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## IN THIS ISSUE...

### COVER ARTICLE

*Easy Drive Delta-Sigma ADCs Deliver Powerful Features and Reduce Design Effort* ..... 1  
Mark Thoren

*Linear Technology in the News* ..... 2

### DESIGN FEATURES

*Current Mode Flyback DC/DC Controller Provides Tremendous Design Flexibility* ..... 8  
Arthur Kelley

*Isolated Forward Controllers Offer Buck Simplicity and Performance* ..... 10  
Charles Hawkes and Arthur Kelley

*Rugged 3.3V RS485/RS422 Transceivers with Integrated Switchable Termination* ..... 14  
Steven Tanghe and Ray Schuler

*Tiny High Efficiency 2A Buck Regulator Directly Accepts Automotive, Industrial and Other Wide Ranging Inputs* ..... 18  
Kevin Huang

*36V Dual 1.4A Monolithic Step-Down Converter has Start-Up Tracking and Sequencing* ..... 21  
Keith Szolusha

*3-Phase Buck Controller Governs One, Two or Three Outputs* ..... 26  
Theo Phillips and Teo Yang Long

### DESIGN IDEAS

..... 30-41  
(complete list on page 30)

*New Device Cameos* ..... 42

*Design Tools* ..... 43

*Sales Offices* ..... 44

# Easy Drive Delta-Sigma ADCs Deliver Powerful Features and Reduce Design Effort

by Mark Thoren

## Introduction

Easy Drive™ delta-sigma ADCs are rich in features but easy to use. The Easy Drive feature simplifies or eliminates active amplification or filtering at the inputs. Even the software interface is significantly less complicated than other ADCs (see sidebar on page 6). Overall, much of the traditional complexity around an ADC, such as external components and software timing, is simply gone, saving significant design time.

Table 1 lists the features of the 18 available Easy Drive devices, including 1-, 4- or 16-channel versions with I<sup>2</sup>C

or SPI interfaces. The 24-bit devices suit very high performance applications, while 16-bit devices are more general-purpose. A programmable gain amplifier (PGA) is available on the 16-bit devices for intermediate requirements or where several input ranges need to be accommodated.

## Easy Drive Technology Simplifies Measurement of High Impedance Sensors

Delta-Sigma ADCs, with their high accuracy and high noise immunity, are ideal for directly measuring many

*continued on page 3*

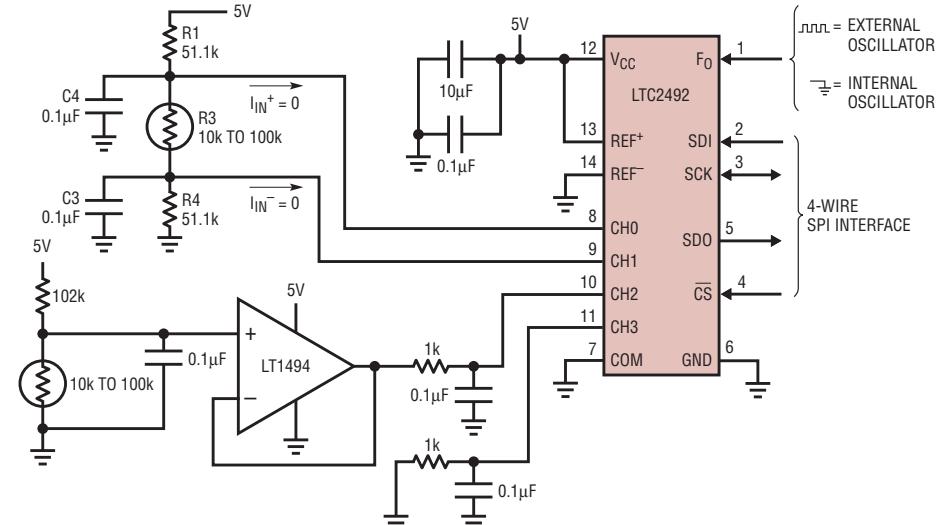


Figure 1. Easy Drive ADCs simplify measurement of high impedance sensors.

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# Linear Technology in the News...

## EDN Innovation Award Finalists

EDN magazine announced that Linear Technology's LTC®6908 Resistor Set Oscillator with Spread Spectrum Modulation is a finalist for their annual EDN Innovation Awards in the Analog ICs category. According to EDN, "Linear Technology developed the LTC6908 silicon oscillator for the reduction of EMI by intelligently controlling the switching regulator clock. It accomplishes this goal in three ways. First, by synchronizing multiple switching regulators out of phase with each other, it decreases the peak switching currents... The second benefit of the LTC6908 in controlling EMI is that its high-accuracy clock frequency allows you to move the switcher EMI to a frequency that is out of band for the receiving electronics. The third and most dramatic improvement to EMI is achievable by continuously varying the switcher's clock frequency."

## EE Times ACE Award Finalist

EE Times announced the selection of Linear Technology's LTC3035 300mA VLDO™ Linear Regulator with Charge Pump Bias Generator as a finalist for the EE Times ACE Awards in the Analog ICs category. EE Times stated, "The LTC3035's tight output voltage  $\pm 2$  percent accuracy, low quiescent and shutdown currents of 100 microamps and 1 microamp, respectively, combined with fast transient response and small solution footprint with few external components, make it practical for battery-powered handheld devices such as Bluetooth-enabled devices, cellular phones, media players, handheld medical and industrial instruments."

## AnalogZone Products of the Year

AnalogZone has awarded two Linear Technology products as Products of the Year: LT5560 RF Active Mixer and LTC3836 Dual Output 2-Phase Synchronous Controller. AnalogZone stated, "With the LT5560 Linear has taken its own product, the LT5525/26, and made it better in almost every way... Conversion gain is up, noise is down, quiescent is down... Another superb product in this Linear family keeping the company well ahead in the industry..."

AnalogZone commented on the LTC3836, "Linear Technology introduced the LTC3836, a dual output 2-phase, low input voltage current mode synchronous step-down switching controller. Operation from an input voltage from 2.75V to 4.5V makes the device ideal for 3.3V, single cell Li-Ion, multi-cell Alkaline or NiMH input sources. ... This is a nice next-generation part obviously resulting from a lot of listening on Linear's side of the fence. Keeping up with the market not only

helps you retain your existing users; it also brings you many more. The LTC3836 will do famously well."

## EE Times China ACE Award Finalists

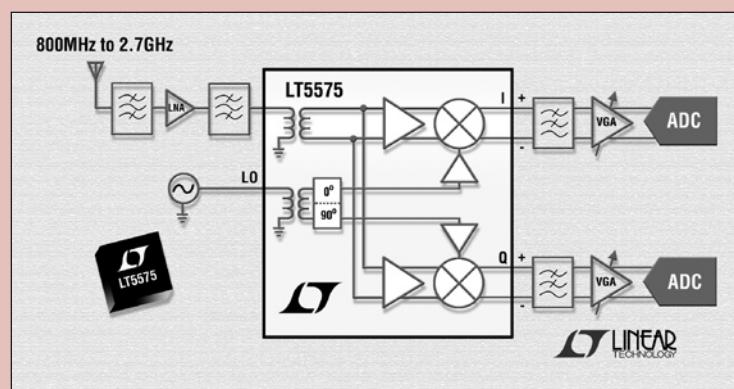
Four Linear Technology products were selected as finalists for EE Times China ACE Awards:

- LTC2208 16-Bit, 130Msps ADC in the AD/DA Converter ICs category
- LTC2859/61 20Mbps RS485 Transceivers with Integrated Switchable Termination in Interface ICs
- LT®6003/04/05 1.6V, 1 $\mu$ A Precision Rail-to-Rail Input and Output Op Amps in Amplifier ICs
- LTM4600 10A High Efficiency DC/DC  $\mu$ Module™ in the Power category

## Linear Unveils Solutions for 3G and WiMAX Basestations

Two new devices from Linear Technology enhance performance and reduce solution cost of 3G and WiMAX basestations. The LT5575 High Linearity Direct Conversion I/Q Demodulator was featured in a cover article in *High Frequency* magazine and in numerous publications worldwide. The device provides an operating frequency range of 800MHz to 2.7GHz, covering all cellular and 3G infrastructure, WiMAX and RFID bands with a single part. Its capability to convert from RF directly to baseband at DC or low frequency results in simplified receiver designs, reduced component count and the ability to use lower cost, low frequency components.

The LT5577 3.3V High Linearity Downconverting Active RF Mixer was also announced worldwide. The device provides the broadest bandwidth of any high performance active mixer on the market, enabling a cost-effective, easy to use solution for 3G wireless and WiMAX basestations, covering frequencies from 400MHz to 3.8GHz. **LTC**



The LT5575 High Linearity Direct Conversion I/Q Demodulator converts from RF directly to baseband at DC or low frequency to reduce component count, and allow the use of lower cost, low frequency components.

*Easy Drive, continued from page 1*

types of sensors. Nevertheless, input sampling currents can overwhelm high source impedances or low bandwidth, micropower signal conditioning circuits. Easy Drive solves this problem by balancing the input currents, thus simplifying or eliminating the need for signal conditioning circuits.

A common application for a delta-sigmaADC is thermistor measurement. Figure 1 shows two examples of thermistor digitization benefiting from Easy Drive technology. The first circuit (applied to input channels CH0 and CH1) uses two equal reference resistors that set the input common mode voltage equal to the reference common mode voltage and balance the differential input source resistance. If reference resistors R1 and R4 are exactly equal, the input current is zero and no er-

rors result. If these resistors have a 1% tolerance, the maximum error in measured resistance is  $1.6\Omega$  due to a shift in common mode voltage, far less than the 1% error of the reference resistors themselves. No amplifier is

required, making this an ideal solution in micropower applications.

Easy Drive also enables very low power, low bandwidth amplifiers to drive the input of the LTC2492. As shown in Figure 1, CH2 is driven by an LT1494. The LT1494 has excellent DC specs for an amplifier with  $1.5\mu A$  supply current, offering maximum offset voltage of  $150\mu V$  and an open loop gain of 100,000. However, its 2kHz bandwidth makes it unsuitable for driving conventional delta-sigma ADCs. Adding a  $1k\Omega$ ,  $0.1\mu F$  filter solves this problem by providing a charge reservoir that supplies the LTC2492 instantaneous current, while the  $1k\Omega$  resistor isolates the capacitive load from the LT1494. The input sampling current of conventional delta-sigma ADCs leads to DC errors as a result

***Input sampling currents  
can overwhelm high  
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the input currents, thus  
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the need for signal  
conditioning circuits.***

Table 1. Complete Easy Drive delta-sigma family

Part Number	# Inputs	Interface	Bits	Temp	PGA	2x	Package
LTC2480	1	SPI	16	⊖	⊖	⊖	3mm × 3mm DFN
LTC2481	1	I <sup>2</sup> C	16	⊖	⊖	⊖	3mm × 3mm DFN
LTC2482	1	SPI	16				3mm × 3mm DFN
LTC2483	1	I <sup>2</sup> C	16				3mm × 3mm DFN
LTC2484	1	SPI	24	⊖		⊖	3mm × 3mm DFN
LTC2485	1	I <sup>2</sup> C	24	⊖		⊖	3mm × 3mm DFN
LTC2486	2/4	SPI	16	⊖	⊖	⊖	3mm × 4mm 14DFN
LTC2487	2/4	I <sup>2</sup> C	16	⊖	⊖	⊖	3mm × 4mm 14DFN
LTC2488	2/4	SPI	16				3mm × 4mm 14DFN
LTC2489	2/4	I <sup>2</sup> C	16				3mm × 4mm 14DFN
LTC2492	2/4	SPI	24	⊖		⊖	3mm × 4mm 14DFN
LTC2493	2/4	I <sup>2</sup> C	24	⊖		⊖	3mm × 4mm 14DFN
LTC2494	8/16	SPI	16	⊖	⊖	⊖	5mm × 7mm QFN
LTC2495	8/16	I <sup>2</sup> C	16	⊖	⊖	⊖	5mm × 7mm QFN
LTC2496	8/16	SPI	16				5mm × 7mm QFN
LTC2497	8/16	I <sup>2</sup> C	16				5mm × 7mm QFN
LTC2498	8/16	SPI	24	⊖		⊖	5mm × 7mm QFN
LTC2499	8/16	I <sup>2</sup> C	24	⊖		⊖	5mm × 7mm QFN

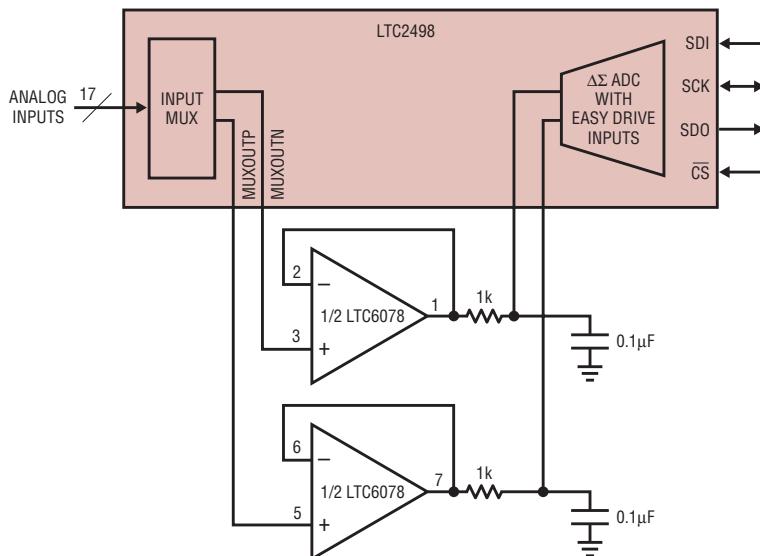


Figure 2. External buffers provide high impedance inputs and amplifier offsets are automatically cancelled.

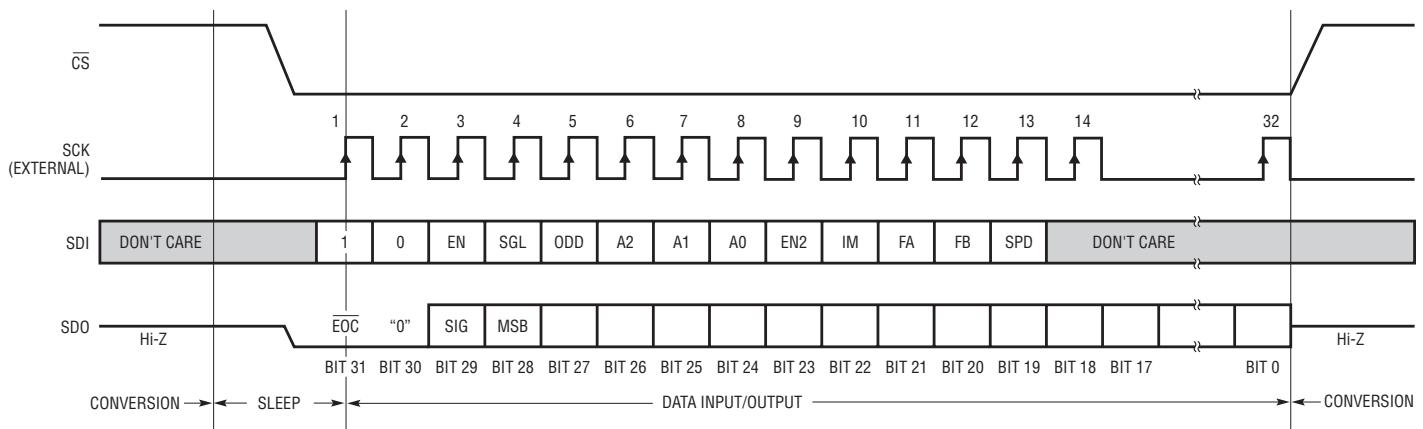


Figure 3. SPI interface, configuration and data output timing



Figure 4. I<sup>2</sup>C conversion sequence

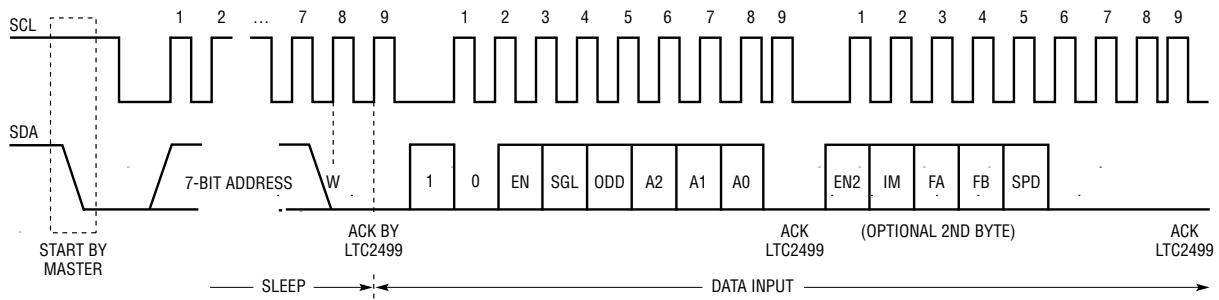
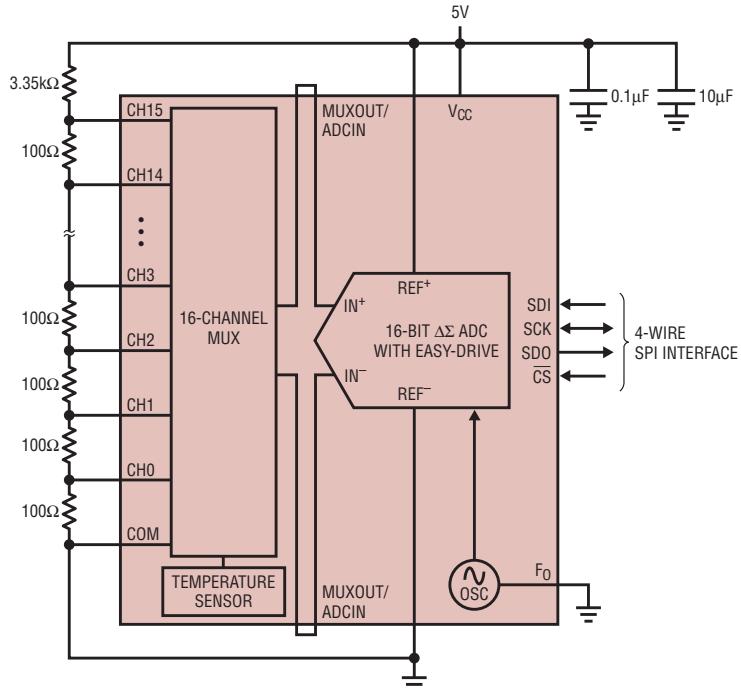


Figure 5. I<sup>2</sup>C configuration and data output timing



**Figure 6.** Use this setup to quickly sort out which SDI word is associated with each input channel.

of incomplete settling in the external RC network. Linear Technology's Easy Drive technology cancels the differential input current. By balancing the negative input (CH3) with a  $1\text{k}\Omega$ - $0.1\mu\text{F}$  RC network, errors due to the common mode input current are cancelled.

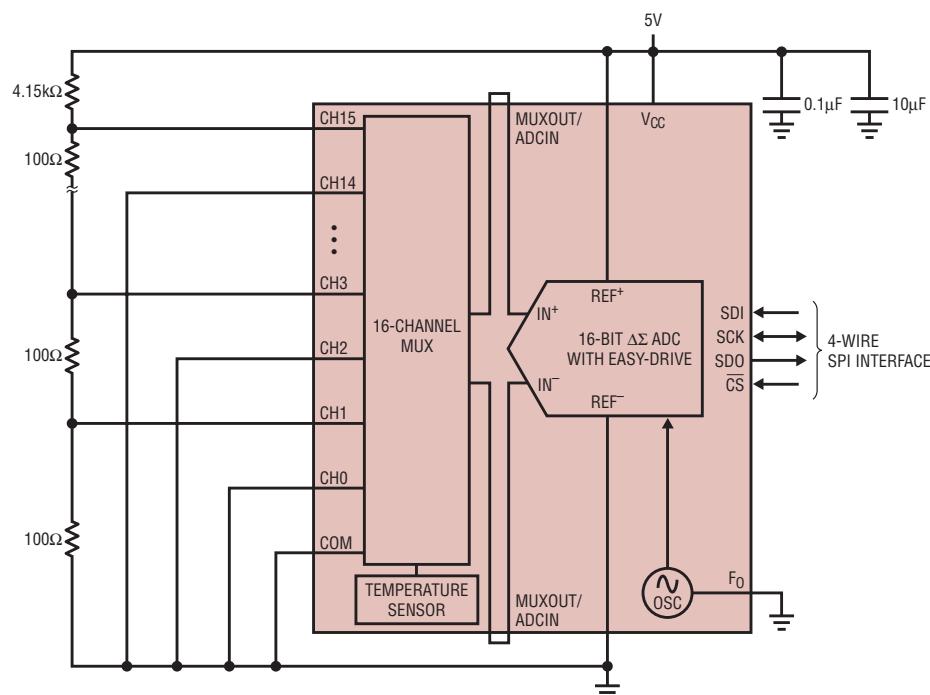
### Complete Easy Drive Delta-Sigma Family

Easy Drive ADCs are at home in a vast array of applications. The 24-bit, 16-channel LTC2498 with integrated temperature sensor is ideal for high performance data acquisition systems. It can directly digitize thermocouples without any signal conditioning and provide cold junction compensation. It can also directly measure low level strain gage outputs. At the same time it can handle industrial sensor voltages with the addition of a simple resistive divider—no active circuitry required.

The 16-bit, 16-channel devices are suitable for measuring voltages and currents on large circuit boards that have several high current supplies. Up to 16 ground referred measurements can be taken if the COM pin is grounded to a common point for all supplies. Using the inputs differentially (up to 8 differential input channels) allows high side sensing of current shunts as long as the shunt common mode voltage is less than or equal to the ADCs' supply voltage. Differential measurements also allow voltages to be sensed remotely, eliminating errors due to large ground currents.

Another big advantage of using a delta-sigma ADC for power supply measurements is the very strong rejection of noise and switching transients. The ADC's internal SINC4 filter, in conjunction with a simple 1-pole filter at the ADC input, is adequate to attenuate switching power supply noise below the ADC noise floor. What is left is an extremely accurate measurement of the DC value of the power supply voltage or current.

The single channel LTC2482 is ideal for cost sensitive applications such as portable medical devices and consumer products. Don't be fooled by its relatively low cost—it is essentially a perfect 16-bit ADC that shares the



**Figure 7.** Use this setup to quickly sort out which SDI word is associated with each differential input channel.

same 600nV input noise floor as the 24-bit parts. This means it would also be ideal for a 4½ digit handheld or bench-top voltmeter with a ±1 count linearity specification.

### Automatic Offset Calibration of External Buffers/Amplifiers

In addition to the Easy Drive input current cancellation, the 16-channel Easy Drive ADCs allow an external amplifier to be inserted between the multiplexer output and the ADC input (see Figure 2). This is useful in applications where balanced source impedances are not possible or where the source impedance is very high. One pair of external buffers/amplifiers can be shared between all 17 analog inputs. The LTC2498 performs an internal offset calibration every conversion cycle in order to remove the offset and drift of the ADC. This calibration is performed through a combination of front end switching and digital processing. Since the external amplifier is placed between the multiplexer and the ADC, it is inside this correction loop. This results in automatic removal of the offset and offset drift of the external amplifier.

The LTC6078 is an excellent amplifier for this function. It operates with supply voltages as low as 2.7V and its voltage noise level is a low  $18\text{nV}/\sqrt{\text{Hz}}$ . The LTC2498's Easy Drive inputs allow an RC network to be added directly to the output of the LTC6078. The capacitor reduces the magnitude of the current spikes seen at the input to the ADC and the resistor isolates the capacitor load from the op amp output enabling stable operation.

### Software Interface

The simplicity of the analog interfacing requirements of Linear Technology's Easy Drive ADCs is matched by the simplicity of their serial interface. The No Latency architecture eliminates the annoyance of having to discard readings after switching channels on the multichannel devices. The start of conversion is directly controlled by the serial interface, so external signal conditioning or sensor excitation can be switched in at the proper

### Sample Code Drivers for Basic Communications with the LTC2448 and LTC2449

```

// Make sure this structure applies in the
// context of the following functions.
struct fourbytes // Define structure of four consecutive bytes
{
    int8 te0;      // To allow byte access to a 32-bit int or float.
    int8 te1;      //
    int8 te2;      // The make32() function in some compilers will
    int8 te3;      // also work, but a union of 4 bytes and a 32-bit int
};               // is more portable because it is standard C.

// Some defines for I2C communication
#define READ      0x01    // bitwise OR with address for read or write
#define WRITE     0x00

*****Blocking version of read_LTC2498() function. When called,
it will wait for the LTC2498 to finish converting and then
read data. The longest this function should ever take to return
is the maximum conversion time of the LTC2498. It is a good
idea to use a watchdog when your program has blocking functions
like this.

The spi_readwrite() function simultaneously reads and writes
an 8-bit byte from the SPI port. Most compilers that support
processors that have a hardware SPI port have a similar function.

As a starting point, configure the SPI port for data transitions
on the falling clock edge, valid on the rising edge.

Arguments: channel - channel to program for the next conversion
           config - configuration bits for next conversion

Returns:   32 bit word from the LTC2498 when the conversion finishes
*****Int32 read_LTC2498(char channel, char config);

{
    // Create a union of the four-byte structure and a 32-bit
    // signed integer.
    union// adc_code.bits32    all 32 bits
    {
        // adc_code.by.te0      byte 0
        signed int32 bits32;  // adc_code.by.te1      byte 1
        struct fourbytes by; // adc_code.by.te2      byte 2
        } adc_code;          // adc_code.by.te3      byte 3

        output_low(CS_);    // Lower Chip Select, enabling serial port
        while(input(SDO)); // Wait for SDO to go low. You can also put a
                           // timeout here in case something bad happens
        adc_code.by.te3 = spi_readwrite(channel);
        adc_code.by.te2 = spi_readwrite(config);
        adc_code.by.te1 = spi_readwrite(0);
        adc_code.by.te0 = spi_readwrite(0);
        return adc_code.bits32;
    } // end of read_LTC2498()

*****Non-blocking version of read_LTC2498() function. When called,
it will see if the LTC2498 has finished converting. If so,
data will be read and returned. If not, zero will be returned.
Since all zeros is NOT a valid code from the LTC2498, the calling
program can ignore the return result if zero.

Arguments: channel - channel to program for the next conversion
           config - configuration bits for next conversion

Returns:   32 bit word from the LTC2498 if conversion is done,
           zero if not.
*****Int32 read_LTC2498(char channel, char config);

{
    // Create a union of the four byte structure and a 32 bit
    // signed integer.
    union// adc_code.bits32    all 32 bits
    {
        // adc_code.by.te0      byte 0
        signed int32 bits32;  // adc_code.by.te1      byte 1
        struct fourbytes by; // adc_code.by.te2      byte 2
        } adc_code;          // adc_code.by.te3      byte 3

```

```

    output_low(CS_); // Lower Chip Select, enabling serial port
    while(input(SDO)); // Wait for SDO to go low. You can also put a
                       // timeout here in case something bad happens
    adc_code.by.te3 = spi_readwrite(channel);
    adc_code.by.te2 = spi_readwrite(config);
    adc_code.by.te1 = spi_readwrite(0);
    adc_code.by.te0 = spi_readwrite(0);
    return adc_code.bits32;
} // end of read_LTC2498()

```

\*\*\*\*\*  
Non-blocking read\_LTC2499() function.

the i2c\_xxxx() functions do the following:

```

void i2c_start(void): generate an i2c start or repeat start condition
void i2c_stop(void): generate an i2c stop condition
char i2c_read(boolean): return 8 bit i2c data while generating
                        an ack or nack
boolean i2c_write(): send 8 bit i2c data and return ack or
                     nack from slave device

```

These functions are very compiler specific, and can use either a hardware i2c port or software emulation of an i2c port. This example uses software emulation.

