, the LTC4361, R_{SENSE} and MOSFET are removed and the same hot-plug is repeated with IN shorted to OUT. Figure 3 compares the two hot-plug waveforms. Due to the low capacitance at the IN pin, there is little overshoot and inrush current for the case with the

LTC4361 circuit. A higher voltage rated MOSFET can be used to protect the system against even higher transient or DC voltages up to the BV_{DSS} of the MOSFET. For example, a MOSFET with a 60V BV_{DSS} used with the LTC4361 is able to withstand transient and DC voltages up to 60V at IN.

The circuit in Figure 4 illustrates a worst case overvoltage situation that can occur at a mobile device power input. In a device with dual power inputs, a 20V wall adapter is mistakenly hot-plugged into the 5V adapter input with the 5V USB input already live. The LTC4360 detects the overvoltage at IN quickly and cuts off the MOSFET. But the large current built up in L_{IN} causes an inductive spike at IN. The body diode of the avalanche breakdown rated MOSFET breaks down to discharge this energy into C_{OUT} , clamping IN at about 40V, well below the 85V that IN can withstand. If the avalanche capability of the MOSFET is exceeded or the voltage rise at V_{OUT} due to the discharge of the energy in L_{IN} into C_{OUT} is not acceptable, an additional external clamp like the SMAJ24A can be placed between IN and GND.

CONCLUSION

The LTC4360 and LTC4361 overvoltage protection controllers use small footprint and low cost external N-channel MOSFETs while the LTC4362 incorporates this MOSFET into a 2mm × 3mm DFN package. Although these overvoltage protection circuits occupy very little PCB space, they are rich in features like an 85V rating at the input side and fast response in the event of overvoltage or overcurrent. In addition, there is a $\overline{\text{PWRGD}}$ status flag for the downstream circuits and a low power mode enabled by a CMOS compatible input to save battery power when necessary. The LTC4360, LTC4361 and LTC4362 form a simple yet effective and rugged barrier between the sensitive electronics inside a mobile device and real life accidents like faulty, substandard power adapters or a user's absent-mindedness in plugging in the wrong adapter. ■

Monolithic, Dual 3A Input/Output Buck with 3V–36V Operating Range Simplifies and Shrinks DC/DC Converters in Automotive, Industrial and Distributed Power Applications

Jonathan Paolucci

Automotive, industrial, and distributed power supplies often require buck converters to step down their poorly regulated outputs to produce the plurality of rails used by low voltage mixed signal systems. These supplies subject the step-down converters to a vast assortment of supply voltage transients, underscoring the need for rugged and efficient buck converters that provide tightly regulated outputs from a wide range of input voltages. The LT3692A, a monolithic dual 3A step-down converter, satisfies power demands imposed by these systems. Its wide 3V–36V input operating range and overvoltage transient protection up to 60V, allows it to easily reign in unruly automotive or industrial sources. Flexible configuration options allow the designer to power the LT3692A from one or two separate input supplies while producing two independent outputs, or to parallel the outputs to create one high current supply.

A TRUE DUAL SWITCHER

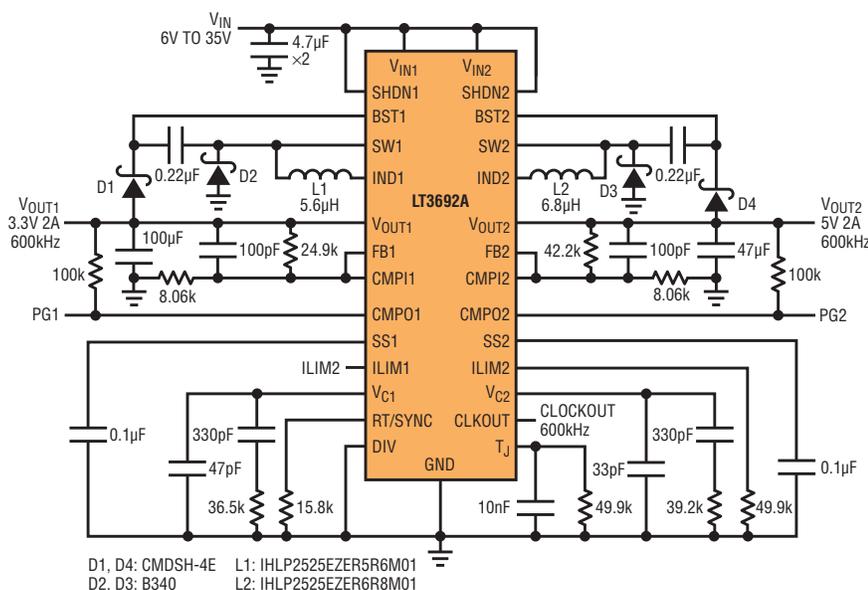
The LT3692A simultaneously offers high performance, high power, uncompromising features and high voltage operation in a dual monolithic switching converter. The two buck channels of the LT3692A shown in Figure 1 are completely independent. The channels can have different

input voltages, output voltages, current limits, power good outputs, soft-start, undervoltage lockouts and even different synchronized switching frequencies. Independent programmable undervoltage lockout permits a customizable operating range within 3V to 36V while withstanding up to 60V input transients.

The LT3692A tolerates low line conditions as well, thanks to an enhanced dropout scheme, which maintains greater than 95% maximum duty cycles regardless of switching frequency. Two independent programmable output current limits minimize component size and provide overload protection, while independent soft-start eliminates input current surges during start-up. Channel-independent internal thermal shutdown circuitry lends additional overload protection by allowing one switcher to continue operating despite a brief overload on the other channel.

Programmable power good pins, combined with a die junction temperature output pin, greatly simplify power sequencing and the task of monitoring the LT3692A supply. Adjustable or synchronized fixed-frequency operation spans 250kHz to 2.25MHz and a synchronized clock output allow multiple regulators to be synchronized to the LT3692A. A unique clock divide feature optimizes solution

Figure 1. Compact, dual-output converter produces 5V/2A and 3.3V/2A outputs from a 6V–36V input.



The two buck channels of the LT3692A are completely independent. Each can have its own input voltage, output voltage, current limit, power good output, soft-start ramp, undervoltage lockout and even its own synchronized switching frequency.

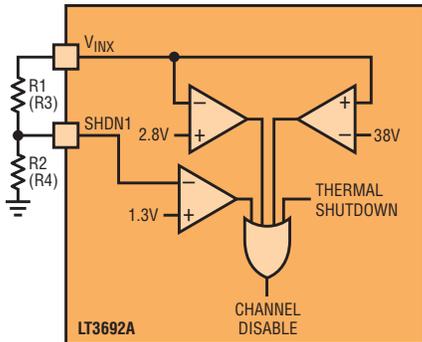


Figure 2. Block diagram shows undervoltage and overvoltage lockout functionality of the LT3692A.

size, efficiency and system cost by permitting channel 1 to operate at a synchronized frequency 1-, 2-, 4- or 8-times slower than the master clock frequency. The combination of a wide feature set and independent channel operation simplifies complex power supply designs.

UNDervOLTAGE AND OvERvOLTAGE LOCKOUT

A switching regulator appears as negative impedance to the source, potentially causing a latched fault if the source voltage drops and the regulator draws increasingly more current. Programmable undervoltage lockout (UVLO) offers an easy way to avoid this problem by preventing the buck converter from drawing current if the input voltage is too low to support full load operation. Overvoltage lockout (OVLO), on the other hand, prevents the converter from operating above its desired range. A default undervoltage and overvoltage lockout is internally set to 2.8V and 36V, respectively, but can be programmed to any value.

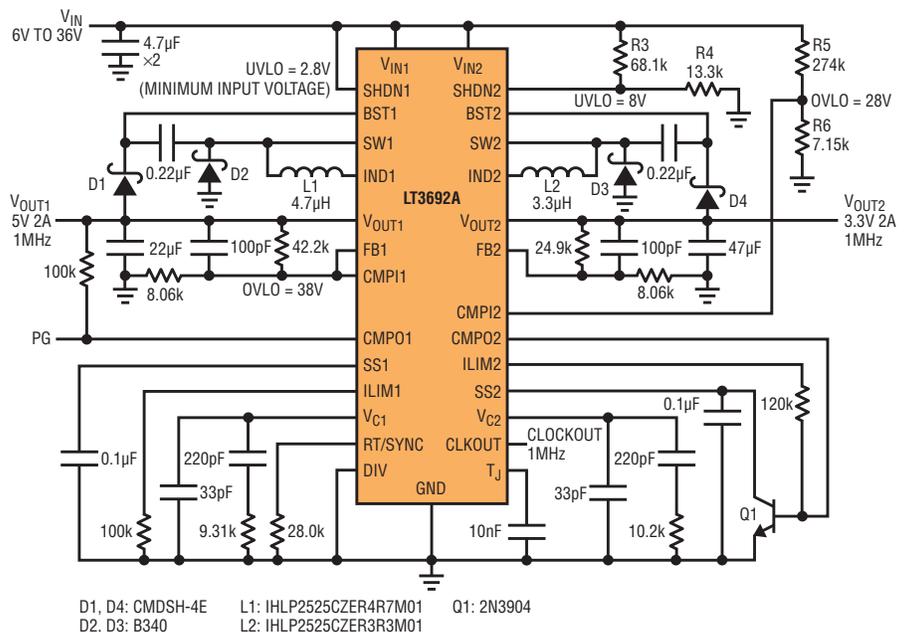
Referring to Figure 2, the LT3692A enters shutdown if SHDN1 is below 1.3V or V_{IN1} falls below 2.8V, protecting battery-powered systems from excessive discharge. All internal regulators are controlled by channel 1, effectively shutting down the entire IC if channel 1 enters shutdown. With sufficient V_{IN} voltage, Channel 1 is allowed to operate if SHDN1 exceeds 1.3V. The single voltage divider composed of the R1/R2 or R3/R4 combination controls the UVLO levels.

The circuit in Figure 3 shows how the LT3692A can be configured for

programmable UV/OVLO on one channel while utilizing the default UV/OVLO protection on the other channel.

A shutdown UV/OVLO or overtemperature condition causes an internal power-on reset latch to be enabled, discharging the soft-start and V_C pin capacitors. This latch remains set until the shutdown condition terminates, whereupon the LT3692A initiates a full start-up sequence. The soft-start voltage waveforms in Figure 4 show how the calculated UV/OVLO limits in Figure 3 protect the LT3692A during undervoltage and overvoltage power supply transients.

Figure 3. Dual converter with default and programmable UV/OVLO

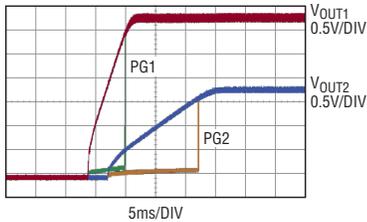


D1, D4: CMDSH-4E L1: IHLP2525CZER4R7M01 Q1: 2N3904
D2, D3: B340 L2: IHLP2525CZER3R3M01

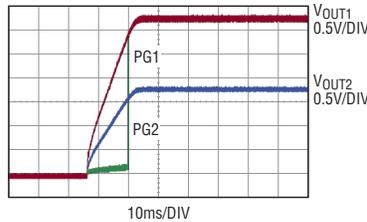
UNDervOLTAGE AND OvERvOLTAGE CALCULATIONS

V_{IN1} : (DEFAULT UV AND OV)	V_{IN2} :	V_{IN2} :
UVLO = 2.8V (MINIMUM INPUT VOLTAGE)	UVLO = 8V	OVLO = 28V
OVLO = 38V: R1 = 0Ω, R2 = OPEN (FIG 2)	SHUTDOWN THRESHOLD = 1.3V	CMPI THRESHOLD = 0.72V
	R4/(R3 + R4) = 1.3V/8V	R6/(R5 + R6) = 0.72V/28V
	R4 = 13.3k, R3 = 68.1k	R6 = 7.15k, R5 = 274k

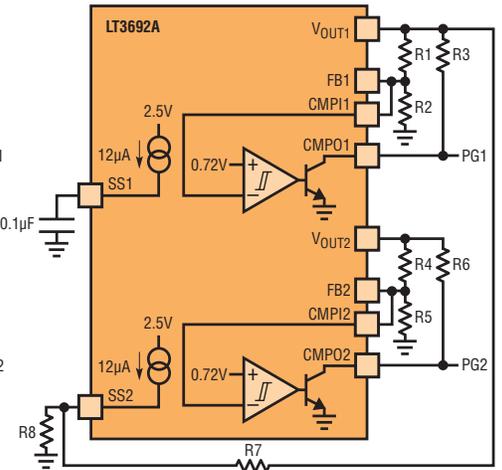
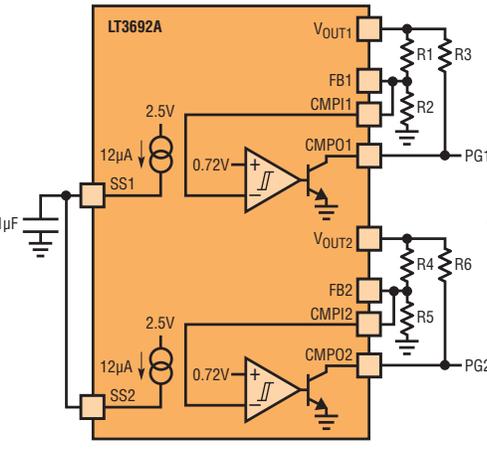
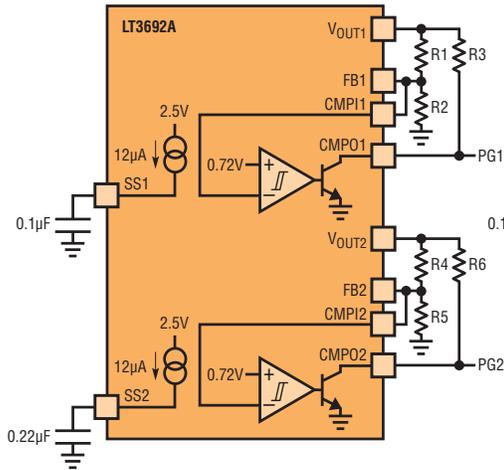
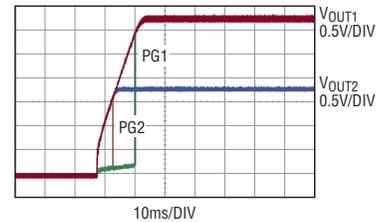
INDEPENDENT START-UP



RATIOMETRIC START-UP



ABSOLUTE START-UP



PROGRAMMABLE POWER GOOD AND START-UP SEQUENCING

The LT3692A provides access to the positive inputs of the power good (PG) comparators via the CMPI pins. Each negative comparator input is fixed at 0.72V to allow tying of the input to the feedback pin (806mV reference) for a standard 90% power good signal. Other inputs (divided down) could come from the internal junction temperature pin (T_J) for overtemperature indication or the input voltage to indicate input power good. The comparator output could be tied to one of the soft-start pins to disable a channel, the DIV pin to change the frequency, the ILIM pin to reduce the current, or any external device to communicate information. These comparators are versatile and allow for custom, compact solutions.

Start-up sequencing and control is vitally important in modern electronics. Complex output tracking and sequencing between channels can be implemented using the LT3692A's SS and PG pins. Figure 5

shows various output start-up waveforms and their associated schematics.

The ss pins also double as independent channel shutdown pins. Pulling either channel's soft-start pin below 115mV disables switching for that channel.

PROGRAMMING THE SWITCHING FREQUENCY

Programming the LT3692A switching frequency could not be easier. The RT/SYNC pin accurately sources 12µA, so only a single resistor (R_{SET}) is required to set the pin voltage and thus the switching frequency as given by the following:

$$R_{SET}(k\Omega) = 1.86E^{-6} \cdot f_{SW}^2 + 0.0281 \cdot f_{SW} - 1.76$$

with the switching frequency (f_{SW}) in kHz for frequencies between 150kHz and 2.25MHz.

To avoid start-up problems, the LT3692A limits the minimum switching frequency to a typical value of 110kHz. This feature, coupled with adding a small capacitor in parallel with the frequency-programming resistor,

adds a user-programmable frequency foldback function during start-up.

ELIMINATE THE CLOCK

More rails mean more converters. If any of those converters are operating at different frequencies, then the interference beat frequencies produce radiated and conducted EMI in addition to the switching fundamental and harmonic frequencies. For example, a converter switching at 1.015MHz and a converter switching at 1.005MHz combine for a beat frequency of 10kHz, right in the audio band.

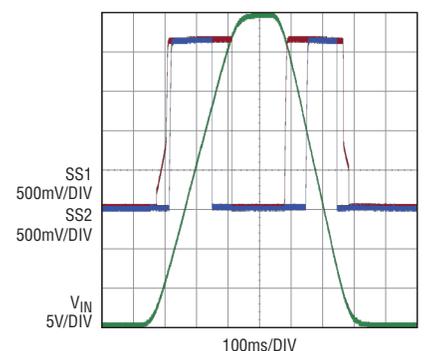
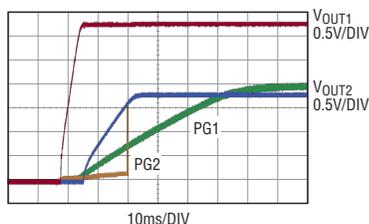


Figure 4. Soft-start voltage during UVLO/OVLO

OUTPUT SEQUENCING



CONTROLLED POWER UP AND DOWN

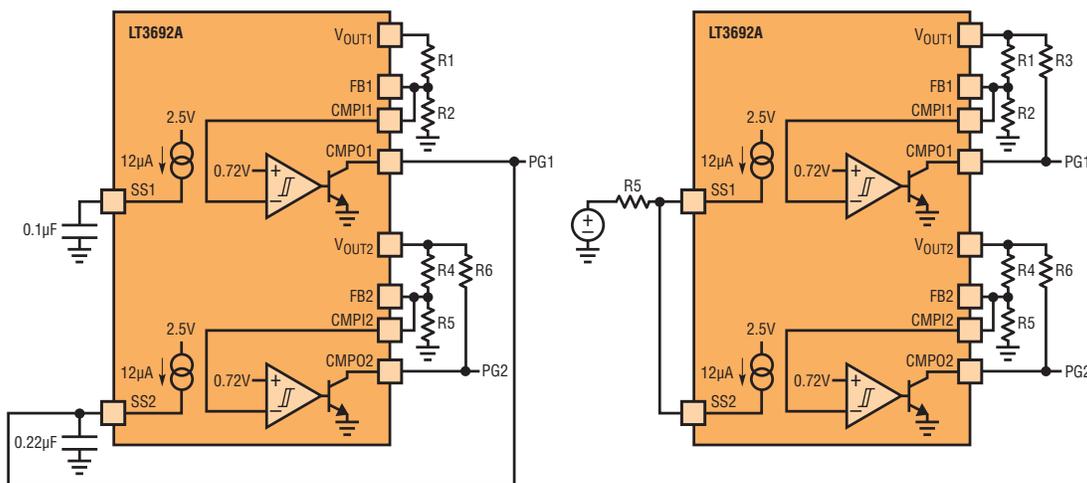
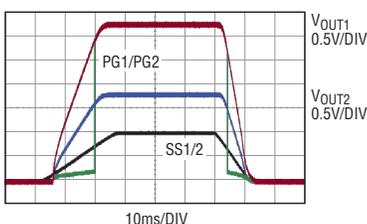


Figure 5. Soft-start pin configurations

Beat frequencies can easily interfere with any signal path with similar frequencies. Traditionally, the solution involves synchronizing the converters by means of an external oscillator. The LT3692A outputs a 0-to-2.5V square wave on the CLOCKOUT pin, which matches its free running internal oscillator or the signal on the RT/SYNC pin. Since the LT3692A can be used as an oscillator source, this eliminates the need for an external oscillator, reducing cost and solution footprint. The circuit in Figure 7 shows how the CLOCKOUT signal

can synchronize two LT3692A converters operating at 1MHz. A single high current 3.3V/10A output rail is created by connecting the V_{OUT}, FB, SS and V_C pins between the two LT3692As. Additionally, the finite synchronization signal-to-switch delay allows the four channels to be synchronized with a 90° phase shift between each channel (shown in Figure 8), reducing the output voltage ripple and bulk input and output capacitances.

LT3692A SYNCHRONIZATION

The LT3692A RT/SYNC input offers a unique synchronization feature—the duty cycle of the input synchronization signal controls the switching phase difference between the two channels. Channel 1’s rising switch edge synchronizes to the rising edge of the signal; channel 2’s rising switch edge synchronizes to the falling edge of the signal. By varying the synchronization duty cycle, the LT3692A dual switches can be operated anti-phase and in some cases non-overlapping, effectively reducing the input current ripple and required input capacitance.

For example, the input ripple voltage shown in Figure 9 has a peak of 472mV for a typical anti-phase dual 14.4V-to-8.5V and 14.4V-to-3.3V regulator. Figure 10 shows that the input ripple voltage is decreased to 160mV by driving the LT3692A with a 71% duty cycle synchronization signal to generate a 256° phase shift between the channels.

