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 I2C 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

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**EDITOR’S PAGE**

**Linear Technology in the News…**

**EDN Innovation Award Finalists**

*EDN* magazine announced that Linear Technology’s LT6908 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 ±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, 1µA Precision Rail-to-Rail Input and Output Op Amps in Amplifier ICs
- LTM4600 10A High Efficiency DC/DC µModule™ 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 LT5557 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.
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-sigma ADC 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 errors result. If these resistors have a 1% tolerance, the maximum error in measured resistance is 1.6Ω 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 1.5µA supply current, offering maximum offset voltage of 150µV and an open loop gain of 100,000. However, its 2kHz bandwidth makes it unsuitable for driving conventional delta-sigma ADCs. Adding a 1kΩ, 0.1µF filter solves this problem by providing a charge reservoir that supplies the LTC2492 instantaneous current, while the 1kΩ resistor isolates the capacitive load from the LT1494. The input sampling current of conventional delta-sigma ADCs leads to DC errors as a result

Table 1. Complete Easy Drive delta-sigma family

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<th>Part Number</th>
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**DESIGN FEATURES**

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

**Figure 3.** SPI interface, configuration and data output timing

<table>
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<th>S</th>
<th>7-BIT ADDRESS</th>
<th>R/W</th>
<th>ACK</th>
<th>DATA</th>
<th>Sr</th>
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<td>DATA INPUT/OUTPUT</td>
<td>CONVERSION</td>
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**Figure 4.** I^2C conversion sequence

**Figure 5.** I^2C configuration and data output timing
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 1kΩ-0.1µF 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
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 cancellation 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 18μV/√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

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

//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.
*******************************************************************************/

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(config);
  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.
*******************************************************************************/