A good starting point when porting to other processors is to write your own i2c functions. Note that each processor has its own way of configuring the i2c port, and different compilers may or may not have built-in functions for the i2c port.

Arguments: addr - LTC2499 I2C address  
              channel - channel to program for the next conversion  
              config - configuration bits for next conversion

Returns: 32 bit word from the LTC2499 if conversion is done,  
          zero if not.  
\*\*\*\*\*

```

signed int32 read_LTC2499(char addr, char channel, char config)
{
    union
    {
        signed int32 bits32;           // adc_code.bits32      all 32 bits
        struct fourbytes by;          // adc_code.by.te0      byte 0
        struct fourbytes by;          // adc_code.by.te1      byte 1
        struct fourbytes by;          // adc_code.by.te2      byte 2
        struct fourbytes by;          // adc_code.by.te3      byte 3
    } adc_code;

    // Start communication with LTC2481:
    i2c_start();
    if(i2c_write(addr | WRITE))// If no acknowledge, return zero
    {
        i2c_stop();
        return 0;
    }
    i2c_write(channel);
    i2c_write(config);
    i2c_start();
    i2c_write(addr | READ);
    adc_code.by.te3 = i2c_read();
    adc_code.by.te2 = i2c_read();
    adc_code.by.te1 = i2c_read();
    adc_code.by.te0 = i2c_read();
    i2c_stop();
    return adc_code.bits32;
} // End of read_LTC2499()

```

\*\*\*\*\*  
Note: you can create a non-blocking version of this function  
by repeatedly attempting to write the LTC2499 address, sending  
a stop condition if there is no acknowledgement to keep the bus free.  
When the LTC2499 acknowledges, read the data and return.  
\*\*\*\*\*

time. The implicit offset and gain calibration that takes place in every conversion eliminates the need for complicated internal register set or calibration cycles. Communication for both the SPI and I<sup>2</sup>C interface parts is a simple read/write operation where data from one conversion is read as the configuration for the next channel is programmed into the ADC.

Figure 3 shows the data input/output operation for the LTC2498. This is the SPI-interface ADC with the most channels and features—other SPI parts have similar interfaces.

Figure 4 shows the data input/output operation for the LTC2499. Likewise, this is the most feature-laden I<sup>2</sup>C part—other I<sup>2</sup>C parts have similar interfaces. Figure 5 shows the details of writing the channel and configuration to the input registers.

To help the software/firmware designer get started, see the sidebar for C code drivers for basic communications with the LTC2448 and LTC2449. These functions can be easily ported to any C compiler and can easily be adapted to the other Easy Drive ADCs.

### Try this Trick!

While the Easy Drive serial interface is easy to program—just read the data for sample N while programming the channel for sample N+1—it can still be tricky to figure out what was just read when looking at a microcontroller's registers through a debugger. Here is a hardware trick that can significantly reduce code design headaches. Figure 6 shows a simple circuit that applies a known voltage to each single-ended input. With the values shown, CH0 has a voltage of 101mV, CH1 202mV, and so on up to CH15, which produces 1.616V. Figure 7 shows the equivalent circuit for differential inputs. Use this setup to quickly sort out which SDI word is associated with each input channel. □

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# Current Mode Flyback DC/DC Controller Provides Tremendous Design Flexibility

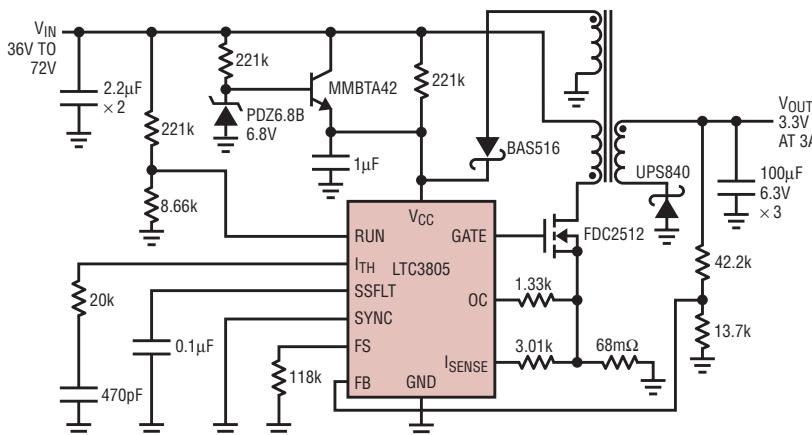
by Arthur Kelley

## Introduction

By its nature, a flyback DC/DC converter is one of the most versatile power converter topologies. Because it uses a transformer, it can step up or step down voltages and provide DC isolation if needed. Applications include power supplies for networking equipment, Power-over-Ethernet (PoE), automotive, consumer and general system house keeping. The LTC3805 has been designed to enhance the flexibility of the basic flyback converter, making it possible to optimize a single design for diverse applications. The converter input and output voltage is limited only by the rating of external components such as the power MOSFET and the transformer. The LTC3805 can be programmed for frequency, slope compensation, soft-start, input voltage RUN/STOP thresholds (including programmable hysteresis), synchronization to an external frequency source, and overcurrent protection to protect the converter from faults.

## 36V-72V to 3.3V at 3A Non-Isolated Flyback

Figure 1 shows the LTC3805 in a non-isolated flyback converter with an input voltage range of 36V to 72V and an output voltage of 3.3V at 3A.



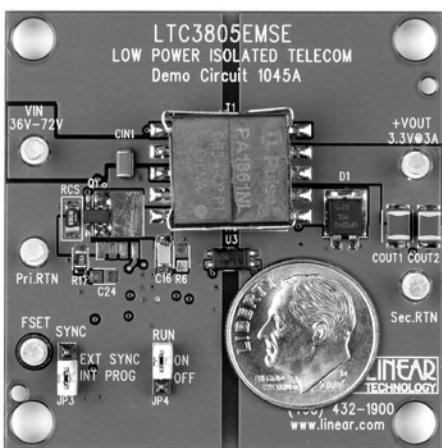
**Figure 1.** Non-isolated 36V to 72V to 3.3V 3A flyback converter

The remainder of this section details the design decisions made in creating this converter and describes methods for altering the design for various applications. An isolated version of the converter is described in the next section.

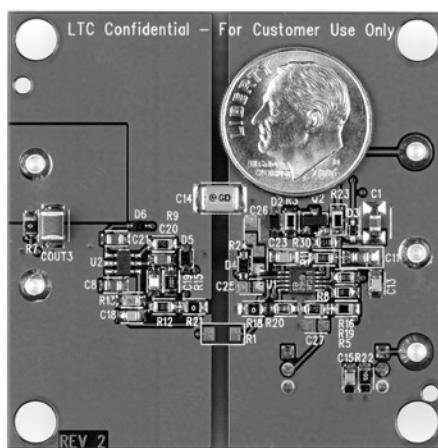
## **V<sub>CC</sub> Power and Start-Up**

In this design, start-up  $V_{CC}$  power for the LTC3805 is provided by an external pre-regulator using an NPN transistor, a zener diode and two resistors. Once the converter begins operation, a winding on the transformer provides a bias supply which turns off

the NPN transistor to save power and increase efficiency. Alternately, since the LTC3805 has an ultralow shutdown current of  $40\mu A$ , a simple trickle charger could be used to eliminate the NPN pre-regulator. The LTC3805 has a  $V_{CC}$  rising threshold of 8.5V and a falling threshold of 4V so there is plenty of hysteresis to implement a trickle charger. In either case, note that  $V_{CC}$  is not connected to  $V_{IN}$  so that almost any input supply above 8.5V can be accommodated by proper selection of external components and that, once started, the LTC3805 can run with input supplies down to 4V.



**Figure 2.** Isolated 36V to 72V to 3.3V 3A flyback converter



## Programming V<sub>OUT</sub>

The FB pin monitors the output voltage by comparing it—via a resistive divider—to the 0.8V internal reference of the LTC3805. Since the FB pin is not connected directly to the output, the LTC3805 can accommodate any output voltage down to 0.8V simply by adjustment of the resistor values.

## Selecting Frequency

The 200kHz operating frequency is programmed by the  $118\text{k}\Omega$  resistor on the FS pin. By changing this resistor, the operating frequency can

be set anywhere between 70kHz and 700kHz. High power designs tend to use lower frequencies while low power designs tend to use higher frequencies. The frequency programmability of the LTC3805 allows selection of the optimum frequency for any given design.

### Programming the $V_{IN}$ Thresholds

The rising threshold on  $V_{IN}$ , which is independent of the thresholds on  $V_{CC}$ , is set by the 221k $\Omega$  and 8.86k $\Omega$  resistors connected to the RUN pin. The rising threshold on the RUN pin is 1.2V while its absolute maximum voltage is 18V—a 15:1 ratio. Therefore the RUN pin accommodates designs with a wide range of input voltages and still has a high enough voltage rating to survive a transient overvoltage on  $V_{IN}$ . Once started, the LTC3805 sources a 5 $\mu$ A current from the RUN pin. Multiplied by the 221k $\Omega$  resistor, this current sets the hysteresis on  $V_{IN}$  to 1.1V. A different hysteresis, with the same rising threshold, can be selected by changing the values of the 221k $\Omega$  and 8.86k $\Omega$  resistors while keeping their ratio constant.

### Setting the Soft-Start

The rate of change of  $V_{OUT}$  at start-up is programmed by the capacitor on the SSFLT pin—0.1 $\mu$ F in this case. A major consideration in the selection of the SSFLT capacitor is the filter capacitor used to bypass  $V_{OUT}$ . Generally, a larger output filter capacitor requires a slower soft-start to limit the inrush current caused by the charging filter capacitor. Conversely, if the converter has a small output filter capacitor, the SSFLT capacitor can be omitted and the LTC3805 internal soft-start ramps up the output voltage in 1.8ms.

### Programming Slope Compensation and Overcurrent Operation

The 68m $\Omega$  resistor monitors the current through the main NMOS switch and implements both current mode control and overcurrent protection via the  $I_{SENSE}$  and OC pins, respectively. The  $I_{SENSE}$  pin monitors the current through the main switch and turns it off when the current exceeds a level

set by the voltage on the  $I_{TH}$  pin. The 3.01k $\Omega$  resistor sets the amount of slope compensation using a ramp of current that is sourced by the LTC3805.

The overcurrent protection level is set by the 1.33k $\Omega$  resistor in series with the OC pin using a constant 10 $\mu$ A current sourced by the OC pin. Several behaviors can be programmed using this resistor. This particular design is set to regulate output voltage up to 3A and then overcurrent trip just above that. An alternate strategy, using a smaller resistor, would be to allow the output voltage to sag as the converter goes into current limiting and then trip on overcurrent only to prevent damage. In either case, once there is an overcurrent trip the LTC3805 shuts down, waits for a time out interval determined by discharging the capacitor on the SSFLT pin and then restarts if the overcurrent fault has been removed. If the fault is not removed, the LTC3805 enters a hiccup mode in which it periodically tries to restart with the period determined by the capacitor on the SSFLT pin. Thusly, the LTC3805 completely protects a flyback converter from short circuits on the output.

### Frequency Synchronization to an External Source

Although shown grounded in Figure 1, the SYNC pin is used to synchronize the frequency of operation of the LTC3805 to an external source. The synchronization signal can be applied and removed without any particular sequencing requirement—it can be

present before the LTC3805 begins operation or it can be applied after the LTC3805 has begun operation using the frequency programmed by the resistor on the FS pin. When the synchronization signal is applied, the LTC3805 locks on to the signal within two cycles of operation. When the synchronization signal is removed, the LTC3805 takes no more than two cycles to jump back to the frequency programmed by the FS pin.

### Isolated Converter Design

The basic design shown in Figure 1 can be modified to provide DC isolation between the input and output by the addition of a reference, such as the LT4430, on the secondary side of the transformer and an optoisolator to provide feedback from the isolated secondary to the LTC3805. Figure 2 shows a photo of the DC1045 demonstration circuit, which is an isolated converter with the same basic design and performance as the converter in Figure 1, and is representative of the size of both the isolated and non-isolated designs. Figure 3 shows the efficiency of the isolated converter and is also representative of the non-isolated converter.

### Modifications for Different Input or Output Voltages

The two applications described above represent typical non-isolated and isolated 10W flyback converters. It is fairly easy to take this basic design and change the input or output voltage by scaling the external components in direct proportion to the change in voltage. These changes are transparent to the LTC3805 and can be accomplished with a circuit no more complex than that of Figure 1 and a board no bigger than that shown in Figure 2.

A decrease of the input voltage, and increase of the input current, mainly involves selecting a NMOS power switch with a lower voltage and higher current rating and selecting a transformer primary winding with a reduced number of turns and a proportionally larger wire size. For the input filter capacitor, the voltage rating can be

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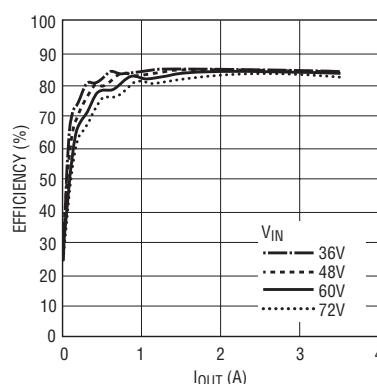


Figure 3. Efficiency for isolated and non-isolated 36V-72V to 3.3V 3A flyback converter

# Isolated Forward Controllers Offer Buck Simplicity and Performance

by Charles Hawkes and Arthur Kelley

## Introduction

Buck converter designers have long benefited from the simplicity, high efficiency and fast transient response made possible by the latest buck controller ICs, which feature synchronous rectification and PolyPhase® operation. Unfortunately, these same features have been difficult or impossible to implement in the buck converter's close relative, the forward converter. That is, until now. The LTC3706/26 secondary-side synchronous controller and its companion smart gate driver, the LTC3705/25, make it possible to create an isolated forward converter with the simplicity and performance of the familiar buck converter.

## The Benefits of Secondary-Side Control Made Accessible

Many isolated supplies place the controller IC on the input (primary) side and rely on indirect synchronous

rectifier timing and optoisolator feedback to control the output (secondary). This architecture is commonly known as primary-side control. By contrast, secondary-side control places the controller IC on the secondary side, and uses a gate-drive transformer to directly control the primary-side MOSFETs. This approach eliminates the need for an optoisolator and puts the controller where it is really needed: with the load. This results in a significantly faster response, taming large-signal overshoot and reducing output capacitance requirements. In addition, secondary-side control simplifies the design of the loop compensation to that of a simple buck converter.

With the apparent advantages of secondary-side control, why is it not used in more isolated applications? This is primarily because of the need for a separate bias supply to power

up the controller on the secondary side, since there is initially no voltage present there. With the introduction of the LTC3706/26 and LTC3705/25, however, this barrier has now been completely eliminated. All of the complex issues associated with start-up and fault monitoring in a secondary-side control forward converter have

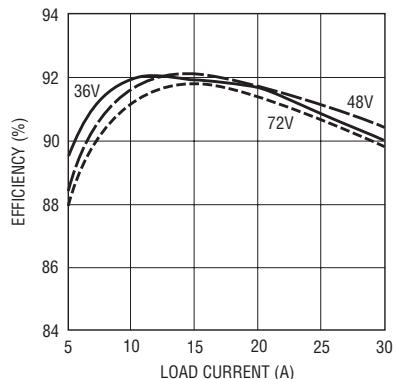


Figure 2. Efficiency of the converter shown in Figure 1

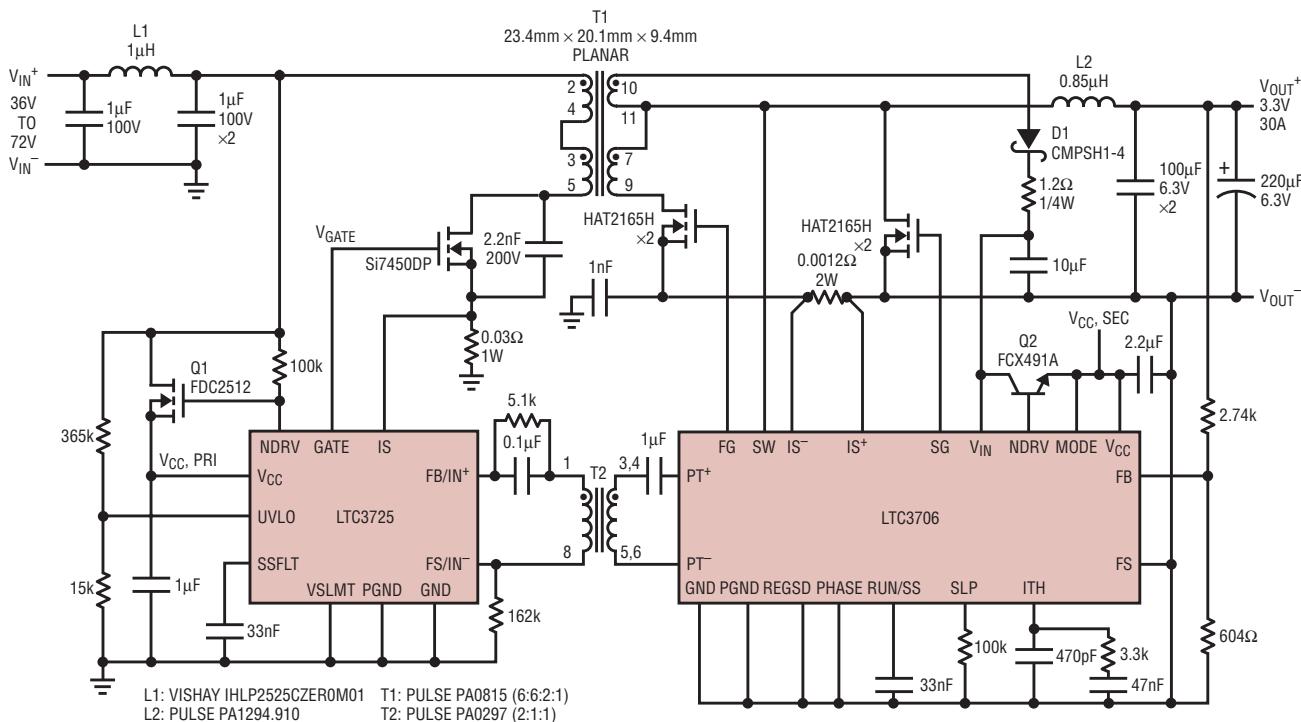


Figure 1. Complete 100W single-switch high efficiency, low cost, minimum part count, isolated telecom converter. Other output voltages and power levels require only simple component changes.

been seamlessly integrated into these powerful new products. Moreover, a proprietary scheme is used to multiplex gate drive signals and DC bias power across the isolation barrier through a single, tiny pulse transformer. This eliminates the primary-side bias winding that is otherwise needed. The result is an isolated supply that has been architected from the ground up to achieve unprecedented simplicity and performance. Figure 1 illustrates how this remarkable new architecture is used to make a complete 100W forward converter with minimal design effort and complexity.

## **Family of Products Supports Single or Dual Switch Topologies**

Table 1 summarizes how the LTC3706/26 and LTC3705/25 products can be combined to cover a broad range of applications. The LTC3706 is a full-featured product available in a 24-lead SSOP package. For high precision applications, the LTC3706 includes a 1% accuracy output voltage, a remote-sense differential amplifier and a power good output voltage monitor. The high voltage linear regulator controller simplifies the design of the bias supply, and PLL frequency synchronization with selectable phase angle enables PolyPhase operation with up to twelve phases. In addition, the flexible current-sense inputs allow

**Table 1.** LTC3705/06/25/26 combinations

	LTC3706	LTC3726
LTC3705	Dual-Switch, PolyPhase	Dual-Switch, Single Phase
LTC3725	Single-Switch, PolyPhase	Single-Switch, Single Phase

for the use of either resistive or current transformer sensing techniques. Protection features include an output overvoltage crowbar as well as current-limiting and over-current protection. The 16-lead LTC3726 does not include the remote voltage sensing or linear regulator features, so it is more suitable for a single phase application. Both the LTC3706 and the LTC3726 have a selectable maximum duty cycle limit of either 75% or 50% to support a single or dual-switch forward converter application, respectively.

The LTC3725 primary driver is intended for use in single-switch forward converter. The LTC3725 includes a start-up linear regulator and an integrated bridge rectifier for bias generation. Protection features include volt-second limit, over-current protection and a fault monitoring system that detects a loss of encoded gate-drive signal from the signal transformer. The LTC3705 is a dual-switch forward driver, and includes an 80V (100V transient) high side gate driver. The integration of this high side driver into

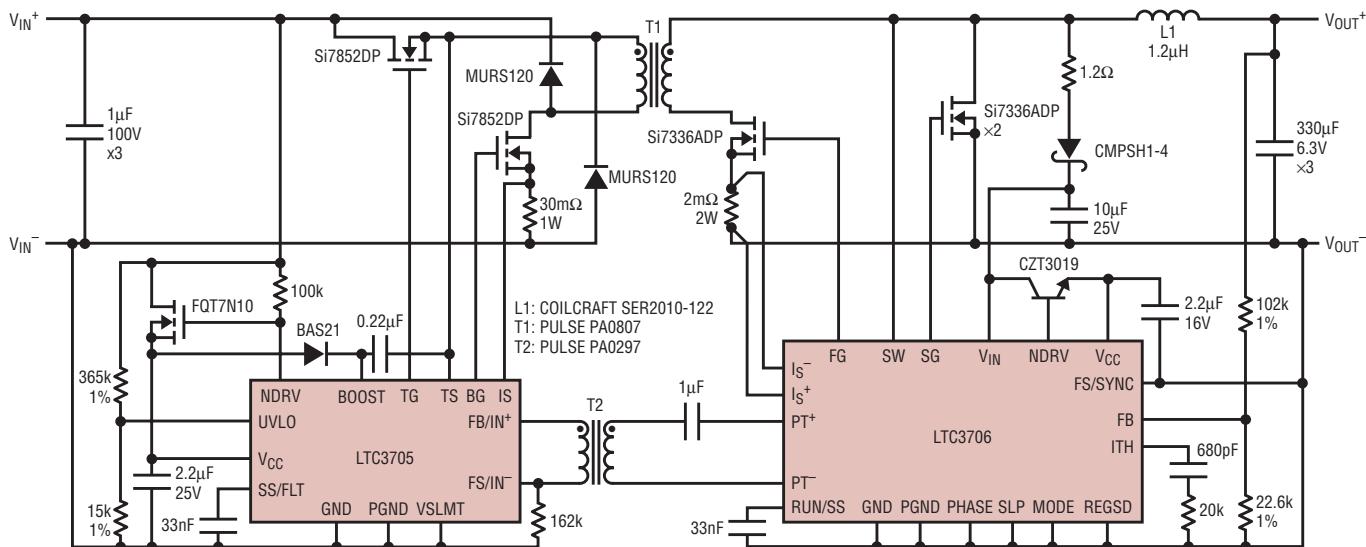
the LTC3705 greatly facilitates the use of the simple and robust dual switch forward converter topology. Figure 3 shows a typical dual-switch converter application using the LTC3705 and the LTC3706.

Table 2 highlights some of the relative merits of using either single or dual switch forward converter topologies. In general, for applications that have a limited input voltage variation, or where a robust and simple design is a priority, the dual-switch forward converter may be preferred. For a wide input voltage application (greater than 2:1), or whenever a lower cost or size justifies the complication of the transformer reset design, a single-switch forward should be used.

## **Bringing the Power of PolyPhase to Isolated Supplies**

The LTC3706/26 defies typical forward converter limits by allowing simple implementation of a PolyPhase current share design. PolyPhase operation allows two or more phase-interleaved power stages to accurately share the load. The advantages of PolyPhase current sharing are numerous, including much improved efficiency, faster transient response and reduced input and output ripple.

The LTC3706/26 supports standard output voltages such as 5V, 12V, 28V and 52V as well as low voltages down to 0.6V. Figure 4 shows how



**Figure 3.** Isolated forward converter for 36V-72V input to 3.3V/20A out

easy it is to parallel two 1.2V supplies to achieve a 100A supply. Figure 5 shows excellent output inductor current tracking during a 0A to 100A load current step and the smooth handoff during start-up to secondary-side control at approximately  $V_{OUT} = 0.25V$ .