DROPOUT ENHANCEMENT

Switching regulator dropout performance is vitally important in systems where the input voltage may drop close to, and sometimes below, the regulated output voltage. During a low input voltage condition, the converter should supply an output voltage as close to the regulation voltage as possible in order to keep the output running. Ideally, in such cases, the switching regulator would run at 100% duty cycle, simply passing the input to the output, but this is not possible because of the minimum switch off-time, which limits the switching duty cycle.

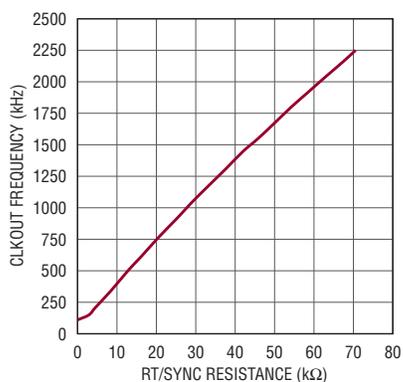


Figure 6. Switching frequency vs RT/SYNC resistance

The LT3692A tolerates low line conditions as well, thanks to an enhanced dropout scheme, which maintains greater than 95% maximum duty cycles regardless of switching frequency.

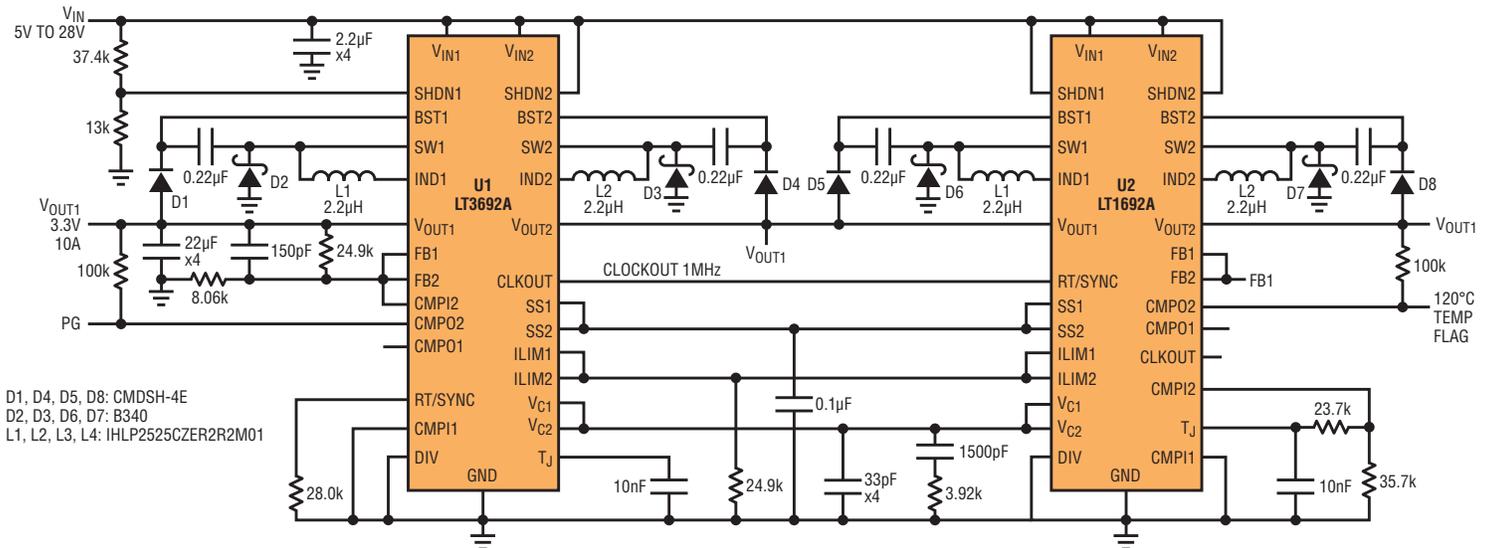


Figure 7. 3.3V, 10A 4-phase converter with UVLO, power good, 120°C junction temperature flag, and minimal input current ripple

Because the minimum switch off-time is a fixed value, the maximum switching duty cycle can be increased simply by decreasing the switching frequency, but a lower switching frequency necessitates larger filter components to achieve low output voltage ripple. The

LT3692A circumvents dropout limitations by keeping the monolithic high side switch on for multiple switch cycles, only terminating the extended switch cycle when the boost capacitor needs to be recharged. This unique dropout switching technique allows the LT3692A to

achieve up to a 95% maximum duty cycle, independent of switching frequency. The graph in Figure 11 compares the dropout performance of a LT3692A to a similar buck converter at 200kHz and 2MHz. Both converters show similar dropout performance at 200kHz; however, at

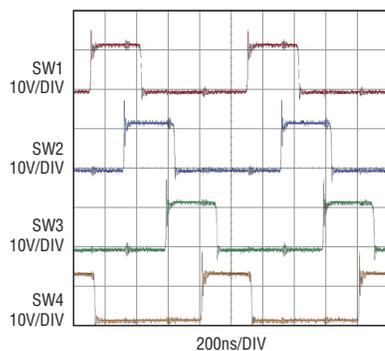


Figure 8. 4-phase converter switch waveforms

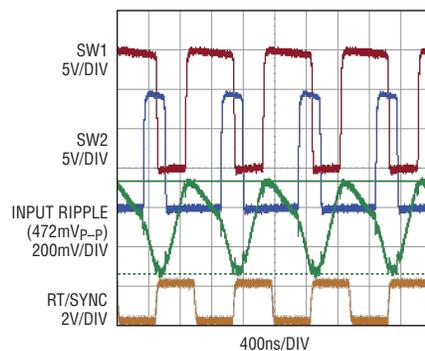


Figure 9. Dual 14.4V/8.5V, 14.4V/3.3V with standard 180° phase shift between channels

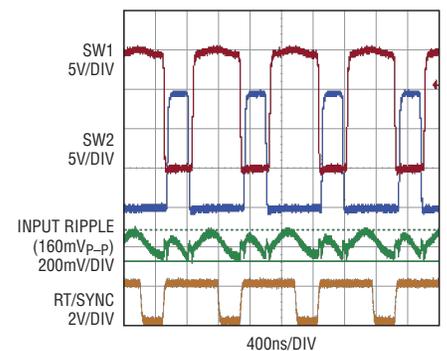


Figure 10. Dual 14.4V/8.5V, 14.4V/3.3V with 256° phase shift between channels shows significant reduction in input voltage ripple. Phase shift is programmed by the duty cycle of the input synchronization signal.

Separate input supply pins (V_{IN1}/V_{IN2}) allow the LT3692A's two channels to be operated in cascade, with the output of one buck powering the input of the other. A cascade configuration allows high input/output ratios at high frequencies while simultaneously creating two rails.

2MHz, the LT3692A regulates the output to 5V at a much lower input voltage.

NEVER SKIP A PULSE

High frequency switching permits smaller components, but it also means shorter pulse widths. Buck converters have inherent minimum on-times that prohibit high step-down ratios at high frequency. When the input voltage rises too high, the converter skips a pulse. Though using the built-in pulse skipping inherent in many buck converters sounds appealing, the output voltage ripple suffers significantly, as shown in Figure 12.

Pulse skipping can be avoided by reducing the switching frequency, but in a dual converter, one channel may benefit from switching at a higher frequency than the other channel. For instance, consider a dual buck converter with an input voltage range of 7V to 36V and output voltages of 5V and 1.8V. At the high end of the input voltage range, the switching

frequency required to avoid pulse skipping on the 5V channel is almost three times greater than that required by the 1.8V channel. By running a dual converter at the lower frequency—chosen to avoid pulse skipping on the 1.8V channel—the 5V channel requires inductor and capacitor values that are three times larger than it would if run at the higher frequency.

The LT3692A avoids this predicament by adding a DIV pin that divides the clock by 1, 2, 4, or 8, allowing channel 1 to run at a lower synchronized frequency. Figure 13 shows an application that runs at 250kHz and 1MHz for the low voltage and higher voltage channels, respectively. Figure 14 shows the switching waveforms. If channel 1 ($V_{OUT} = 1.8V$) runs at 1MHz, the maximum input voltage for constant output voltage ripple is only 15V, but at 250kHz the maximum voltage for constant output ripple exceeds the LT3692A overvoltage limit of 38V. Table 1 shows the maximum

input voltage for constant output voltage ripple for various switching frequencies.

INDEPENDENT SUPPLY INPUTS

Separate input supply pins (V_{IN1}/V_{IN2}) allow the LT3692A's two channels to be operated in cascade, with the output of one buck powering the input of the other. A cascade configuration allows high input/output ratios at high frequencies while simultaneously creating two rails. For instance, the converter in Figure 15 is designed for 3.3V/2.5A at 550kHz and 1.2V/1A at 2.2MHz across the full input voltage range.

The benefits of cascading both converters on the same chip are numerous:

- The switching frequency is already synchronized with anti-phase switching to reduce ripple
- Custom start-up options are readily available
- Pulse-skipping mode is easily avoided

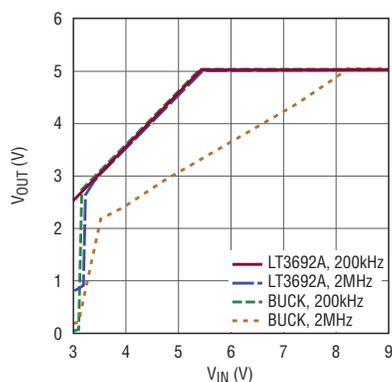


Figure 11. The LT3692A dropout enhancement feature improves dropout performance over a standard buck regulator at high switching frequencies.

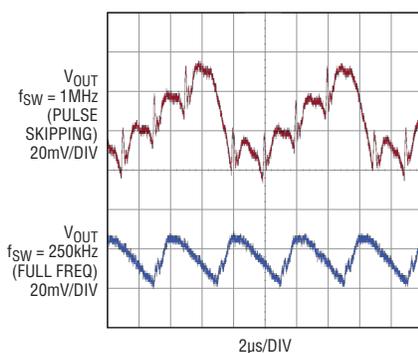


Figure 12. Many regulators will enter pulse-skipping mode when they can't support the large step-down ratio that occurs when the input voltage rises too high. The pulse-skipping solution is automatic and easy, but it significantly increases output noise.

FREQUENCY (kHz)	RT/SYNC (kΩ)	$V_{IN(MAX)}$ (V)
250	5.90	38
500	13.0	30
1000	28.0	15
1500	44.2	10
2250	69.8	6

Table 1. Maximum input voltage for constant output voltage ripple ($V_{OUT} = 1.8V$)

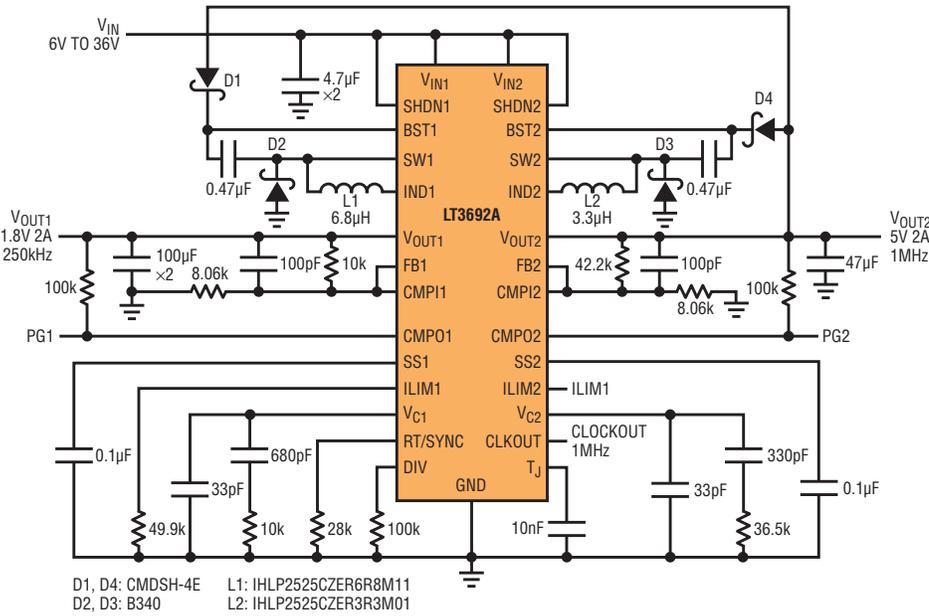


Figure 13. The LT3692 can avoid pulse skipping by decreasing the operating frequency of its low voltage channel, while leaving the higher voltage channel at a higher frequency. By running the higher voltage channel at a higher switching frequency, one can still use a small inductor and output capacitor for that channel. Here, channel 2 (5V) runs four times faster than channel 1 (1.8V) by setting the DIV pin to 1.2V.

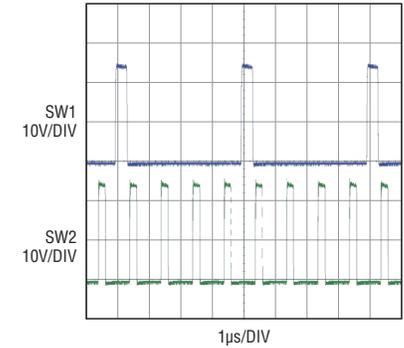


Figure 14. A 5V and 1.8V dual multi-frequency converter avoids pulse-skipping mode for each channel throughout the input range while minimizing component sizes on each channel.

- The overall solution takes much less space than multi-IC solutions.

ONE SIZE DOESN'T FIT ALL

Even if a switching regulator, such as the LT3692A, can safely withstand overload conditions, all the external components,

such as the inductors and diodes, must be sized to withstand steady-state overload conditions as well. If the maximum load drawn from a buck output is 1A, but the buck converter's internal current limit is set to 4A, then all external components must be rated for the maximum 4A load

in order to ensure safe functionality. By sizing the external components for fault conditions, rather than typical operating conditions, the overall solution tends to be oversized and unnecessarily expensive.

Figure 15. A 3.3V and 1.2V dual 2-stage converter

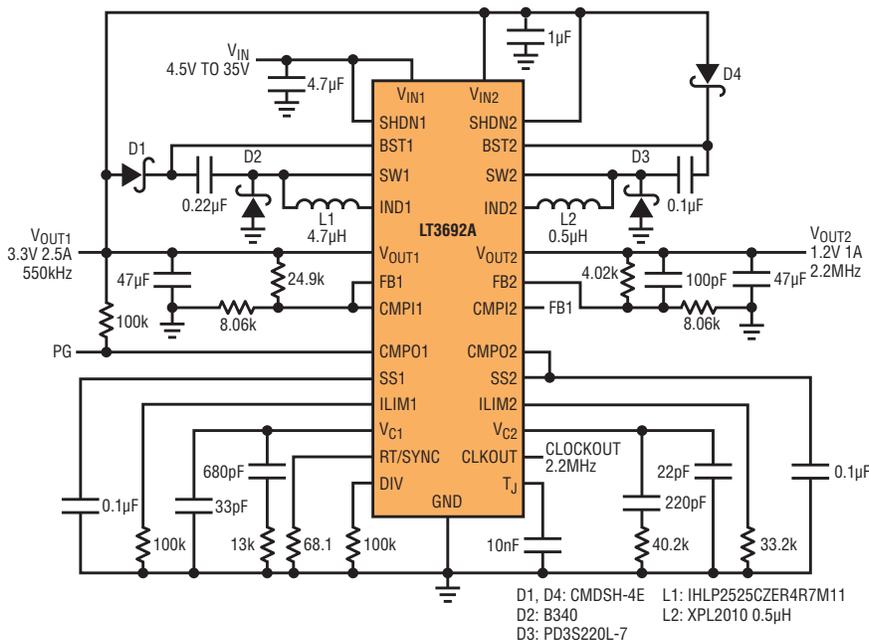
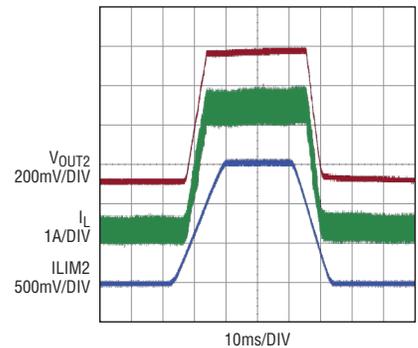


Figure 17. Current limit programming with ILIM voltage



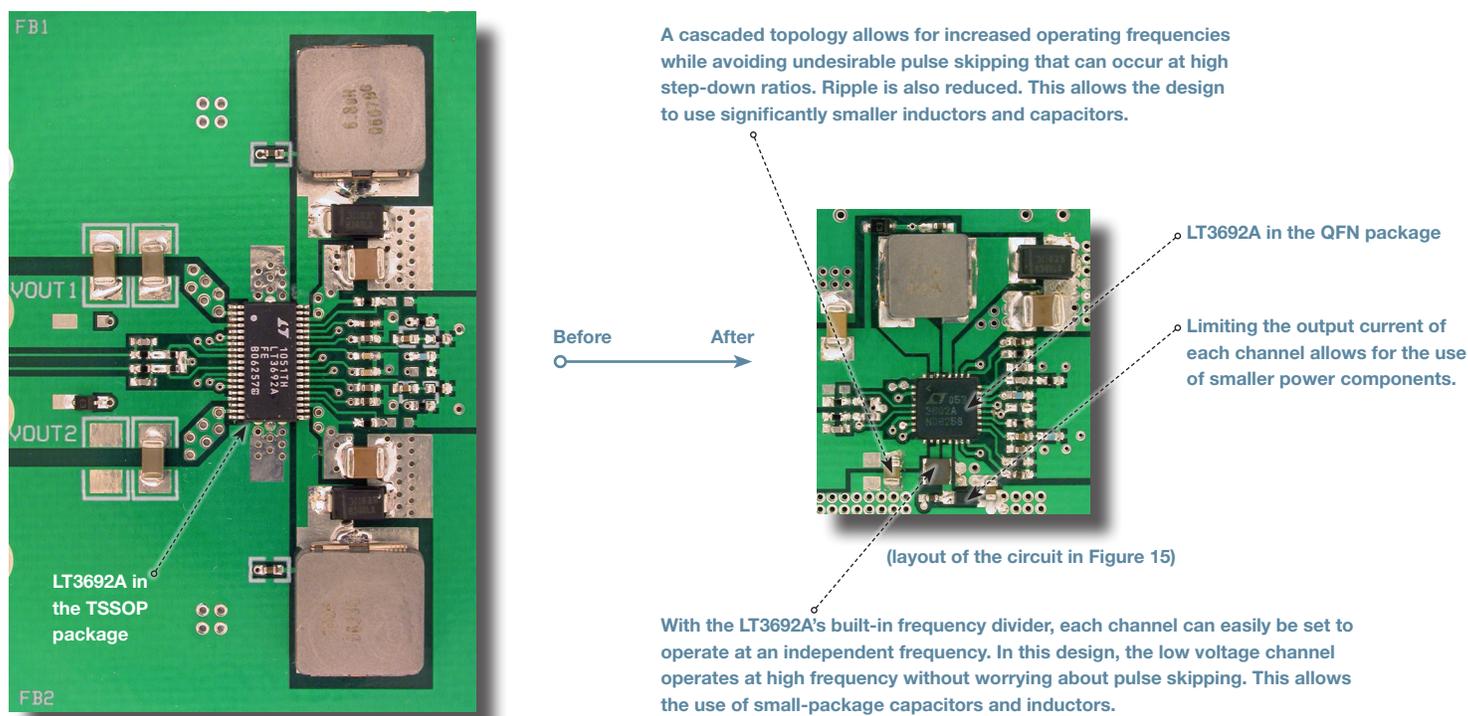


Figure 16. Comparison of two designs for a dual-output 3.3V/2.5A and 1.2V/1A converter using the LT3692A. The smaller version of the circuit saves board space by taking advantage of features that the larger circuit does not, including current-limiting the outputs, cascading the channels and running the two channels at different switching frequencies.

The LT3692A remedies this problem by providing an independent current limit pin (ILIM). If full output current capability is not needed on one or both channels, the user-selectable current limit allows the use of smaller, cheaper components. Each channel's current limit can be set from 2A to 4.8A by the ILIM pin voltage. An accurate 12 μ A internal current source allows the current limit to be programmed with a single external resistor or voltage on the ILIM pin. The ILIM pin may be grounded as well, limiting the maximum output current to 2A. This feature allows the user to implement current foldback during start-up simply by placing a small value capacitor in parallel with the current-limit-programming resistor. The 12 μ A internal current source charges the optional ILIM cap from zero volts to its final steady-state value, allowing the current limit to gracefully ramp from 2A to 4.8A.

Board space is significantly reduced by using the ILIM feature, as shown in Figure 16. By employing the ILIM pin function, as well as operating the channels in cascade with independent switching frequencies, the power components from the circuit in Figure 15 reduce board space 3-fold, underscoring the usefulness of the ILIM pin.

OVERLOAD CONDITIONS

If the load exceeds the maximum output current, the output voltage drops below the normal regulation point. The drop in output voltage activates the v_C pin clamp and discharges the ss capacitor, lowering the ss voltage. The LT3692A regulates the feedback voltage to the lowest voltage present at either the ss pin or the internal 806mV reference. As a result, the output is regulated to the highest voltage that the maximum output current can support. Once the overload condition is removed, the output

soft-starts from the temporary voltage level to the normal regulation point.

