An Easy to Build High-Performance, High Reliability Isolated Power Supply

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Background

Prefabricated isolated DC/DC converters and modules offer a simple but relatively expensive solution to efficiently convert distribution bus voltages to isolated low voltages. However, off-the-shelf designs may not have all the required features, so a custom design is needed in many applications. Build-your-own solutions using discrete PWM controllers are much less expensive and provide the flexibility to meet demanding requirements such as special form factors or non-standard input and output voltages.

Recent advancements in controller technology provide for additional features and functionality, which are also simplifying the task of designing an isolated power supply. As a result, designers are now taking another look at whether a discrete design makes sense in their end application. In particular, the forward converter with active clamp reset has been widely used in custom supplies because of its excellent efficiency and reduced component stress. While forward converters are among the simplest of the isolated buck topologies, the active clamp reset technique introduces performance limitations and potential reliability concerns that have limited the scope of their use.

Using a patent-pending technique, Linear Technology’s second generation LTC3765/LTC3766 chip-set eliminates both the reliability concerns and performance limitations of the forward converter with active clamp reset. Moreover, this remarkable chipset dramatically simplifies the design of high-performance forward converters, making them an easy to build and compelling alternative to prefabricated alternatives.

The Chipset

The LTC3765 and the LTC3766 combine to form an isolated synchronous forward converter chipset that includes active clamp transformer reset and Direct Flux Limit, which prevents power transformers from saturating under all conditions. The LTC3765 is a primary-side intelligent controller that works in concert with the LTC3766 to implement a robust and simple self-starting isolated power supply. After start-up, the LTC3765 receives timing signals and bias power from the secondary-side LTC3766 controller through a tiny pulse transformer. This secondary-side control scheme puts the brains near the load, ensuring reliable monitoring and control of the output voltage and current while providing the fastest transient response. In addition, this architecture simplifies the design and reduces component count by eliminating the need for an opto-isolator or bias supplies. Figure 1 shows a typical application schematic and Figure 2 shows the associated transient response and efficiency/power loss curves.
Figure 1. LTC3765/66 Applications Circuit, \( V_{IN} \) Range: 18V to 72V, \( V_{OUT} \): 12V @ 11A, 12.5A Peak

Conditions: 48V\(_{IN}\), 6A to 12A Step Load

\( V_{OUT} \): 500mV/Div

Time - 100\( \mu \)s/Div
The LTC3765/66 contains all the necessary control circuitry to implement an active clamp transformer reset technique enabling higher efficiencies (up to 95%) and greater power densities when compared to conventional catch winding or resonant reset techniques. High current gate drivers for the main switch, the active clamp switch and the synchronous switches include adjustable delays to achieve maximum efficiency. However, in traditional active clamp forward converters any sudden change in switching duty cycle can cause the power transformer to saturate, potentially resulting in converter failure. Direct Flux Limit prevents transformer saturation under all conditions, thereby increasing overall converter reliability while maintaining an excellent transient response when compared to alternative solutions.

Additional features include a fast and accurate average current limit, fixed-frequency adjustable operation from 75kHz to 500kHz, clean start-up into pre-biased loads, multiphase operation for high power designs, overtemperature protection and true remote output voltage sense. The LTC3765 is available in a thermally enhanced MSOP-16 package. The LTC3766 is available in a 4mm x 5mm QFN-28 and SSOP-28 packages and both devices are available in extended, industrial, high temperature and military grades.

**Direct Flux Limit**

Maintaining a volt-second balance in any transformer is necessary for proper operation. Equal positive the negative volt-seconds must be applied during the converter's on and off times. Any imbalance will result in the core's normally symmetric magnetizing current and flux density “walking” towards saturation. The active clamp converter uses an additional switch and capacitor to apply a reset voltage during the converter's off-time. This technique results in the lowest possible switch voltages and highest efficiency. The transformer's own magnetizing current acts to charge or discharge the reset capacitor to the correct voltage which varies with duty cycle. This works well under steady state conditions but, if the duty cycle changes too quickly, the capacitor's voltage can't keep up, resulting in core saturation. When a transformer is saturated, it appears as a short-circuit, which can damage other power supply components.

Until now, this fundamental issue has been indirectly addressed with slow feedback loops, duty cycle limits, soft-stops and other “band-aids,” none of which guarantee that the core will not saturate. Using this approach, it is always a possibility that transformer saturation may occur at some “corner” of operation that were overlooked in the design and testing.