### Anatomy of a Start-Up: A Simple Isolated 3.3V, 30A Forward Converter

The circuit of Figure 1 shows a complete 100W, one-switch forward converter. In this example, the LTC3706 controller is used on the secondary and the LTC3725 driver with self-starting capability is used on the primary. This design features off-the-shelf magnetics and high efficiency (see Figure 2). The start-up behavior of this supply is illustrated in Figure 6. When input voltage is first applied, the LTC3725 uses Q1 to generate a bias voltage  $V_{CC,PRI}$ , and begins a controlled soft-start of the output voltage. As the output voltage begins to rise, the LTC3706 secondary controller is quickly powered up by using T1, D1 and Q2 to generate  $V_{CC,SEC}$ . As shown in Figure 6, the  $V_{CC,SEC}$  voltage rises very quickly as compared with the output voltage  $V_{OUT}$  of the converter. The LTC3706

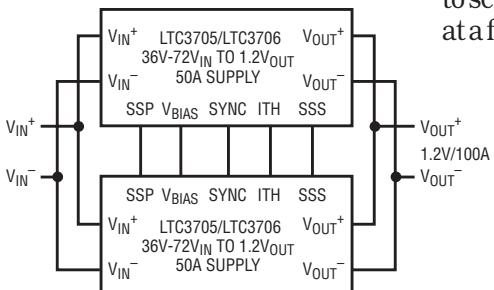


Figure 4. Paralleling supplies for higher power operation

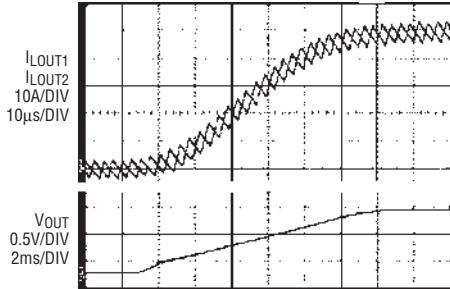


Figure 5. 1.2V, 100A load current step (top trace) and start-up (bottom trace)

Table 2. Single and dual switch forward converter relative merits

Requirement	Single-Switch	Dual-Switch
<b>Simple Design</b>	- Requires Design Transformer Reset Circuit to Prevent Saturation	+ Reset Circuit not Required—Can't Saturate
<b>Wide Input Supply Range</b> (>2:1)	+ 75% Max Duty	- 50% Max Duty
<b>High Efficiency</b>	+ Good	+ Good
<b>Low Switch Voltage Stress</b>	- Can be $2 \times V_{IN}$ or Greater	+ Limited to $V_{IN}$
<b>Low Cost</b>	+ One FET	- Two FETs
<b>Small Size</b>	+ One FET and Better Transformer Utilization	- Two FETs and 50% Transformer Utilization

then assumes control of the output voltage by sending encoded PWM gate pulses to the LTC3725 primary driver via signal transformer T2. As soon as the LTC3725 begins decoding these PWM gate pulses, it shuts down the linear regulator by tying NDRV to  $V_{CC}$  and begins extracting bias power for  $V_{CC,PRI}$  from the signal transformer T2. This complete transition from primary to secondary control occurs seamlessly at a fraction of the output voltage. From

that point on, operation and design simplifies to that of a simple buck converter. Even the design and optimization of the feedback loop makes use of the familiar and proven OPTI-LOOP® compensation techniques.

### A 10V-30V Input, 15V Output at 5A Forward Converter

Figure 7 highlights the flexibility of the LTC3706 and LTC3725 by illustrating a 12V/24V input application.

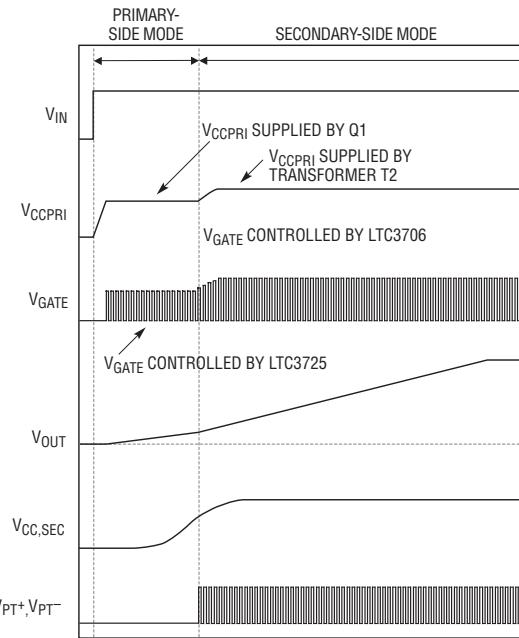
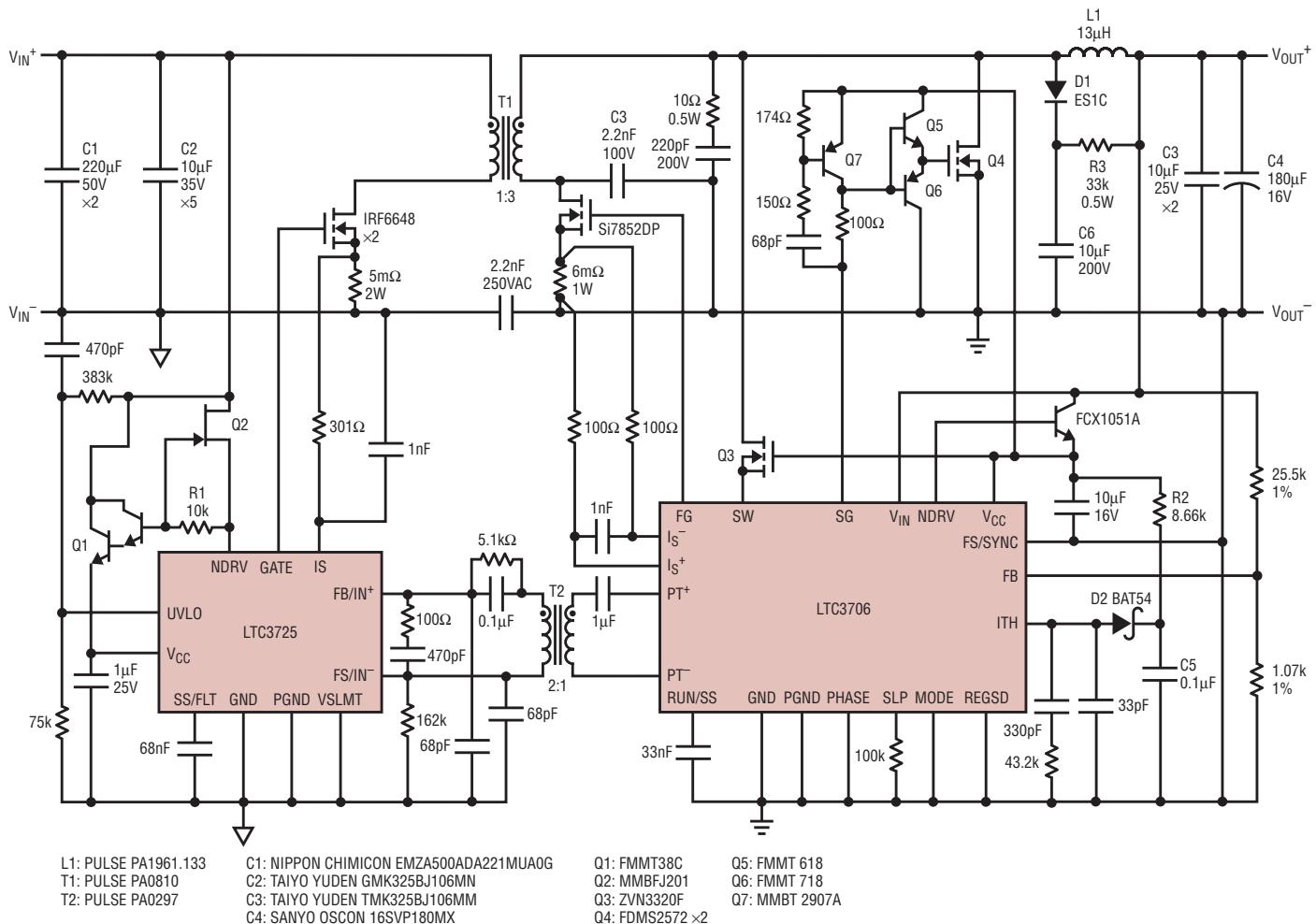


Figure 6. Anatomy of a start-up



**Figure 7.** Isolated forward converter for 10V-30V input to 15V/5A out

In this circuit, the main transformer T1 is used to step up the voltage so that the output can be either higher or lower than the input. This circuit is an excellent alternative to a flyback converter where higher efficiency or lower noise is a priority.

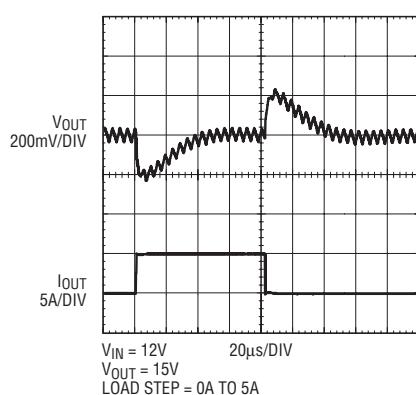
The UVLO on the LTC3725 has been set to turn on at  $V_{IN} = 9.5V$  and off at  $V_{IN} = 7.5V$ , and a linear regulator (Q1) is used to establish bias for start-up. Note that the LTC3725 requires that the NDRV pin be at least 1V above the  $V_{CC}$  pin for proper linear regulator operation. To meet this requirement, while providing the lowest possibly dropout voltage, a darlington transistor is used (Q1). JFET Q2 is used to provide adequate bias current for the NDRV pin at low input voltage, while limiting the maximum current seen at high input voltage. R11 is needed to prevent back-feeding of current from the NDRV pin into base of Q1 (and

gate of Q2) during normal operation when  $V_{CC} = V_{NDRV} = 12V$  and  $V_{IN}$  is less than 12V.

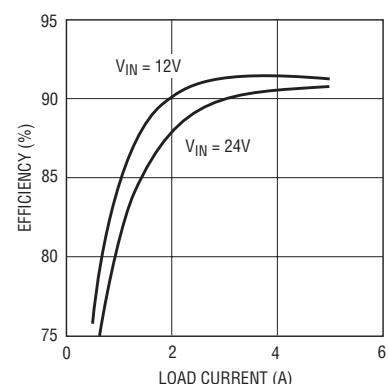
On the secondary side, the output voltage is used directly as a source of bias voltage for the LTC3706. This is possible for output voltages of 9V or greater. Q3 is used to limit the peak voltage seen by the SW pin on

the LTC3706, while still allowing the detection circuits in the LTC3706 to function normally. Capacitor C3 is used to establish the resonant reset of the main transformer T1 during the off-time of the primary-side switches. In order to reduce the inrush current during start-up, D2, R2 and C5 are

*continued on page 39*



**Figure 8.** Transient response of the circuit in Figure 7



**Figure 9. Efficiency of the circuit in Figure 7**

# Rugged 3.3V RS485/RS422 Transceivers with Integrated Switchable Termination

by Steven Tanghe and Ray Schuler

## Introduction

Medium and high speed RS485 networks must be terminated to avoid data-corrupting reflections. This means a termination resistor is placed at each end of the bus. Of course, if the network is expanded or reconfigured, the termination resistors must also move. The 3.3V LTC2854 and LTC2855 transceivers eliminate the cumbersome task of shuffling termination resistors. These devices have an integrated termination resistor connected across the receiver inputs that can be enabled or disabled with simple logical control of an input pin, making network configuration and reconfiguration a snap. These devices come in tiny packages and are extremely robust, withstanding ESD strikes of up to  $\pm 25\text{kV}$  HBM (LTC2854) on the line I/O pins—the industry's highest protection level for an RS485 transceiver.

Other features of the LTC2854 and LTC2855 include a receiver with balanced thresholds for excellent duty cycle performance, high input

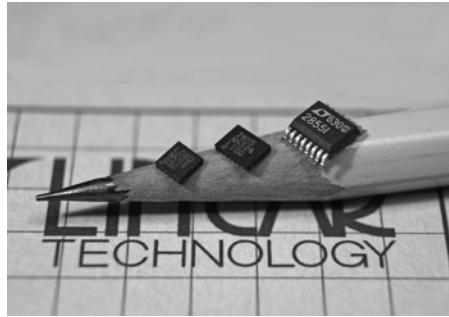


Figure 1. Photograph of the (left to right) LTC2854 3mm x 3mm DFN, LTC2855 4mm x 3mm DFN, and the LTC2855 SSOP

resistance allowing as many as 256 devices to be connected to one bus, and a full failsafe output. The driver offers low power operation, which in conjunction with the receiver and integrated termination resistor, provide a single die impedance-matched network solution. Parts are available in half- and full-duplex configurations in tiny packages including 10- and 12-pin DFN as well as 16-lead SSOP (see Table 1 and photo in Figure 1).

Block diagrams for the LTC2854 and LTC2855 are shown in Figure 2.

## Switchable Termination

Differential signals propagating down a twisted pair transmission line are partially reflected when an impedance mismatch is encountered. The reflected signal causes constructive and/or destructive interference on the line that can corrupt data. To prevent this condition and optimize system performance, transmission lines should be terminated at each end with a resistor matching the characteristic impedance of the cable.

The LTC2854 and LTC2855 transceivers integrate this termination resistor so that it can be selectively included or excluded simply by controlling the Termination Enable pin (TE). The resistor is effectively connected across the receiver input pins by setting TE high and disconnected when TE is low or the device is unpowered. This arrangement is nearly ideal from a system management

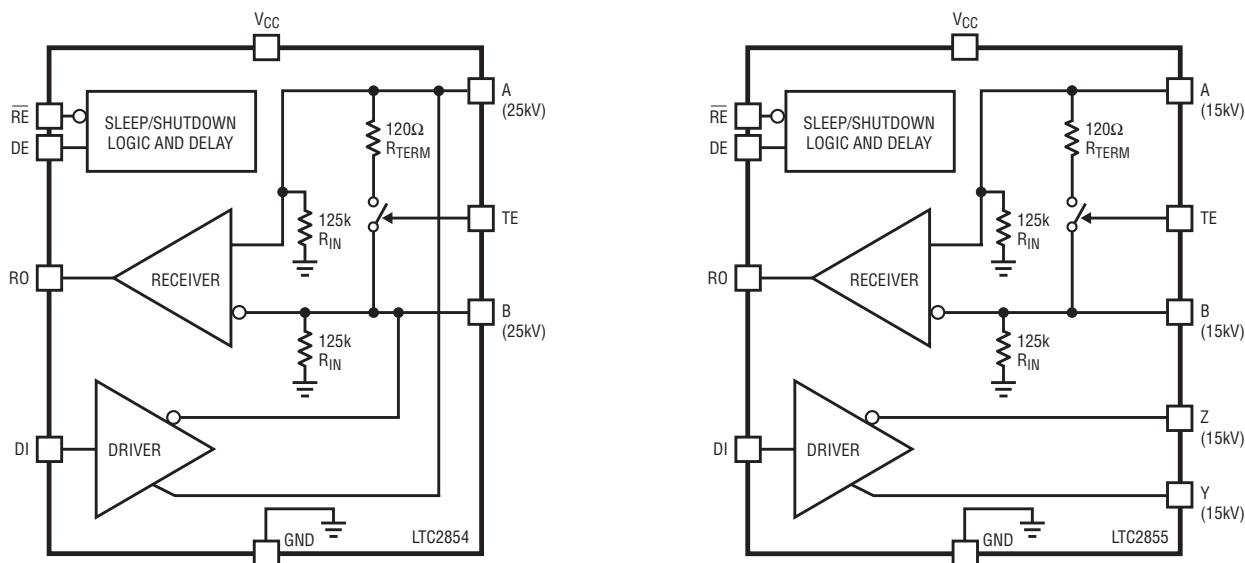


Figure 2. Block diagrams of the LTC2854 and LTC2855

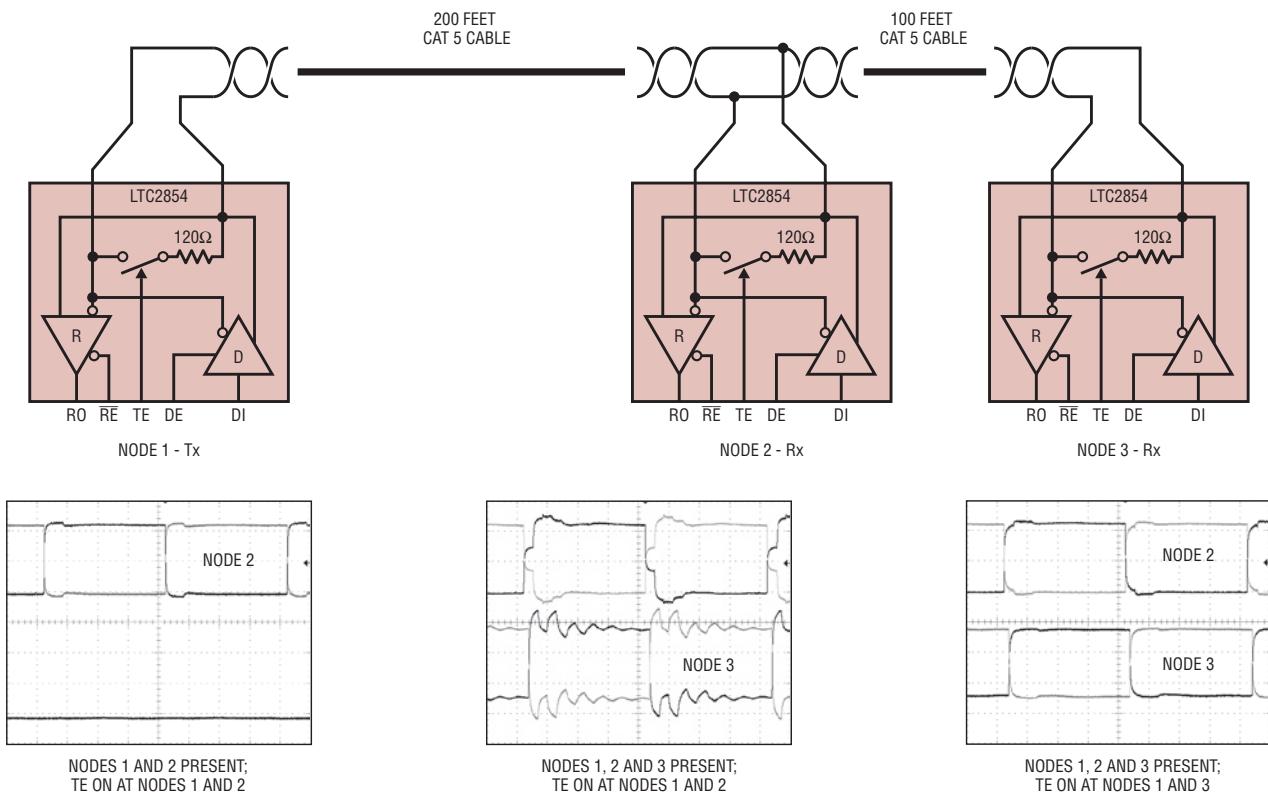


Figure 3. Effects of termination placement with network expansion

standpoint, especially under conditions where a network configuration changes and the termination resistor needs to be moved to the new end of the bus. In this case, manual removal and placement of a discrete resistor is not necessary; rather the change is controlled digitally with the appropriate selection of TE pins on the LTC2854 or LTC2855.

To illustrate the importance of termination placement, consider the configuration shown in Figure 3 where the effects of network expansion are presented. The initial configuration consists of nodes 1 and 2, made up of LTC2854 transceivers connected with 200 feet of Cat 5 cable. The waveforms in the lower left of the figure show the signal received at node 2, driven

from node 1. Both ends of the cable are terminated by setting the TE pins high on both transceivers. The received signal looks clean because the bus is properly terminated. A small impedance mismatch between the cable characteristic impedance of  $100\Omega$  and the termination resistor of  $120\Omega$ , results in a slight bump in the waveform. This effect is minor and the figure serves to illustrate that the termination resistor in the LTC2854 and LTC2855 is compatible with popular low cost  $100\Omega$  cables.

The second set of waveforms on the bottom of Figure 3 show the results of introducing a third node to the system through 100 feet of added cable but without moving the termination resistor to the new end location. The

waveforms at node 3 and node 2 are both severely distorted from reflections caused by the improper termination.

In the third set of waveforms, the termination placement has been corrected by setting TE high at nodes 1 and 3 only, thereby cleaning up the signals received at nodes 2 and 3. The logic-selectable termination resistors in the LTC2854 permit this correction with no physical intervention required.

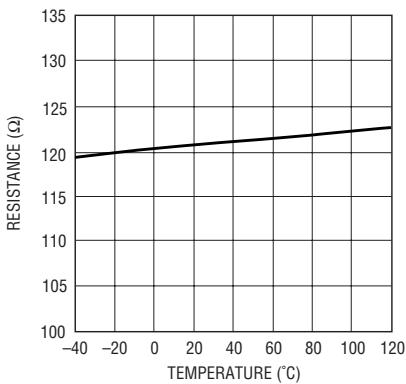
The termination resistance is well maintained over temperature, common mode voltage and frequency (as illustrated in Figure 4). Furthermore, the termination network adds only insignificant capacitive loading to the receiver pins. The input capacitance on the LTC2855's A and B pins is approximately  $9\text{pF}$  measured to ground and  $3.5\text{pF}$  differentially.

Table 1. Product selection

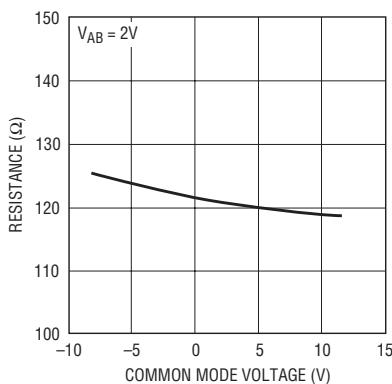
PART NUMBER	DUPLEX	PACKAGE	ESD on Line I/O (HBM)
LTC2854	HALF	DFN-10	$\pm 25\text{kV}$
LTC2855	FULL	SSOP-16, DFN-12	$\pm 15\text{kV}$

### Balanced Threshold Receiver with Full Failsafe

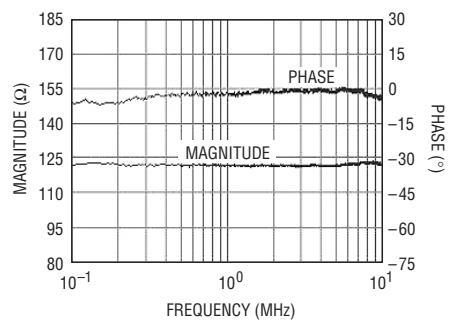
The LTC2854 and LTC2855 feature a low power receiver that draws only  $450\mu\text{A}$ . The single-ended input resistance to ground on each of the



(a)



(b)



(c)

Figure 4. LTC2855 termination resistance vs (a) temperature, (b) common mode voltage, and (c) frequency.

receiver inputs is greater than  $96\text{k}\Omega$  when the termination is disabled. This is eight times higher than the requirements specified in the TIA/EIA-485-A standard and thus this receiver represents a one-eighth unit load. This, in turn, means that  $8\times$  the standard number of receivers, or 256 total, can be connected to a line without loading it beyond what is called out in the standard.

The receiver implements a full failsafe design that drives RO high when the inputs to the receiver are shorted, left open, or terminated (externally or internally) but not driven.

A key element of the LTC2854/LTC2855 receiver is that it uses a window comparator with two voltage thresholds balanced around zero for excellent duty cycle performance. As illustrated in Figure 5, for a differential signal approaching from a negative direction, the threshold is  $+65\text{mV}$ . When approaching from the positive direction, the threshold is  $-65\text{mV}$ . Each of these thresholds has  $20\text{mV}$  of hysteresis (not shown in the figure). This windowing around  $0\text{V}$  preserves duty cycle for small inputs with heavily slewed edges. This performance is highlighted in Figure 6, where a

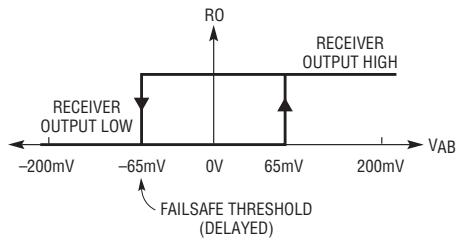


Figure 5. Receiver input threshold characteristics

signal is driven through 4000 feet of Cat 5e cable at 3Mbps. The top set of traces show the signals coming into the receiver after traveling down the long cable. The middle trace is the difference of the top two signals and the bottom trace is the resulting waveform out of the receiver at the RO pin. It is clear that even though the differential signal peaks at just over  $\pm 100\text{mV}$  and is heavily slewed, the output maintains a nearly perfect signal with almost no duty cycle distortion.

Few devices can match this level of performance because the balanced receiver thresholds are at odds with shorted failsafe requirements. Other parts typically include a negative threshold in the receiver so that when the inputs are shorted together (i.e.,  $0\text{V}$  differential) the receiver output drives high, indicating a failsafe condition. Unfortunately, the negative offset can cause severe duty cycle distortion for small, slow-edge rate signals like those presented in Figure 6.

The LTC2854 and LTC2855 avoid this problem by using a method to

detect the shorted failsafe condition that preserves normal signal integrity. In normal operation, the two thresholds shown in Figure 5 are used to determine the receiver output state. However, if the receiver inputs remain between thresholds for more than about  $3\mu\text{s}$ , the receiver output is driven high, reflecting this failsafe condition.

## Driver

The differential driver of the LTC2854 and LTC2855 easily delivers RS485/RS422 signals at data rates up to 20Mbps. Figure 7 shows the clean edges and excellent zero crossings of the LTC2854 driver running at 20Mbps into a  $54\Omega$  load. Figure 8 shows a single 50ns pulse (equivalent to one bit at 20Mbps) delivered through 100 feet of standard unshielded Cat 5 cable and received by a second LTC2854 transceiver.

Driver outputs have current limiting that offers protection from short circuits to any voltage within the absolute maximum range of ( $V_{CC}-15\text{V}$ )

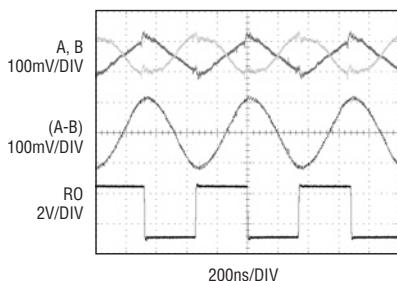


Figure 6. A 3Mbps signal driven down 4000 feet of Cat 5e cable. Top traces: received signals after transmission through cable; middle trace: math showing difference of top signals; bottom trace: receiver output.

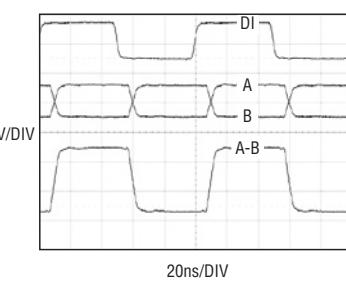
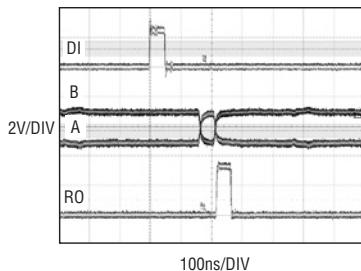


Figure 7. The LTC2854 driver toggling at the maximum data rate of 20Mbps into  $54\Omega$ . A and B are the driver outputs.