Figure 17 shows the output voltage and inductor current for the 1.2V channel in Figure 15 when loaded by a 0.2 Ω load. As the ILIM pin voltage is varied from 0V to 1.5V, the output voltage is regulated between 0.32V and 0.96V, limiting the current between the range of 1.6A and 4.8A.

WATTS FROM HERE AND WATTS FROM THERE

Ever wanted to draw power from a rail, but needed just a few more watts? A last-minute increase in power requirements leaves you stuck in a bind? Now you can draw power from two different sources with programmable limits for each source. The independent v_{IN} and ILIM pins allow the two independent input supplies in Figure 18 to be programmed to different current limits. With the ss, v_C , and v_{OUT} pins tied together, the two inputs serve a single output rail. The

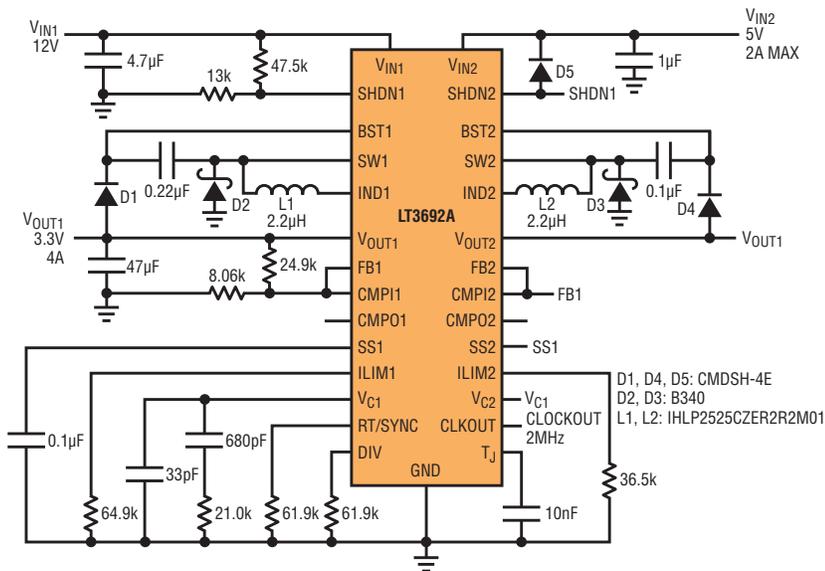


Figure 18. Dual input single 3.3V output converter

power drawn from each rail is shown in Figure 19. This solution provides flexibility in rail voltages and utilization of available power, making it easy to solve power-sharing problems.

ALWAYS KNOW YOUR JUNCTION TEMPERATURE

The LT3692A T_J pin outputs a voltage proportional to the internal junction temperature. At a junction temperature of 25°C, the T_J pin outputs 250mV and has a slope of 10mV/°C. Without the aid of external circuitry, the T_J pin output is valid from 20°C to 150°C with a maximum load of 100µA. To extend the operating temperature range of the T_J output below 20°C, connect a resistor from the T_J pin to a negative supply as shown in Figure 20. The negative rail voltage and T_J pin resistor may be calculated using the following equations:

$$V_{NEG} \leq \frac{(2 \cdot \text{TEMP}_{MIN}(\text{°C}))}{100}$$

$$R1 \leq \frac{|V_{NEG}|}{33\mu\text{A}}$$

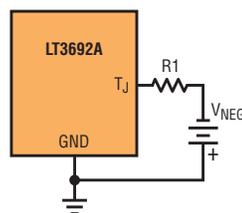


Figure 20. Circuit to extend T_J operating region

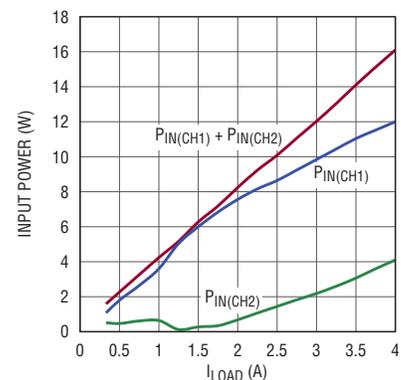


Figure 19. Power draw from two sources for single output

where TEMP_{MIN} is the minimum temperature where a valid T_J pin output is required. V_{NEG} = regulated negative voltage supply.

For example,

$$\text{TEMP}_{MIN} = -40\text{°C}$$

$$V_{NEG} \leq -0.8\text{V}$$

$$V_{NEG} = -1$$

$$R1 \leq \frac{|V_{NEG}|}{33\mu\text{A}} = 30.2\text{k}$$

The simple charge pump circuit in Figure 21 uses the CLKOUT pin output to generate a negative voltage, eliminating the need for an external regulated supply. Surface mount capacitors and dual-package Schottky diodes minimize the board area needed to implement the negative voltage supply.

CONCLUSION

The LT3692A squeezes two complete regulators, including dual monolithic 3.8A switches, into a 38-lead exposed pad TSSOP or a 5mm × 5mm 32-lead exposed pad QFN package. The two channels operate independently, making it possible to produce two high performance buck converters with one part, thus minimizing circuit size and simplifying complex designs. Separate soft-start, current limit, power good, and UV/OVLO features enable the designer to address unique power sharing, solution area, and start-up sequencing requirements. With a wide operating range and a rich feature set, the LT3692A easily tackles a wide variety of automotive, industrial and distributed supply challenges. ■

Notes

* Many thanks to Scott McClusky for his assistance in producing this article

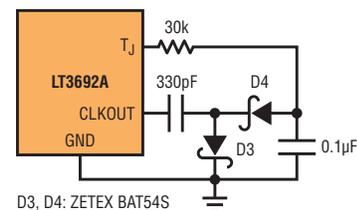


Figure 21. Negative rail generated from CLKOUT

3A Output, 96% Efficient Buck-Boost DC/DC Converter Sets the Standard for Power Density and Noise Performance

Richard Cook

High power density has become a primary requirement for DC/DC converters, as they must keep up with ever increasing functional density of electronics. Likewise, power dissipation is a major concern for today's functionally rich, tightly packed devices pushing the need for highly efficient solutions to minimize temperature rise. For applications where the input voltage source can be above or below the regulated output voltage, finding an efficient compact solution can be a challenge, especially at elevated power levels. Conventional design approaches, such as using a dual inductor SEPIC converter, produce relatively low efficiencies and relatively large solution sizes.

The LTC3113 single inductor buck-boost converter offers a compact, highly efficient alternative. Internal low resistance switches allow the converter to support an impressive 3A of load current in a tiny 4mm × 5mm package. The LTC3113 offers an extended input and output operating voltage range from 1.8V to 5.5V, with peak efficiencies reaching 96%. The internal PWM controller is designed for low noise performance and offers a seamless transition between buck and boost modes. The combination of these features

allows the LTC3113 to easily meet challenging high density power requirements.

Figure 1 shows an 11mm × 14mm × 2.5mm LTC3113-based solution that can supply up to 12W of output power from a Li-ion battery. This translates to a power density of 31mW/mm³ (511W/in³). A complete SEPIC design would require twice as much PCB area, resulting in half the power density and significantly lower efficiency, which complicates thermal design.

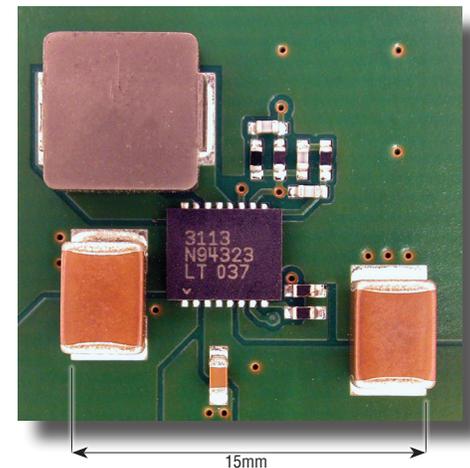
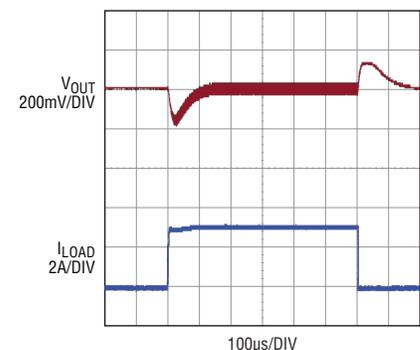
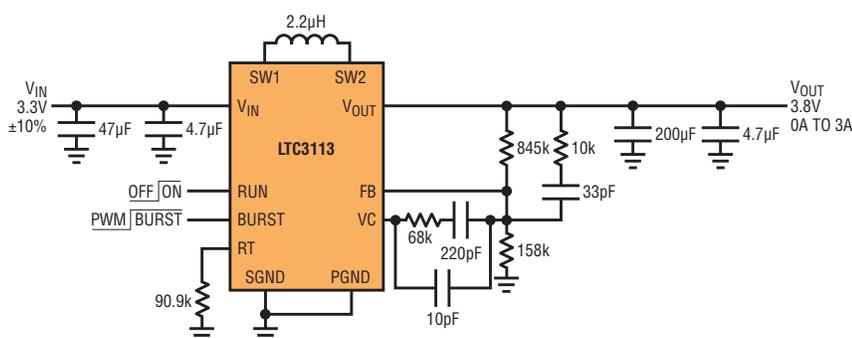


Figure 1. A typical application occupies 154mm²

The LTC3113 offers a number of options to optimize performance for specific applications, including the ability to adjust the operating frequency from 300kHz to 2MHz, internal soft-start, user selectable Burst Mode[®] operation for improved efficiency at light load currents, and a host of fault protection features including short-circuit protection and thermal shutdown. The LTC3113 is available in both a 4mm × 5mm DFN and a 20-pin thermally enhanced TSSOP.

Figure 2. Pulsed load or portable RF power amplifier power supply and typical output response



The LTC3113 single inductor buck-boost converter offers a unique combination of features to meet challenging high density power requirements. Internal low resistance switches allow the converter to support an impressive 3A of load current in a tiny 4mm × 5mm package, with peak efficiencies reaching 96%. The internal PWM controller is designed for low noise performance and offers a seamless transition between buck and boost modes.

GSM APPLICATION

Many GSM applications require expensive supercapacitors on the DC/DC output supply rail to support the temporary heavy loads placed on the output by the power amplifier during transmission bursts. In many cases, the high output current capability of the LTC3113 is sufficient to support the transmit current without the need for supercapacitors. Figure 2 shows such a circuit and associated typical load transient for an RF power amplifier using a standard, inexpensive 100µF ceramic capacitor on the 3.8V output.

The oscilloscope photo shows the response of the 3.8V output when a 3A load pulse lasting 580µs is applied. For this extreme case the output voltage undershoots only 150mV (4.5%) and quickly recovers. The output voltage overshoot when the load is removed shows a similar response. For this external load pulse, the transient response has been optimized by tailoring the compensation to minimize the effects of the load step.

NOISE PERFORMANCE

Many applications, including RF transmission, are sensitive to noise generated by switching converters. The LTC3113 uses a low noise switching architecture to reduce unwanted subharmonic frequencies, which occur below the operating frequency and can interfere with other sensitive circuitry. These subharmonics usually occur when V_{IN} and V_{OUT} are approximately equal. Buck-boost converters operating in this region typically produce pulse width and frequency jitter—a result of all four switches changing state during a single switching cycle. The LTC3113 minimizes the magnitude of the jitter or subharmonic frequencies to satisfy the requirements of noise-sensitive RF applications.

Figure 3 shows worst-case spectral comparisons of the LTC3113 and a competitive buck-boost converter without the low noise architecture of the LTC3113. The worst-case condition was achieved by placing a fixed 1A load on the output and slowly increasing or decreasing the input voltage until the greatest harmonic content in the converter spectrum

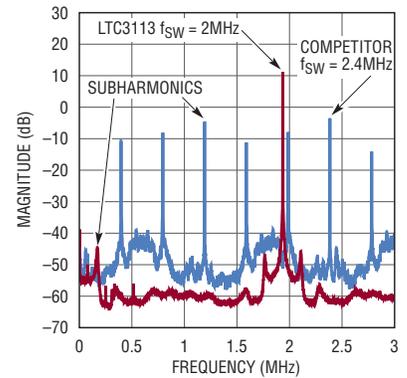
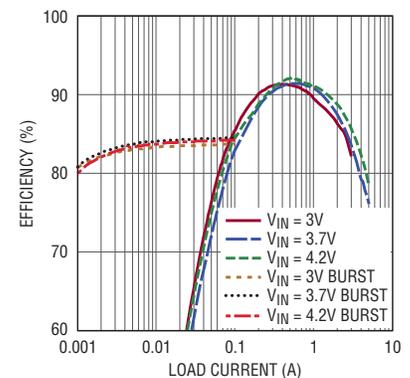
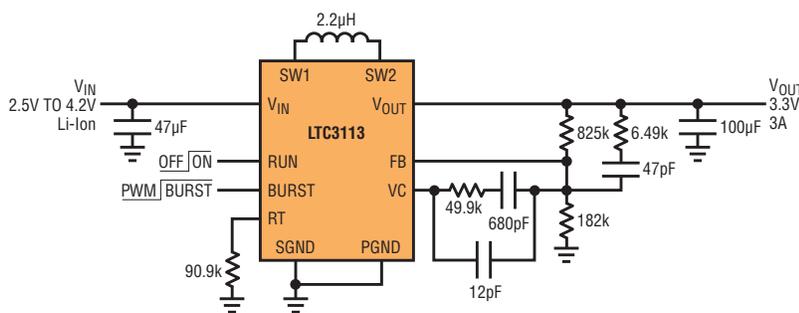


Figure 3. Spectral comparison of the LTC3113 and typical competitor's part

was observed. The LTC3113 exhibits an expected single large magnitude tone at its switching frequency of 2MHz. In contrast, the competing buck-boost exhibits several high magnitude subharmonic and harmonic tones across the entire frequency range, indicative of significant pulse width jitter and potential noise interference issues. Note also that the overall noise floor of the LTC3113 is 10dB to 20dB lower than the competition across the entire frequency range.

Figure 4. Li-ion to 3.3V supply and efficiency



The LTC3113 monolithic buck-boost converter breaks new ground in power density, low noise operation and high efficiency across a wide range of load currents.

SINGLE LI-ION TO 3.3V, 10W CONVERTER

Besides generating bias voltages for RF power amplifiers, creating a 3.3V rail from an input source such as a Li-ion battery is another common application for a buck-boost converter. The LTC3113 can provide up to 10W (3.3V/3A) of output power over the Li-ion battery's usable range. Figure 4 shows a typical application schematic used to generate 3.3V. Also shown are the associated efficiency curves for different battery voltages over a range of load currents for this application. The efficiency peaks at 92% and efficiencies greater than 80% are achieved from loads ranging from 60mA to 3A. Burst Mode operation employs a variable frequency-switching algorithm to maintain highly efficient conversion at lighter loads.

Setting the BURST pin to a voltage greater than 1.2V allows the LTC3113 to enter Burst Mode operation at light loads to maximize efficiency. For noise sensitive applications the converter can be forced into fixed frequency operation by keeping the voltage on the BURST pin below 0.3V.

BACKUP POWER SYSTEMS

Figure 5 shows a supercapacitor-powered backup power supply system, where the LTC3113 is used to provide a regulated 3.3V output at a constant 1.5A load. In this application, two series 30F supercapacitors have been charged to 4.5V during normal operation to provide the needed backup energy when the primary power is lost.

The scope photo shows that the LTC3113 can regulate the output for 22.5s when powered only by the two series 30F capacitors. Over this time, the capacitors discharge from an initial 4.5V to just below 1.8V—output regulation over this input range is only possible because of the LTC3113's low input voltage capability. In this example, the amount of energy supplied by the input is:

$$E_{IN} = \frac{1}{2} \cdot C \cdot \left[(V_{INITIAL})^2 - (V_{FINAL})^2 \right]$$

$$E_{IN} = \frac{1}{2} \cdot 15F \cdot (4.5V^2 - 1.8V^2) = 127.6J$$

The output is regulated to 3.3V with a constant load of 1.5A for 22.5s, which yields output energy of:

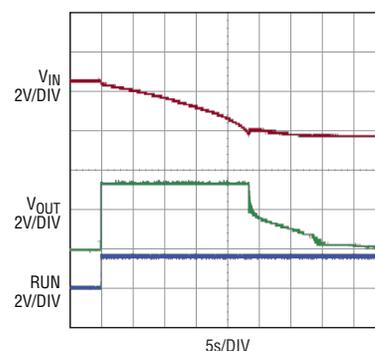
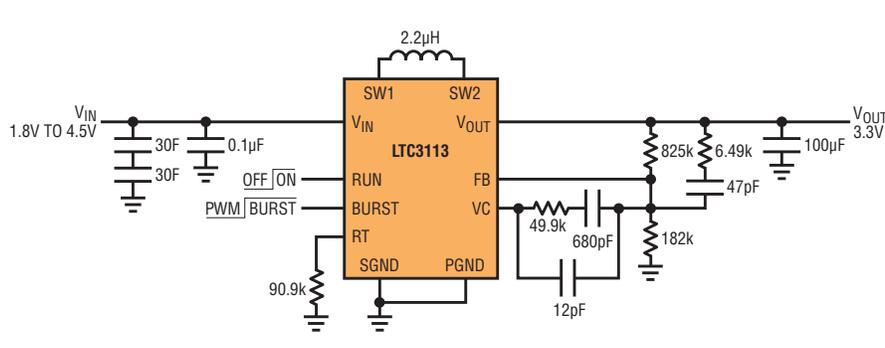
$$\begin{aligned} E_{OUT} &= I_{OUT} \cdot V_{OUT} \cdot t \\ &= 1.5A \cdot 3.3V \cdot 22.5s \\ &= 111.4J \end{aligned}$$

This shows that about 87% of the available input energy is converted to output power. The solution size for this application is about 11mm × 14mm, excluding the area of the supercapacitors.

CONCLUSION

The LTC3113 monolithic buck-boost converter breaks new ground in power density, low noise operation and high efficiency across a wide range of load currents. The LTC3113 is an ideal solution for battery-powered products, backup power supply systems and RF or other noise-sensitive applications. ■

Figure 5. Supercapacitor-powered supply and typical output response with 1.5A load



Intermediate Bus Buck Regulator Maintains 5V Gate Drive During Automobile Cold Crank Conditions

Theo Phillips and Tick Houk

DC/DC converters in today's automobiles often take their inputs from a loosely regulated 5V intermediate bus, instead of directly from the battery voltage (which can vary from 4V during cold crank to above 24V from double-battery jump-starts and other transients). Incorporating an intermediate voltage bus has a number of advantages, one of which is the expanded range of DC/DC converter options available to power downstream electronics. Power supply designers can choose from a wide variety of low dropout (LDO) and switching post-regulators that have 6V absolute maximum input voltage ratings. Because typical post-regulator outputs are substantially lower than 5V—from 3.3V down to 1V—they can continue to operate even as their inputs drop below the nominal 5V. With this in mind, the ideal intermediate step-down regulator would continue to provide power even under cold crank conditions, where the battery voltage can drop below 5V.

A synchronous buck regulator often makes the best intermediate bus converter for these applications because of its high efficiency over a wide input range when compared to linear regulators. In this buck topology, 40V MOSFETs are necessary to tolerate double battery and high voltage transients, so the regulator should provide the required minimum 4.5V gate drive for the power MOSFETs during cold engine cranking.

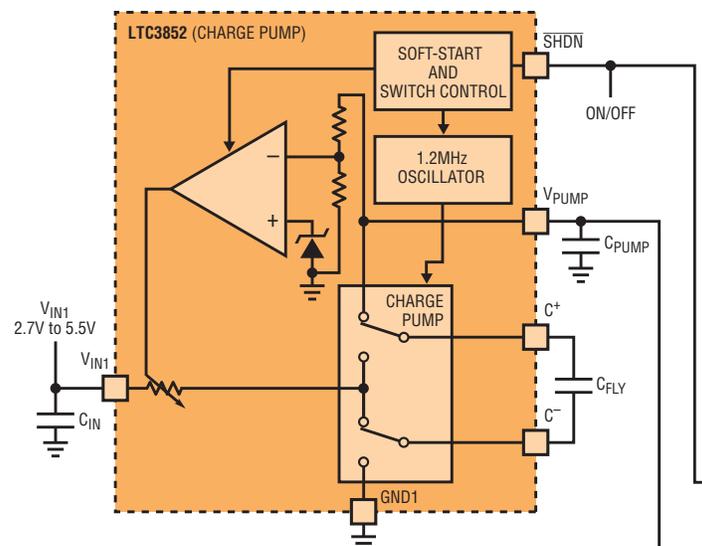
Buck regulator controllers have traditionally provided gate drive power through either an external 5V supply or through an onboard LDO. Both of these supply options can only step down an input voltage, so the gate drive potential drops with the input voltage, limiting the operating range of the regulator. The ideal controller would require no auxiliary supply and would provide the required 5V gate drive voltage even when the input supply

voltage drops below the minimum specified V_{GS} rating of the power MOSFETs.