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
```
DESIGN FEATURES

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                         // 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
  // Start communication with LTC2491:
  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 acknowledge to keep the bus free.
When the LTC2499 acknowledges, read the data and return.
***************************************************************

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.

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.

Vcc Power and Start-Up
In this design, start-up Vcc 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 40µA, a simple trickle charger could be used to eliminate the NPN pre-regulator. The LTC3805 has a Vcc 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 Vcc is not connected to VIN 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.

Programming VOUT
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 118kΩ resistor on the FS pin. By changing this resistor, the operating frequency can be altered.
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\textsubscript{IN} Thresholds
The rising threshold on V\textsubscript{IN}, which is independent of the thresholds on V\textsubscript{CC}, is set by the 221\,k\Omega and 8.86\,k\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\textsubscript{IN}. Once started, the LTC3805 sources a 5\,\mu A current from the RUN pin. Multiplied by the 221\,k\Omega resistor, this current sets the hysteresis on V\textsubscript{IN} to 1.1V. A different hysteresis, with the same rising threshold, can be selected by changing the values of the 221\,k\Omega and 8.86\,k\Omega resistors while keeping their ratio constant.

Setting the Soft-Start
The rate of change of V\textsubscript{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\textsubscript{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\textsubscript{SENSE} and OC pins, respectively. The I\textsubscript{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\textsubscript{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

\[ I_{\text{OUT}} (A) \]

\[ V_{\text{IN}} \]

\[ \text{EFFICIENCY} (\%) \]

\[ \text{DESIGN FEATURES} \]
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 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.

Figure 2. Efficiency of the converter shown in Figure 1.
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 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...
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 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\textsuperscript{®} 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.

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

### Table 2. Single and dual switch forward converter relative merits
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
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 ±25kV 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 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).

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 perspective.
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 100Ω and the termination resistor of 120Ω, 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 100Ω 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 9pF measured to ground and 3.5pF differentially.

### Balanced Threshold Receiver with Full Failsafe

The LTC2854 and LTC2855 feature a low power receiver that draws only 450µA. The single-ended input resistance to ground on each of the

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**Table 1. Product selection**

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>DUPLEX</th>
<th>PACKAGE</th>
<th>ESD on Line I/O (HBM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTC2854</td>
<td>HALF</td>
<td>DFN-10</td>
<td>±25kV</td>
</tr>
<tr>
<td>LTC2855</td>
<td>FULL</td>
<td>SSOP-16, DFN-12</td>
<td>±15kV</td>
</tr>
</tbody>
</table>
receiver inputs is greater than 96kΩ 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 8x 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 +65mV. When approaching from the positive direction, the threshold is –65mV. Each of these thresholds has 20mV of hysteresis (not shown in the figure). This windowing around 0V preserves duty cycle for small inputs with heavily slewed edges. This performance is highlighted in Figure 6, where a 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 ±100mV 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., 0V 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 3µs, 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 54Ω 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 (VCC–15V).
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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 ±25kV HBM with respect to ground or Vcc. The full-duplex LTc2855 withstands ±15kV 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 Vcc is on, shorted to ground, or disconnected.

When a line I/O pin on the LTc2854/LTc2855 is hit with an 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

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.

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

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.

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

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

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 $V_{OUT}$ 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

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

* LT: SUMIDA CORT7043MN0P-100NC
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 30µA and 80µA 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 1µA) 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 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

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

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

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

**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.**
voltage ripple \( V_{pp} \) 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.
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 1. Dual 1.4A monolithic step-down converter with 3.3V and 5V outputs

Figure 2. Efficiency for circuit of Figure 1
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 \( V_{\text{IN}} \) 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 \( V_{\text{IN}} \) pins for each channel offer uncommon design flexibility. For instance, the converter can satisfy high \( V_{\text{IN}}/V_{\text{OUT}} \) 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,
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...
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 reference voltage. With 130ns minimum on-time, the maximum input voltage is calculated by:

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

\( V_F \) 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\textsubscript{IN} to 3.3V\textsubscript{OUT}, \( f_{OSC} \) must be below 790kHz. To achieve 36V\textsubscript{IN} to 1.8V\textsubscript{OUT}, \( f_{OSC} \) 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\textsubscript{IN} to 5V\textsubscript{OUT} and 3.3V\textsubscript{OUT} 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\textsubscript{IN} to 1.8V\textsubscript{IN} is possible if one output is set for 7.7V and tied to the V\textsubscript{IN} 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 10\textmu F and 22\textmu F 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\textsubscript{P-P} for both the 3.3V output and the 5V output. The response time is about 20\textmu s to 40\textmu s, 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\textsubscript{IN1} and V\textsubscript{IN2} are tied together, the undervoltage lockout is at 3.7V or below. If the two inputs are used separately, then V\textsubscript{IN1} has an undervoltage lockout of 3.7V or below and V\textsubscript{IN2} has an undervoltage lockout of 3V or below. Because the internal supply runs off V\textsubscript{IN1}, channel 2 will not operate unless V\textsubscript{IN1} is above its undervoltage lockout. The dropout of the 5V\textsubscript{OUT} 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 sufficient voltage on the boost capacitor. Eventually, the voltage on the boost capacitor falls and requires refreshing. A bigger boost capacitor allows for a 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:

\[
V_{\text{IN(MIN)}} = \left( V_{\text{OUT}} + V_f \right) \left( 1 + \frac{1}{\beta_{SW}} \right) - V_f + V_{\text{SW}}.
\]

\(\beta_{SW}\) 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 (<2\mu A), 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\textsubscript{IN}. 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\textdegree C/W junction-to-ambient thermal impedance and 10\textdegree 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\textsubscript{IN} pins for each channel provide the capability of cascading channels and achieving extreme V\textsubscript{IN} to V\textsubscript{OUT} 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 18µA 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 ±1% over temperature.

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

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.
DESIGN FEATURES

Figure 3. Ratiometric tracking in action. Channel 1’s reference does not exceed the lesser of \( V_{\text{fb1}} \) 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, \( V_{\text{fb}} \) and I\(_{\text{th}}\) 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 ages or hiccupping on channels 2 and 3. However, the 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 dividers between $V_{OUT1}$ and ground. Figure 4 shows the clean results. If sequencing is required, the LTC3773’s shut-off (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 1.5μA. 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 ±10% of the 0.600V internal reference for 100μs, the open drain power good output PG00D pulls low.

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.

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

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 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 VEE 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$^2$. 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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Shrink MP3 Players and Digital Cameras with Two New Dual-Input USB/Wall-Adapter Linear Li-Ion/Li-Polymer Battery Chargers

by Alfonso Centuori

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 48mm² 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 voltage accuracy of ±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 PW r 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:

$$I_{\text{CHG}} = \frac{1000V}{R_{\text{DC} \text{ or USB}}}$$

Both the LTC4096 and LTC4097 terminate the charge cycle based on the battery current. The current detection threshold, $$I_{\text{ITERM}}$$, is set by connecting a resistor, $$R_{\text{ITERM}}$$, 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.
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 (≤500mA) or low power (≤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 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), 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.
Four Rails from One Small Footprint Regulator

**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 number 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.

**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 LT3544B 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\(^2\).

**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

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**Figure 1.** The LT3544B is designed to facilitate simple and compact board layout

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

**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.
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 ultra flat profile 3mm x 3mm DFN package. A version without trickle charge is also available (the LTC4096X). The LTC4097 is available in a small 12-lead ultra low profile 3mm x 2mm DFN package.

**Conclusion**

The LTc3773 is the most versatile 3-phase DC/DC controller on the market.
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 RSENSETM synchronous buck controller that can accept input voltages as low 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 RSENSE 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 x 3mm DFN package.

1.8V Buck Converter in 1.5in²

Figure 1 shows an example of a LT3740 synchronous buck converter. The design produces 1.8V at 10A from a 3V–12V input. All of the capacitors are ceramic. 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 1.5in² 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.

Figure 2. Efficiency for the circuit in Figure 1
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 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.

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.
resistors and a power-saving enable feature. The high 600MHz bandwidth and >3000V/µs 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 137Ω resistor is selected to match the input impedance of the LT6411 stage to the 100Ω 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 10V/V. Because the gain and 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, 49.9Ω) 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.

**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.

**Conclusion**

The LT6411 is a dual high speed amplifier with flexible features and superb AC characteristics, making it suitable for use as a high data rate receiver. The ability to select different gain configurations with minimal external components makes the LT6411 easy to use. Its small footprint and low power consumption allow it to fit into almost any application without painful compromises, especially for portable or peripheral applications where space and power are at a premium.
**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 × 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$_{IN}$, 5.0V$_{OUT}$ at 1MHz is shown in Figure 1. As shown in the figure, the LTC3458L is more efficient (especially at load currents above 250mA) and 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.

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

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

**Figure 3. Transient response for USB cable insertion and 22µF $C_{OUT}$**
Another challenge in this application is responding to a step change on input voltage when the USB cable is inserted or removed. The LTC3458L’s current mode architecture and programmable compensation allow the designer to minimize the resulting transient on the output. Figure 3 shows the LTC3458L’s transient response with a 3.6V to 5V input step with the configuration of Figure 2. The resulting ripple on \( V_{OUT} \) is less than 35mV with a 22\( \mu \)F 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 \( \frac{1}{10,000} \)) 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 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 \( R_{BURST} \) using the following formula:

\[
I_{LED} = \frac{10,000 \cdot V_{REF}}{R_{BURST}}
\]

where \( V_{REF} = V_{FB} = 1.23V \). Since FB regulates above the 1V Burst Mode threshold, the part operates in fixed frequency mode. A zener diode \( Z1 (V_F = 6.8V) \) 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.
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 2MHz 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.

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

The LTC2246H is a 25Mmps 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 ±1LSB INL (typ), ±0.5LSB DNL (typ) and no missing codes over temperature. The transition noise is a low 1LSBRMS.

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 RST outputs assert. The low fixed threshold voltage 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, VCC, or left unconnected during normal operation. This allows the different polarities to be selected without the need for external components.

The RST and RST outputs each have a weak internal pull-up to VCC 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.
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