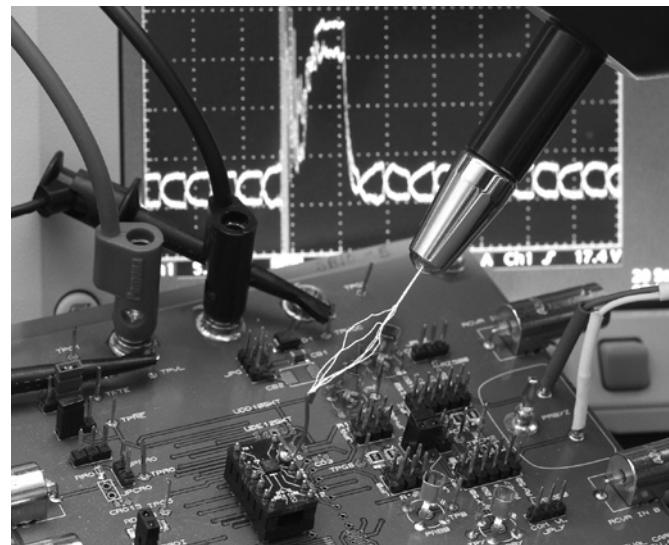
**Figure 8.** The LTC2854 driver delivering a single 50ns pulse through 100ft of Cat 5 cable, which is received by another LTC2854. Both parts have their on-chip termination enabled. Top trace is the input to the transmitting device and the middle and bottom traces are observed at the receiving part.

to +15V, with typical peak current not exceeding 180mA. Additionally, thermal shutdown protection disables the driver, receiver, and terminator if excessive power dissipation causes the device to heat to temperatures above 160°C. When the temperature drops below 140°C, normal operation resumes.

### Extreme ESD Protection

The driver output pins and receiver input pins on the LTC2854 are protected to ESD levels of  $\pm 25\text{kV}$  HBM with respect to ground or  $V_{CC}$ . The full-duplex LTC2855 withstands  $\pm 15\text{kV}$  ESD. These protection levels exist for all modes of device operation including power-down, standby, receive, transmit, termination and all combinations of these. Furthermore, the protection level is valid whether  $V_{CC}$  is on, shorted to ground, or disconnected.

When a line I/O pin on the LTC2854/LTC2855 is hit with an



**Figure 9.** The LTC2854 sending data (see scope traces in background) while hit with multiple 30kV ESD strikes on the 'A' pin.

ESD strike during operation, the part undergoes a short disturbance of duration similar to the ESD event and then fully recovers. The device does not latch up and there is no need to toggle states or cycle the supply to recover. This is true whether the part is in a static state or sending/receiving data and for the full range of ground common mode voltages called out in the RS485 standard. The photo in Figure 9 shows the LTC2854 absorbing the energy from an ESD gun (configured for IEC air discharge) delivering repeated 30kV strikes to the 'A' pin while transmitting data. The oscilloscope traces in the background show data toggling happily on the A and B pins before and after a strike, with a positive glitch only during the ESD

event. This device can handle many such strikes without damage.

### Conclusion

The LTC2854 and LTC2855 break new ground in the world of 3.3V RS485/RS422 transceivers. The inclusion of a selectable termination resistor provides a complete solution to RS485 networking with the ability to remotely configure the network for optimal data transfer. Unparalleled ESD performance provides outstanding ruggedness while a balanced-threshold receiver with full failsafe capability makes this family of small-footprint devices a natural choice for modern RS485/RS422 systems. ▶

LTC3805, continued from page 9

reduced and the capacitance increased in proportion. Also, the resistor divider connected to the RUN pin must be adjusted for the new input voltage. Finally, the 68mΩ current sense resistor should be reduced in value to account for the higher input current. For an increase in input voltage, everything is changed proportionally in the opposite direction.

Similarly, a change in the output voltage involves a change in the diode,

the number of turns in the secondary winding of the transformer and the voltage rating and value of the output filter capacitor along with the appropriate change to the voltage divider that senses the output voltage. If the output voltage is between 4V and 9V, the design of non-isolated converters is very simple because  $V_{CC}$  can be provided by a diode connected directly to the output instead of the third winding on the transformer.

### Conclusion

Because of its flexibility, the flyback converter is the most widely used transformer-based converter. The LTC3805 maximizes the flexibility of the flyback converter by making it possible to use the same basic circuit for a wide range of converter input and output voltages. Simply scale component values to match voltage and current conditions, greatly simplifying board design and updates. ▶

# Tiny High Efficiency 2A Buck Regulator Directly Accepts Automotive, Industrial and Other Wide Ranging Inputs

by Kevin Huang

## Introduction

Automotive batteries, industrial power supplies, distributed supplies and wall transformers are all sources of wide-ranging, high voltage inputs. The easiest way to step down these sources is with a high voltage monolithic step-down regulator that can directly accept a wide input range and produce a well-regulated output. The LT3480 is a new step-down regulator that accepts input from up to 38V (60V transient) while providing excellent line and load regulation and dynamic response. The LT3480 offers high efficiency solutions over wide load range and keeps the output ripple low during Burst Mode® operation.

## LT3480 Features

Available in either a 10-pin MSOP or a 3mm × 3mm DFN package, the LT3480 offers an integrated 3.5A power switch and external compensation for design flexibility. The LT3480 employs a constant frequency, current mode architecture. The switching frequency can be set between 250kHz and

2.4MHz by using a resistor tied from the RT pin to ground. This allows a trade off between component size and efficiency. The switching frequency can be synchronized to an external clock for noise sensitive applications. An external resistor divider programs

**The LT3480 is a new step-down regulator that accepts input from up to 38V (60V transient).**

the output voltage to any value above the part's 0.8V reference.

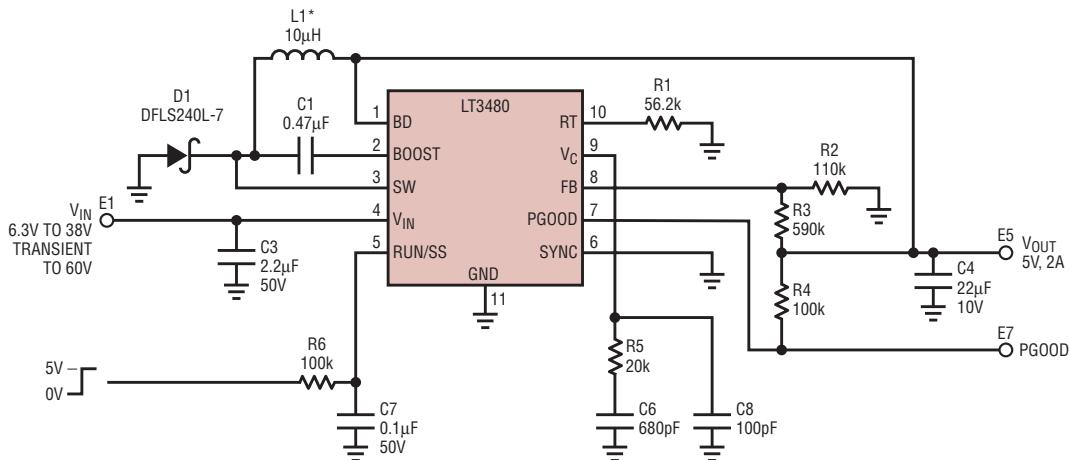
The LT3480 offers soft-start via a resistor and capacitor on the RUN/SS pin, thus reducing maximum inrush currents during start-up. The LT3480 can withstand a shorted output. A cycle-by-cycle internal current limit protects the circuit in overload and limits output power; when the output voltage is pulled to ground by a hard short, the LT3480 reduces its operating frequency to limit dissipation

and peak switch current. This lower frequency allows the inductor current to safely discharge, thus preventing current runaway.

The high side bootstrapping boost diode is integrated into the IC to minimize solution size and cost. When the output voltage above 2.5V, the anode of the boost diode can be connected to output. For output voltages lower than 2.5V, the boost diode can be tied to a separate rail or to the input (<28V). For systems that rely on a well-regulated power source, the LT3480 provides a power good flag that signals when V<sub>OUT</sub> reaches 90% of the programmed output voltage.

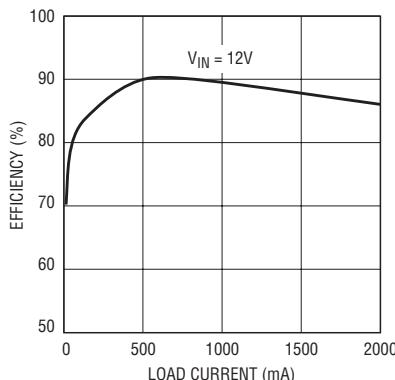
## Modes of Operation: Low Ripple Burst and Forced Continuous

Two modes of operation can be selected through the SYNC pin. Applying a logic low to the SYNC pin enables low ripple Burst Mode operation, which maintains high efficiency at light load while keeping the output voltage ripple low. During Burst Mode



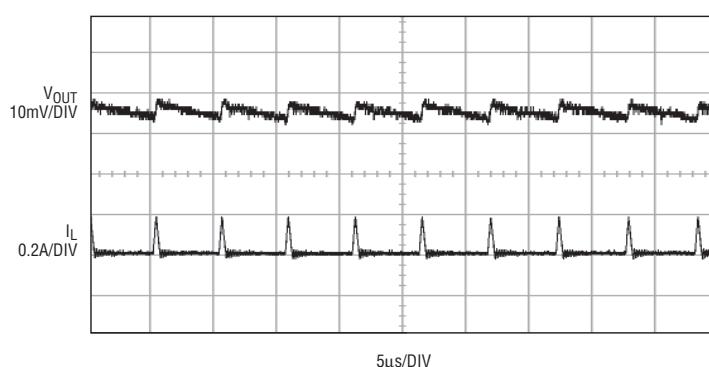
\* L1: SUMIDA CDR7D43MNNP-100NC

Figure 1. A 600kHz 6.3V-38V input DC/DC Converter using the LT3480 delivers 2A at 5V output.

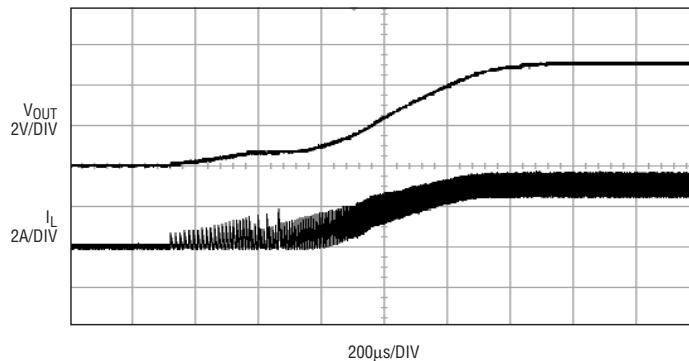


**Figure 2.** Efficiency for circuit in Figure 1

operation, the LT3480 delivers single cycle bursts of current to the output capacitor followed by sleep periods when the output power is delivered to the load by the output capacitor. Between bursts, all circuitry associated with controlling the output switch is shut down, reducing the input supply current and BD quiescent current to 30 $\mu$ A and 80 $\mu$ A respectively. As the load current decreases to a no load condition, the percentage of time that LT3480 operates in sleep mode increases and the average input current is greatly reduced, resulting in high efficiency. The LT3480 has a very low (less than 1 $\mu$ A) shutdown current which significantly extends battery life in applications that spend long periods of time in sleep or shutdown mode. For applications that require constant frequency operation even at no load, the LT3480 can be put into



**Figure 3.** LT3480 Burst Mode operation at 10mA load



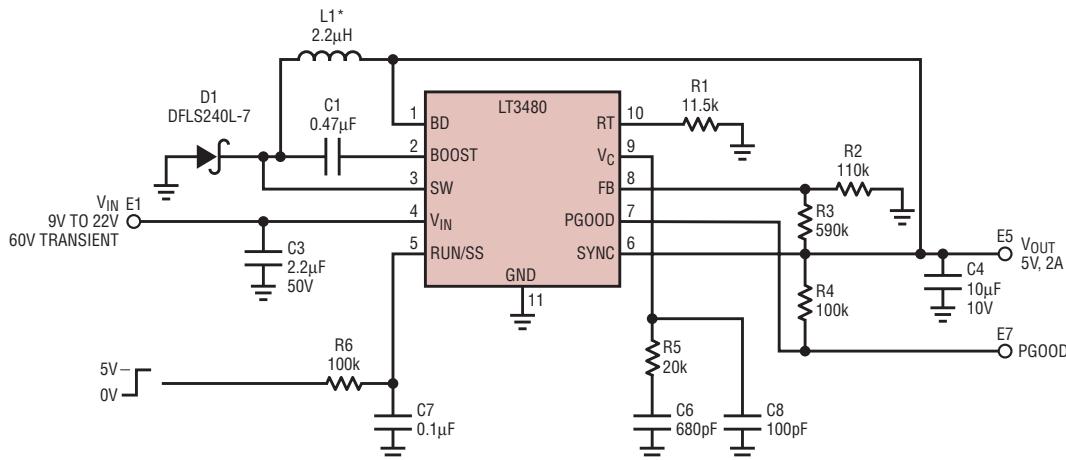
**Figure 4.** Soft-start of LT3480

forced continuous mode operation by tying the SYNC pin above 2.5V.

### 6.3V-38V to 5V, 2A DC/DC Converter with All Ceramic Capacitors

Figure 1 shows the LT3480 producing 5V at 2A from an input of 6.3V to 38V with 60V transient. The circuit is programmed for a 600kHz switching

frequency. Figure 2 shows the circuit efficiency at 12V input. The efficiency peaks at 90% and remains high across the entire load range. The SYNC pin is tied to the ground to enable Burst Mode operation and achieve high efficiency at light load. Figure 3 shows the inductor current and output voltage ripple under single pulse Burst Mode operation at 10mA load. The output



\* L1: SUMIDA CDRH4D22/HP-2R2NC

**Figure 5.** High operating frequency allows the use of small inductors and capacitors. This 2MHz, 9V-22V input DC/DC converter using the LT3480 delivers 2A at 5V output.

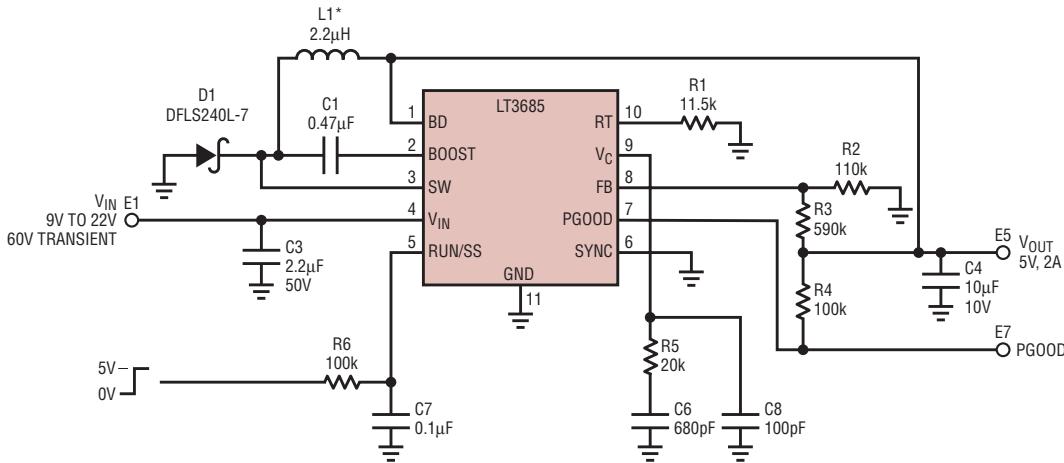


Figure 6. A 2MHz 9V-22V input DC/DC converter using the LT3685 delivers 2A at 5V output.

voltage ripple  $V_{P-P}$  is less than 10mV as a result of low ripple Burst Mode operation.

An external signal can drive the RUN/SS pin through a resistor and capacitor to program the LT3480's soft-start, reducing maximum inrush current during start-up. Figure 4 shows the start-up waveform.

### 2MHz, 9V-22V to 5V, 2A DC/DC Converter with All Ceramic Capacitors

Figure 5 shows a step-down DC/DC converter using all ceramic capacitors. This circuit provides a regulated 5V output at up to 2A from an input of 9V to 22V. The high 2MHz switching frequency allows the use of small inductor and capacitors.

In typical automotive battery-voltage applications, high voltage line transients, such as during a load-dump condition, must be accommodated. The circuit shown in Figure 5 can operate through intermittent high voltage excursions to 60V. This converter is an ideal choice for operation near an AM radio receiver because it operates above the broadcast band and the switching noise can be filtered in a predictable manner. The SYNC pin is tied to output to disable Burst Mode operation in order to eliminate AM band interference. The efficiency of this circuit reaches 85%.

The LT3685, similar to the LT3480 without Burst Mode operation, is also

a good candidate for this application. Figure 6 shows the circuit using the LT3685 for this application.

### Dual Output Converter

Dual output supplies are required for many applications. The circuit in Figure 7 uses an LT3480 to generate both positive and negative 5V supplies. The two inductors shown are actually two windings on a coupled inductor. The load current on the positive output should be larger than the load on the negative output. With this restriction satisfied, the voltage magnitude of the

negative output tracks the positive output within 5%. For a more complete description of this circuit, see Linear Technology Design Note 100.

### Conclusion

The wide input range, low quiescent current, small size and robustness of the LT3480 make it an easy fit in automotive, industrial and distributed power applications. It is highly efficient over the entire load range. Its unique low ripple Burst Mode operation helps to save battery power life while maintaining low output ripple. **LT**

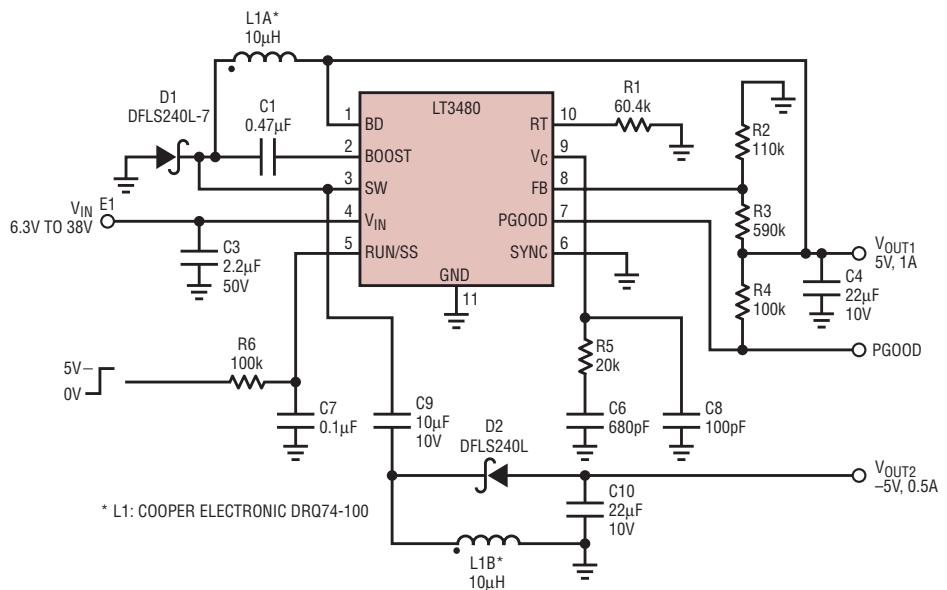


Figure 7. A ±5V dual output DC/DC converter. As long as the load on the negative channel is less than the load on the positive channel, the voltage magnitude of the negative output tracks the positive output within 5%.

# 36V Dual 1.4A Monolithic Step-Down Converter has Start-Up Tracking and Sequencing

by Keith Szolusha

## Introduction

The latest DSPs and microcontrollers found in automotive electronics, industrial supplies, and even wall-transformers typically require power supplies with output voltages of both 1.8V and 3.3V and output current capability of 1A or greater. DSL and cable modems also require multiple supplies, usually a combination of a single 5V supply rail and either a 3.3V or 1.8V rail. PCI Express and motherboard interconnect devices supply 3.3V or 5V in addition to a 12V intermediary source. In all of these cases, the supplies must follow a specific start-up sequence or track each other to avoid system latch up or worse.

One common challenge in these applications is producing well-regulated outputs from wide ranging inputs. For instance, a 12V automotive battery produces a voltage range from a low of 4V to a high of 36V. 24V industrial supplies and rectified 12V wall transformers produce similarly wide voltage ranges.

The LT3508 simplifies the design of dual output, wide-input-range power converters—especially those that require power supply tracking and sequencing. It is a dual output current mode PWM step-down DC/DC converter with internal power switches capable of generating a pair of 1.4A outputs. Its wide 3.6V to 36V input range makes it suitable for regulating power from a wide variety of sources, including automotive batteries, 24V industrial supplies and unregulated wall adaptors. Both converters are synchronized to a single oscillator programmable from 250kHz up to 2.5MHz and run with opposite phases, reducing input ripple current. The high operating frequency allows the use of small, low cost inductors and ceramic capacitors, resulting in low, predictable output ripple. Each regulator has independent tracking and soft-start circuits and generates a power good signal when its output is in regulation, making power supply sequencing and

interfacing with microcontrollers and DSPs easy.

Cycle-by-cycle current limit, frequency foldback and thermal shutdown provide protection against shorted outputs, and soft-start eliminates input current surge during start-up. The low current (<2µA) shutdown mode enables easy power management in battery-powered systems.

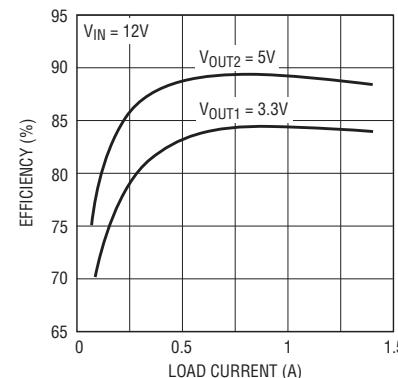


Figure 2. Efficiency for circuit of Figure 1

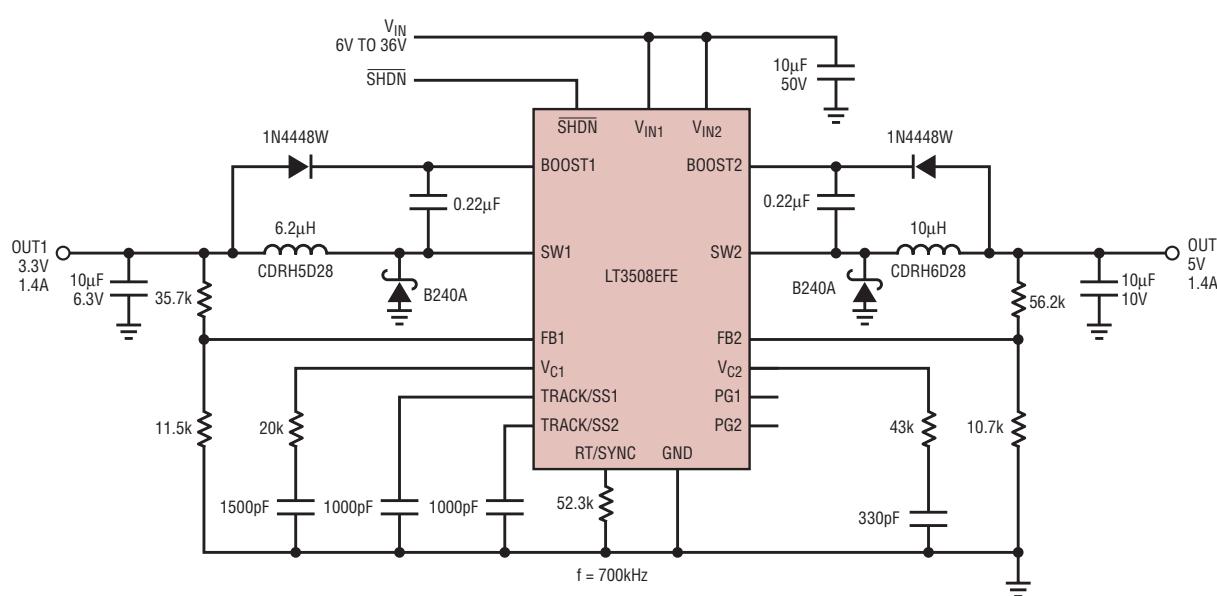


Figure 1. Dual 1.4A monolithic step-down converter with 3.3V and 5V outputs

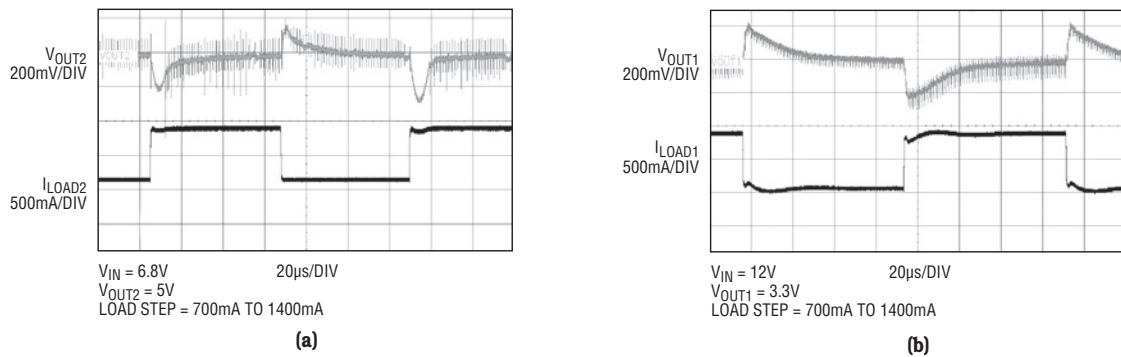


Figure 3. Dual step-down 5V (a) and 3.3V (b) output voltage transient response

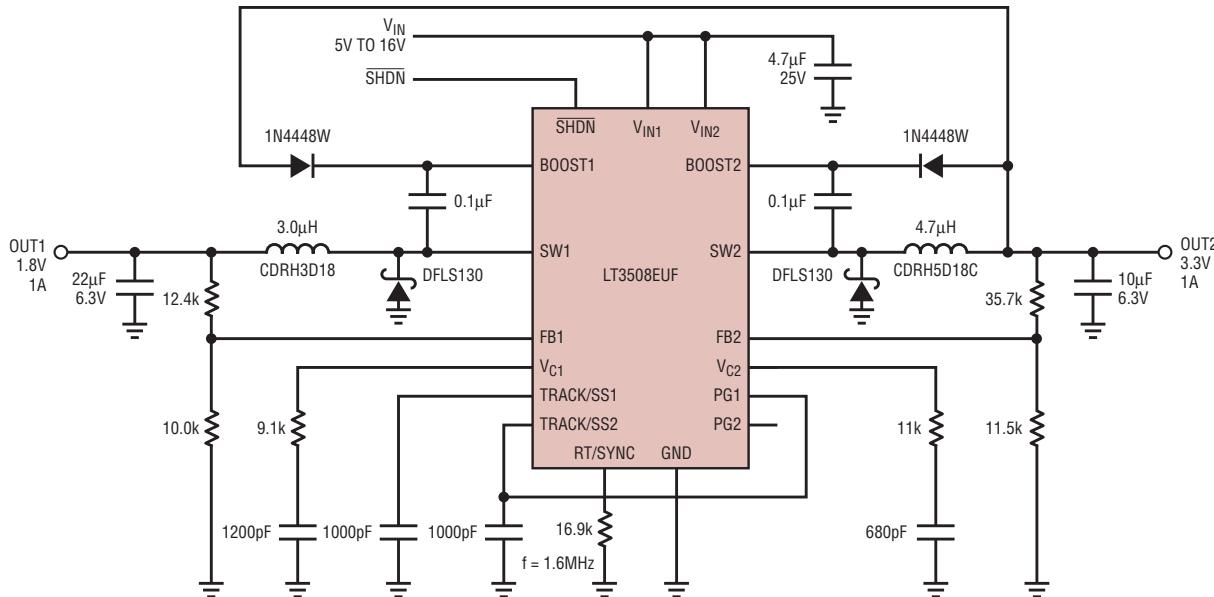


Figure 4. Small dual step-down 1.8V and 3.3V schematic with output sequencing

### Versatility Comes from Independent Control of Two 1.4A Channels

Each channel has its own power good, track/soft-start and, unlike most dual channel converters, each has its own  $V_{IN}$  pin (more about this below). The boost pin for each channel can be tied to the higher of the two outputs, one to each output (if the channels are turned on and off separately), the input, or an external source. The boost pin voltage must be at least 3V above the switch pin voltage for saturation of the internal power switch.

