Isolated Forward Controllers Offer Buck Simplicity and Performance

by Charles Hawkes and Arthur Kelley

Introduction

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

The Benefits of Secondary-Side Control Made Accessible

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

With the apparent advantages of secondary-side control, why is it not used in more isolated applications? This is primarily because of the need for a separate bias supply to power up the controller on the secondary side, since there is initially no voltage present there. With the introduction of the LTC3706/26 and LTC3705/25, however, this barrier has now been completely eliminated. All of the complex issues associated with start-up and fault monitoring in a secondary-side control forward converter have

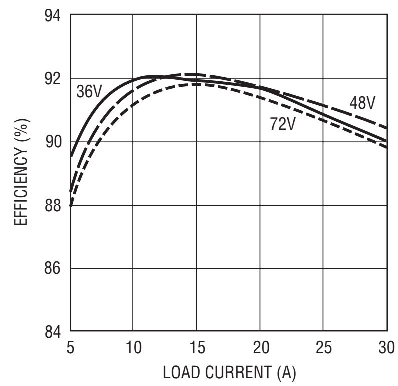


Figure 2. Efficiency of the converter shown in Figure 1

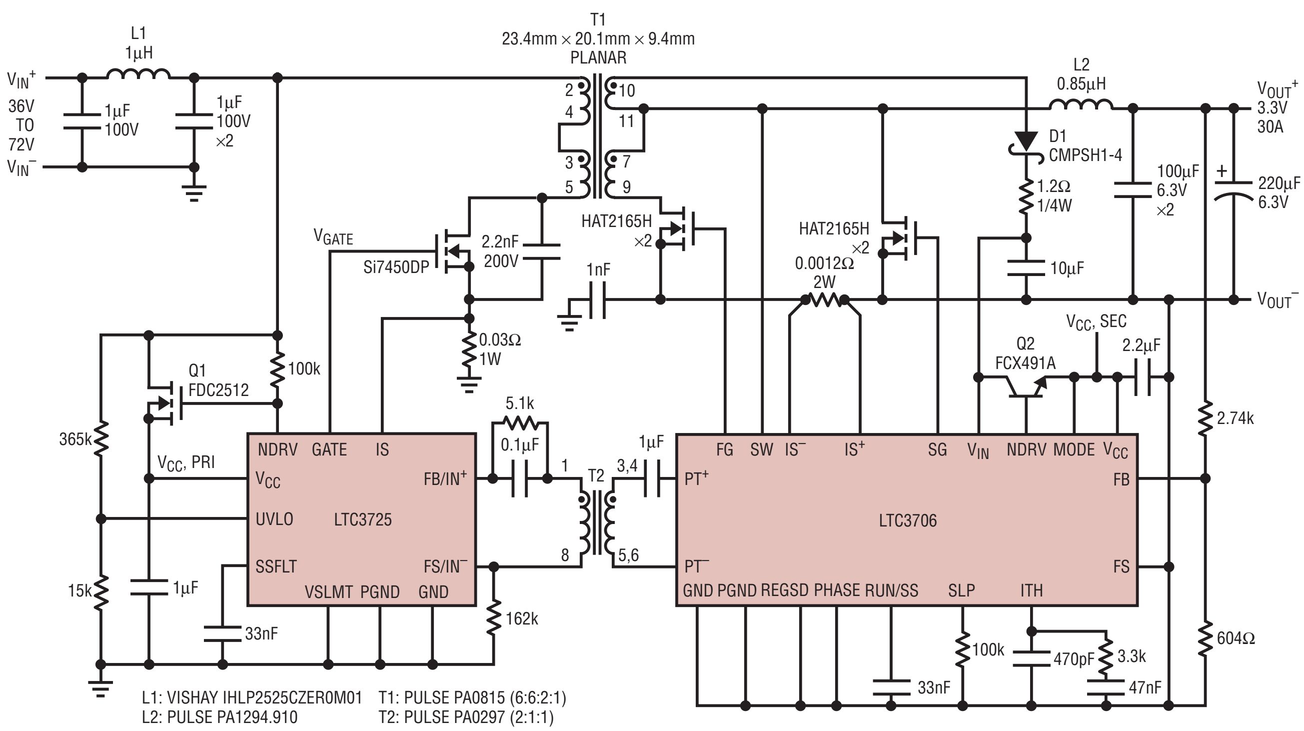


Figure 1. Complete 100W single-switch high efficiency, low cost, minimum part count, isolated telecom converter. Other output voltages and power levels require only simple component changes.