BEST OF BOTH WORLDS

The LTC3852 is a synchronous step-down DC/DC controller with a low voltage charge pump designed to provide 5V drive to external MOSFETs even when the input drops below 5V. Figure 1 shows the block diagram of the IC. The

Figure 1. The two core circuit blocks of the LTC3852: a step-down DC/DC controller block and a charge pump doubler block, which allows the controller to continue running even when inputs drop below 5V.

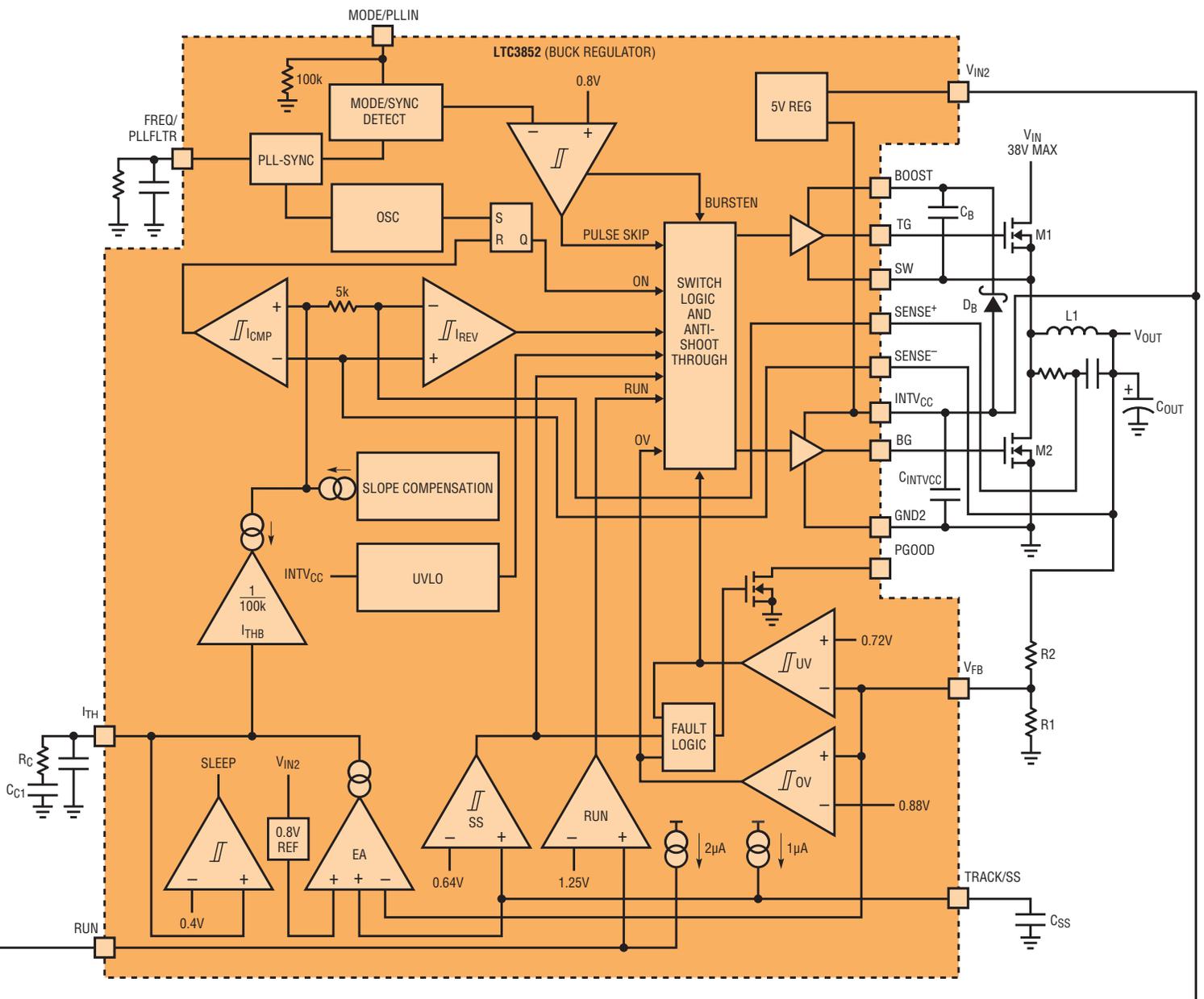


The ideal intermediate step-down regulator would continue to provide power even under cold crank conditions, where the battery voltage can drop below 5V. The LTC3852 does just that—even when its input drops below 5V, its integrated low voltage charge pump produces the necessary 5V drive for the external MOSFETs.

LTC3852 contains two core circuit blocks, a step-down DC/DC controller and a charge pump doubler. The LTC3852 can be configured to operate from voltages as low as 2.7V, as shown in Figure 2,

or as high as 38V, as shown in Figure 3. Figure 4 shows a DC/DC converter that operates over a wide input voltage range and provides 5V gate drive to the MOSFETs even when V_{IN} falls below 5V.

The charge pump doubler inside the LTC3852 provides a regulated 5V output at V_{PUMP} . As the schematic of Figure 4 shows, V_{PUMP} is typically connected to V_{IN2} , the main supply for the DC/DC buck



If V_{IN} falls below 5V, the switching regulator enters dropout operation. V_{OUT} also falls, but remains high enough for the post-regulator LDOs to continue regulating their output voltages.

Figure 2. A high efficiency step-down converter that provides 5V gate drive over a 2.7V to 5.5V input range

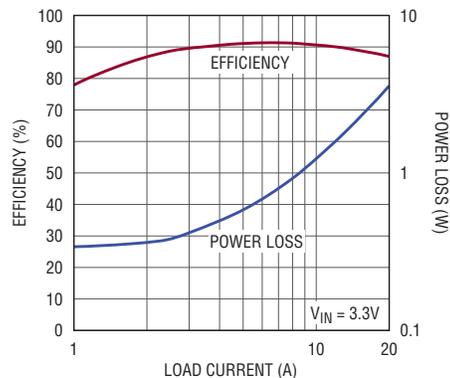
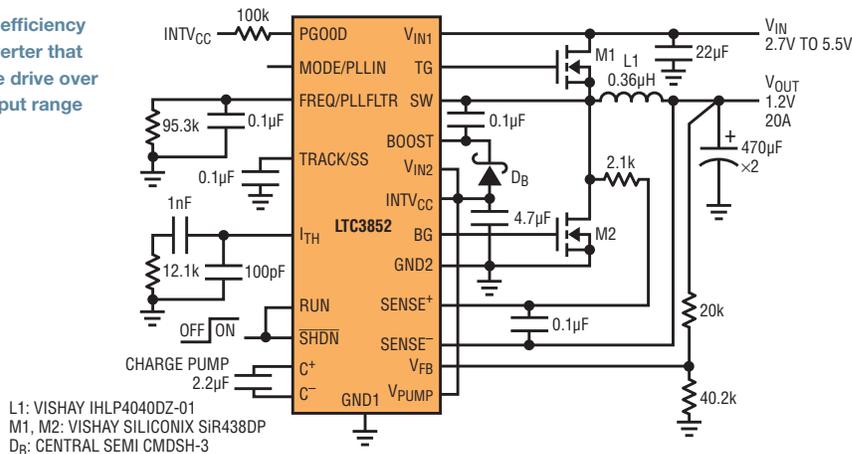
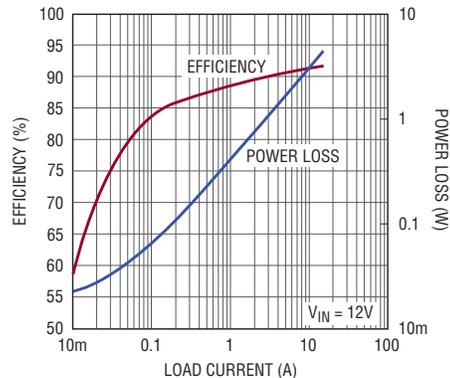
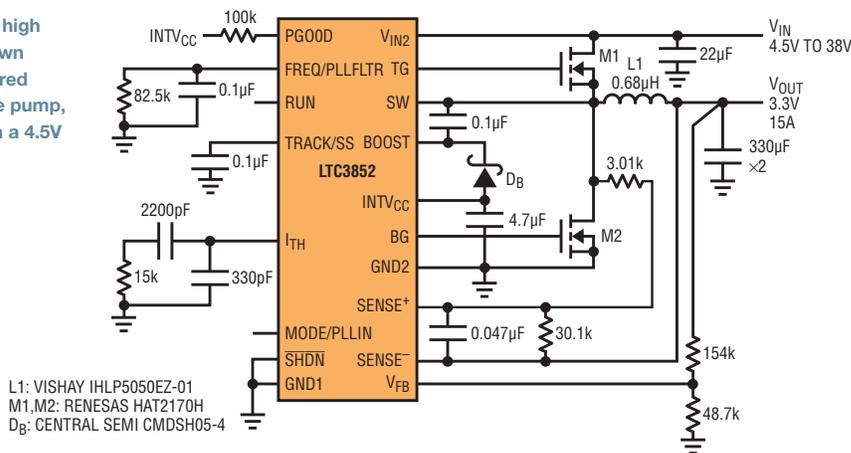


Figure 3. A similar high efficiency step-down converter, configured without the charge pump, that operates from a 4.5V to 38V input range



converter, and $INTV_{CC}$, the gate drive supply to the external MOSFETs M1 and M2.

The input to the charge pump (V_{IN1}) draws its supply current from one of two sources. At start-up, Q1, D1 and R1 form a simple linear regulator, supplying current to the charge pump from the input voltage. Once V_{OUT} is up and regulating, diode D2 turns off Q1 and supplies voltage to the charge pump from the output of the converter. This bootstrap configuration increases the

power supply's efficiency, since the current required to drive the power MOSFETs comes from the DC/DC converter itself.

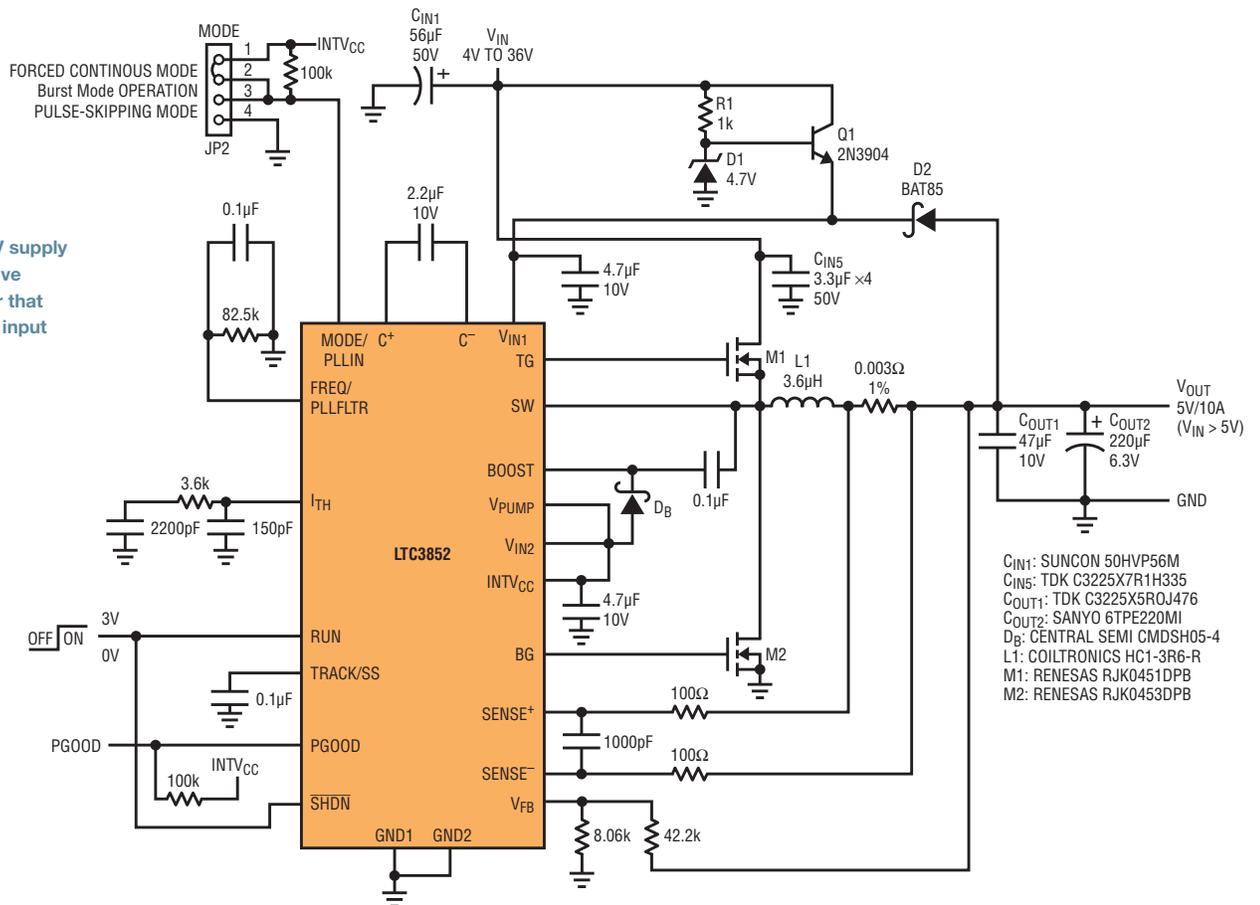
If V_{IN} falls below 5V, the switching regulator in Figure 4 enters dropout operation, keeping M1 on most of the time. V_{OUT} also falls, but remains high enough for the post-regulator LDOs to continue regulating their output voltages. Meanwhile, the charge pump maintains

its 5V output, providing solid gate drive to the MOSFETs, as shown in Figure 5.

Under normal operating conditions the converter has a 12V input and the LTC3852 behaves just like a conventional synchronous buck controller. Figure 6 shows the efficiency vs load current for the converter in Figure 4. The peak efficiency is 96% at a load current of 6A and efficiency remains high over a wide range of load currents.

The LTC3852 can be configured to operate from voltages as low as 2.7V, with no external gate drive supply required, or as high as 38V.

Figure 4. No access to a 5V supply is needed for this automotive intermediate bus converter that produces 5V gate drive for input voltages below 5V



CONCLUSION

The LTC3852 is a synchronous step-down DC/DC controller with a charge pump doubler that provides 5V gate drive, even when V_{IN} drops below 5V. The application presented here powers an intermediate 5V bus from an automotive 12V battery input. Strong drive to the MOSFETs is maintained even during cold crank events, and high efficiency is maintained over all operation conditions. The LTC3852 is offered in a 3mm × 5mm thermally enhanced QFN package. ■

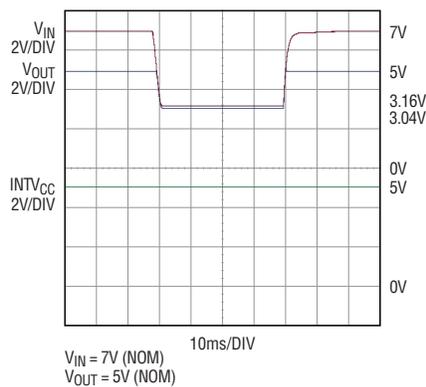


Figure 5. Line transient response for the intermediate bus converter in Figure 4, illustrating 5V gate drive during a cold crank event

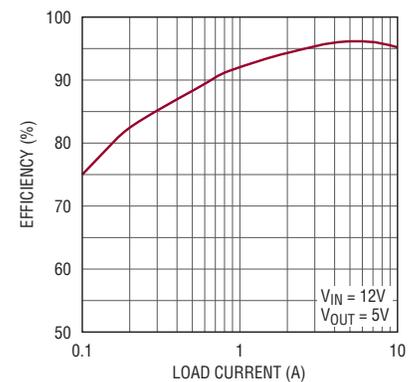


Figure 6. Efficiency vs load current for the intermediate bus converter in Figure 4

Low I_Q , Triple Output Boost/Buck/Buck Synchronous Controller Keeps Electronics Running Through Battery Transients in Automotive Start-Stop and Always-On Systems

Joe Panganiban and Jason Leonard

Several automotive manufacturers use the concept of a “start-stop” system to improve fuel economy and reduce emissions for vehicles that spend a significant amount of time at traffic lights and in heavy, stop-and-go traffic. This system automatically turns off the internal combustion engine whenever the car is at a complete stop and then restarts it immediately when the driver wants to go. This reduces the amount of time the engine spends idling, thus saving fuel. Start-stop systems have been installed in hybrid-electric vehicles for years, but are now becoming more common in traditional vehicles (with both manual and automatic transmissions) that lack a hybrid-electric powertrain.

Typically, a central control unit coordinates the start-stop system to ensure that driver comfort and safety are not compromised. For example, the system is not activated if the air conditioner has not brought the cabin to the desired temperature or if the driver moves the steering wheel. However, there are many systems, such as navigation, telematics and infotainment systems (CD and DVD players, audio systems, etc.) that remain active when the engine is off. These systems often operate from 5V–10V supplies generated by step-down (buck) converters from the nominally 12V car battery. When the engine starts, the battery voltage can dip to well below 5V, potentially causing these systems to glitch or reset.

In a vehicle with a start-stop system, the engine by definition restarts frequently. While it may not present a safety risk if your DVD or CD player restarts every time you stop at a traffic light, it certainly is annoying, especially for a parent relying on the DVD player to babysit the kids in the back seat.

Fortunately, Linear Technology has the solution. The LTC3859 combines a synchronous boost controller with two

synchronous buck controllers in a single package. To achieve the wide input voltage range required in the automotive applications described above, the part can be configured with the vehicle battery feeding the input to the boost converter and the boost converter’s output feeding the inputs to the buck converters. This allows the two buck outputs to maintain regulation whether the battery is above or below the buck outputs. The outputs can stay regulated through the entire input range presented by the vehicle battery, handling transients as low as 2.5V during engine restart or cold crank and transients as high as 38V during load dump.

THINK OF IT AS A DUAL BUCK-BOOST

In this configuration, the LTC3859 can be thought of as a dual output buck-boost controller, in that it produces two regulated outputs that can be above or below the input voltage. When the input is low, the boost converter operates and steps up the voltage to an intermediate rail that provides enough headroom for the buck converters to operate. When the input voltage is high enough, the boost converter stops switching

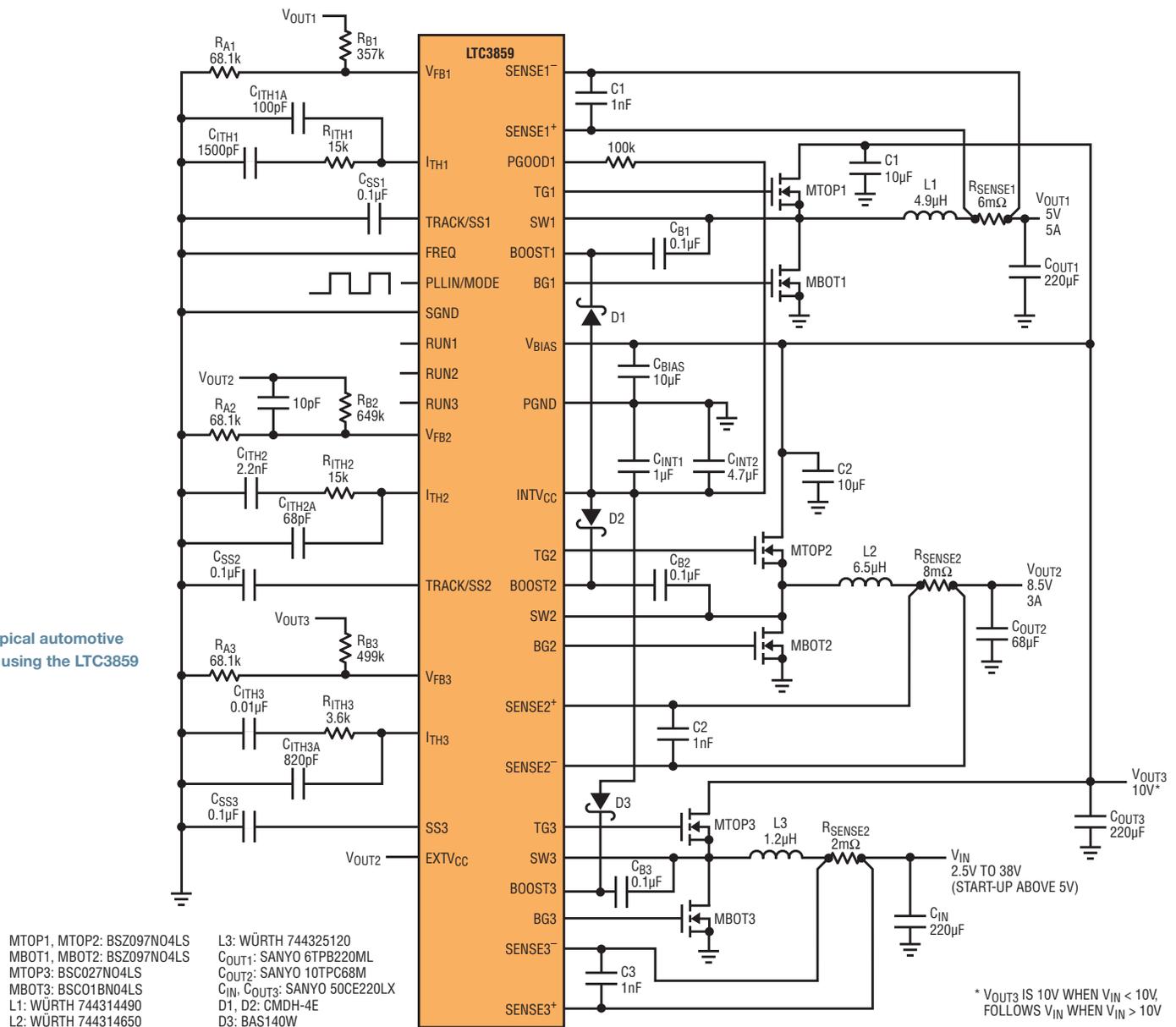
and simply turns on the top switch to pass the input voltage through to the intermediate rail to feed the bucks.