Individual track/soft-start and power good pins offer a variety of supply tracking and sequencing options. The channels can track each other coincidentally or ratiometrically. The power good pins can be used for sequencing the two channels or

simply interfacing with an external microcontroller.

The unique, separate  $V_{IN}$  pins for each channel offer uncommon design flexibility. For instance, the converter can satisfy high  $V_{IN}/V_{OUT}$  ratio applications that might be otherwise limited by a single converter's typical minimum

duty cycle constraints. Simply cascade the two converters by attaching the output of one channel to the input of the other channel. This allows the input voltage to be twice as high for a given output voltage and switching frequency without violating minimum duty cycle constraints. In some cases,

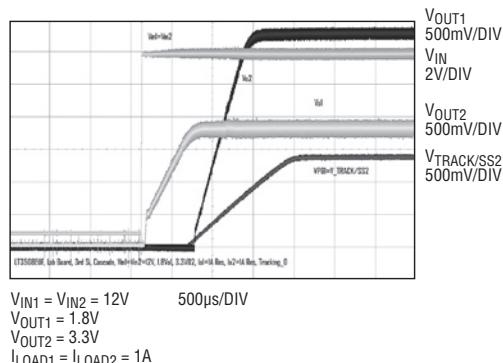


Figure 5. Dual step-down 1.8V and 3.3V start-up with output sequencing

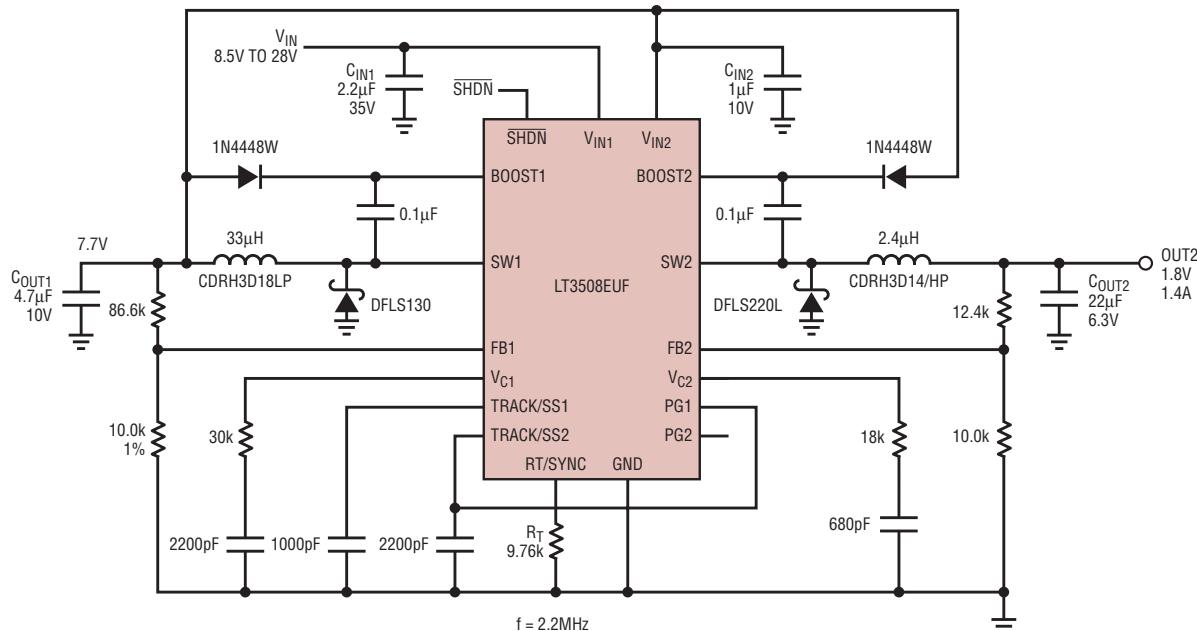


Figure 6. 2.2MHz 28V to 1.8V step-down with cascaded channels and output sequencing

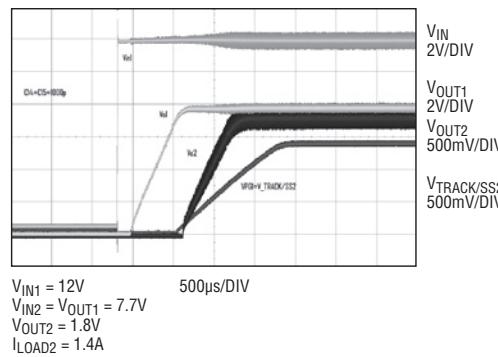


Figure 7. 2.2MHz 28V to 1.8V step-down start-up with output sequencing

the separate  $V_{IN}$  pins also allow the two channels to be run from two separate current-limited sources that may not have enough power alone to provide full power to both channels' outputs.

The LT3508's two channels run 180° out of phase to minimize input current ripple and voltage ripple, thus limiting EMI and reducing the required size of the input capacitor.

### High $V_{IN}$ , Low $V_{OUT}$ and Adjustable Switching Frequency

The wide input range of 3.6V to 36V makes the LT3508 suitable for regulating power from a wide variety of sources, including automotive batteries, 24V industrial supplies and unregulated wall adaptors. The operating frequency for the converters can be programmed by a single resistor

or synchronized to an external clock ranging from 250kHz to 2.5MHz. High operating frequency allows the use of

small, low cost inductors and ceramic capacitors, resulting in low, predictable output ripple. However, selecting

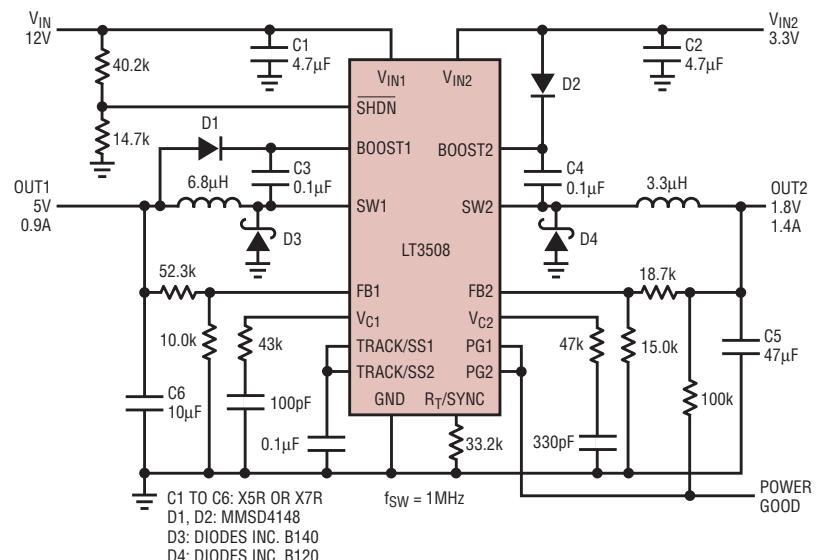


Figure 8. PCI Express power supply with separate inputs

a low operating frequency makes it possible to produce high input voltage, low output voltage applications by reducing the duty cycle. The LT3508's low minimum switch on time of 130ns offers the benefits of high frequency even in high input-output ratio applications. For instance, a frequency of 700kHz is low enough to provide 6V to 36V input voltage range for both 5V and 3.3V outputs at full 1.4A load current (see Figure 1).

The output voltage for the LT3508 can be set as low as the 0.8V refer-

ence voltage. With 130ns minimum on-time, the maximum input voltage is calculated by:

$$V_{IN(MAX)} = \frac{(V_{OUT} + V_F)}{t_{ON(MIN)} \cdot f_{OSC}} - V_F + V_{SW}$$

$V_F$  is the forward voltage of the catch diode,  $V_{SW}$  is the internal switch saturation voltage, and  $f_{OSC}$  is the oscillator frequency. For 36V<sub>IN</sub> to 3.3V<sub>OUT</sub>,  $f_{OSC}$  must be below 790kHz. To achieve 36V<sub>IN</sub> to 1.8V<sub>OUT</sub>,  $f_{OSC}$  must be 470kHz or less. Likewise, a simple 12V to

3.3V step-down ratio is possible with a switching frequency of 2.3MHz. An application converting 12V<sub>IN</sub> to 5V<sub>OUT</sub> and 3.3V<sub>OUT</sub> can take advantage of a high switching frequency of 2.2MHz and remain above the AM band for automotive electronics.

In cases where both a high switching frequency and a high step down ratio are required (as in the case of an automotive power supply that requires a 2.2MHz switching frequency to keep interference outside of the AM band), a cascaded solution can

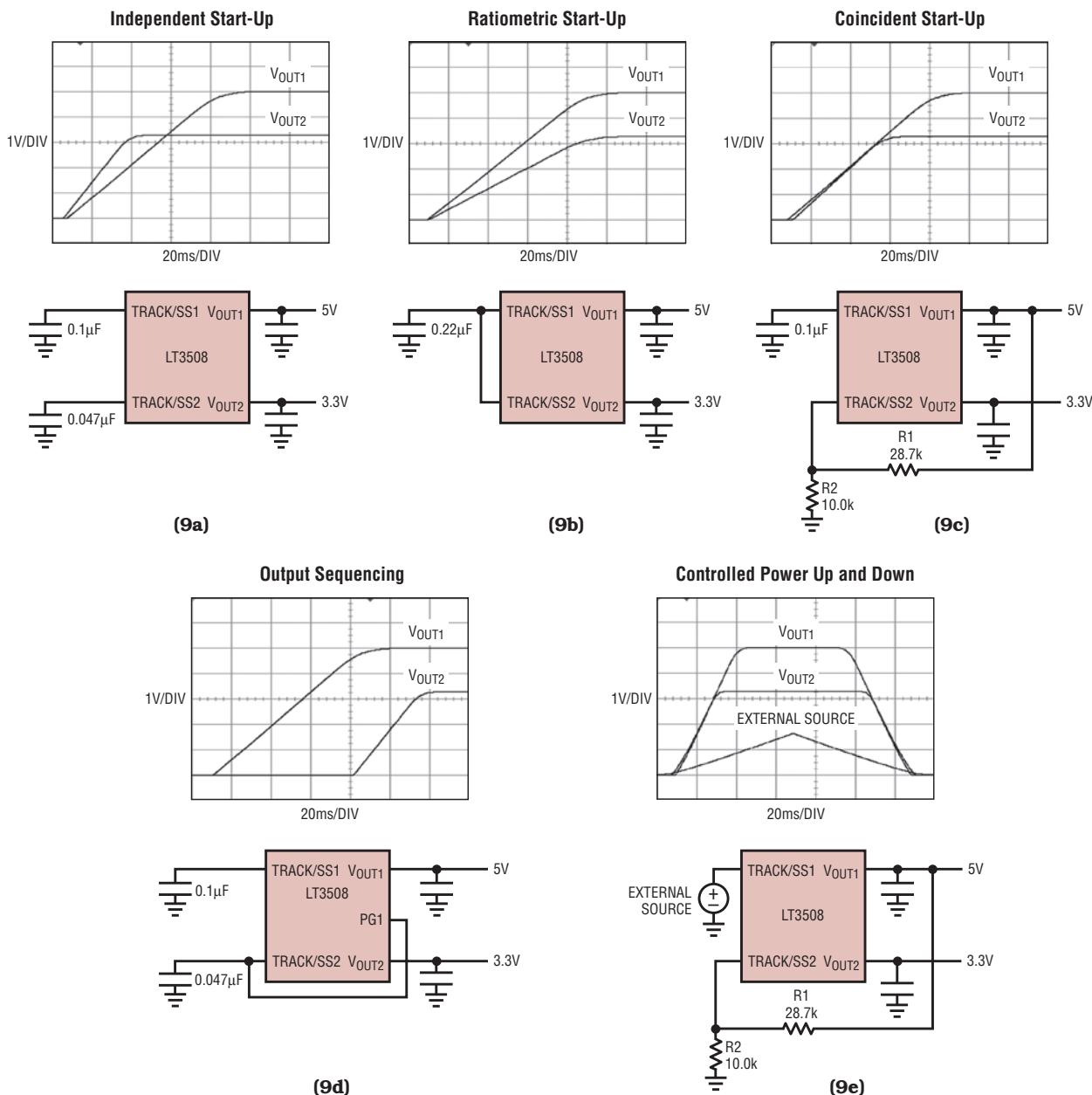


Figure 9. Tracking and soft-start options

be used. As shown in Figure 6, 28V<sub>IN</sub> to 1.8V<sub>IN</sub> is possible if one output is set for 7.7V and tied to the V<sub>IN</sub> pin of the 1.8V channel. Higher switching frequency reduces inductor and capacitor sizes and achieves faster transient response.

### Fast Transient Response

The current mode architecture of the LT3508 control loop yields fast transient response with small, ceramic output capacitors and simple compensation. Small 0805 and 1206 case size 10µF and 22µF 6.3V ceramic output capacitors are typical for up to 1.4A output applications. High temperature coefficient capacitors such as X5R and X7R ceramics are recommended for most designs.

Figure 3 shows the transient response for a typical LT3508 application. Transient response ripple is about 200mV<sub>P-P</sub> for both the 3.3V output and the 5V output. The response time is about 20µs to 40µs, excellent for 1.4A outputs. This is an important feature when the power supply is used with DSPs and microcontrollers that are sensitive to voltage ripple.

### Low Dropout

The LT3508 features low dropout for output voltages above 3V. The minimum operating voltage of the device is determined either by the LT3508's undervoltage lockout or by its maximum duty cycle. If V<sub>IN1</sub> and V<sub>IN2</sub> are tied together, the undervoltage lockout is at 3.7V or below. If the two inputs are used separately, then V<sub>IN1</sub> has an undervoltage lockout of 3.7V or below and V<sub>IN2</sub> has an undervoltage lockout of 3V or below. Because the internal supply runs off V<sub>IN1</sub>, channel 2 will not operate unless V<sub>IN1</sub> is above its undervoltage lockout. The dropout of the 5V<sub>OUT</sub> circuit shown in Figure 1 is less than 1V, with start-up occurring at a minimum of 5.9V and the converter running down to 5.5V before dropout occurs.

Unlike many fixed frequency regulators, the LT3508 can extend its duty cycle by turning on for multiple cycles. The LT3508 will not switch off at the end of each clock cycle if there is suf-

ficient voltage on the boost capacitor. Eventually, the voltage on the boost capacitor falls and requires refreshing. A bigger boost capacitor allows for higher maximum duty cycle. Circuitry detects a depleted boost capacitor and forces the switch to turn off, allowing the inductor current to charge up the boost capacitor. This places a limitation on the maximum duty cycle. The minimum input voltage can be calculated as:

$$V_{IN(MIN)} = (V_{OUT} + V_F) \left( 1 + \frac{1}{\beta_{SW}} \right) - V_F + V_{SW}$$

$\beta_{SW}$  is the switch current to boost current ratio. Refer to the data sheet section "Minimum Operating Voltage" for details.

### Track/Soft-Start and Power Good Pins Simplify Supply Sequencing

DSPs and microcontrollers require power supply sequencing and tracking. Both LT3508 channels have independent tracking and soft-start circuits and each generates a power good signal when its output is in regulation. Most start-up/shut-down scenarios are possible by combining the function of the track/soft-start (TRACK/SS) with the power good (PG) pins. Figure 9 shows how easy it is to implement independent channel soft-start, ratiometric start-up, coincident start-up, output sequencing, and externally controlled power up and power down.

Soft-start prevents inrush current spikes, which can drag down the source voltage upon start-up and cause other system problems. Simple soft-start of each channel requires only a capacitor on the pin (Figure 9a). The rate of soft-start is determined by the size of capacitor and by the capabilities of the power source.

As the name suggests, the TRACK/SS pins also facilitate supply tracking, including ratiometric, coincident and externally controlled start-up and shut-down. Figure 9d shows how to connect the PG pin of one channel to the track pin of another channel to

sequence the two—one channel is held off until the other channel is good.

The track/soft-start function can also be used to power a channel down, but to minimize current draw, shut down the regulator via the shutdown (SHDN) pin as described below.

### Low Shutdown Current

When the shutdown pin is pulled low, both channels turn off and the part consumes a very low quiescent current (<2µA), saving battery energy and extending lifetime. The shutdown pin can also be used as a 2.63V accurate undervoltage lockout (UVLO) with a resistor divider from V<sub>IN</sub>. In shutdown, the power good comparator is disabled and not valid and the soft-start capacitors are reset.

### TSSOP-16 and QFN Packages

The LT3508 is available in two types of thermally-enhanced packages. The UF package is a 4mm × 4mm 24-pin QFN. The FE package is a 16-pin thermally-enhanced TSSOP surface mount with an exposed thermal pad. Both packages have equally low 40°C/W junction-to-ambient thermal impedance and 10°C/W junction-to-case impedance, important for applications that require a high input voltage, high switching frequency and high load current, all of which raise the junction temperature.

### Conclusion

The LT3508 is a wide input voltage 36V dual 1.4A monolithic step-down converter with tracking/soft-start pins and power good pins for power supply sequencing and simple diagnostic interface with DSPs and microcontrollers. It has adjustable switching frequency from 250kHz to 2.5MHz, either set by a resistor or synchronized to an external source. Its thermally enhanced packages and E- and I-grade temperature ratings allow it to be used in thermally demanding environments. Separate V<sub>IN</sub> pins for each channel provide the capability of cascading channels and achieving extreme V<sub>IN</sub> to V<sub>OUT</sub> ratios by using the output of one channel as the input for the other. □

# 3-Phase Buck Controller Governs One, Two or Three Outputs

by Theo Phillips and Teo Yang Long

## Introduction

The LTC3773 is an efficient, 3-phase DC/DC controller capable of handling inputs as high as 36V and supporting one, two, or three output voltages from 0.6V to 5V with currents in excess of 15A per phase. Two channels may be tied together for a 30A output, or three channels for a single 45A output. In all cases the channels are operated out of phase to minimize stress on the input capacitors.

Each channel provides for ratiometric or coincident tracking of any supply, and sequencing requires just an external capacitor. When all three channels are disabled, the controller typically draws just 18 $\mu$ A in shutdown mode. Three light load operating modes satisfy the priorities of various applications. Burst Mode operation yields maximum efficiency while forced continuous mode sacrifices some efficiency for low, predictable current ripple. Pulse skipping mode is a compromise between the two.

Switching frequency can be phase-locked to an external source from 160kHz to 700kHz, or can be set with a DC voltage on the PLLFLTR pin. Typical pin-selectable frequencies of 220kHz, 400kHz and 560kHz are also available. In either case, the CLKOUT pin expresses the operating frequency at zero, 60, or 180 degrees with respect to channel 1's switching frequency, a useful feature where multiple controller ICs operate from the same set of input capacitors.

## Three Outputs, One Controller

Where three 15A outputs are required in the smallest possible footprint, the LTC3773 is the obvious choice. Figure 1 shows a single-controller schematic delivering three low voltage, high current outputs from a single, loosely regulated supply. Each output reference is guaranteed to remain within  $\pm 1\%$  over temperature.

During start-up, ratiometric tracking holds the feedback references of  $V_{OUT2}$  and  $V_{OUT3}$  to  $0.6V \times (V_{OUT1}/2.5)$ , so that the three outputs reach their nominal operating levels at the same time (Figure 3). TRACK1 ramps up by charging the  $0.01\mu$ F capacitor with an internal  $1\mu$ A source. Where tracking is not required, all TRACK pins can

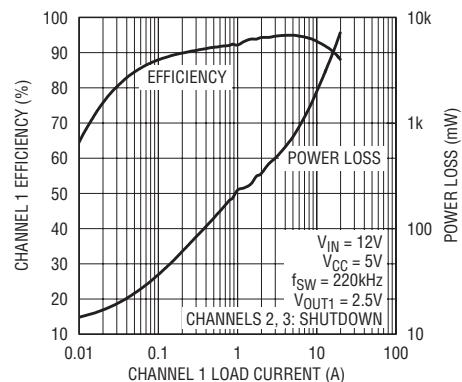


Figure 2. Efficiency in Burst Mode operation for the circuit of Figure 1.

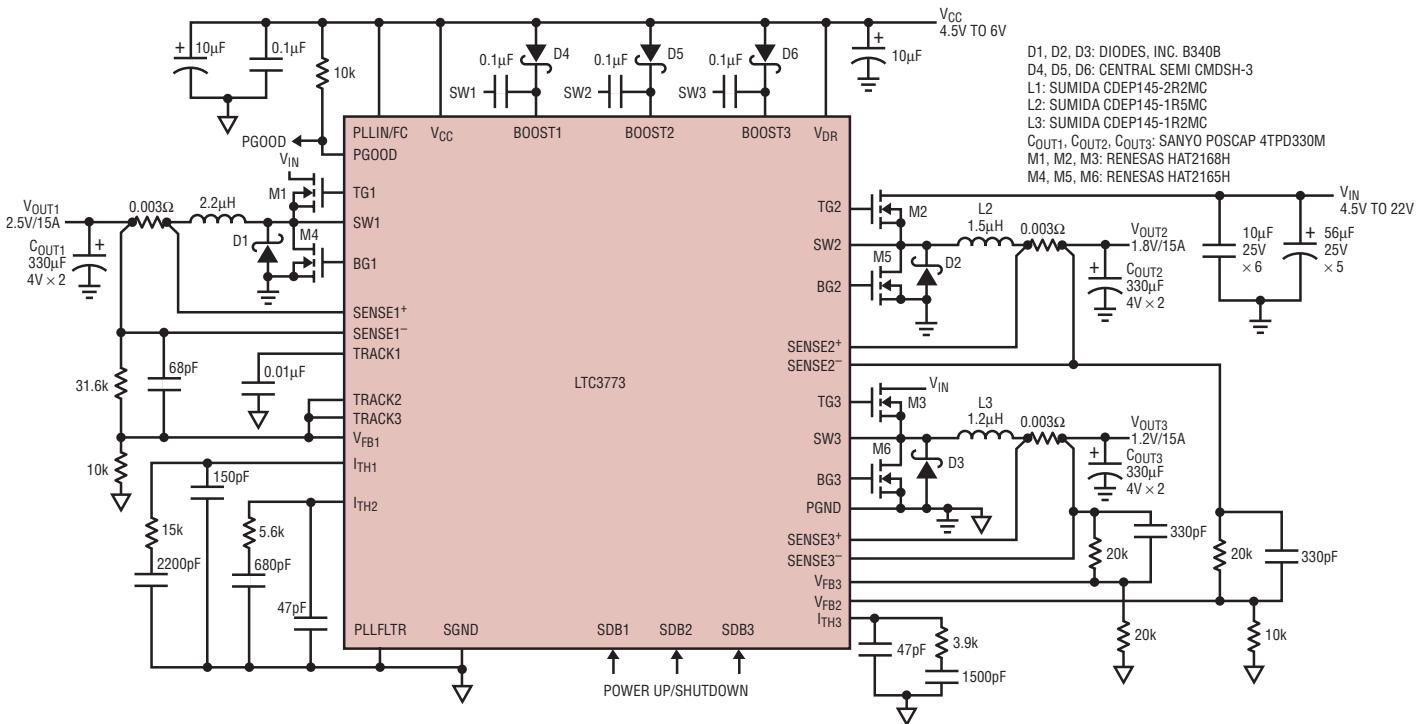
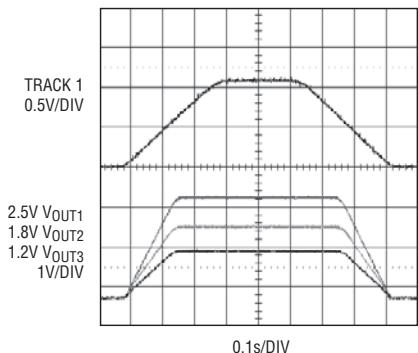
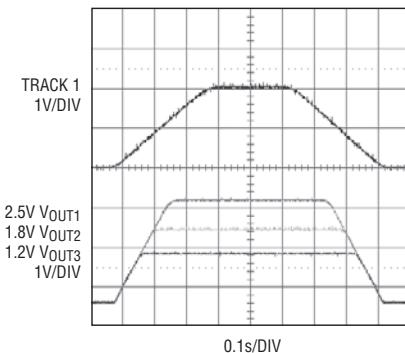


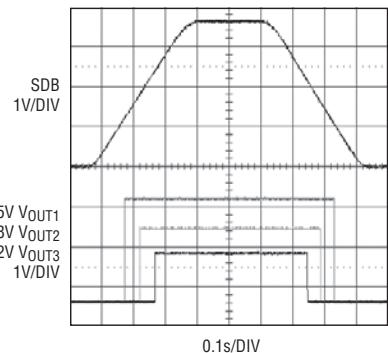
Figure 1. The LTC3773 regulates three high current outputs with ratiometric tracking, providing 2.5V, 1.8V, and 1.2V from a 4.5V-22V supply.



**Figure 3.** Ratiometric tracking in action. Channel 1's reference does not exceed the lesser of  $V_{\text{TRACK}1}$  or 0.6V. The same is true for channels 2 and 3, except that their track voltages follow channel 1's reference. This ensures that channels 2 and 3 follow channel 1.