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

Family of Products Supports Single or Dual Switch Topologies

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

Table 1. LTC3705/06/25/26 combinations

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

The LTC3725 primary driver is intended for use in single-switch forward converter. The LTC3725 includes a start-up linear regulator and an integrated bridge rectifier for bias generation. Protection features include volt-second limit, over-current protection and a fault monitoring system that detects a loss of encoded gate-drive signal from the signal transformer. The LTC3705 is a dual-switch forward driver, and includes an 80V (100V transient) high side gate driver. The integration of this high side driver into the LTC3705 greatly facilitates the use of the simple and robust dual switch forward converter topology. Figure 3 shows a typical dual-switch converter application using the LTC3705 and the LTC3706.

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

Bringing the Power of PolyPhase to Isolated Supplies

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

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

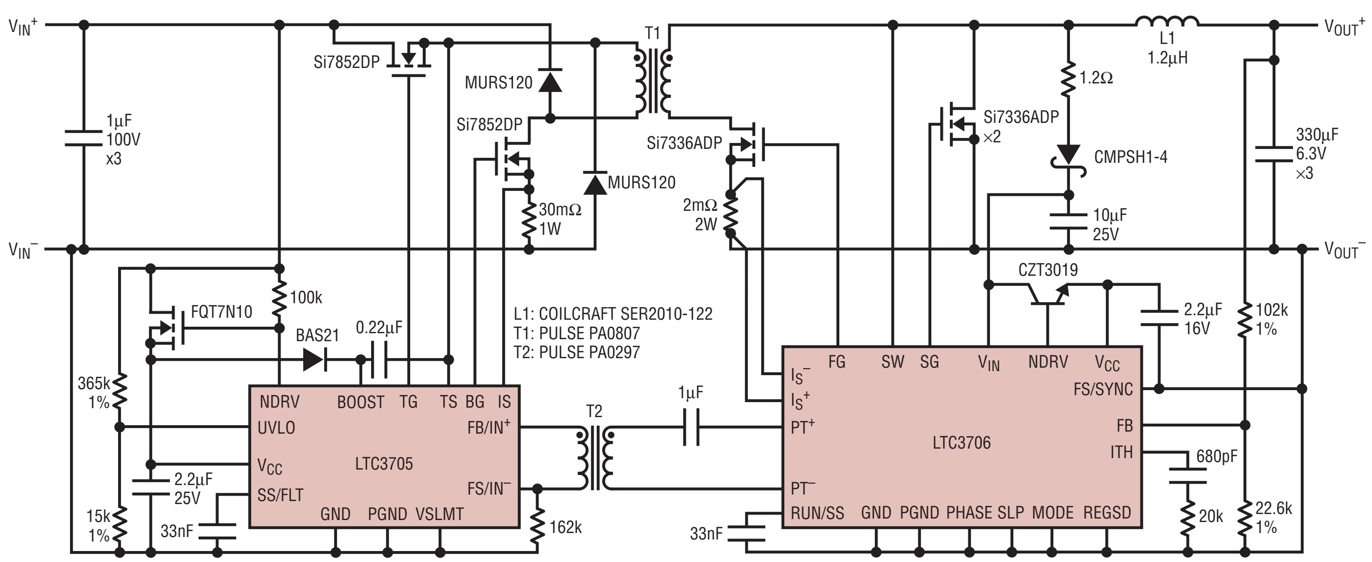


Figure 3. Isolated forward converter for 36V–72V input to 3.3V/20A out

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

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

The circuit of Figure 1 shows a complete 100W, one-switch forward converter. In this example, the LTC3706 controller is used on the secondary and the LTC3725 driver with self-starting capability is used on the primary. This design features off-the-shelf magnetics and high efficiency (see Figure 2). The start-up behavior of this supply is illustrated in Figure 6. When input voltage is first applied, the LTC3725 uses Q1 to generate a bias voltage $V_{CC,PRI}$, and begins a controlled soft-start of the output voltage. As the output voltage begins to rise, the LTC3706 secondary controller is quickly powered up by using T1, D1 and Q2 to generate $V_{CC,SEC}$. As shown in Figure 6, the $V_{CC,SEC}$ voltage rises very quickly as compared with the output voltage V_{OUT} of the converter. The LTC3706 then assumes control of the output voltage by sending encoded PWM gate pulses to the LTC3725 primary driver via signal transformer T2. As soon as the LTC3725 begins decoding these PWM gate pulses, it shuts down the linear regulator by tying NDRV to V_{CC} and begins extracting bias power for $V_{CC,PRI}$ from the signal transformer T2. This complete transition from primary to secondary control occurs seamlessly at a fraction of the output voltage. From that point on, operation and design simplifies to that of a simple buck converter. Even the design and optimization of the feedback loop makes use of the familiar and proven OPTI-LOOP® compensation techniques.