BOOST CONTROLLER

The LTC3859’s boost controller is based on Linear Technology’s new LTC3788/LTC3787/LTC3786 family of high voltage, constant frequency, current-mode synchronous boost controllers that drive all N-channel MOSFET power stages. It can boost to output voltages as high as 60V from a 4.5V to 38V (40V abs max) input voltage. If the LTC3859 is biased from V_{OUT} or another supply, the boost converter can operate from an input voltage as low as 2.5V after start-up. Synchronous rectification eliminates both the high power loss in the catch diode and the need for a heat sink at high output currents. Strong internal gate drivers reduce switching losses at high output voltages.

The control architecture senses current at the input supply using a sense resistor in series with the inductor (or by using inductor DCR sensing). The inductor current is constantly monitored and no blanking is required, enabling it to achieve very low bottom MOSFET duty cycles with a very small 110ns minimum on-time.

Figure 1. Typical automotive application using the LTC3859



In a boost converter, the duty cycle gets smaller as the input voltage approaches the programmed output voltage and equals 0% when $v_{IN} = v_{OUT}$. Traditional non-synchronous boost controllers that sense the bottom FET current do not smoothly handle the transition as v_{IN} approaches the programmed v_{OUT} , often having excessive, unpredictable, low frequency ripple that begins when the minimum on-time is reached. Most of those controllers have relatively long minimum on-times (often greater than 200ns), which means that high ripple can occur over a relatively wide band of input voltages.

In contrast, the LTC3859 boost controller gracefully handles the transition as v_{IN} moves up or down through the programmed output voltage without creating excessive ripple. Because of the small minimum on-time, constant frequency operation is maintained until v_{IN} is just below v_{OUT} , at which point the part skips bottom FET on cycles as needed until it is off continuously (0% duty cycle) and the synchronous top FET is on continuously (100% duty cycle). Unlike most boost converters, the LTC3859's ripple during this transition region is substantially smaller than it is at lower v_{IN} during "normal" boosting.

The LTC3859 is able to keep the synchronous MOSFET on continuously by integrating a small charge pump inside its driver. This charge pump maintains the voltage on the bootstrap capacitor that serves as the floating supply (BOOST3-SW3 voltage) for the top driver. Otherwise, the voltage on this capacitor might decay due to board or diode leakage current.

DUAL BUCK CONTROLLERS

Along with the single boost controller, the LTC3859 also integrates a pair of synchronous buck (step-down) controllers based on the LTC3857/58 family of low quiescent buck controllers. They

drive all N-channel MOSFETs and feature a precision 0.8V reference. They accept inputs up to 38V (40V abs max) and the outputs can be programmed between 0.8V to 24V (28V abs max). The 95ns minimum on-time allows high frequency operation at low duty cycles.

OTHER FEATURES

The LTC3859 shares many of the same popular features of the LTC3788 and LTC3857 families on which it was based. The MOSFET drivers and control circuits are powered by INTV_{CC}, which by default is generated from an internal low dropout (LDO) regulator from the main bias supply pin (V_{BIAS}). To reduce power dissipation due to MOSFET gate charge losses and improve efficiency, a supply between 5V and 14V (abs max) may be connected to the EXTV_{CC} pin. When a supply is detected on EXTV_{CC}, the V_{BIAS} LDO is disabled and another LDO between EXTV_{CC} and INTV_{CC} is enabled. EXTV_{CC} is commonly connected to one of the output voltages generated by the buck controllers.

The switching frequency can be programmed between 50kHz and 900kHz using the FREQ pin, or synchronized via the PLLIN/MODE pin to an external clock between 75kHz and 850kHz using an integrated phase-locked loop. The buck controllers (channels 1 and 2) operate 180° out-of-phase to minimize the capacitance required on their

input. The boost controller (channel 3) operates in phase with channel 1.

All outputs have independent enable (RUN_{1,2,3}) and soft-start (TRACK/SS_{1,2} and SS₃ pins). The TRACK/SS pins on the buck controllers can also be used to track other supplies during start-up. The PGOOD₁ and OV₃ are open-drain pins that respectively indicate whether buck channel 1 is in regulation and whether the boost channel is in overvoltage (V_{IN} > programmed V_{OUT} + 10%). Protection features include short-circuit and overvoltage protection for the bucks and overtemperature protection. At light loads, the user can select from three modes of operation—Burst Mode operation, pulse-skipping mode, or forced continuous mode—using the PLLIN/MODE pin.

LOW I_Q FOR ALWAYS-ON SYSTEMS

When Burst Mode operation is selected, the LTC3859 features an ultralow operating quiescent current (55μA with one buck on, 65μA with one buck and the boost on, or 80μA with all three channels on). This makes the LTC3859 ideal for always-on systems, where one or more outputs are always enabled and low quiescent current is required to extend run-times and preserve battery life. Automobiles have an increasing number of these systems (regardless of whether they also have start-stop systems) that remain on even when the vehicle is parked for days or weeks. Examples of

these include telematics systems, anti-theft systems, and keyless-entry systems.

5V AND 8.5V OUTPUTS FROM AUTOMOTIVE BATTERY, EVEN DURING COLD CRANK

Figure 1 shows a highly integrated solution that utilizes the unique features of the LTC3859 to efficiently solve the design challenges associated with automotive start-stop and always-on systems. In this circuit, the boost controller input is connected directly to the car battery, and the boost output, which is programmed to 10V, serves as the input to the two buck controllers, which generate the 5V and 8.5V outputs. The 5V supply might typically be used to power an always-on system and the 8.5V supply for a DVD player.

The LTC3859 V_{BIAS} pin is powered from the output of the boost converter. The EXTV_{CC} pin is connected to the 8.5V (or alternatively the 5V supply) to improve efficiency, particularly at high battery voltage.

Normally, the battery sits around 12V–14V, so the input to the boost converter is higher than its programmed 10V output. Under these conditions, the control loop forces the top MOSFET on continuously. The internal charge pump maintains the supply voltage (BOOST₃-SW₃) for the top MOSFET driver (TG₃ to ensure 100% duty cycle operation). With the top MOSFET on continuously, the boost converter simply passes the battery voltage directly through to the buck inputs, minimizing power loss.

During engine start-up, when the battery voltage can dip to 5V or lower, the boost converter starts switching when the battery voltage drops below 10V and keeps the buck inputs pinned at 10V. This prevents the buck converters from ever going into dropout, allowing the bucks to maintain output regulation at 5V and 8.5V although the car battery can fall below these voltages. The LTC3859 boost controller's very low 2.5V input common mode range allows for a regulated

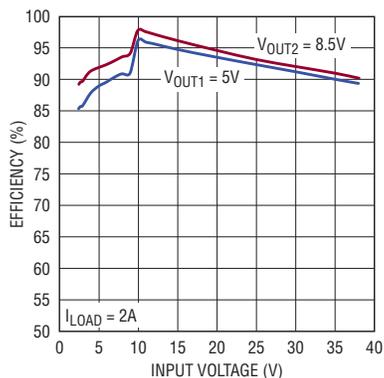


Figure 2. Efficiency vs input voltage for Figure 1.

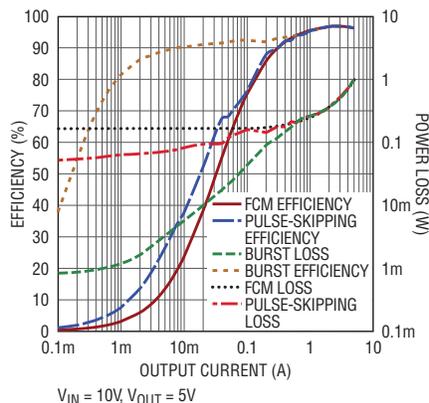


Figure 3. Efficiency and power loss vs load current of 5V output for Figure 1.

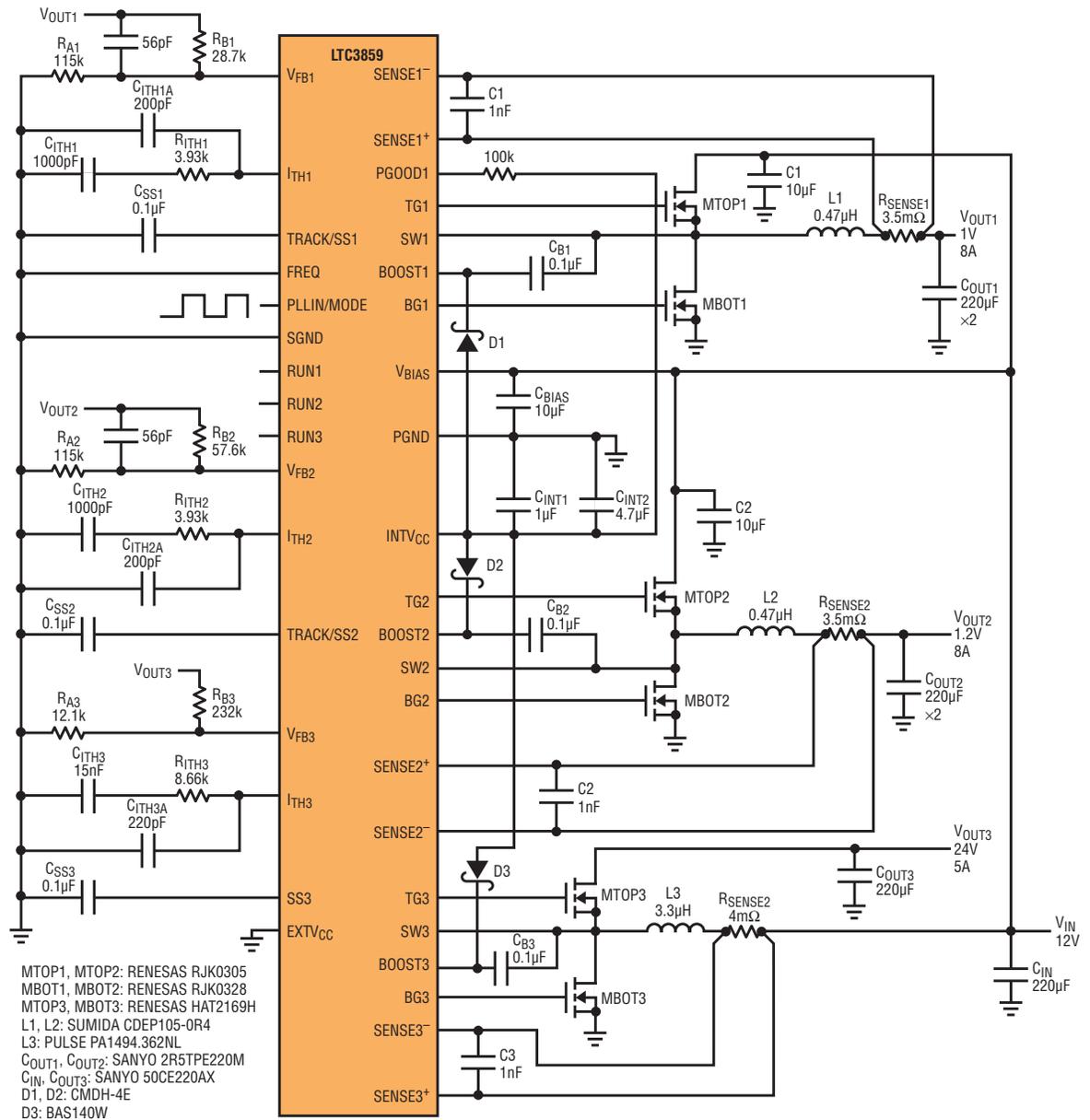


Figure 4. General purpose triple output application using the LTC3859

boost output voltage, and thus stable buck output voltages, even through some of the harshest cold crank transients.

Figure 2 shows the total efficiency at 2A load with V_{IN} spanning from 2.5V to 38V. The low quiescent current allows the 5V supply to remain on at all times without significantly deteriorating the vehicle battery life. Figure 3 shows the efficiency and power loss of the 5V output over a broad load range.

GENERAL PURPOSE TRIPLE OUTPUT CONTROLLER

As impressive as the LTC3859 is in these dual buck-boost applications, it of course can also be configured as a simple triple output converter. Figure 4 shows a circuit generating 24V, 1V and 1.2V outputs from a 12V input.

CONCLUSION

The LTC3859 is a low I_Q triple output controller that offers a compelling, compact solution to the demanding design

challenges in modern automotive electronics. Configuring the synchronous boost controller in front of the two synchronous buck controllers provides dual supply voltages that maintain regulation over the entire voltage range of the car battery. This makes the LTC3859 ideal for high efficiency power conversion in always-on and start-stop systems. The LTC3859 packs all of this and more into small, thermally enhanced 38-pin 5mm × 7mm QFN or 38-lead TSSOP packages. ■

How to Drive Low Power, 1MSPS, $\pm 2.5V$ Differential-Input, 16-Bit ADC with a Variety of Single-Ended Signals

Guy Hoover

It can be difficult to match a sensor's output to an ADC input range, especially when faced with the variety of output voltage swings produced by today's sensors. This article presents easy, but high performance, ADC input driver solutions for differential, single-ended, unipolar and bipolar signals covering a variety of spans. All circuits in this article achieve 92dB SNR, with the LTC2383-16 ADC acting alone or in conjunction with the LT6350 ADC driver.

The LTC2383-16 is a low noise, low power, 1MSPS, 16-bit ADC with a $\pm 2.5V$ fully differential input range. The LT6350 is a rail-to-rail input and output low noise, low power single-ended to differential converter/ADC driver featuring fast settling time. Using the LT6350, single-ended input ranges of $0V-2.5V$, $0V-5V$ and $\pm 10V$ can be easily converted to the $\pm 2.5V$ fully differential input range of the LTC2383-16.

FULLY DIFFERENTIAL DRIVE

Figure 1 shows the building block that is used for all of the circuits described here. It serves a DC-coupled fully differential signal to the LTC2383-16 analog inputs. Resistors R1, R2 and capacitor C1 limit the input bandwidth to approximately 500kHz. Resistors R3 and R4

reduce the effect of the ADC input sampling spike that can disturb the sensor or ADC driver outputs.

This circuit is useful for sensors with low impedance differential outputs. The common mode voltage driving A_{IN+} and A_{IN-} needs to be $V_{REF}/2$ to satisfy the common mode input range requirements of the LTC2383-16.

The circuit in Figure 1 can be AC-coupled to match the common mode voltage of the ADC input to the sensor if necessary. Simply bias A_{IN+} and A_{IN-} to V_{CM} ($V_{CM} = V_{REF}/2$) through a 1k resistor and couple the sensor output to A_{IN+} and A_{IN-} through a $10\mu F$ capacitor. This is shown in Figure 2.

When driving a low noise, low distortion ADC such as the LTC2383-16, proper

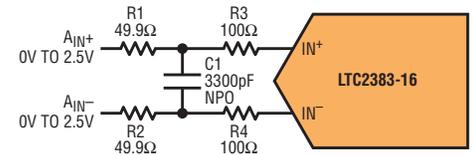


Figure 1. Fully differential drive circuit

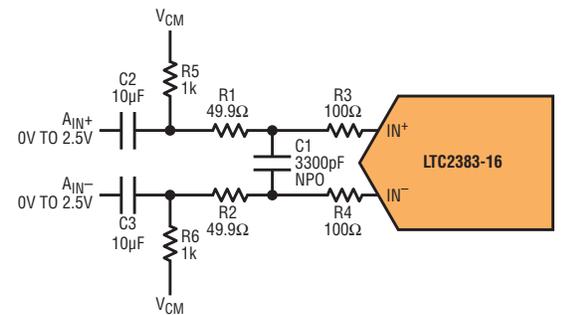


Figure 2. AC-coupled fully differential drive circuit

component choice is essential for maintaining performance. All of the resistors used in these circuits are relatively low values. This keeps the noise and settling time low. Metal film resistors are recommended to reduce distortion caused by self-heating. An NPO capacitor is used for C1 because of its low voltage coefficient, which minimizes distortion.

Figure 3. Single-ended to differential converter

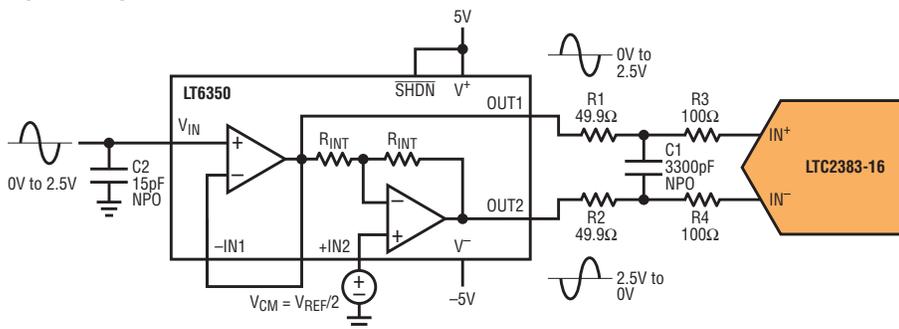
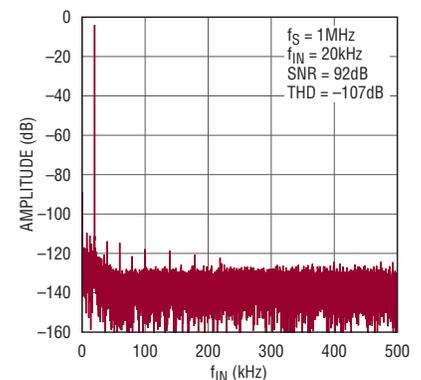


Figure 4. FFT of circuit of Figure 3



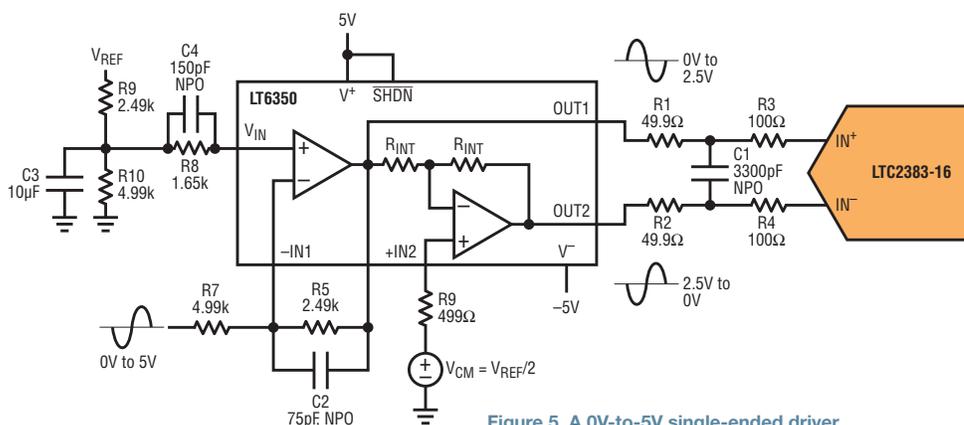


Figure 5. A 0V-to-5V single-ended driver

SINGLE-ENDED TO DIFFERENTIAL CONVERSION

Of course, not all sensor outputs are differential. Here are some ways to drive the LTC2383-16 from single-ended signals.

0V–2.5V Single-Ended Input

The circuit of Figure 3 converts a single-ended 0V-to-2.5V signal to a fully differential ± 2.5 V signal. This circuit also has a high impedance input so that most sensor outputs should be able to drive it directly. The common mode voltage at v_{IN} can be matched to the ADC by AC-coupling v_{IN} as shown in Figure 2. The common mode voltage of the second amplifier is set at the +IN2 pin of the LT6350. The 32k-point FFT in Figure 4 shows the performance of the LTC2383-16 combined with the LT6350 using the circuit shown in Figure 3.

The measured SNR of 92dB and THD of -107 dB match closely with the typical data sheet specs for the LTC2383-16. This indicates that little, if any, degradation of the ADC's specifications result from inserting the single-ended to differential converter into the signal path.