**Figure 4. Coincident Tracking**



**Figure 5. Supply sequencing**  
**implemented by applying a single**  
**external ramp to all three SDB pins.**  
**The power-up thresholds for SDB1,**  
**2, and 3 are 1.2V, 1.8V, and 2.4V.**

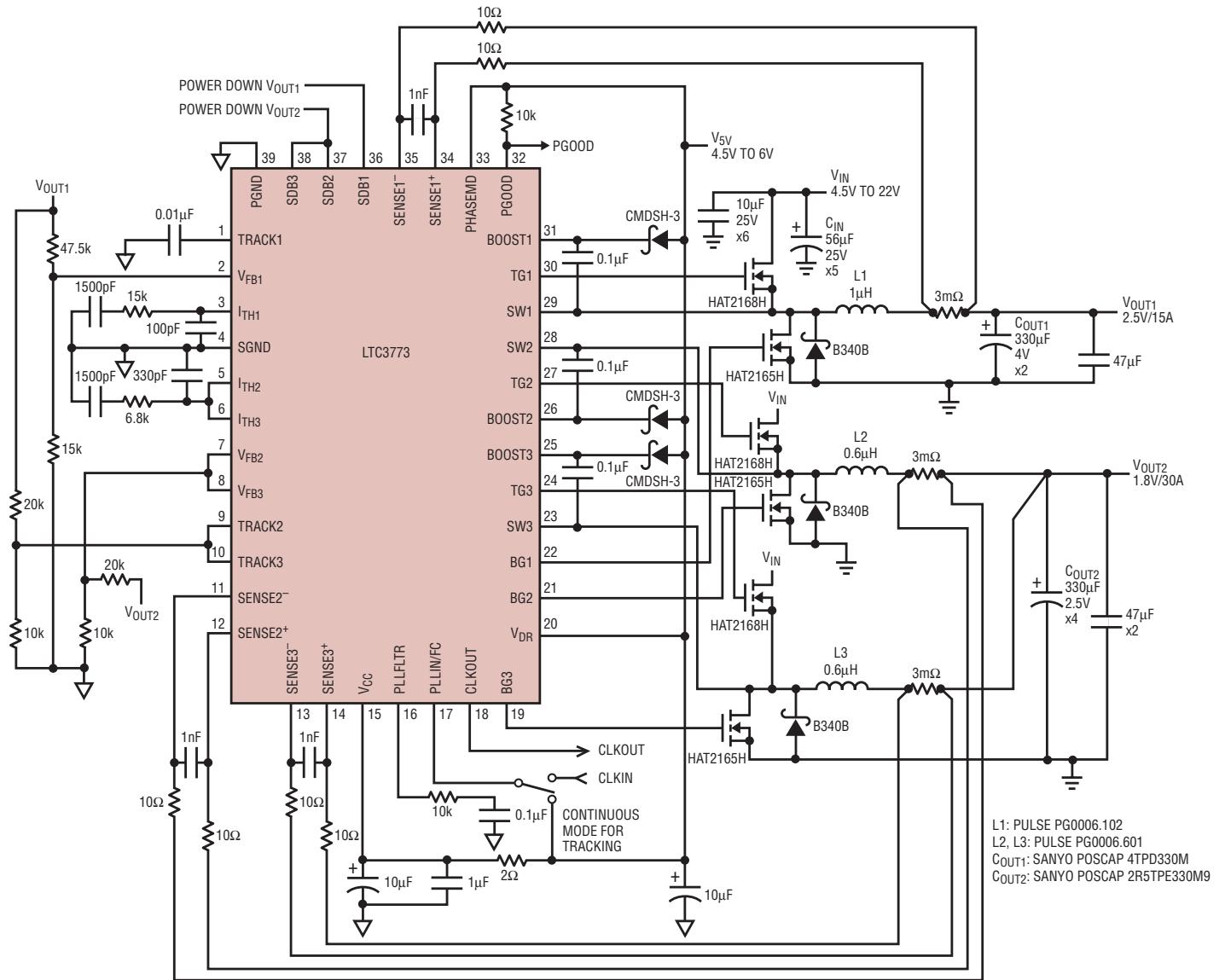
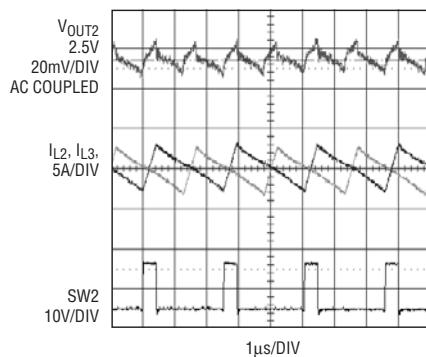


Figure 6. 3-phase, dual output converter with coincident tracking. The 1.8V output is operated in an antiphase configuration, using channels 2 and 3 of the LTC3773. This is implemented by tying PHASEMD high, which causes TG1 to lead TG2 and TG3 by 90° and 270°, respectively, and by connecting together the TRACK, SDB,  $V_{FB}$  and  $I_{TH}$  pins of channels 2 and 3.

be connected to external capacitors, so that they soft-start their respective channels without regard to external voltage sources.

What happens to channels 2 and 3 if channel 1's output is shorted? Pulling the positive node of a TRACK divider to zero doesn't always produce zero volts at the respective output; the minute pull-up current in the TRACK pins could create offsets in the voltage dividers to which they are connected, producing unwanted low output voltages or hiccupping on channels 2 and 3. But the LTC3773 uses a 30mV offset in its tracking circuits, disabling each channel's driver until its TRACK pin sees at least 30mV. This offset disappears as the TRACK level rises to 100mV, so that channels 2 and 3 can track predictably when they are anywhere near their final values.

The LTC3773 also allows simultaneous ramping of output voltages (coincident tracking). Just connect TRACK2 and TRACK3 to resistor dividers of the same ratio as their respective feedback networks and tie these

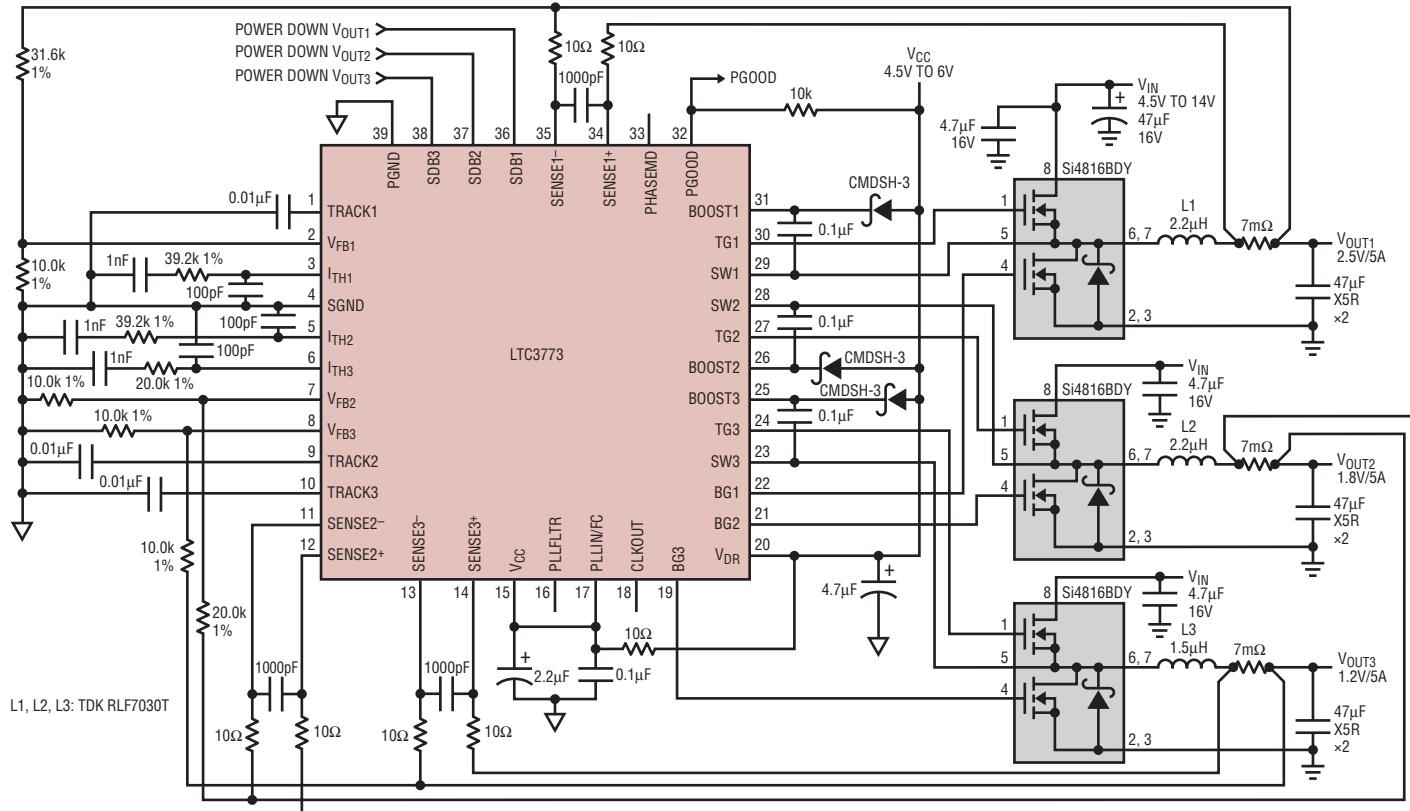


**Figure 7. Waveforms for the circuit of Figure 6** show excellent current sharing between channels 2 and 3, and minimal output voltage ripple at twice the switching frequency of each channel.

dividers between  $V_{OUT1}$  and ground. Figure 4 shows the clean results. If sequencing is required, the LTC3773's shutdown (SDB) pins offer the simplest solution. Higher numbered channels have higher enable thresholds at SDB, so that applying a single rising voltage ramp to all of them will cause them to turn on consecutively. The configuration can be as simple as the SDB pins'

internal current sources charging up a single external capacitor with  $1.5\mu\text{A}$ . An externally controlled ramp can be applied where needed (Figure 5).

Accurate current limiting is provided by monitoring the sense resistor in series with the inductor. If a small increase in efficiency is needed, the LTC3773 can be configured for DCR sensing across the inductor. The controller protects against excessive inrush current during start-up and limits current through the inductor and main MOSFET during short-circuits on the output. It pulls the output down by turning on the synchronous MOSFET whenever the feedback pin  $V_{FB}$  is 3.75% above the 0.6V reference voltage, protecting the output capacitors and the load. It shuts off whenever the bias supply  $V_{CC}$  drops below 3.94V, ensuring that the external MOSFETs operate at safe gate drive levels. When the feedback voltage of any channel is not within  $\pm 10\%$  of the 0.600V internal reference for  $100\mu\text{s}$ , the open drain power good output PGOOD pulls low.



**Figure 8. Schematic for a 3-output, all ceramic  $C_{OUT}$  regulator**

## A Better Alternative for Two Outputs

Compared to single phase switching regulators, 2-phase converters impose lower ripple current on the input capacitors, reducing their size and cost. This technique interleaves the current pulses coming from the switches, greatly reducing the amount of time when they overlap and add together. Lower ripple current means less power dissipated and higher efficiency, as well as reduced electromagnetic interference. 2-phase converters also double the effective switching frequency, lowering the output ripple voltage.

To fully realize these benefits, the two channels should be operated 180° out of phase. The LTC3773 allows channels 2 and 3 to be operated out of phase, a useful option when they are tied together as a single, high current output. Figure 6 shows the schematic for such a converter. Channel 1's output is 2.5V/15A and the combined 2-phase channel's output is 1.8V/30A. The 2-phase channel exhibits excellent current sharing, no channel-to-channel interaction, and minimal output ripple (at twice the switch nodes' operating frequency), as Figure 7 demonstrates.

## A Low Ripple, 3-Output Supply with All Ceramic Output Capacitors

Figure 8 shows the schematic for a triple output supply which converts 12V to three 5A outputs: 2.5V, 1.8V, and 1.2V. Each channel is stable with just two 47µF ceramic capacitors at its output, providing very low ripple at moderate to heavy loads and the fastest possible transient response. With current-mode operation, the converter responds quickly to input voltage transients, correcting the pulse width cycle-by-cycle as the input voltage swings widely (Figure 9). Channel-to-channel interaction is practically nonexistent during a substantial load step on one channel, as Figure 10 shows.

With the PLLIN/FC tied to ground, the LTC3773 enters Burst Mode

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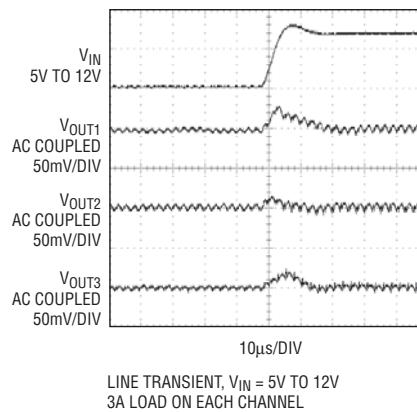


Figure 9. Line transient for the circuit of Figure 8

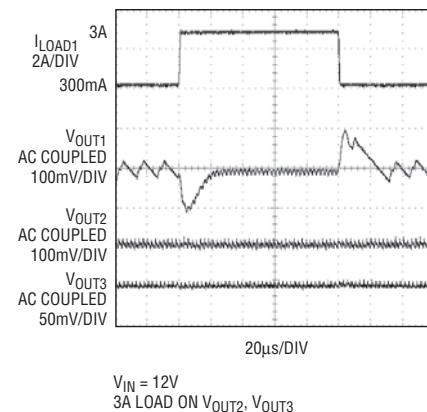


Figure 10. Load transient for the circuit of Figure 8, showing a negligible coupling effect on the two other outputs

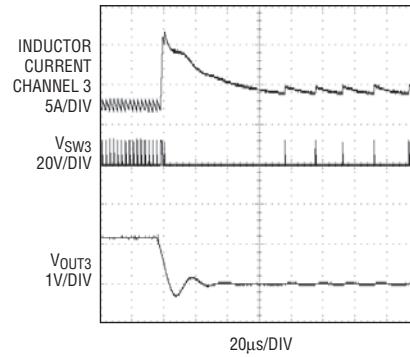


Figure 11. Short circuit for circuit of Figure 8. The LTC3773's typical maximum current comparator threshold is 75mV/R<sub>SENSE</sub>, resulting in a peak inductor current (or maximum MOSFET current) of just over 10A in this application. This limit protects the components during the initial short circuit. Subsequently, current foldback initiates cycle-skipping, which limits short-circuit ripple current even further.

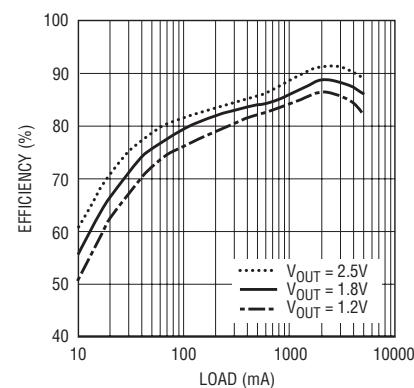
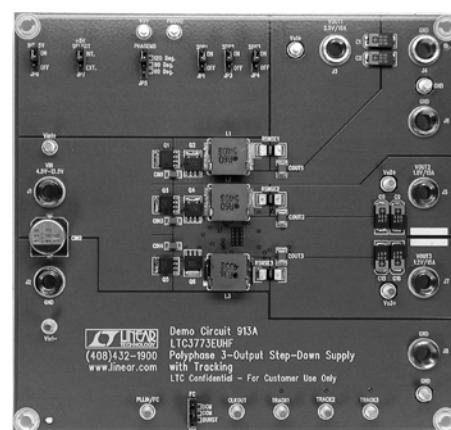
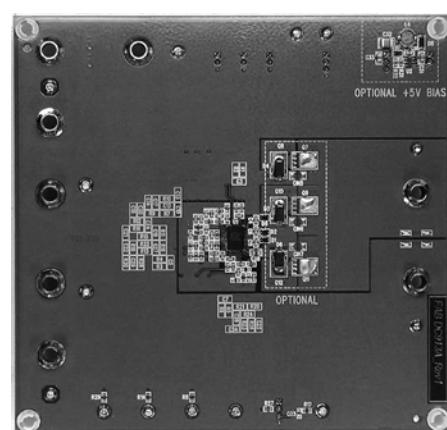


Figure 12. Efficiency curve for the circuit of Figure 8



(a)



(b)

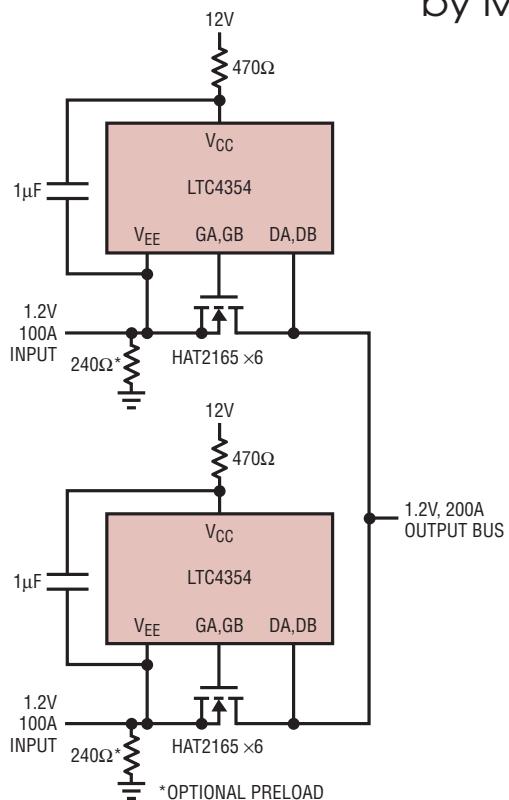
Figure 13. One of several evaluation boards available for the LTC3773, which is offered in 5mm x 7mm QFN and small 36-lead SSOP packages. With (a) top and (b) bottom layers populated, the core of this dual output, 15A application occupies just 17mm<sup>2</sup>.

# Use an Ideal Diode to Combine Low Voltage Supplies for High Current

by Mitchell Lee

A common method of delivering high currents at low voltages to power microprocessors is to combine the outputs of several lower current DC/DC converters. Although simple in principle, the implementation can be complicated. The outputs cannot just be soldered together directly; low voltage, high current converters use synchronous topologies, so some means of preventing back feeding from one converter output to another is necessary. Diodes come to mind, but the losses, even with low forward voltage Schottky diodes, are prohibitive at the necessary currents, suggesting an active solution is necessary.

An unlikely candidate is the LTC4354 negative voltage diode-OR controller. Intended for -48V telecom applications, this device functions equally well in positive low voltage applications. The circuit shown in Figure 1 combines the outputs of



**Figure 1. Positive low voltage diode-OR combines multiple switching converters.**

## DESIGN IDEAS

**Use an Ideal Diode to Combine Low Voltage Supplies for High Current.....30**  
Mitchell Lee

**White LED Driver in 3mm x 2mm DFN Drives Ten LEDs.....31**  
Molly Zhu

**Shrink MP3 Players and Digital Cameras with Two New Dual Input USB/Wall-Adapter Linear Li-Ion/Li-Polymer Battery Chargers....32**  
Alfonso Centuori

**Four Rails from One Small Footprint Regulator .....**34  
Kevin Soch

**Synchronous Buck Controller Regulates from Input Voltages as Low as 2.2V .....**36  
David Ng

**Dual High Speed Amplifier Doubles as Differential 100Mbps Line Receiver .....**37  
Cheng Wei Pei and Mitchell Lee

**1A Synchronous Boost Converters for Portable Applications up to 7.5V.....40**  
Eddy Wells

multiple high current switching converters, without concern about back feeding or supply failure shorting out the common bus. Each diode "channel" comprises the LTC4354 and six parallel MOSFETs, supplying 100A to a 1.2V load. The circuit is easily adapted to any supply voltage between 0V and 5V, provided there is a path for up to 4mA  $V_{EE}$  current to ground at either the input or the output. Most high current switching converters can easily sink 4mA and no preload is necessary. No circuit changes are necessary for operation over a range of nearly zero to 5V.

The circuit features two notable improvements beyond serving as an ideal diode. First, the forward drop across the MOSFET is regulated at a low level, about 30mV. By regulating the forward drop, any tendency to oscillate—a problem associated with hysteretic systems—is eliminated,

without compromising forward losses. Second, the LTC4354 has two levels of turn-off when blocking reverse current flow. The LTC4354 responds slowly to small reverse overdrives, and responds quickly whenever the reverse voltage exceeds 120mV. Thus, the circuit accommodates a moderate amount of reverse current on a transient basis, preserving the dynamic performance of synchronous DC/DC converters, which sink current to achieve good load step regulation.

Dissipation in the ORing MOSFETs is about 500mW each at 100A, exclusive of distribution losses. While two power stages are combined in Figure 1, the technique is extensible to three or more stages with no circuit changes.

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# White LED Driver in 3mm × 2mm DFN Drives Ten LEDs

by Molly Zhu

## Introduction

The LT3591 is a step-up white LED driver that drives up to ten LEDs from a single Li-Ion battery. Its high level of integration minimizes solution size, board space and the number of external components—a complete LED driver requires only 30mm<sup>2</sup>. The high side sense feature of the LT3591 allows for a 1-wire current source, and makes the LT3591 applicable in buck and buck-boost circuits as well.

## Driving up to Ten LEDs

The LT3591 can drive up to ten white LEDs, as long as the maximum switch current is below 500mA. Figure 1 shows a typical application circuit driving ten white LEDs from a single Li-Ion battery. The LEDs are connected in series, which results in accurate LED current matching regardless of variations in their forward voltages—no additional circuitry required.

The power switch, Schottky diode, compensation components and open-LED protection are all integrated into the LT3591's tiny 3mm × 2mm DFN package. Only four external components are used in Figure 1. This minimizes the design effort, solution cost and board space. The fixed 1MHz switching frequency allows the use of tiny inductors and capacitors, while still keeping efficiency high. All these make the LT3591 ideal for portable applications.

## High Side Sense

The high side sense of LT3591 brings unique benefits for a wide range of applications. First, it allows for a 1-wire current source, meaning that the end of the string can be connected directly to ground instead of returning to the driver, as is required with many LED drivers. This simplifies the wiring design when the driver and the LEDs are on separate boards, which is often the case in cell phones, or the LEDs and driver are some distance apart.

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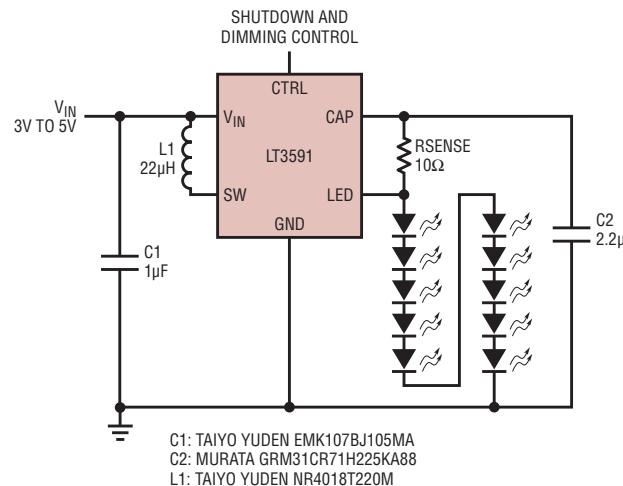


Figure 1. Li-Ion powered driver for ten white LEDs

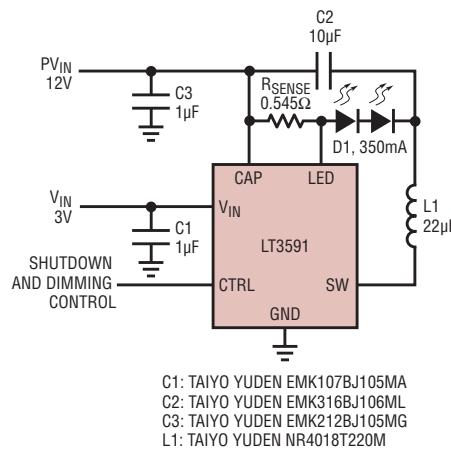


Figure 2. A buck converter drives two LEDs at 350mA from a 12V input.

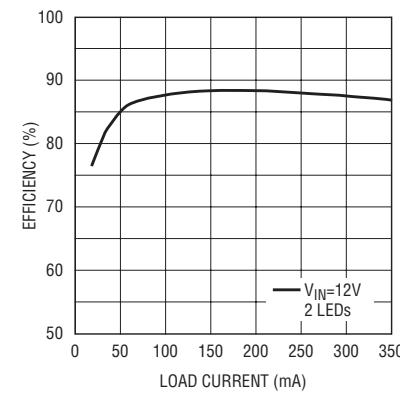


Figure 3. Efficiency of the circuit in Figure 2

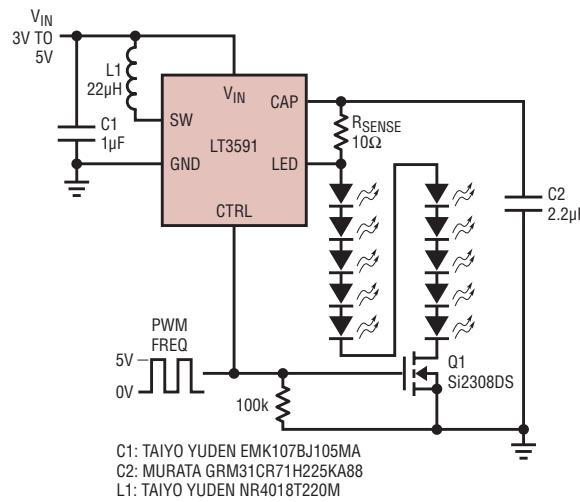


Figure 4. Li-Ion to ten LEDs with direct PWM dimming

# Shrink MP3 Players and Digital Cameras with Two New Dual-Input USB/Wall-Adapter Linear Li-Ion/Li-Polymer Battery Chargers

## Introduction

USB or wall adapter? Many of today's digital cameras, PDAs, mobile phones and MP3 players can charge their batteries from either source, requiring a flexible charging circuit. The LTC4096 and LTC4097 are specifically designed to charge single cell lithium-ion/lithium-polymer batteries from a wall adapter or another input such as a USB port, all in just 48mm<sup>2</sup> of board space (LTC4097).

Using a constant current/constant voltage algorithm, these chargers can deliver up to 1.2A of charge current (programmable) from the wall adapter and up to 1A of charge current (programmable) from the other power input (usually USB), with a final float volt-

age accuracy of  $\pm 0.6\%$ . The LTC4096 and LTC4097 each include two internal P-channel power MOSFETs and thermal regulation circuitry with no blocking diode or external sense resistor required—a basic charger circuit requires only three external components.

Both parts simplify status reporting, start-up, charging and shutdown with simple hookup. The CHRG open-drain status pin indicates the battery charge state. The PWR open-drain status pin of the LTC4096 (VNTC pin of the LTC4097) reports when at least one of the inputs has sufficient voltage to charge a battery. The PWR pin can source up to 120mA of current to

power up a microprocessor or other general circuitry, solving potential start-up problems. The LTC4097 has an additional safety feature in that it can qualify charging based on battery temperature via the NTC input. The ITERM pin provides a means to implement programmable current based termination schemes.