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

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

Table 2. Single and dual switch forward converter relative merits

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

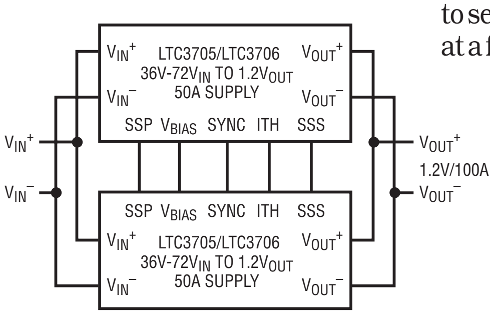


Figure 4. Paralleling supplies for higher power operation

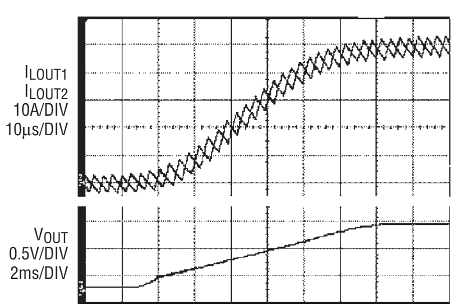


Figure 5. 1.2V, 100A load current step (top trace) and start-up (bottom trace)

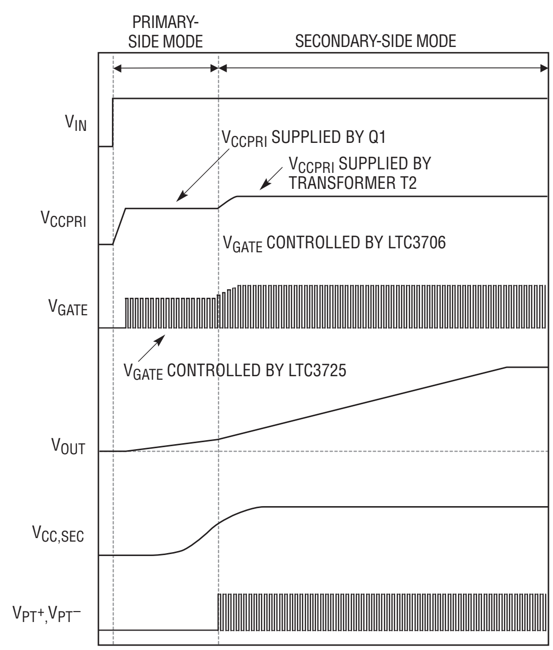
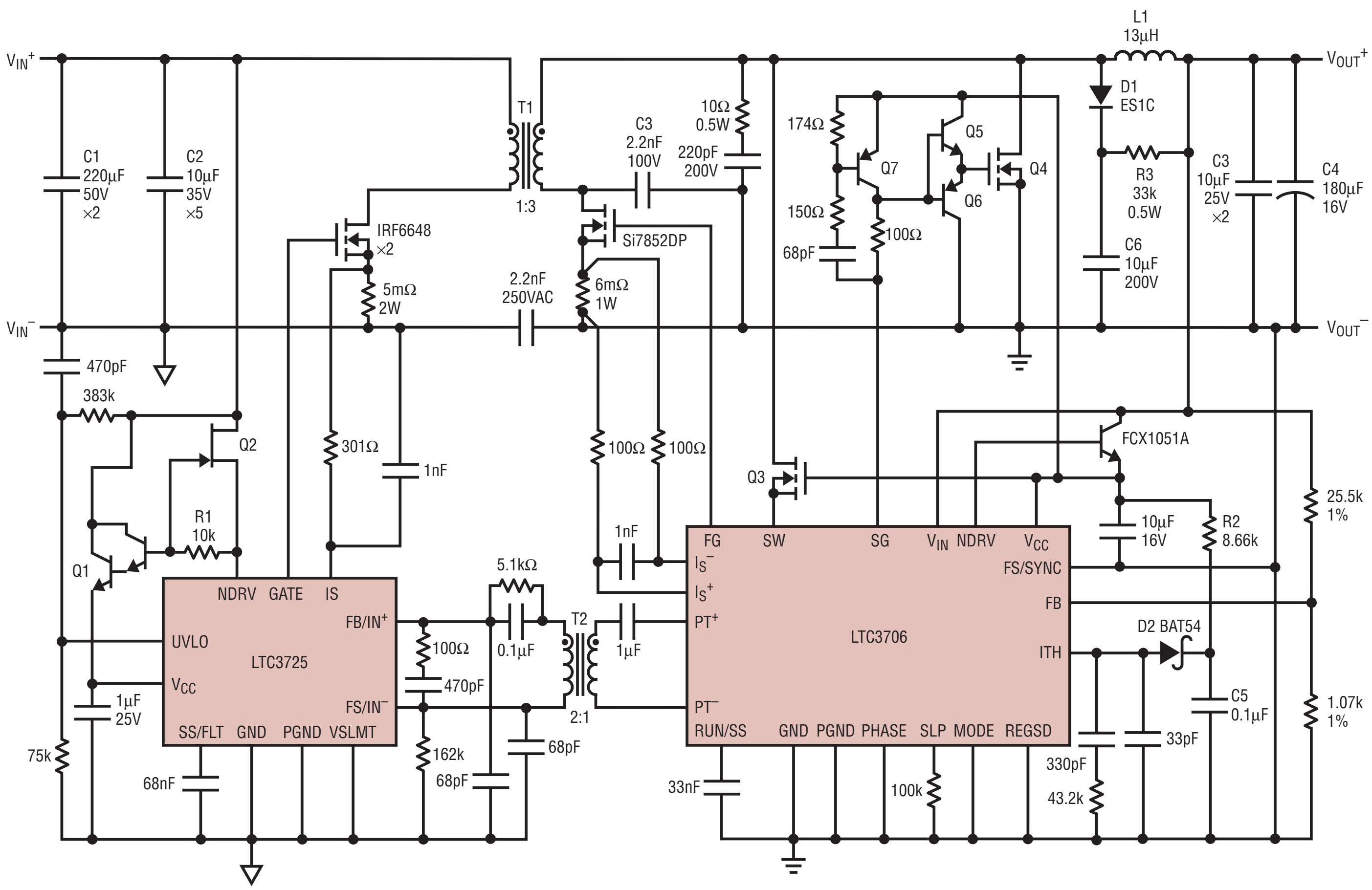