0V–5V Single-Ended Input

If a wider input range is required, the minus input of the LT6350 can be driven, allowing the input voltage to be attenuated by the first stage of the LT6350. The circuit of Figure 5 converts a single-ended 0V to 5V signal to a differential ± 2.5 V signal that drives the inputs of the LTC2383-16. The input impedance of this circuit is equal to R_7 . Increasing R_7 results in higher input impedance, making it easier to drive. This is done at the expense of slightly increased

R7,R10 (k Ω)	R5,R9 (k Ω)	R8 (k Ω)	SNR (dB)	THD (dB)
2	1	0.665	92	-100
4.99	2.49	1.65	92	-101
10	4.99	3.32	91	-100
49.9	24.9	16.5	91	-97
100	49.9	33.2	91	-94

Table 1. Noise and distortion vs input resistance for 0V-to-5V driver

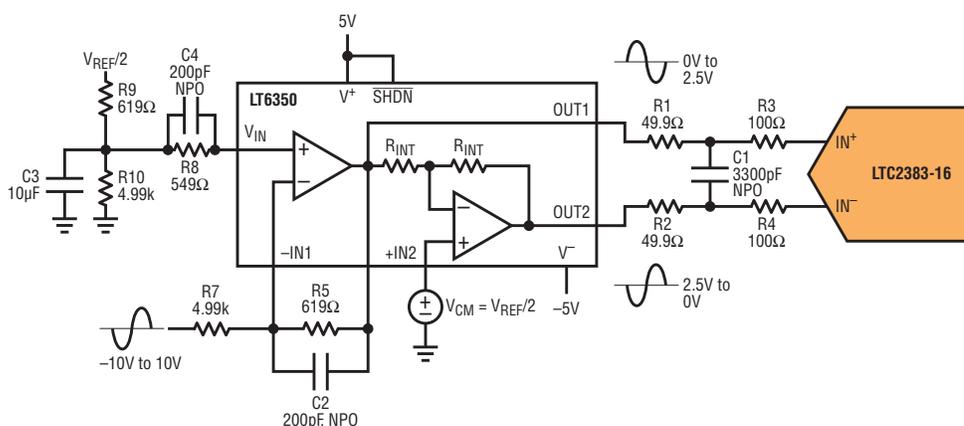
noise and distortion if R_7 is increased above 4.99k, as shown in Table 1.

± 10 V Single-Ended Input

Some sensors provide an output voltage that goes above and below ground. The circuit of Figure 6 converts a ± 10 V ground-referred single-ended signal to a differential ± 2.5 V signal that drives the inputs of the LTC2383-16. Again, the input impedance is set by R_7 . Table 2 shows noise and distortion vs input impedance for the circuit of Figure 6.

CONCLUSION

The LTC2383-16 is a low power, low noise, 16-bit ADC that can be easily interfaced with a wide variety of sensor outputs, including unipolar, bipolar, differential and single-ended signals over a wide range of spans. ■

Figure 6. A ± 10 V single-ended driverTable 2. Noise and distortion vs input resistance for ± 10 V driver

R7,R10 (k Ω)	R5,R9 (k Ω)	R8 (k Ω)	SNR (dB)	THD (dB)
3.24	0.402	0.357	92	-97
4.99	0.619	0.549	92	-97
10	1.24	1.10	92	-96
49.9	6.19	5.49	91	-96
100	12.4	11.0	91	-97

Easy, Isolated Low Power Telecom Supply: No Opto-Isolator Required

Mayur Kenia

Isolated power delivery in telecom systems is traditionally a challenging design problem. High input voltages and isolation requirements lead to complex schemes involving complicated magnetics and opto-couplers in the feedback loop. The LT3511 and LT3512 monolithic switching regulators bring simplicity to isolated power supplies with a non-traditional approach. Figure 1 shows the significant difference in complexity between traditional designs versus a new simplified approach. The LT3511 and LT3512 are specifically designed for the isolated flyback topology with no third winding or opto-isolator required for regulation—the isolated output voltage is sensed directly from the primary-side waveform.

INTEGRATION

A high level of integration simplifies the overall application solution. The LT3511 features an integrated 240mA, 150V power switch while the LT3512 features a 420mA, 150V power switch. A pre-regulator is integrated in both parts, allowing a wide input operating voltage range from

4.5V to 100V. In addition, internal isolated sensing circuitry allows programming of the output voltage with two external resistors and the transformer turns ratio. An accurate internal threshold offers a programmable undervoltage lockout using the EN/UVL pin. Finally, a resistor from the T_C pin to ground

provides adjustable temperature compensation to compensate for the temperature coefficient of the output diode.

48V-TO-5V ISOLATED POWER WITH EXCELLENT LOAD REGULATION

Figure 2 shows an isolated 5V application, from a 36V-to-72V input, using the LT3511. A Zener in series with a diode placed

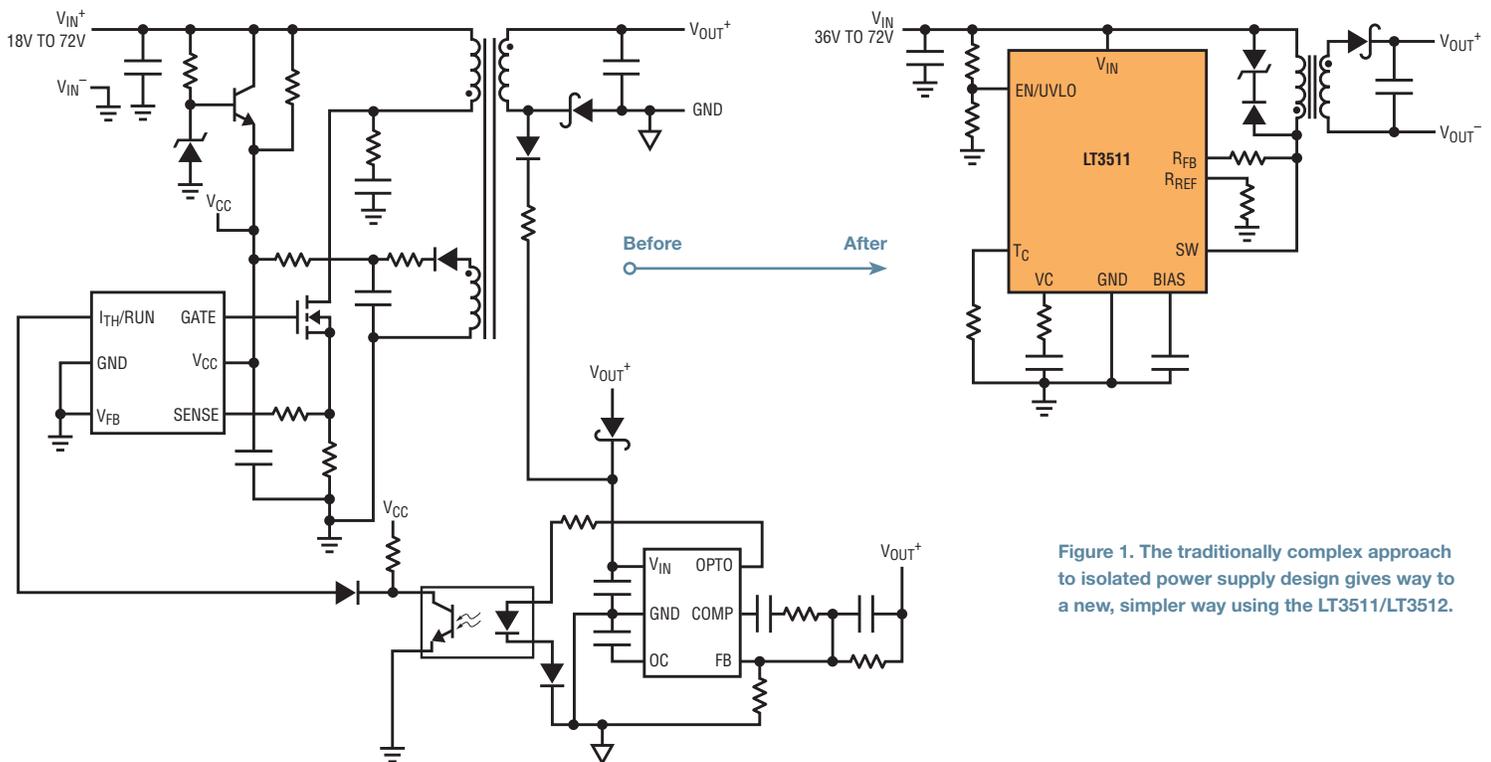


Figure 1. The traditionally complex approach to isolated power supply design gives way to a new, simpler way using the LT3511/LT3512.

The LT3511/LT3512 infers the isolated output voltage by examining the primary-side flyback pulse waveform. In this manner, neither an opto-isolator nor an extra transformer winding is required to maintain regulation, and the output voltage is easily programmed with two resistors.

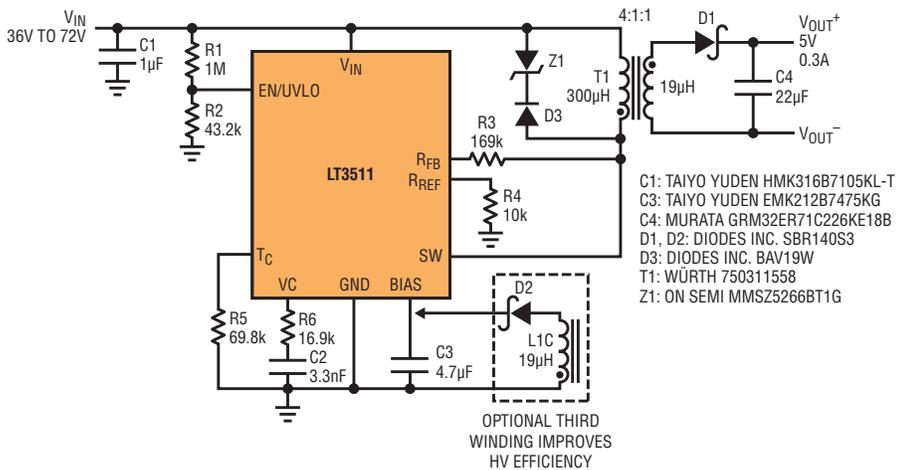


Figure 2. A 48V-to-5V isolated flyback converter using the LT3511 requires remarkably few components

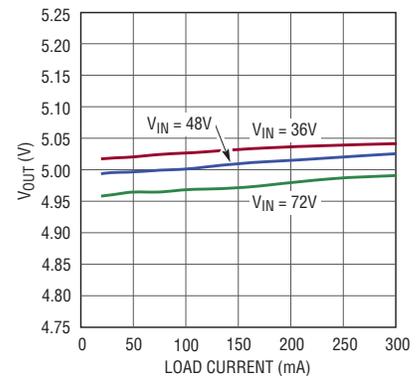


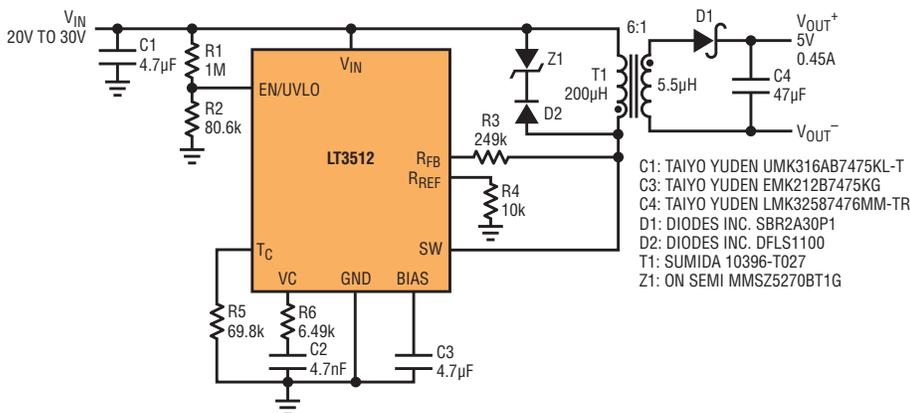
Figure 3. Load regulation for application in Figure 2

from the SW pin to the V_{IN} pin ensures that the switch node stays below 150V across all operating conditions and transients. The application produces excellent load regulation across its input voltage range. Figure 3 shows load regulation at 36V, 48V and 72V at the input. The LT3512 is pin-compatible with the LT3511 and delivers 500mA at 5V with a similar scheme.

24V-TO-5V ISOLATED POWER

Figure 4 shows the LT3512 generating an isolated 5V from 24V at V_{IN}. The lower input voltage allows the use of a larger turns ratio. The application can deliver 450mA of output current, while the LT3511 can be used in a similar configuration to deliver 250mA of output current.

Figure 4. A 24V to 5V isolated flyback converter using the LT3512



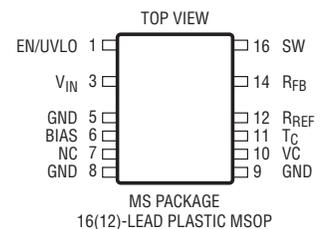
HIGH VOLTAGE PIN SPACING

The LT3511 and LT3512 are available in an MS16 package with pins removed to provide adequate spacing for high voltage operation. Figure 5 shows the pins removed.

CONCLUSION

The LT3511 and LT3512 provide a simple, elegant solution to isolated power delivery. A high level of feature integration minimizes the number of external components and lowers the overall solution cost. Most importantly, the LT3511 and LT3512 ease the design of isolated high voltage power supplies. ■

Figure 5. LT3511/LT3512 MS16 high voltage pin spacing



4mm × 5mm, Dual Input/Output, Synchronous Monolithic Buck Regulator Converts 12V to 1.2V at 4MHz

Phil Juang

Systems that are powered from a battery stack or a single 12V supply typically incorporate a number of relatively low power point-of-load power supplies. These supplies are typically low enough power that using DC/DC controllers with external power MOSFETs would make them unnecessarily large and complex. In such applications, a monolithic DC/DC converter can save significant space and design time.

The LTC3633 is a dual output 3A/channel synchronous monolithic step-down converter capable of operating from input supply voltages anywhere between 3.6V and 15V. It uses a patented controlled on-time architecture, which allows very large step-down ratios at high switching frequencies and provides extremely fast transient response.

The LTC3633 also includes a number of important features, including high efficiency Burst Mode operation, resistor-programmable switching frequency, external clock synchronization, output tracking capability, programmable input undervoltage lockout, short-circuit protection and selectable $0^\circ/180^\circ$ degrees phase

shift between channels. Synchronous switching eliminates external Schottky diodes and maintains efficiencies above 90% over a wide range of input and load conditions. An internal compensation option further simplifies designs. A 10mA linear regulator provides a fixed 2.5V output that can be used as a bias voltage or a low power supply rail.

The LTC3633 is offered in a tiny, thermally enhanced 4mm × 5mm 28-lead QFN package as well as a thermally enhanced 28-lead TSSOP package.

SHORT ON-TIMES ALLOW FAST SWITCHING FREQUENCIES AND SMALLER COMPONENT SIZE

One limitation of many current mode control schemes for step-down converters is the minimum on-time of the main power switch, typically in the range of 60ns–100ns. The minimum on-time is the amount of time needed to accurately sense the peak inductor current through the main power MOSFET, commonly used in current-mode control architectures. Unfortunately, the minimum on-time constrains the duty cycle and maximum switching frequency. This is typically not a problem when the duty cycle is more than 25%, which is usually the case if the input voltage is 5V or less, but when using a 12V input supply or a Li-ion battery stack, output voltages of 1.8V and 2.5V often run into the minimum on-time constraint at high switching frequencies. In this case, the only remedy is to operate at a lower

Figure 1. Switch waveform with 30ns on-time

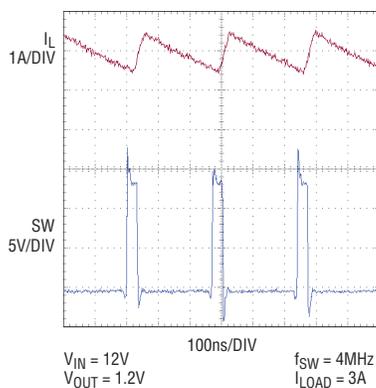
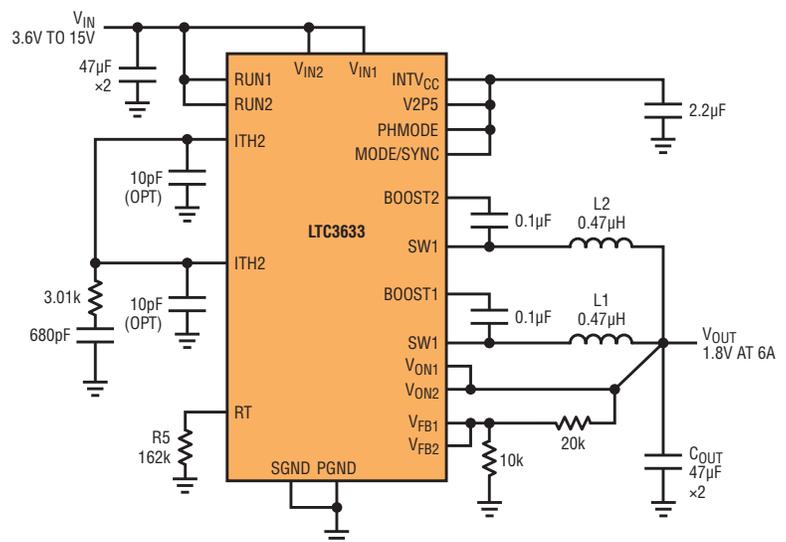


Figure 2. The LTC3633 configured as a 6A single-output buck converter



switching frequency, which typically requires larger input and output capacitors to meet voltage ripple requirements.

The LTC3633 control loop solves this problem by sensing the inductor current during the off-time, which allows the minimum on-time to be extremely low (20ns typical) and frees the switching converter of the minimum duty cycle constraint. Although this control scheme imposes a minimum off-time constraint and limits the *maximum* duty cycle of the converter, the off-time constraint is often less critical when operating from high input supply voltages. The result is a step-down converter that can easily handle extremely low duty cycles while operating well above 1MHz. Figure 1 shows a scope capture of the LTC3633 configured to step down from 12V to 1.2V with a switching frequency of 4MHz.

The ability to operate at such high frequencies is advantageous for space-constrained designs which require smaller bypass capacitors as well as applications designed to operate the switching converter above the AM band to prevent electromagnetic interference (EMI).

UNIQUE CONTROL ARCHITECTURE PROVIDES SHORT ON-TIMES AND CONTROLLED SWITCHING FREQUENCY

One commonly used method of sensing inductor current during the off-time is “constant on-time” current-mode control, in which the top switch is forced on for a fixed period of time. One drawback of this method is that the switching frequency can change with input/output voltage, temperature and load current conditions. This is a problem in systems that require a well controlled switching frequency to avoid EMI or satisfy other noise concerns. It also precludes synchronizing the switch edges to a known clock signal.

Linear Technology’s patented “controlled on-time” architecture solves this problem

by incorporating a phase-locked loop that servos the on-time to match the switching frequency to a known clock signal. Thus, the LTC3633 steady-state switching frequency is constant over all temperature and load current conditions. A program resistor can be used to set the frequency of an on-chip oscillator or the LTC3633 can be synchronized to an external clock signal.

DUAL OUTPUTS AND INPUTS

The LTC3633’s dual inputs and outputs allow it to meet the specifications of a wide variety of power supplies. For instance, the two outputs can be paralleled to form a single output capable of sourcing 6A, as shown in Figure 2.

Connecting the ITH pins together forces the LTC3633 to share the load current equally between channels. For lower input and output voltage ripple, the PHASE pin can set the converters to switch 180° out-of-phase. Although only one compensation network is needed to stabilize the converter, optional 10pF capacitors are recommended to bypass each ITH pin and prevent parasitic board capacitances from injecting noise into the ITH signal path.

The LTC3633’s two separate inputs allow each step-down channel to draw power from different supplies. Multiple inputs can also be used when the outputs are tied together, as in Figure 2. This is useful when a single supply rail is not sufficient to satisfy the output power requirements. When operating from different supplies, it is important to note that V_{IN1} must always be powered, as it supplies the gate drive for the internal power MOSFETS.

THERMALLY ENHANCED PACKAGES REDUCE HEAT DISSIPATION

When running at the maximum allowable output loads (3A per channel), heat dissipation must be managed properly. The LTC3633 is offered in thermally enhanced packages—at extremely high power levels, the PCB should be designed to sink as much heat as possible by tying the exposed

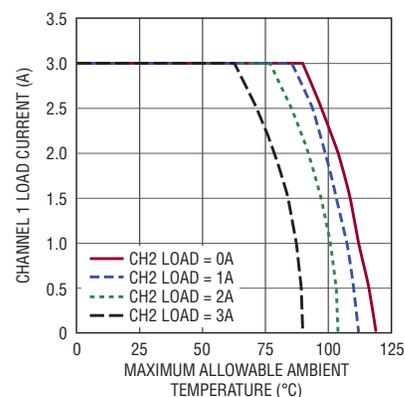


Figure 3. Thermal derating curve for LTC3633 demo circuit (DC1347)

pad of the package to a ground plane and flooding any unused areas of the PCB with copper tied to ground. A top layer ground plane is preferred, but if it is not available, the PCB should use as many vias as possible to connect to the ground plane.