Internal thermal feedback regulates the charge current to maintain a constant die temperature during high power operation or high ambient temperature conditions.

Both devices can be shut down to reduce the drain on any of the input sources. In shutdown, the DCIN (wall adapter) supply current reduces to 20µA, the USBIN supply reduces to 10µA and the battery drain to less than 2µA.

## Programmability

The LTC4096 and LTC4097 provide a great deal of design flexibility, including programmable charge current and programmable current termination. The charge currents are programmed using a resistor from the IDC and IUSB pins to ground as follows:

$$I_{CHG} = \frac{1000V}{R_{IDC}} \text{ (Wall Adapter Present)}$$

$$I_{CHG} = \frac{1000V}{R_{IUSB}} \text{ (USB, HPWR = High for LTC4097)}$$

Both the LTC4096 and LTC4097 terminate the charge cycle based on the battery current. The current detection threshold,  $I_{ITERM}$ , is set by connecting a resistor,  $R_{ITERM}$ , from ITERM to ground. The following

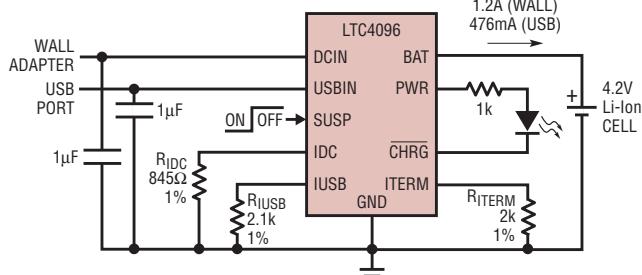


Figure 1. Just a few components are needed to create feature-laden, LTC4096-based, dual input USB/wall-adapter Li-Ion or Li-Polymer battery charger.

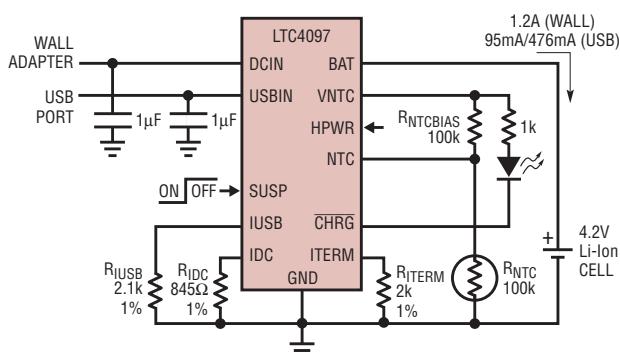


Figure 2. This LTC4097 USB/wall-adapter battery charger is similar to the charger in Figure 1, but adds NTC battery-temperature monitoring safety and the ability to change USB power modes on the fly.

Table 1. Power source selection

$V_{DCIN} > 4.2V$ and $V_{DCIN} > BAT + 30mV$	$V_{USBIN} > 4.2V$ and $V_{USBIN} > BAT + 30mV$	$V_{USBIN} < 4.2V$ or $V_{USBIN} < BAT + 30mV$
$V_{DCIN} > 4.2V$ and $V_{DCIN} > BAT + 30mV$	Charger powered from wall adapter source $V_{PWR} = V_{DCIN} - R_{DC-PWR} \cdot I_{PWR}$ USBIN current < 25µA	Charger powered from wall adapter source $V_{PWR} = V_{DCIN} - R_{DC-PWR} \cdot I_{PWR}$
$V_{DCIN} < 4.2V$ or $V_{DCIN} < BAT + 30mV$	Charger powered from USB source $V_{PWR} = V_{USBIN} - R_{USB-PWR} \cdot I_{PWR}$	No charging PWR: Hi-Z

formula programs the termination current:

$$I_{TERM} = \frac{100V}{R_{TERM}}$$

The condition of the CHRG pin indicates the charge state. A strong pull-down on the CHRG pin indicates that the battery is charging. When the current termination threshold is reached, the CHRG pin assumes a high impedance state and the charge cycle is terminated.

## USB Compatibility

Both chargers are USB compatible. Figures 1 and 2 show USB compatible setups for the LTC4096 and

LTC4097, respectively. In both cases, wall adapter input takes priority over USB input, with the maximum charge current set to 1.2A by the 845Ω IDC resistor. When a wall adapter is not present and USB power is available, the devices draw current from USBIN. The 2.1k resistor at the IUSB pin sets the USB charge current to 476mA, well within the limits of the high power USB specification.

The LTC4097 has an additional pin, HPWR, that allows mode selection of high power ( $\leq 500mA$ ) or low power ( $\leq 100mA$ ) USB charging on the fly. A logic high on the HPWR pin sets the charge current to 100% (476mA) of the current programmed by the IUSB pin resistor, while a logic low on the HPWR

pin sets the charge current to 20% (95mA) of the current programmed by the IUSB pin resistor. If the HPWR pin is not driven externally, a weak pull down on the HPWR pin defaults to the low power state. The HPWR pin provides a simple control for managing charge current as shown in Figure 2 with HPWR in its high state and 95mA with HPWR in its low state for LTC4097 (or just 476mA for LTC4096).

## Avoiding Unnecessary Charge Cycles

LTC4096 and LTC4097 are designed to avoid unnecessary charge cycles to extend the life of Li-Ion or Li-Polymers batteries. When power is first applied or when exiting shutdown, the LTC4096 and LTC4097 check the voltage on the BAT pin to determine its initial state. If the BAT pin voltage is below the recharge threshold of 4.1V (4.15V for LTC4096), which corresponds to approximately 80%–90% battery capacity, LTC4096 and LTC4097 enter charge mode and begin a charge cycle. If the BAT pin is above 4.1V (4.15V for LTC4096), the battery is nearly full and the charger does not initiate a charge cycle and enters standby mode. When in standby mode, the chargers continuously monitor the BAT pin voltage. When the BAT pin voltage drops below the recharge threshold, the charge cycle is automatically restarted. This feature eliminates the need for periodic charge cycle initiations, ensures that the battery is always fully charged and reduces the number of unnecessary charge cycles, thereby prolonging battery life.

## PWR/VNTC Functionality

Both parts provide a power supply status output pin (PWR in the LTC4096

continued on page 35

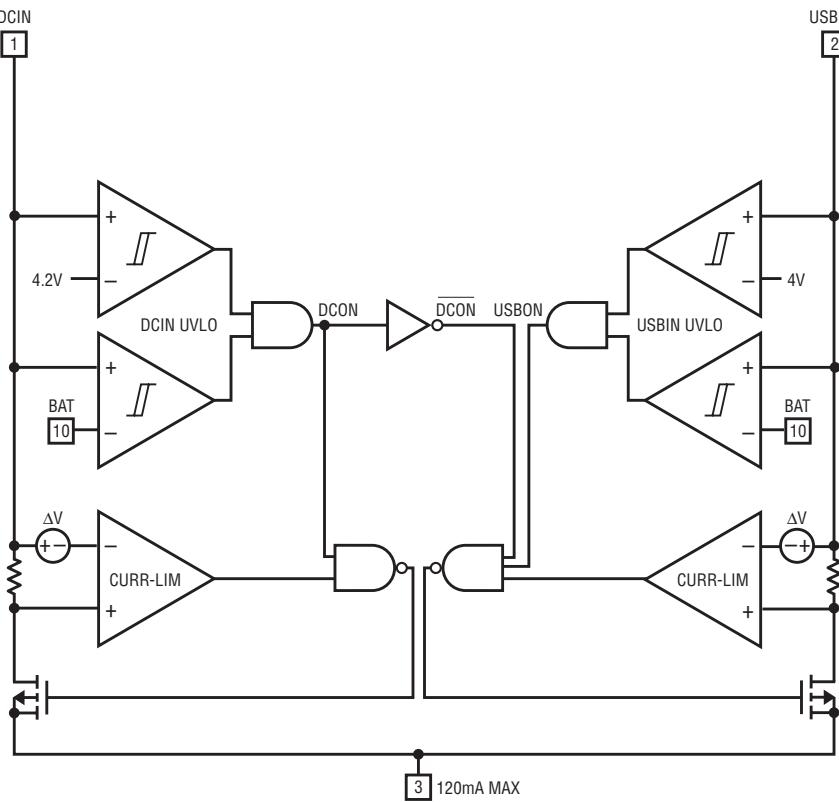


Figure 3. Simplified schematic shows the output of the power present output (PWR) pin (VNTC on LTC4097) as it relates to the DCIN and USBIN inputs.

# Four Rails from One Small Footprint Regulator

by Kevin Soch

## Introduction

The quad output LTC3544B is a monolithic buck regulator capable of simultaneously providing four independent voltage supply rails at over 90% efficiency. The four outputs are rated at maximum output currents of 300mA, 200mA, 200mA, and 100mA. At light load currents, pulse skipping operation maintains both high efficiency and low output voltage ripple. The input voltage can range from 2.25V to 5.5V and the output voltage levels are independently programmable from 0.8V to  $V_{IN}$ . Space saving features of the LTC3544B include a 3mm × 3mm, 16-pin QFN package and a fixed, 2.25MHz switching frequency, which allows the use of a minimum num-

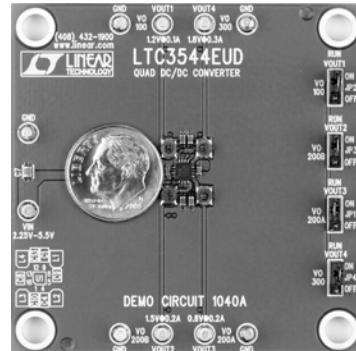


Figure 1. The LTC3544B is designed to facilitate simple and compact board layout

ber of small, surface mount external components.

## High Level of Integration

The LTC3544B provides a simple, extremely compact solution for applications requiring multiple voltage supply rails. Many of the components typically required to operate switching regulators have been integrated into the LTC3544B. Internal loop compensation eliminates the need for external compensation resistors and capacitors. Integrated synchronous switches eliminate the need for external Schottky diodes. An integrated soft-start function eliminates the need for external capacitors or control ramps.

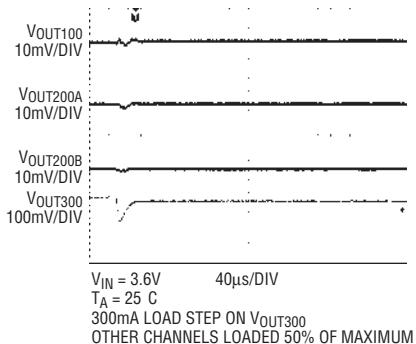


Figure 2. Channel to channel load transient crosstalk is negligible.

## Easy Board Layout

Particular attention was paid to the placement of the package pins to ensure a logical and compact board layout, particularly with respect to the power paths. Figure 1 is a photo of the LTC3544B demo board with the power components primarily on the top. The feedback elements (not shown) reside on the bottom of the board. Total circuit footprint for this board is approximately 225mm<sup>2</sup>.

## Minimal Channel Cross-Talk

A potential problem with multiple output regulators is the interaction between channels when one of the channels undergoes a load transient. Figure 2 shows the response on the

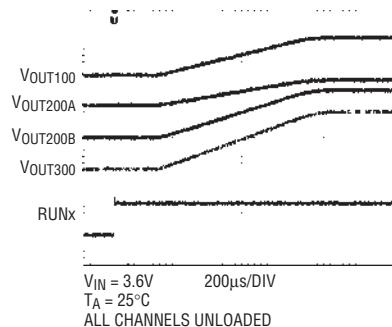


Figure 3. Integrated soft-start limits inrush current and prevents voltage overshoot.

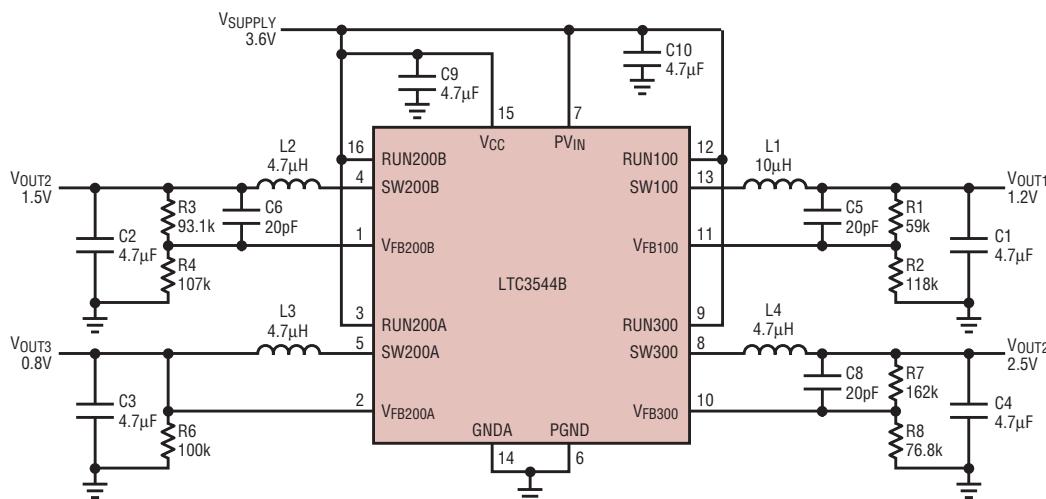


Figure 4. Minimal external components are required to create four separate voltage rails.

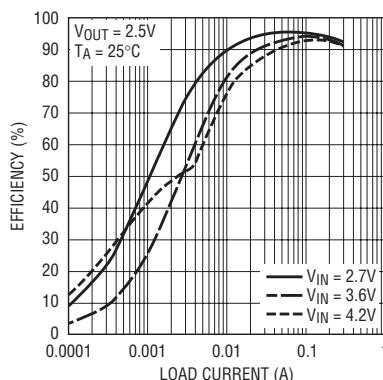


Figure 5. Pulse skipping assures both low ripple and high peak efficiency.

100mA and both 200mA channels to a 0mA to 300mA load step on the 300mA channel. Here, the first three channels are each loaded at 50% of their rated load. In each case, the crosstalk is on the order of 1mV to 2mV.

### Soft-Start Prevents Inrush Currents

The LTC3544B includes an integrated soft-start function. By ramping up the output voltage over a period of approximately 1ms, soft-start reduces

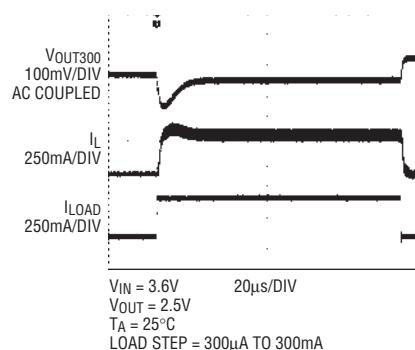


Figure 6. Current mode architecture assures fast recovery from load transients.

the inrush currents associated with rapid charging of the output filter caps during start-up. Figure 3 shows the output of each of the four channels during start-up. In addition to limiting the inrush currents, soft-start also prevents output voltage overshoot when starting up under light loads.

### High Overall Efficiency

Figure 4 shows a typical use of the LTC3544B to generate 100mA at 1.2V, 200mA at both 0.8V and 1.5V, and 300mA at 2.5V. Efficiency versus

LTC3773, continued from page 29  
operation at light loads for high efficiency across a wide range of loads (Figure 12). Burst Mode operation clamps minimum inductor current peaks to 20% of the maximum programmed current limit, and does not allow inductor current to reverse. The pin can also be tied to V<sub>CC</sub> for continuous conduction mode, which operates at a constant frequency and

allows inductor current to reverse, regardless of load. Discontinuous mode (PLLIN/FC floating) does not allow inductor current to reverse, and does not set a minimum peak inductor current, resulting in constant frequency operation at light loads.

### Conclusion

Rather than providing a single output like other 3-phase buck controllers,

load current and supply, and transient response for the 300mA channel are shown in Figures 5 and 6. In addition to the obvious board real-estate savings, a 4-output monolithic regulator has another important advantage over four individual regulators. Overall efficiency is improved because internal overhead circuitry such as the oscillator and voltage reference are shared between the four regulators, thereby minimizing the power loss per regulator.

### Conclusion

The LTC3544 is a unique part with tremendous flexibility. It greatly simplifies system and board design where multiple voltage supply rails are needed without sacrificing the features and performance found in individual regulators. The LTC3544B is ideally suited for battery powered applications where multiple or isolated voltage rails are required, board space is at a premium and a minimum number of external components are desired. □

the LTC3773 regulates one, two or three outputs ranging from 0.6V to 5V. They may be tracked, sequenced, or allowed to start up and shut down independently. With an array of protection features, adjustable frequency, and three modes of switching operation, the LTC3773 is the most versatile 3-phase DC/DC controller on the market. □

LTC4096/97, continued from page 33  
and VNTC in the LTC4097), which indicates when sufficient input power is available to the charger. Given its 120mA drive capability, it can be used for many applications where immediate input power is necessary to start-up a microprocessor or some other circuitry. Its output voltage is equal to DCIN or USBIN if either input source is present (above undervoltage lockout thresholds). If both DCIN and USBIN are present, the voltage at PWR

and VNTC equal the DCIN voltage (even if USBIN voltage is higher). If neither DCIN nor USBIN is valid (below undervoltage lockout thresholds), then PWR and VNTC assume a high impedance state. Table 1 shows how these output pins work and Figure 3 shows their basic electrical schematics.

### Conclusion

The LTC4096 and LTC4097 are complete linear Li-Ion or Li-Polymer battery chargers compatible with portable

USB applications. They are designed to accommodate charging from a wall adapter or a USB input. Their versatility, low quiescent current, simplicity, high level of integration and small size make them an easy fit in many portable USB applications. LTC4096 is available in a small, 10-lead low profile 3mm × 3mm DFN package. A version without trickle charge is also available (the LTC4096X). The LTC4097 is available in a small 12-lead low profile 3mm × 2mm DFN package. □

# Synchronous Buck Controller Regulates from Input Voltages as Low as 2.2V

by David Ng

## Introduction

Low voltage power supplies require special design considerations, especially if a low voltage bus must support more than a few amps. The difficulty usually arises in balancing electronic efficiency and volumetric efficiency.

Suppose, for example, that a system requires several amps of 1.8V power, and that both 3.3V and 12V are locally available as input buses. Assuming that sufficient current is available from both, there are compelling reasons to choose the lower voltage bus for the input power source: it allows a small valued inductor, yields reduced magnetic core loss and less switching voltage stress, benefiting both the design footprint and efficiency.

Unfortunately, many control ICs available for this type of application derive their MOSFET drive power from the input voltage. This means that, if 3.3V is chosen for the input bus, those ICs are only able to provide about 2.5V to the MOSFET gates. The designer is either required to add circuitry to generate a higher voltage for the MOSFET driver or select a MOSFET that operates reliably and efficiently with a gate voltage of only 2.5V.

The LT3740 is a valley mode, No  $R_{SENSE}$ <sup>TM</sup> synchronous buck controller that can accept input voltages as low

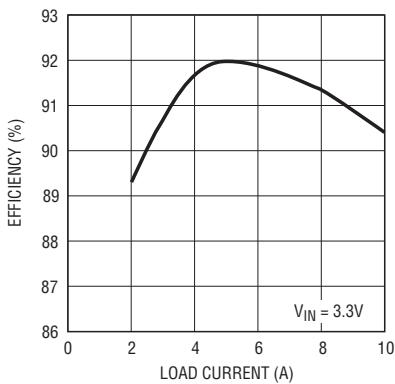


Figure 2. Efficiency for the circuit in Figure 1

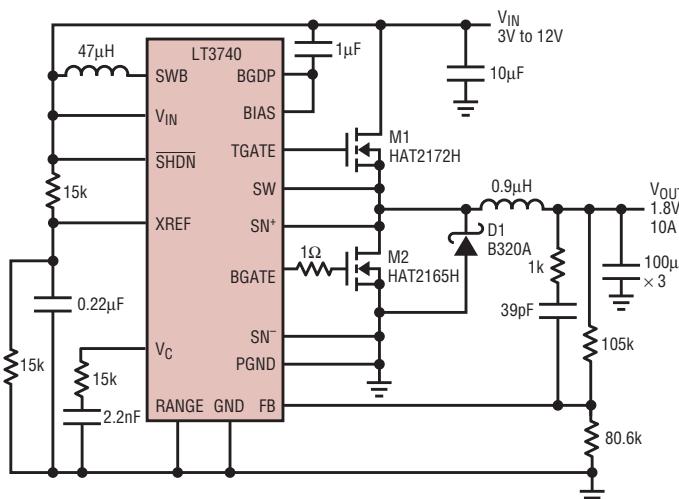


Figure 1. Synchronous buck converter produces 1.8V at 10A from a 3V-12V input. All capacitors are ceramic.

as 2.2V, and as high as 25V, but still provides at least 7V to the MOSFET gate drives through an internal boost regulator. It features No  $R_{SENSE}$  operation to maximize efficiency, three user selectable current limit ranges and a flexible soft-start system capable of tracking an external command voltage. The LT3740 is available in a space saving 5mm × 3mm DFN package.

## 1.8V Buck Converter in 1.5in<sup>2</sup>

Figure 1 shows an example of a LT3740 synchronous buck converter. The design produces 1.8V at 10A from an input range of 3V to 12V. All of the capacitors are ceramic. The internal boost converter, along with L1 and C1, regulates the voltage at the BIAS pin to 7V above the input voltage. The voltage at the BIAS pin is used internally to power the top MOSFET driver. The bottom gate drive power pin, BGDP, is connected to BIAS, so it is also 7V above the input voltage. The IC internally limits the amplitude of both the top and bottom gate driver output voltages to about 6V, which is high enough to ensure that the MOSFET is fully on, but low enough to keep switching losses down.

The LT3740's switching frequency optimizes both electrical and volumetric efficiency. The IC's 300kHz operation is high enough to allow the user to choose physically small power inductors and capacitors, but is also low enough to keep switching losses to a minimum. The regulator in Figure 1 takes up less than 1.5in<sup>2</sup> of board space.

The design takes advantage of the LT3740's ability to read the switch current through the bottom MOSFET on-resistance. The chip features three user selectable current limit thresholds to optimize efficiency: 50mV, 80mV and 110mV. For an output voltage as low as 1.8V, the voltage given up to resistively sense the current can have an appreciable impact on the converter efficiency, so the lowest current threshold is used by simply grounding the RANGE pin. For higher input and output voltages, the higher current limit settings may be used for improved signal to noise ratio. The efficiency of the LT3740 design, plotted against output load in Figure 2, peaks at 92% at half load and is still above 90% at full load.

continued on page 39

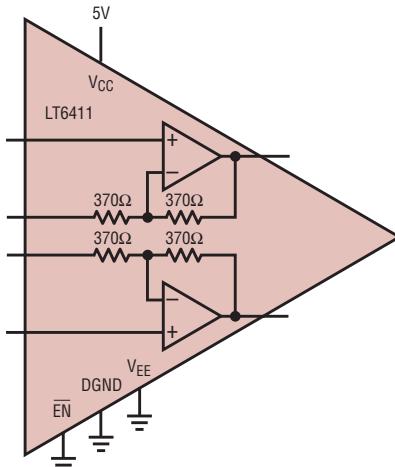
# Dual High Speed Amplifier Doubles as Differential 100Mbps Line Receiver

by Cheng Wei Pei and Mitchell Lee

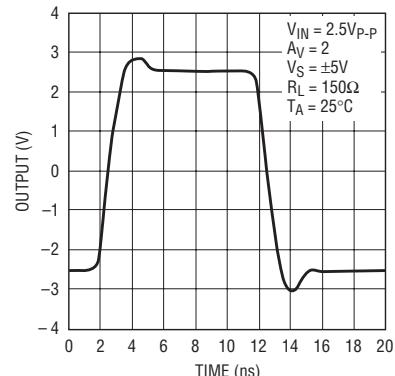
## Introduction

Increasing the data rate on unshielded twisted-pair cable such as Category 5 (Cat 5) cable increases the demands on line drivers and receivers, including the need for short propagation delays, clean transient response and blazing fast rise/fall times. For line receivers, the challenge is reproducing the original signals with good fidelity despite signal losses over hundreds of feet of cable. The receivers must be able to resolve the attenuated digital signals and convert them into full-scale logic levels. When nothing else will do the job, high speed dual amplifiers can act as digital data receivers for high data rate applications. Translated into traditional amplifier terminology, high speed data receivers require amplifiers with high slew rate, large bandwidth, fast output overdrive recovery and a clean transient step response. The LT6411 dual amplifier meets all of these requirements while maintaining low power consumption (80mW with a single 5V supply) and small size (3mm x 3mm x 1mm 16-pin QFN package). In addition, the LT6411 has flexibility of selecting different gains for different applications with a minimal number of additional components.

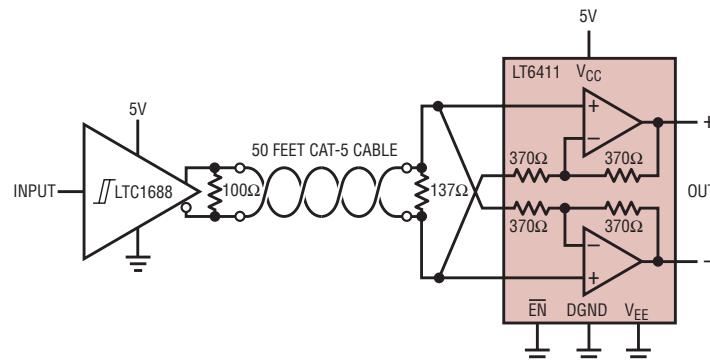
Figure 1 shows the internal block diagram of the LT6411. It is a high speed dual amplifier with built-in gain resistors are included internally, which means minimal external components are necessary for operation.



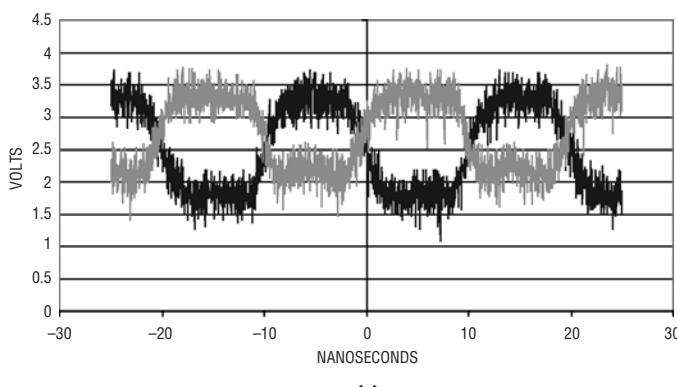
**Figure 1.** Block diagram of the LT6411. Gain resistors are included internally, which means minimal external components are necessary for operation.