Figure 6. Anatomy of a start-up



L1: PULSE PA1961.133
T1: PULSE PA0810
T2: PULSE PA0297

C1: NIPPON CHIMICON EMZA500ADA221MUA0G
C2: TAIYO YUDEN GMK325BJ106MN
C3: TAIYO YUDEN TMK325BJ106MM
C4: SANYO OSCON 16SVP180MX

Q1: FMMT38C
Q2: MMBFJ201
Q3: ZVN3320F
Q4: FDMS2572 ×2

Q5: FMMT 618
Q6: FMMT 718
Q7: MMBT 2907A

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

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

The UVLO on the LTC3725 has been set to turn on at V_{IN} = 9.5V and off at V_{IN} = 7.5V, and a linear regulator (Q1) is used to establish bias for start-up. Note that the LTC3725 requires that the NDRV pin be at least 1V above the V_{CC} pin for proper linear regulator operation. To meet this requirement, while providing the lowest possibly dropout voltage, a darlington transistor is used (Q1). JFET Q2 is used to provide adequate bias current for the NDRV pin at low input voltage, while limiting the maximum current seen at high input voltage. R11 is needed to prevent back-feeding of current from the NDRV pin into base of Q1 (and gate of Q2) during normal operation when V_{CC} = V_{NDRV} = 12V and V_{IN} is less than 12V.

On the secondary side, the output voltage is used directly as a source of bias voltage for the LTC3706. This is possible for output voltages of 9V or greater. Q3 is used to limit the peak voltage seen by the SW pin on the LTC3706, while still allowing the detection circuits in the LTC3706 to function normally. Capacitor C3 is used to establish the resonant reset of the main transformer T1 during the off-time of the primary-side switches. In order to reduce the inrush current during start-up, D2, R2 and C5 are

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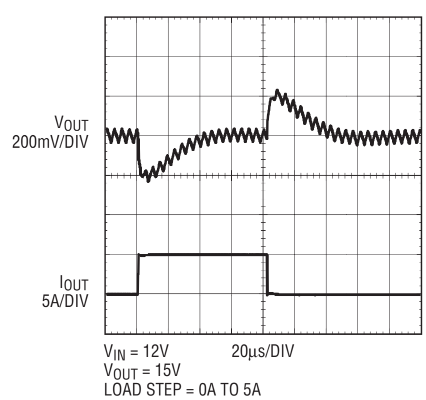