At high ambient temperatures, full output loads can cause excessive heating of the die. Although the LTC3633 uses a thermal shutdown circuit to prevent the die temperature from exceeding 160°C, prolonged temperatures above 125°C may impact long-term reliability of the IC. Figure 4 shows the thermal derating curve for the tiny 4mm × 5mm QFN package, as measured on the LTC3633 demo circuit (DC1347). Although larger in size, the TSSOP package’s thermal performance is nearly 40% better than the QFN, allowing the designer to trade off improved thermal performance for more board space.

CONCLUSION

With its unique control loop that allows extremely low duty cycles, the LTC3633 is well suited to operate from a wide range of input supply voltages and provides two efficient low voltage power supplies at the point of load. It offers a multitude of features, including the ability to parallel the outputs and handle inputs from different supply voltages. It is easy to use, with the basic application requiring only seven external components for each channel. ■

Isolated Flyback Converters Eliminate Opto-Coupler

Yat Tam

The flyback converter is widely used in isolated DC/DC applications because it solves the problem of *isolation*, not because it is the favorite topology of switch-mode power supply designers. Traditionally, flyback converters demand careful attention to a number of parameters, including complex trade-offs involving transformer design, control loop analysis and power device selection. Fortunately, this is not the case with Linear's family of breakthrough monolithic ICs—including the LT3573, LT3574 and LT3575—which make it easy to build flyback converters (see Table 1).

The LT3574 operates over input ranges of 3V to 40V at output power levels of up to 3W, and can be used in a wide variety of industrial, medical, datacom and automotive applications requiring isolated power. The LT3573 and LT3575 are higher power versions, extending the output power delivery up to 7W and 14W, respectively. This family of ICs packs many popular features—such as programmable soft start, undervoltage lockout, adjustable current limit and output voltage temperature compensation—in a 16-lead

MSOP package for LT3573 and LT3574, or 16-lead TSSOP package for LT3575.

SENSING OUTPUT VOLTAGE WITHOUT OPTO-COUPLEDERS

Traditional flyback converters normally require opto-couplers or an additional transformer winding to feed back output voltage information used to maintain load regulation across the isolation barrier. Opto-couplers consume output power and obviously add to the cost and physical size of the design. In addition, opto-couplers introduce nonlinearities,

and have unit-to-unit variations and aging over life that complicates loop compensation. Opto-couplers also require a secondary side voltage reference and error amplifier, adding two or three packages to the layout. Circuits that employ extra transformer windings can increase transformer size and cost, sacrifice the transient response performance and degrade load regulation.

Figure 1 shows how a typical LT3574 application performs without an opto-coupler or extra transformer winding. Figure 2 shows the efficiency of the application in Figure 1. Figure 3 shows an alternate configuration that employs

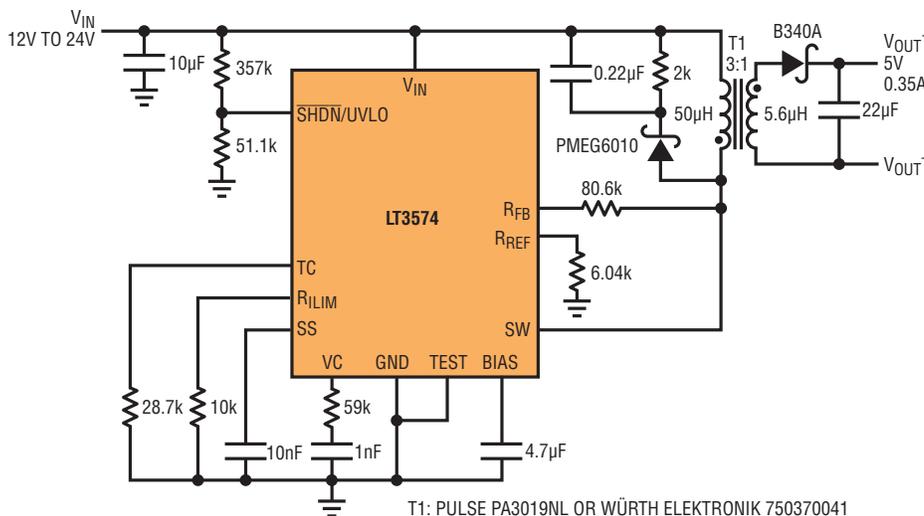


Figure 1. A 12V–24V input, 5V/350mA output flyback converter

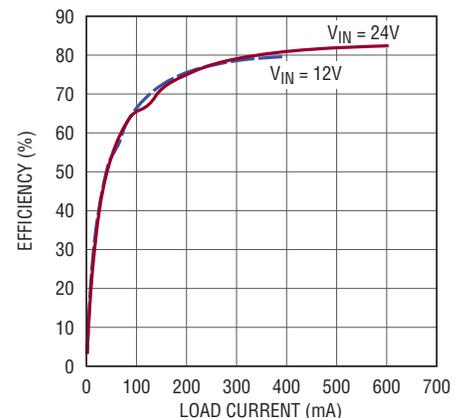


Figure 2. Efficiency of the circuit in Figure 1

PRODUCT	V _{IN} RANGE	POWER SWITCH	POWER LEVEL	PACKAGE
LT3573	3V to 40V	1.25A, 60V	Up to 7W	16-Lead MSOP (thermally enhanced)
LT3574	3V to 40V	0.65A, 60V	Up to 3W	16-Lead MSOP
LT3575	3V to 40V	2.5A, 60V	Up to 14W	16-Lead TSSOP (thermally enhanced)

Table 1. This family of flyback converters eliminates the need for an opto-coupler.

an optional third winding on the BIAS pin for higher input voltage operation. Use the third winding to boost efficiency by 3%–4% at high input voltages.

The LT3574 derives its information about the output voltage by examining the primary-side flyback pulse waveform. The output voltage, programmed by resistors R₃ and R₄, is accurately measured from the switch node waveform during the off-time of the power switch.

BOUNDARY MODE SAVES SPACE AND IMPROVES LOAD REGULATION

The LT3573, LT3574 and LT3575 utilize boundary mode operation, which is a variable frequency current mode switching scheme. When the internal switch turns on, the primary current increases

until its controlled current limit is reached. The switch node voltage rises above the input by an amount equal to the output voltage divided by the secondary-to-primary turns ratio. When the secondary current through the diode falls to zero, the switch node voltage falls back to the input voltage. An internal discontinuous conduction mode (DCM) comparator detects this latter event and turns the switch back on and repeats the cycle.

Boundary mode returns the secondary current to zero every cycle, so parasitic resistive voltage drops do not cause load regulation errors. This results in a tight regulation band over a wide input voltage range and output load current range, as shown in Figure 4. Here, total regulation is better than $\pm 1\%$, while

$\pm 5\%$ load regulation is easily achievable for most applications. Boundary mode permits the use of a smaller transformer compared to continuous conduction mode (CCM) and eliminates concerns related to subharmonic oscillation.

CONCLUSION

The LT3573, LT3574 and LT3575 significantly simplify the design of an isolated flyback DC/DC converter by eliminating the need for an opto-coupler, external power switch, secondary-side reference voltage and error amplifier, and extra third winding off the power transformer. They provide space saving, cost efficient solutions without sacrificing overall performance, while maintaining primary to secondary isolation with only one component crossing the isolation barrier. This family of ICs operates from 3V to 40V input and delivers up to 3W, 7W and 14W of continuous output power. ■

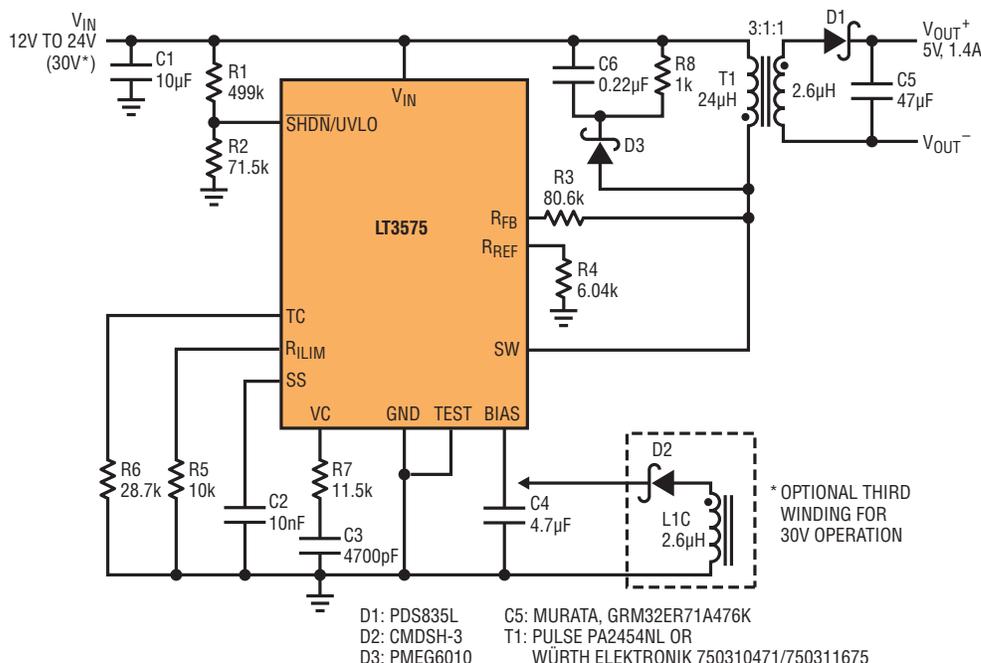


Figure 3. A 12V–24V input, 5V/1.4A output flyback converter

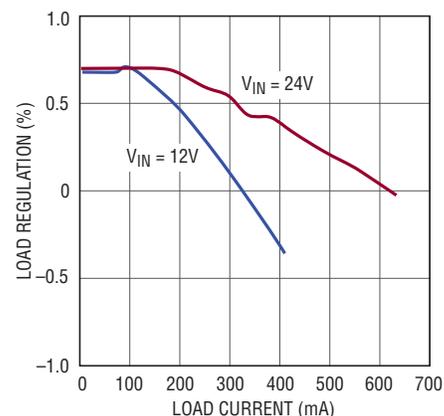


Figure 4. Tight load regulation is achieved from the circuit in Figure 1.

Buck-Boost Converter with Accurate Input Current Limit Maximizes Power Utilization from USB and PCMCIA Sources

Michael Munroe

Input power source current limitations, such as those imposed by USB or PCMCIA, pose a problem for applications demanding high peak power—such as charging capacitors to support the pulsed load currents required by GSM modems. The LTC3127 buck-boost DC/DC converter simplifies powering such applications with an accurate programmable input current limit. High accuracy ($\pm 4\%$ at 1A) allows the designer to push the current draw to just below the capability of the input source. This capability, along with the LTC3127's high efficiency over a wide input voltage range, maximizes the available output current. The LTC3127 also eliminates inrush current during start-up, maintaining control of the current seen by the input supply when low ESR output reservoir capacitors are charged.

The LTC3127 is offered in either a $3\text{mm} \times 3\text{mm} \times 0.75\text{mm}$ DFN or 12-lead MSOP package (see Figure 1). The 1.35MHz switching frequency and integrated low resistance, low gate charge switches produce an efficient, compact and low profile solution for pulsed load applications. Additional features include

anti-ringing control for EMI suppression, selectable Burst Mode operation, output disconnect and thermal overload protection. Together with an external bulk or reservoir capacitor, the LTC3127 can satisfy pulsed loads with peak currents that far exceed the capabilities of the source, without overloading it.

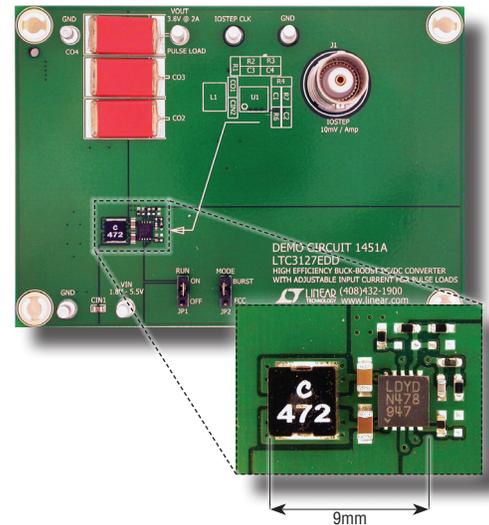


Figure 1. A complete, low profile power converter solution for pulsed load applications

POWERING GSM/GPRS MODEMS FROM USB OR PCMCIA

The LTC3127 solves the problem of using current-limited power sources to drive high current pulsed load applications or to charge high density ultra-capacitors. For instance, a USB or PCMCIA powered GSM/GPRS modem typically requires a 3.8v bias to produce a transmission modulated to 2A pulses, which occupy one

Figure 2. USB (5.0V/500mA max) to a 3.8V output, Class 10 GPRS pulsed load

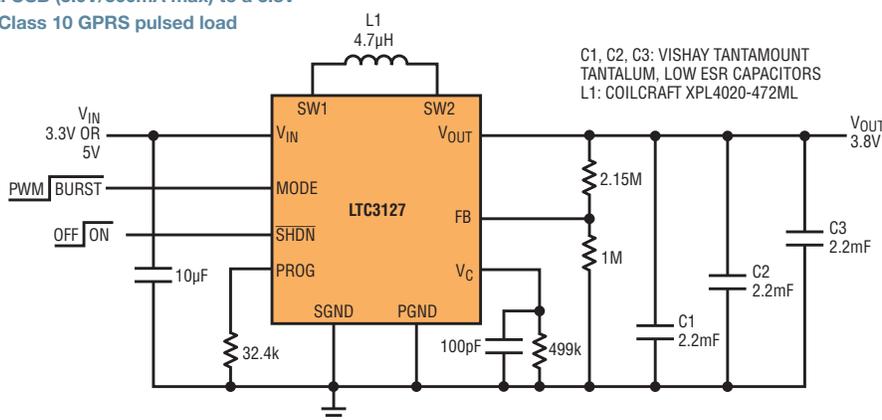
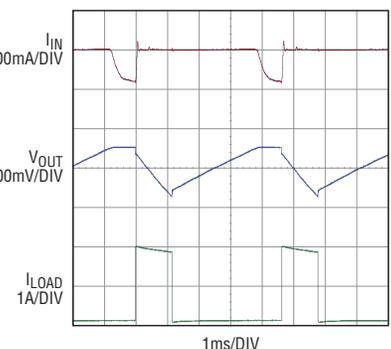


Figure 3. Waveforms of input current and V_{OUT} for a pulsed load current of circuit in Figure 2



or more of the eight available 577 μ s time slots. During the remaining time slots, the required load is reduced to less than 100mA, typically. Producing 2A directly from the DC/DC converter would overload the input source, since the pulsed load would draw well in excess of the 500mA guaranteed by USB and PCMCIA. The solution is to use the DC/DC to charge output capacitors to store energy that can be released as needed to satisfy the modem's pulsed-load current draw.

The advantage of using the LTC3127 with its high accuracy input current limit, is that the current draw from the limited source can be maximized. More available input power results in faster charging, which allows the output capacitors to be minimally sized, reducing overall solution cost and size.

For a GPRS Class 10 standard, a 2A load pulse is on for two 577 μ s cycles with the transmitter idle for the remaining six cycles. In Figure 2, the supply must be able to handle a pulse of 2A for 1.15ms out of every 4.6ms, for an average load current of 575mA. With properly sized output capacitors, operating from a 5V input, the LTC3127 can supply this load current at 3.8V without exceeding an input current of 500mA for USB2.0/PCMCIA applications or 900mA for USB3.0 applications.

In Figure 2, three 2200 μ F, low profile, Vishay TANTAMOUNT solid tantalum

capacitors supply energy to the load and maintain the output voltage within specified limits during the 2A pulses. Using the LTC3127 configured with proportional gain provides loop stability with any output capacitor value greater than 1000 μ F. Figure 2 shows the LTC3127 powered from a standard 5.0V/500mA USB port. The 500mA input current limit is set by the 32.4k resistor tied to the PROG pin.

Given the magnitude and duration of the pulsed load current, the capacitors must be chosen to meet the output voltage droop specification of the transmitter, typically 300mV. The total output voltage droop can be calculated by:

$$V_{\text{DROOP}} = \left[I_{\text{PULSE}} - \left(\frac{V_{\text{IN}} \cdot I_{\text{IN(MAX)}} \cdot \eta}{V_{\text{OUT}}} - I_{\text{STANDBY}} \right) \right] \cdot \left(\frac{D \cdot T}{C_{\text{OUT}}} + R_{\text{ESR}} \right)$$

where V_{DROOP} is the change in output voltage, I_{PULSE} is the pulsed load current, V_{IN} is the input voltage, $I_{\text{IN(MAX)}}$ is the programmed input current limit, η is the fractional converter efficiency ($\eta = 1$ is 100% efficiency), V_{OUT} is the programmed output voltage, I_{STANDBY} is the idle output current of the converter between pulses, D is the duty cycle of the pulsed load, T is the period of the pulsed load, C_{OUT} and R_{ESR} are the total output capacitance and capacitor's equivalent series resistance, respectively.

For a given pulsed load application, regardless of how much capacitance is

on the output of the converter, there is a maximum average load that can be supported for a given input current. The maximum pulsed load that the converter can support with a programmed input current limit is given by:

$$I_{\text{LOAD(MAX)}} = \frac{V_{\text{IN}} \cdot I_{\text{IN(MAX)}} \cdot \eta}{D \cdot V_{\text{OUT}}}$$

The minimum capacitance required for a desired V_{OUT} droop during the load pulse (assuming that $R_{\text{ESR}} = 0$) can be calculated by:

$$C_{\text{OUT(MIN)}} = \left[I_{\text{PULSE}} - \left(\frac{V_{\text{IN}} \cdot I_{\text{IN(MAX)}} \cdot \eta}{V_{\text{OUT}}} - I_{\text{STANDBY}} \right) \right] \cdot \frac{D \cdot T}{V_{\text{DROOP}}}$$

The typical pulsed load response for the circuit in Figure 2 is shown in Figure 3.

CHARGING HIGH DENSITY CAPACITORS

When charging high density ultra-capacitors for backup purposes, the converter operates at full current for minutes, even hours, depending on the size of the ultra-capacitor. The LTC3127 accurately limits the input current to the programmed value through the entire charging cycle. Once charged, the ultra-capacitors can provide power to other circuitry in the event of a power source failure or removal. Figures 4 and 5 show the schematic and the response of the LTC3127 charging stacked 400F, 2.5V supercapacitors to a V_{OUT} of 5.0V with a USB input.

(continued on page 43)

Figure 4. High density capacitor charger

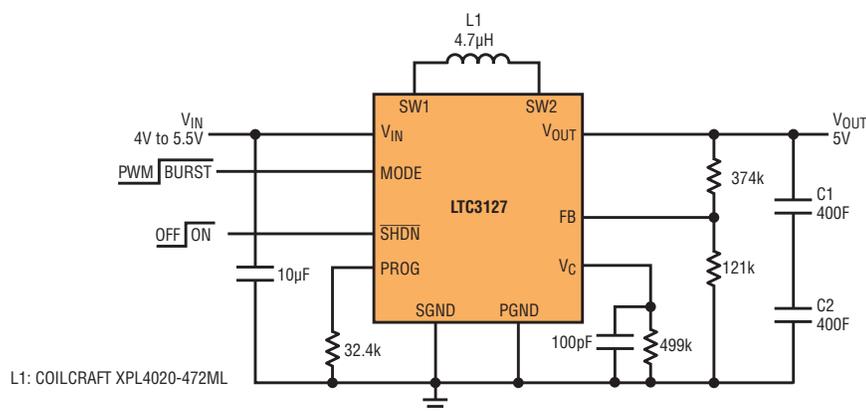
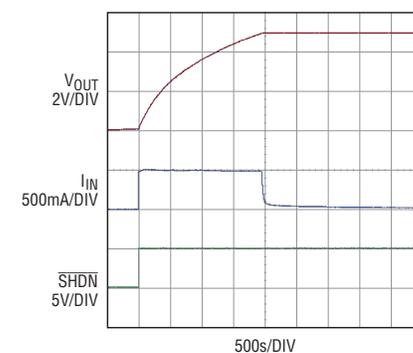


Figure 5. Waveforms of input current and V_{OUT} —charging a high density capacitor from 0V using circuit of Figure 4.