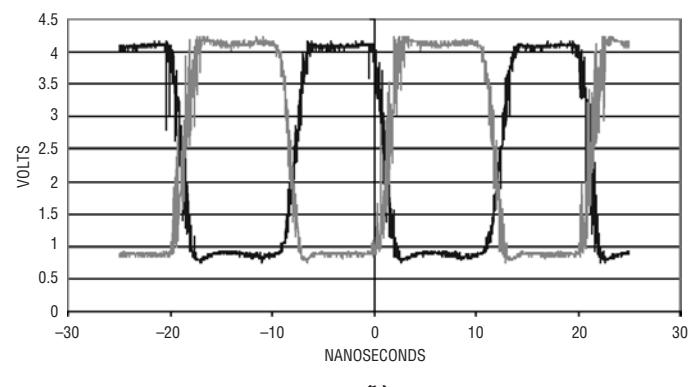
**Figure 2.** Large-signal transient response of the LT6411. Slew rate is shown to be approximately 3000V/μs, and overshoot/ringing is minimal. Settling time is only 4ns.



**Figure 3.** The LTC1688 100Mbps differential driver drives 50 feet of Category 5E (Enhanced) twisted pair cable, and the LT6411 receives and buffers the signal. The LT6411's gain of 3 configuration restores the signal amplitude after cable attenuation.



(a)



(b)

**Figure 4.** Figure 4a shows the attenuated 100Mbps input to the LT6411 (after 50 feet of cable), and figure 4b shows the LT6411 output. Input-to-output propagation delay is less than 4ns, which includes the LT6411's output overdrive recovery time.

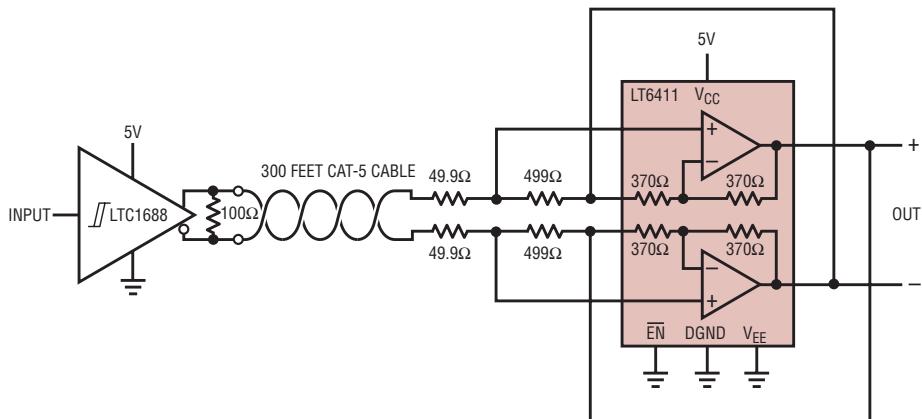


Figure 5. The LT6411's simple architecture allows higher gain settings when necessary. This circuit shows a gain of 10 configuration to recover the signal after the of 300 feet of Category 5 cable (non-Enhanced).

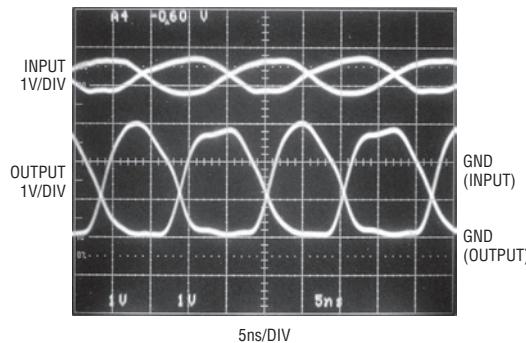


Figure 6. The top trace shows the LT6411's input, attenuated by the 300 feet of cable. The bottom trace shows the output of the LT6411. Propagation delay from input to output with a gain of 10 is approximately 4.5ns.

resistors and a power-saving enable feature. The high 600MHz bandwidth and  $>3000\text{V}/\mu\text{s}$  slew rate allows the part to track and buffer signals with high fidelity, and the built-in resistors reduce component count, simplifying high speed board layout. Figure 2 shows the transient step response of the LT6411 to a 2.5V, fast-rise-time pulse with a minimal amount of overshoot and ringing. In data receiver terms, that means minimal eye closure and inter-symbol interference at high data rates.

## Data Receiver

When receiving data from cables, gain is often useful to compensate for cable losses. The higher the data rate (i.e. transmission frequency), the more loss from the transmission medium. Figure 3 shows an LTC1688 100Mbps differential data driver followed by 50 feet of Category 5E (Enhanced) cable. The LT6411 is shown with a gain

of 3V/V. The shunt  $137\Omega$  resistor is selected to match the input impedance of the LT6411 stage to the  $100\Omega$  impedance of the twisted pair cable. Figure 4 (top) shows the differential signal at the input of the LT6411, after attenuation from the cable. The bottom trace in Figure 4 is the LT6411 output. The propagation delay of the LT6411 is under 4ns and the output eye diagram shows a well-behaved transient response with fast edges. The fast, clean output saturation recovery of the LT6411 enables high fidelity digital signal recovery, giving it a logic-level output without the minimum input signal level limitations of logic devices.

## Receiving Longer Cables

When the cable length gets longer, more gain may be necessary to recreate the original input data signal. Figure 5 shows the LT6411 with a gain of  $10\text{V/V}$ . Because the gain and

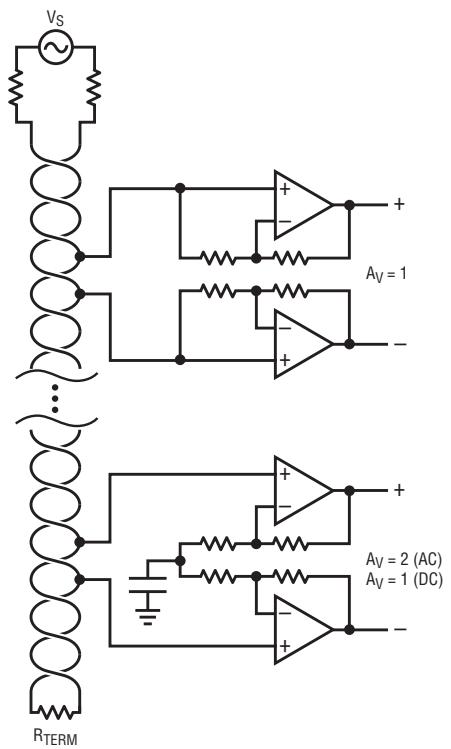


Figure 7. In lower-gain configurations ( $1\text{V/V}$ ), the LT6411 can be set up with a high impedance input, for multi-drop (multiple receivers along the line) applications. For a gain of 2, the gain-setting pins should be tied to an AC ground (as shown). If these pins are tied to DC ground, there will be a DC gain of 2, and the amplifier's output may saturate at the top rail.

feedback resistors of the LT6411 are internal, a cross-coupled configuration is used for higher gains. One benefit of this configuration is that the value of the gain resistors (in this case,  $49.9\Omega$ ) can be selected to match the impedance of the cable. Figure 6 shows the input and output of the LT6411 in this configuration.

## Multiple Receiver Applications

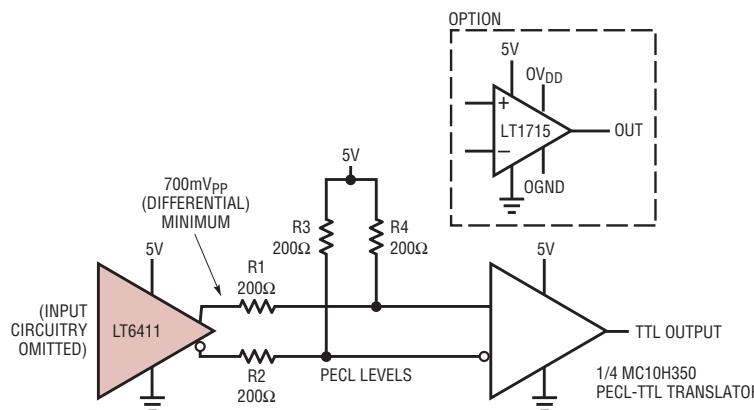
In cases where the transmission cable is short and high gain is unnecessary, the LT6411 can also be used as a high input impedance receiver. One such application is where multiple receivers and/or transmitters are spread along a transmission line and the line is terminated at each end. Figure 7 shows two methods of configuring the LT6411 in a high input impedance configuration, useful for monitoring data on the twisted-pair without improperly loading it.

## Single-Ended Output

The LT6411 produces a differential output, but if a single-ended logic output is needed, there are multiple

options for data conversion. One such way is shown in Figure 8, in which the MC10H350 PECL-TTL translator performs the conversion. To translate

the voltage levels from the LT6411 to PECL input voltage levels, two resistive dividers level-shift and attenuate the output signal of the LT6411. Alternatively, a high speed comparator such as Linear Technology's LT1715 can also perform this task without the level-shifting resistors.



**Figure 8.** If a single-ended output is needed, there are many options available for translators. One example is ON Semiconductor's MC10H350 PECL-TTL translator. The  $200\Omega$  resistors shift the output of the LT6411 up to PECL voltage levels. Alternatively, a level-translating comparator such as the LT1715 could be used to give a variety of logic output levels.

LT3740, continued from page 36

The LT3740 uses a valley mode current control system that boasts a fast response to load changes. As shown in Figure 3, this design responds to 0A-10A step load change in  $10\mu\text{s}$ , yielding a voltage transient of less than 50mV.

## Soft-Start

The LT3740 is also equipped with a flexible soft-start design that allows for either ramped current or tracking. If the XREF pin is held above 1V, and an RC timer is applied to the SHDN pin, the converter soft-starts by ramping the current available to the load. If the SHDN pin is high, enabling the chip, and a 0V to 0.8V tracking signal is applied to the XREF pin, the internal reference of the LT3740 follows the tracking signal.

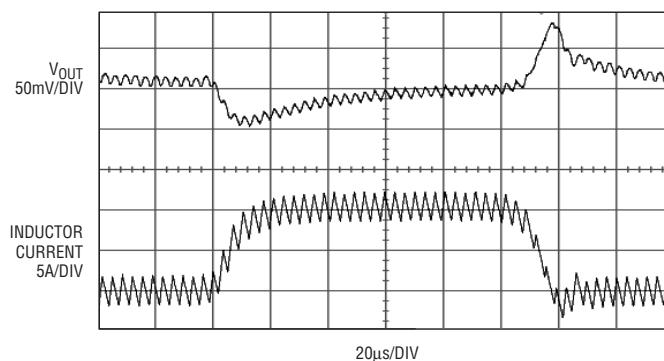
LTC3706/26, continued from page 13

used to provide a gradual increase in peak current during the soft-start interval. The circuit of Figure 7 also includes an optional falling-edge delay circuit on the gate of synchronous switch Q4. This delay has been used to optimize the dead time for this specific application, thereby improving

## Conclusion

The LT3740 is a synchronous buck controller that boasts a rich feature set which allows the designer to optimize power and volumetric efficiency by exploiting the advantages of a low input voltage. Through a combination of its

onboard boost regulator, user programmable current limit thresholds, fast transient response and flexible soft-start system, the designer can produce a small, efficient, full featured converter. □



**Figure 3.** Output voltage and inductor current response to a 0A-10A step load transient applied to the circuit in Figure 1

the efficiency by about 1%. Figure 8 shows the transient response that is achieved using the circuit of Figure 7, and Figure 9 shows the efficiency at  $V_{IN} = 12\text{V}$  and  $V_{IN} = 24\text{V}$ .

## Conclusion

The new LTC3706/26 controller and LTC3705/25 driver bring an un-

precedented level of simplicity and performance to the design of isolated power supplies. Each controller-driver pair works in concert to offer high efficiency, low cost solutions using off-the-shelf components. The devices are versatile and easy to use, covering a broad range of forward converter applications. □

# 1A Synchronous Boost Converters for Portable Applications up to 7.5V

by Eddy Wells

## Introduction

Today's battery powered devices require efficient and compact power conversion solutions with minimal design effort. The LTC3458 and LTC3458L are full-featured, step-up DC/DC converters intended for applications with load currents up to 1A. Their 1.5V–6V input voltage range is well suited for multi-cell alkaline, Li-Ion, or USB power. Despite their small size, both parts are extremely versatile, with programmable output voltage, current limit, switching frequency, burst threshold and soft-start period. Other features include short circuit protection, controlled inrush current and true output disconnect in shutdown.

Both regulators use current mode control, which provides fast transient response to both line and load steps. In fixed frequency operation, the oscillator can be synchronized to an external source or set between 400kHz and 1.5MHz, allowing the designer to optimize component size and efficiency. Burst Mode operation at light loads extends battery life, with typical quiescent currents of just 12µA. The threshold between fixed frequency and Burst Mode operation is adjustable with an external resistor. Both parts are offered in a thermally enhanced 12-pin DFN (4mm x 3mm) package.

The LTC3458 and LTC3458L have identical functions and pin-out, but differ in how they trade-off switch  $R_{DS(ON)}$  with maximum  $V_{OUT}$  rating. The LTC3458L has a 0.2Ω (typical) N-Channel MOSFET and a 0.3Ω P-Channel MOSFET with a maximum  $V_{OUT}$  rating of 6.0V. The LTC3458 has higher switch resistance (0.3Ω N-Channel, 0.4Ω P-Channel), but  $V_{OUT}$  can be programmed as high as 7.5V. An efficiency comparison of the two parts at 3.6V<sub>IN</sub>, 5.0V<sub>OUT</sub> at 1MHz is shown in Figure 1. As shown in the figure, the LTC3458L is more efficient (especially at load currents above 250mA) and

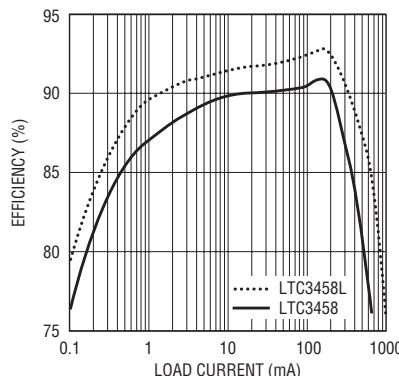


Figure 1. LTC3458 and LTC3458L 5V efficiency vs load current

able to deliver more current to the load. Between 0.1mA and 100mA (threshold programmable), both parts enter into Burst Mode operation, providing

high efficiency over many decades. The LTC3458 is optimized for higher voltage applications with a reduced maximum load current.

## 5V from a Li-Ion/USB Input

Devices requiring a regulated 5V output from a Li-Ion battery or powered USB port must contend with an input voltage range between 3.1V and 5.25V. Although the LTC3458 and LTC3458L are primarily step-up converters, their output-disconnect architecture provides regulation when the output is below the input voltage. Since  $V_{IN}$  is near the regulated 5V output when powered from the USB, converter efficiency is still acceptable even when stepping down.

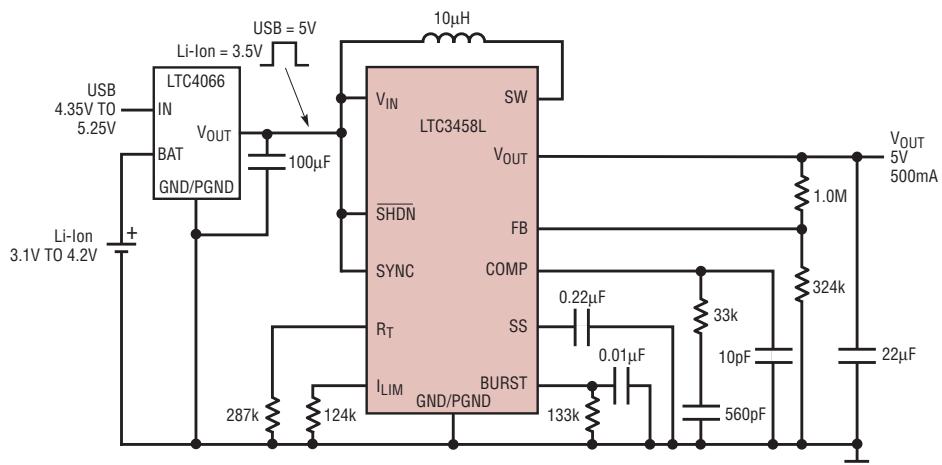


Figure 2. Regulated 5V supply from USB or Li-Ion input

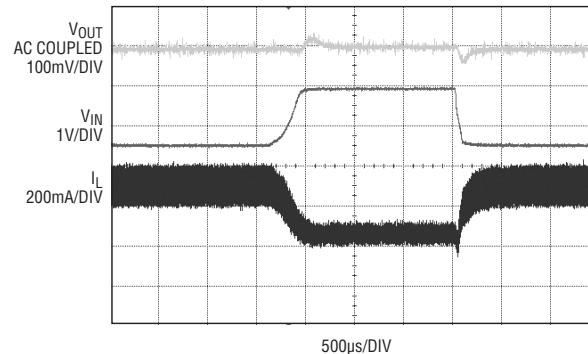
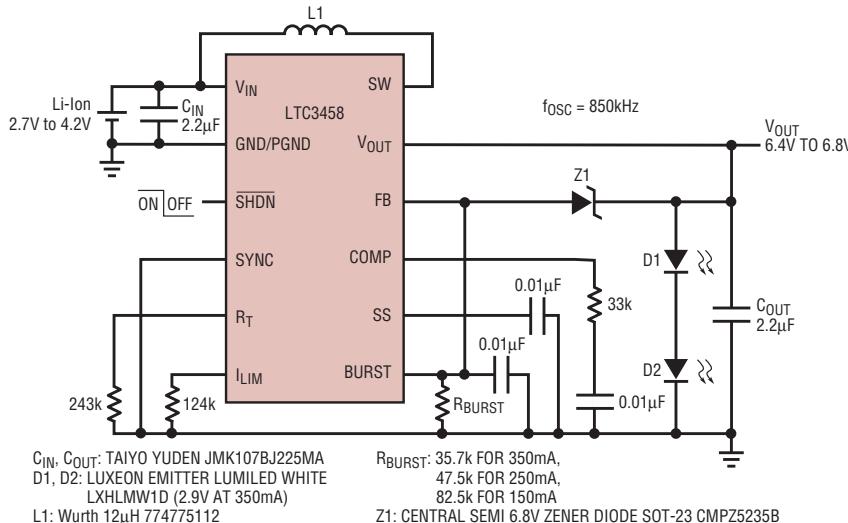


Figure 3. Transient response for USB cable insertion and 22µF Coup



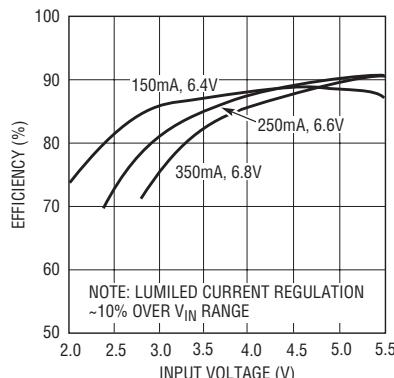
**Figure 4.** Dual Lumiled LED application using the BURST pin to regulate current

Another challenge in this application is responding to a step change on input voltage when the USB cable is inserted or removed. The LTC3458's current mode architecture and programmable compensation allow the designer to minimize the resulting transient on the output. Figure 3 shows the LTC3458's transient response with a 3.6V to 5V input step with the configuration of Figure 2. The resulting ripple on V<sub>OUT</sub> is less than 35mV with a 22μF output capacitor.

### LTC3458 Driving Two High Current White LEDs

The BURST pin is normally used to set the load current threshold where the part transitions between fixed frequency and Burst Mode operation. A fraction of the internal P-channel synchronous rectifier current (approx

1/10,000) is sourced from BURST and internally compared to a 1V threshold. When BURST is >1V the part operates in fixed frequency mode and when <1V in Burst Mode operation. To maximize efficiency through the fixed



**Figure 5.** Efficiency vs V<sub>IN</sub> for the circuit in Figure 4

LT3591, continued from page 31

The LT3591 is also applicable for buck and buck-boost circuits because of its high side sense. Figure 2 gives an example of a buck circuit using the LT3591. The LED current can go up to 350mA. As shown in Figure 3, its efficiency reaches 87%.

### Dimming Control

Three different dimming control methods are available for the LT3591: filtered PWM, DC voltage level and direct PWM

dimming control. The direct PWM dimming circuit has the highest dimming range and maintains a constant chromaticity for the LEDs. A typical dimming

frequency/Burst Mode transition, the threshold is typically set between 50mA to 100mA.

An application where the LTC3458 is used to regulate current (as opposed to output voltage) in a string of high current LEDs is shown in Figure 4. Current regulation in the LED string is achieved by connecting FB to BURST, which mirrors a portion of the output or LED current. Approximate output current is programmed by the value of R<sub>BURST</sub> using the following formula:

$$I_{LED}(\text{mA}) = \frac{10,000 \cdot V_{REF}}{R_{BURST}}$$

where V<sub>REF</sub> = V<sub>FB</sub> = 1.23V. Since FB regulates above the 1V Burst Mode threshold, the part operates in fixed frequency mode. A zener diode Z1 (V<sub>F</sub> = 6.8V) is added to limit the output voltage in case the LED string is opened. The resulting electrical efficiency with respect to input voltage and LED current is impressive and shown in Figure 5. LED current accuracy is near 10% over the entire Li-Ion operating range.

### Conclusion

The LTC3458 and LTC3458L provide compact solutions for battery powered devices requiring step-up conversion. Thermally enhanced packaging and low switch resistance at heavy loads along with Burst Mode operation at light loads result in excellent efficiency over many decades. The programmable function pins allow both parts to be customized for use in a wide variety of applications.

application is shown in Figure 4. The PWM signal controls the turn-on and turn-off of the chip and the LED string. With a 100Hz PWM signal, the dimming range can reach 80:1.

### Conclusion

LT3591 is a white LED driver designed to drive up to ten LEDs in series. It is ideal for portable applications because of its small solution size, high level of integration and high efficiency.

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# New Device Cameos

## DC/DC Converter with Selectable Frequency Modes in a 2mm × 3mm DFN

The LTC3543 is a high efficiency 600mA monolithic step-down switching regulator intended for low power applications such as Lithium-Ion battery powered devices. It operates within a 2.5V to 5.5V input voltage range and has three different frequency modes of operation.

Efficiency is extremely important in battery powered applications, and the LTC3543 keeps efficiency high with an automatic, power saving Burst Mode operation, which reduces gate charge losses at low load currents. With no load, the converter draws only 45µA, and in shutdown, the device draws less than 1µA, making it ideal for low current applications.

Burst Mode operation is an efficient solution for low current applications, but sometimes noise suppression is a higher priority. To reduce noise problems, a pulse-skipping mode is available, which decreases the ripple noise at low currents. Although not as efficient as Burst Mode operation at low currents, pulse-skipping mode still provides high efficiency for moderate loads. In dropout, the internal P-channel MOSFET switch is turned on continuously, thereby maximizing the usable battery life.

Three different frequency modes are possible on the LTC3543: Fixed Frequency, Spread Spectrum, or Synchronous. In Fixed Frequency mode, the regulator operates at a constant 2.25MHz making it possible to use capacitors and inductors that are less than 1.2mm in height. In Spread Spectrum mode, the switching frequency is randomly varied from 2MHz to 3MHz. By spreading the switcher's operating frequency, a significant reduction in peak radiated and conducting noise can be realized. In Synchronous mode, the LTC3543's switching frequency can be synchronized to a 1MHz to 3MHz external clock.

The small size, efficiency, low external component count, and design

flexibility of the LTC3543 make it an ideal DC/DC converter for portable devices using a Lithium-Ion battery.

## 25Msps 14-Bit ADC in 5mm × 5mm TQFP Package for Industrial and Automotive Applications

The LTC2246H is a 25Msps sampling 14-bit A/D converter designed for digitizing high frequency, wide dynamic range signals. The LTC2246H is offered in a leaded 5mm × 5mm TQFP package for use in industrial and automotive applications.

The TQFP leaded package makes the LTC 2246H ideal for applications in high temperature and high vibration environments. The leaded package provides superior strain relief compared to the QFN leadless package. The LTC2246H provides data sheet performance over a temperature range of -40°C to 125°C.

Like the original LTC2246, the LTC2246H provides a 73dB SNR and 80dBFS of spurious free dynamic range for input frequencies up to 140MHz. The DC specs include  $\pm 1\text{LSB}$  INL (typ),  $\pm 0.5\text{LSB}$  DNL (typ) and no missing codes over temperature. The transition noise is a low 1LSB<sub>RMS</sub>.

A single 3V supply allows low power operation, and a separate digital output supply allows the outputs to drive 0.5V to 3.6V logic. A single-ended clock input controls converter operation. An optional clock duty cycle stabilizer allows full performance for a wide range of clock duty cycles.

## Octal Supply Supervisor Allows Monitoring Positive and Negative Voltages

The LTC2910 is an octal voltage monitor intended for monitoring multiple voltages in a variety of applications. Each input has a low 0.5V threshold, featuring 1.5% tight threshold accuracy over the entire operating temperature range. When any input falls below the 0.5V threshold, common RST and  $\overline{\text{RST}}$  outputs assert. The low fixed threshold volt-

age allows monitoring any voltage level with the selection of just two resistances.

Each input also features glitch rejection. The LTC2910 integrates the output of the first stage comparator allowing each input to filter glitches without adding hysteresis, which would cause additional accuracy errors. With this type of glitch filtering, the glitch duration that triggers the output is dependent on the glitch magnitude.

A three-state polarity-select pin (SEL) selects one of three possible polarity combinations for the input thresholds. With this, up to two inputs will trigger when a voltage is above the 0.5V threshold. This allows overvoltage monitoring or negative supply monitoring when used with the available 1V reference (REF). The SEL pin is connected to GND, V<sub>CC</sub>, or left unconnected during normal operation. This allows the different polarities to be selected without the need for external components.

The RST and  $\overline{\text{RST}}$  outputs each have a weak internal pull-up to V<sub>CC</sub> and a strong pull-down to ground. This arrangement allows each pin to have open drain behavior while possessing other beneficial characteristics. The weak pull-up eliminates the need for an external pull-up resistor when the rise time on the pin is not critical. The open drain configuration allows for wired-OR connections when more than one signal needs to pull down on the pin. The output also has an externally adjustable timeout function that holds the pin asserted for a set period of time after all faults have cleared. This assures a minimum reset pulse width allowing a settling time delay for a monitored voltage after it has entered the valid region of operation. By connecting a capacitor between the TMR pin a ground, virtually any timeout value can be chosen.

The LTC2910 is available in space-saving 16-lead SSOP and 16-lead (5mm × 3mm) DFN packages. **D**

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