Figure 8. Transient response of the circuit in Figure 7

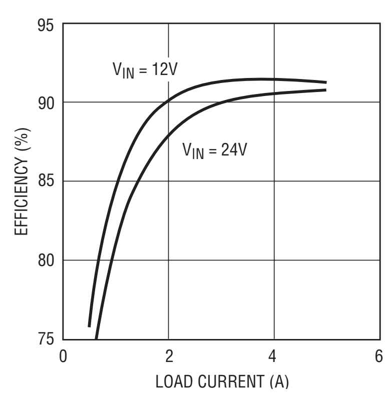

Figure 9. Efficiency of the circuit in Figure 7

Single-Ended Output

The LT6411 produces a differential output, but if a single-ended logic output is needed, there are multiple options for data conversion. One such way is shown in Figure 8, in which the MC10H350 PECL-TTL translator performs the conversion. To translate the voltage levels from the LT6411 to PECL input voltage levels, two resistive dividers level-shift and attenuate the output signal of the LT6411. Alternatively, a high speed comparator such as Linear Technology's LT1715 can also perform this task without the level-shifting resistors.

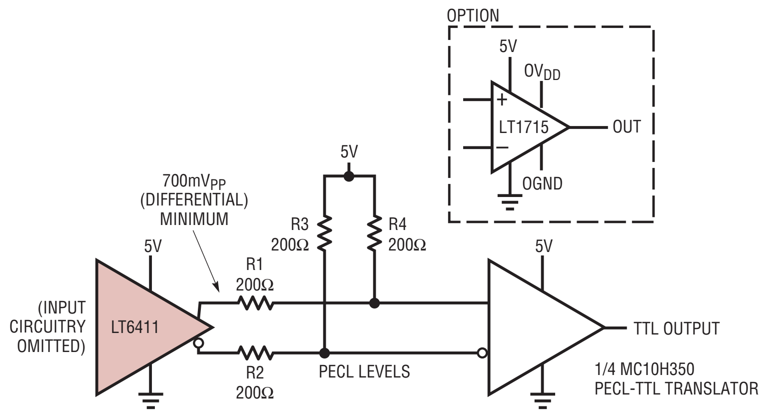

Figure 8. If a single-ended output is needed, there are many options available for translators. One example is ON Semiconductor's MC10H350 PECL-TTL translator. The 200Ω resistors shift the output of the LT6411 up to PECL voltage levels. Alternatively, a level-translating comparator such as the LT1715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

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.

LT3740, continued from page 36

The LT3740 uses a valley mode current control system that boasts a fast response to load changes. As shown in Figure 3, this design responds to 0A–10A step load change in 10µs, yielding a voltage transient of less than 50mV.

Soft-Start

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

Conclusion

The LT3740 is a synchronous buck controller that boasts a rich feature set which allows the designer to optimize power and volumetric efficiency by exploiting the advantages of a low input voltage. Through a combination of its onboard boost regulator, user programmable current limit thresholds, fast transient response and flexible soft-start system, the designer can produce a small, efficient, full featured converter.

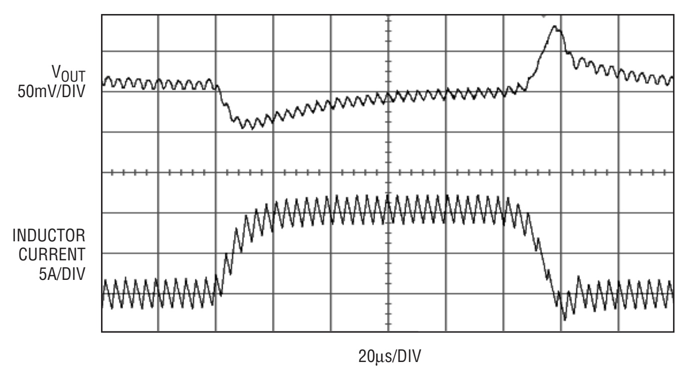

Figure 3. Output voltage and inductor current response to a 0A–10A step load transient applied to the circuit in Figure 1

LTC3706/26, continued from page 13

used to provide a gradual increase in peak current during the soft-start interval. The circuit of Figure 7 also includes an optional falling-edge delay circuit on the gate of synchronous switch Q4. This delay has been used to optimize the dead time for this specific application, thereby improving the efficiency by about 1%. Figure 8 shows the transient response that is achieved using the circuit of Figure 7, and Figure 9 shows the efficiency at V_{IN} = 12V and V_{IN} = 24V.

Conclusion

The new LTC3706/26 controller and LTC3705/25 driver bring an unprecedented level of simplicity and performance to the design of isolated power supplies. Each controller-driver pair works in concert to offer high efficiency, low cost solutions using off-the-shelf components. The devices are versatile and easy to use, covering a broad range of forward converter applications.