Low I_Q , Dual Output Step-Down Controller Converts 60V Directly to 3.3V

Jason Leonard and Joe Panganiban

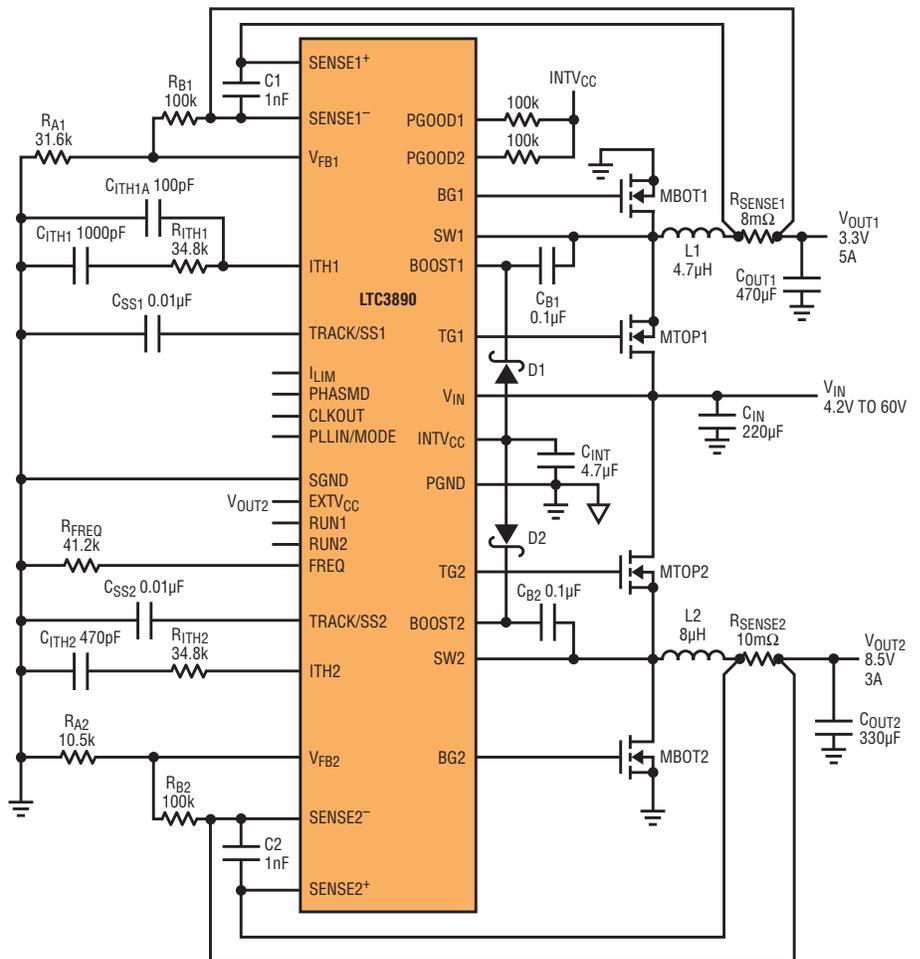
The LTC3890 is a versatile low quiescent current, 2-phase dual output synchronous step-down DC/DC controller ideal for high input voltage applications. It operates from a 4V-to-60V (65V abs max) input supply and regulates two outputs ranging from 0.8V to 24V. Its 50 μ A no-load quiescent current extends operating life in battery-powered systems.

Many high step-down-ratio DC/DC converter designs use a transformer-based topology, external high side drivers, and/or external bias supplies to operate at high input voltages. Others require 2-stage conversion because of duty cycle or on-time limitations. The LTC3890, however, trumps them all with an easy to use, high performance solution that fits in a small footprint.

The LTC3890 uses a proven synchronous buck DC/DC converter topology, but with a very low 95ns minimum on-time, enabling it to directly convert high input voltages to low output voltages. It has integrated high and low side N-channel MOSFET drivers and an integrated LDO, which operates directly from V_{IN} , to power the drivers and the IC. To improve efficiency and minimize power dissipation in the IC, the $EXTV_{CC}$ pin can be used to bypass the LDO at V_{IN} , thus allowing the IC to derive power from one of the outputs after it has started up.

FEATURES

The LTC3890 uses a constant frequency current mode control architecture for fast transient response and easy loop compensation. The two channels run 180° out-of-phase. The switching frequency can be programmed from 50kHz to 900kHz or synchronized to an external clock from 75kHz to 850kHz with the internally compensated phase-locked loop.



MTOP1, MTOP2, MBOT1, MBOT2: RJK0651DPB
 L1: COILCRAFT SER1360-472KL
 L2: COILCRAFT SER1360-802KL
 COUT1: SANYO 6TPE470M
 COUT2: SANYO 10TPE330M
 D1, D2: DFSL1100

Figure 1. High efficiency dual output 3.3V/8.5V step-down converter operates from 4.2V to 60V inputs and can operate down to 4V after start-up. The 99% maximum duty cycle allows the 8.5V output to follow V_{IN} when V_{IN} is less than 8.5V.

The LTC3890 uses a venerable synchronous buck DC/DC converter topology, but with a very low 95ns minimum on-time, allowing it to directly convert high input voltages to low output voltages. It has integrated high and low side N-channel MOSFET drivers and an integrated LDO, which operates directly from V_{IN} to power the drivers and the IC.

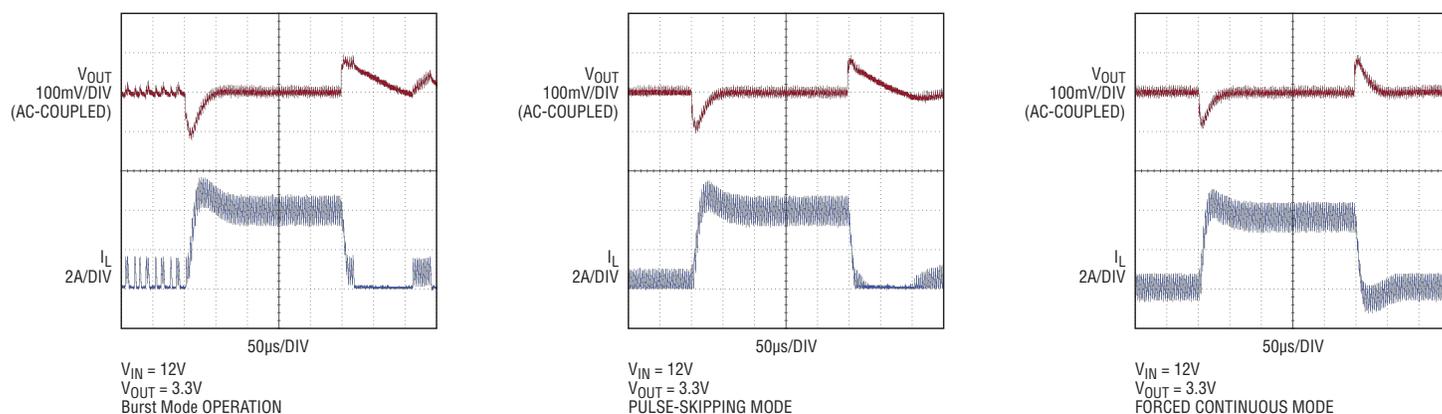


Figure 2. Transient response of Figure 1 for each of the three different modes of operation. At light load, the inductor current is allowed to reverse in forced continuous operation. Burst Mode operation has slightly higher ripple to achieve its much higher efficiency.

The low 95ns minimum on-time allows the LTC3890 to easily handle high step-down ratios (high v_{IN} to low v_{OUT}), even at high frequencies. High frequency capability enables the use of small inductors and capacitors, reducing cost and footprint over slower controllers. The LTC3890 can also run up to 99% duty cycle, providing low dropout when the input falls close to the output in high

v_{OUT} applications. Adjustable soft-start/ tracking input and enable pins are provided for each channel. At light loads, one of three modes—forced continuous, pulse-skipping, or Burst Mode operation—can be selected with the PLLIN/MODE pin to trade off constant frequency operation, output ripple, and quiescent current.

The LTC3890 is the latest in Linear Technology's growing family of low I_Q DC/DC controllers. Its closest relative is the pin-compatible LTC3857, which shares the same core features. The main differences are that the LTC3890 can handle a higher input voltage (65V versus 40V maximum) and the LTC3890's Burst Mode operation significantly improves mid-range efficiency while maintaining very low no-load quiescent current.

LOW I_Q , HIGH VOLTAGE DUAL OUTPUT CONVERTER

Figure 1 shows the LTC3890 in an application that converts a 4V to 60V input into 3.3V/5A and 8.5V/3A outputs. This circuit needs about 4.2V to get started but can operate down to below 4V. The transient responses for the three modes of operation are shown in Figure 2. Figure 3 shows start-up waveforms using standard soft-start and voltage rail tracking.

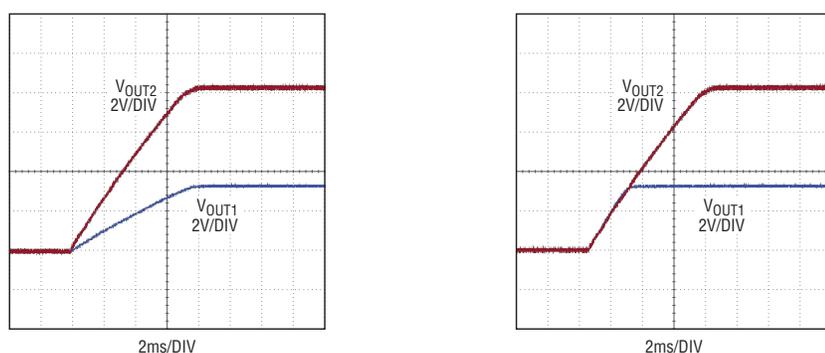


Figure 3. A soft-start capacitor on the TRACK/SS pin can program the ramp time (left), or a resistor divider from one output to the TRACK/SS pin of the other channel can enable the output voltages to track one another during start-up (right).

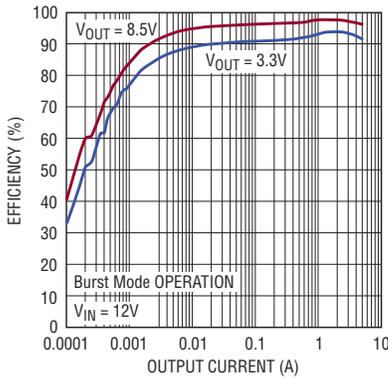


Figure 4. Efficiency in Burst Mode operation for the two outputs. Due to its low I_Q in Burst Mode operation, the LTC3890 maintains high efficiency and low power loss operation down to very light loads.

LOW I_Q AND HIGH EFFICIENCY BURST MODE EXTENDS BATTERY RUN-TIME

In many applications, one or more supplies remain active at all times, often in a standby mode where little or no load current is drawn. In these always-on systems, the quiescent current of the power supply circuit represents the vast majority of the current drawn from the input supply (battery). Having a low I_Q power supply is crucial to extending battery run-times. In Burst Mode operation, the LTC3890 draws only 50 μ A when one output is active with no load, and only 60 μ A when both outputs are enabled. It consumes only 14 μ A when both outputs are shut down. Figures 4 and 5 show the efficiency curves for the circuit in Figure 1. At light loads, the power loss curves are most

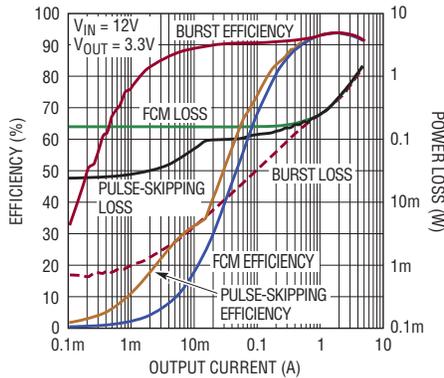


Figure 5. Efficiency and power loss for the three modes of operation. At heavy loads, there is no difference.

informative. Note the significantly lower (by orders of magnitude) power loss in Burst Mode operation at very light load.

MULTIPHASE SINGLE OUTPUT APPLICATIONS

The LTC3890 is normally configured for two independent outputs that run 180° out-of-phase. Operating the channels out-of-phase minimizes the required input capacitance. The LTC3890 can be configured with both power stages driving a single output. In this configuration, both channels' compensation (ITH), feedback (VFB), enable (RUN) and soft-start (TRACK/SS or SS) pins are tied together. Since the channels operate out-of-phase, the effective switching frequency is doubled, reducing not only the input but also the output capacitance,

while improving transient response. The LTC3890 provides inherently fast, accurate cycle-by-cycle current sharing due to its peak current mode control architecture.

Multiple LTC3890s can be used in designs with three or more phases. The CLKOUT pin can drive the PLLIN/MODE pin of other controllers, while the PHASMD pin adjusts the relative phases of each controller. This allows 3-, 4-, 6-, and 12-phase operation.

VERSIONS

The LTC3890 is available in two versions. The standard LTC3890 is the full-featured version available in a small 32-pin 5mm × 5mm QFN package. The LTC3890-1 has slightly fewer features and is offered in a 28-lead narrow SSOP package. These differences are summarized in Table 1.

CONCLUSION

The LTC3890 brings a new level of performance to high voltage step-down converters. This low quiescent current, 2-phase, dual output DC/DC controller enables a highly efficient, easy to design, compact solution for power supplies with a wide range of input and output voltages. ■

Table 1. Key differences between the LTC3890 and LTC3890-1

	LTC3890	LTC3890-1
CURRENT SENSE VOLTAGE (SENSE RESISTOR OR INDUCTOR DCR SENSING)	Adjustable 30mV/50mV/75mV (Set via ILIM pin)	Fixed 75mV
POWER GOOD OUTPUT VOLTAGE MONITOR	Independent Monitors for Each Channel (PGOOD1 and PGOOD2 pins)	Monitor for Channel 1 Only (PGOOD1 Pin)
CLKOUT/PHASMD PINS FOR THREE OR MORE PHASES	Yes	No
PACKAGE	5mm × 5mm QFN	28-Lead Narrow SSOP

Product Briefs

16-BIT 125Msps ADCs

REDUCE POWER TO 185mW

Three new families of low power 16-bit, 25Msps to 125Msps ADCs dissipate approximately half the power of competing 16-bit solutions. The LTC2165 and LTC2185 families are single- and two-channel simultaneous-sampling parallel ADCs, respectively, offering a choice of full-rate CMOS, or double data rate (DDR) CMOS/LVDS digital outputs with programmable digital output timing, programmable LVDS output current and optional LVDS output termination. The LTC2195 family includes 2-channel, simultaneous sampling ADCs with serial LVDS outputs.

Each ADC family offers a choice of pin-compatible converters, sampling from 25Msps up to 125Msps and optimized for the lowest power dissipation at the rated speed. They include such popular features as Linear Technology's digital output randomizer and alternate bit polarity (ABP) mode that minimize digital feedback. These low power 16-bit ADCs enable designers to upgrade performance while maintaining portability in such applications as handheld test and instrumentation, radar/LIDAR, portable medical imaging, PET/SPECT scanners, smart antenna systems and a variety of low power communication systems.

The dual LTC2185/LTC2195 and single LTC2165 consume 185mW/channel at 125Msps and offer signal to noise ratio (SNR) performance of 76.8dB and SFDR of 90dB at baseband. Pin-compatible speed grade options include 25Msps, 40Msps, 65Msps, 80Msps and 105Msps with approximate power dissipation of just 1.5mW/Msps per channel. Further power savings can be achieved by placing the devices in standby (20mW) or shutdown (1mW). Analog full power bandwidth of 550MHz and ultralow jitter of 0.07ps_{RMS} allows undersampling of IF frequencies with excellent noise performance. ■

Table 1. Complete family of 16-bit parallel and serial interface ADCs

		25Msps	40Msps	65Msps	80Msps	105Msps	125Msps
SINGLE CHANNEL	7 × 7 QFN 1.8V Single ADCs, Parallel Outputs	2160	2161	2162	2163	2164	2165
	9 × 9 QFN 1.8V Dual ADCs Parallel Outputs	2180	2181	2182	2183	2184	2185
DUAL CHANNEL	7 × 8 QFN 1.8V Dual ADCs, Serial LVDS Outputs	2190	2191	2192	2193	2194	2195
POWER	(mW/Ch)	40	60	80	100	155	185

(LTC3127, continued from page 39)

CONCLUSION

The compact LTC3127 1.0A buck-boost DC/DC converter with ±4% accurate, programmable average input current limit is an optimal power supply solution for charging capacitors that supply energy in pulsed load or emergency load

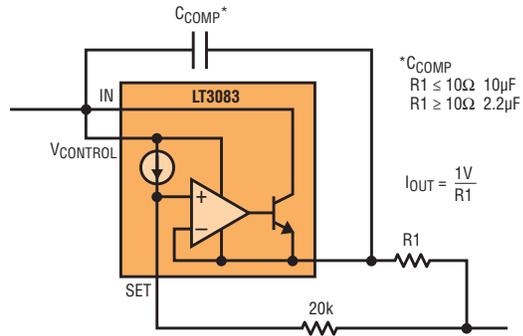
applications. The accuracy of the LTC3127 allows the designer to set the input current limit close to the source's maximum, thus minimizing capacitor charge time, and by extension, minimizing capacitor size and cost. The LTC3127's high efficiency

through all operating modes makes it an ideal fit for a wide variety of power sources including PCMCIA and USB. These features, when combined with low profile supercapacitors, elegantly solve the pulsed load problem in a compact footprint. ■

2-TERMINAL 3A CURRENT SOURCE

The LT3083 is a 3A low dropout linear regulator that can be paralleled to increase output current or spread heat on surface-mounted boards. Architected as a precision current source and voltage follower, this new regulator finds use in many applications requiring high current, adjustability to zero with no heat sink. The device brings out the collector of the pass transistor to allow low dropout operation down to 310mV when used with multiple supplies.

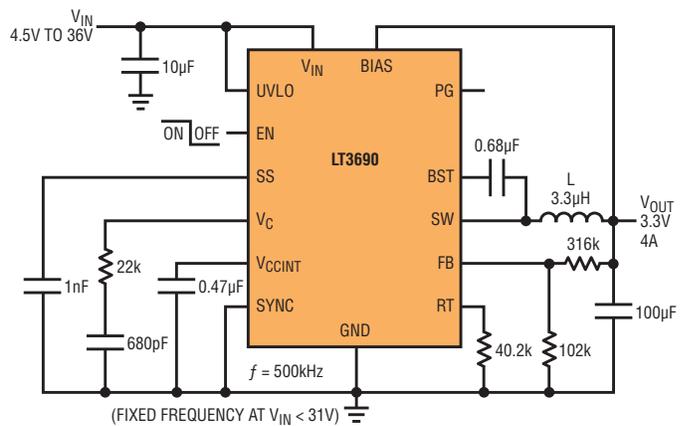
www.linear.com/3083



3.3V STEP-DOWN CONVERTER

The LT3690 is an adjustable frequency monolithic buck switching regulator that accepts input voltages up to 36V. A high efficiency 90m Ω switch is included on the device along with the boost diode and the necessary oscillator, control, and logic circuitry. The internal synchronous power switch of 30m Ω increases efficiency and eliminates the need for an external Schottky catch diode. The low ripple Burst Mode operation maintains high efficiency at low output currents, reducing quiescent current to less than 75 μ A while keeping output ripple below 15mV in typical applications.

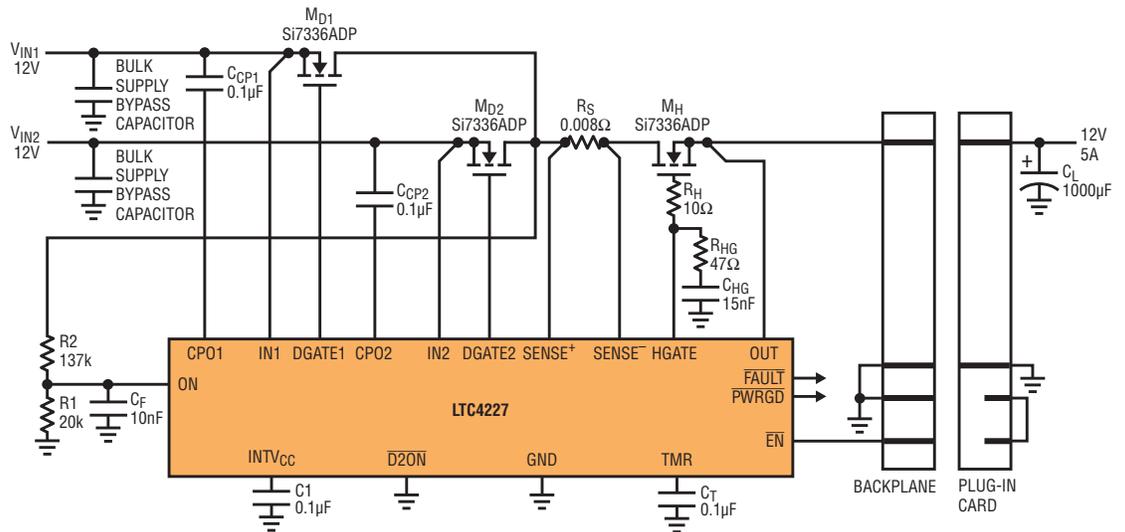
www.linear.com/3690



BACKPLANE RESIDENT DIODE-OR APPLICATION WITH INRUSH CURRENT LIMITING AT 12V SUPPLY INPUTS

The LTC4227 offers ideal diode and Hot Swap™ functions for two power rails by controlling external N-channel MOSFETs. MOSFETs acting as ideal diodes replace two high power Schottky diodes and the associated heat sinks, saving power and board area. A Hot Swap control MOSFET allows a board to be safely inserted and removed from a live backplane by limiting inrush current. The supply output is also protected against short-circuit faults with a fast acting current limit and internal timed circuit breaker.

www.linear.com/4227



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