The LTC3765 and LTC3766 implement a new unique system limiting the flux accumulation in the transformer core by directly monitoring the transformer magnetizing current. During a reset cycle, when the active clamp PMOS is on, the magnetizing current is directly measured and limited through a sense resistor in series with the PMOS source as shown in Figure 3.
When the PMOS turns off and the main NMOS switch turns on, the LTC3765 generates an accurate internal replica of the magnetizing current based on the sensed input voltage on the RUN pin and transformer core parameters customized by a resistor from the RCORE pin to ground. The magnetizing current is then limited during the on-time by this accurate internal replica. Unlike previous methods, Direct Flux Limit directly monitors flux accumulation and guarantees that the transformer will not saturate while providing the fastest possible transient response. This feature also allows the converter to cleanly start up into a pre-biased output (such as battery charger) and restart following momentary line dropouts (no blind soft-stop).

Self-Starting

The LTC3766 is used with the LTC3765 to create a self-starting forward converter with secondary-side control. Since there is initially no bias voltage available on the secondary side, the LTC3765 must manage the start-up in an open-loop fashion on the primary side. When power is first applied on the primary side, the LTC3765 begins an open-loop soft-start using its own internal oscillator. Power is supplied to the secondary by switching the main primary-side MOSFET with a gradually increasing duty cycle from 0% to 70%, as controlled by the rate of rise of the voltage on the SSFLT pin. On the secondary side, the bias voltage can be directly derived from the main output or from the transformer secondary through peak charge or other simple circuit. When the LTC3766 has adequate voltage to satisfy its start-up requirements, it provides duty cycle information to the LTC3765 through a tiny pulse transformer.

The LTC3765 detects this signal and transfers control of the gate drivers to the LTC3766, which continues the soft-start of the output voltage. Typically, this hand-off from primary to secondary side occurs when the output voltage is less than one half of its final level. The LTC3765 then turns off the linear regulator and through an on-chip rectifier, extracts bias power for the primary side MOSFETs from the pulse transformer.

Run Control & Soft-Start

The main on/off control for the LTC3766 is the RUN pin. This pin features precision thresholds with both internal and externally adjustable hysteresis. This pin can be used to monitor the secondary-
side bias voltage or main output voltage, thereby controlling the point at which hand-off from primary to secondary side occurs. Alternatively, it can be driven directly with a control signal.

The LTC3766 will begin a soft-start sequence when the RUN pin is high, adequate voltage is present on both the $V_{IN}$ and $V_{CC}$ pins and switching is detected on the SW pin. Note that the LTC3766 must see switching on the SW pin prior to initiating a soft-start sequence to ensure that the LTC3765 is ready for control hand-off. The soft-start sequence begins by first measuring the voltage on the FB pin and then rapidly pre-setting the soft-start capacitor voltage to a level that corresponds to the output voltage. This is done to provide a smooth ramp on the output voltage as control is transferred from primary to secondary, as well as to avoid any unnecessary start-up delay. Once the voltage on the soft-start capacitor reaches the appropriate level, the LTC3766 sends a brief sequence of pulses through the pulse transformer to establish a communication lock with the LTC3765. At this point, the LTC3766 assumes control of the primary-side MOSFETs and the soft-start capacitor continues to charge to its full voltage. Note that the soft-start voltage is used to limit the effective level of the reference into the error amplifier. This technique maintains closed-loop control of the output voltage during the secondary-side soft-start interval.

**Current Limit & Other Protection Features**

In most DC/DC converters, a current limit is provided to protect the power supply components during an output overload condition. Normally, this current limit is not very accurate and the maximum output current can vary by as much as 50% over changes in input and output voltage. When an accurate current limit is required, such as in battery charging applications, a separate amplifier is often used to create a slow feedback loop to regulate the current at a pre-determined maximum level. Since this loop is slow to ensure stability, it can also allow very high output currents to flow momentarily, which may not be acceptable in some systems.

The LTC3766 implements a unique average current limit scheme that is fast, accurate and easy to use. Instead of using a slow current limit amplifier, it monitors the input and output current, and output voltages or the supply voltage and makes rapid, cycle-by-cycle corrections to keep the average output current essentially constant. Figure 4 illustrates the typical performance of an LTC3765/LTC3766 application circuit that is in current limit. Note that this capability is very well-suited to battery charging applications.

![Figure 4. Typical Current Limit Performance](image-url)
In addition to Direct Flux Limit and average current limit, the LTC3765/LTC3766 chipset includes a wide array of additional protection features. These features include adjustable reverse current protection for the synchronous switch, output over-voltage protection and over-temperature protection, which combine to ensure a reliable and robust power supply even in the harshest of application environments.

**Conclusion**

Isolated DC/DC converter users are moving away from off-the-shelf brick designs due to recent advances in technology, design simplification, simulation, cost savings and complete control over component sourcing. The LTC3765 and LTC3766 combine to form a relatively simple active clamp isolated forward converter with direct flux transformer limiting that reliably protects the converter and allows for a fast transient response, all while reducing the component count when compared to alternative solutions. Whether designing a custom supply intended to meet a certain size, input, and output or cost goal, this remarkable chipset brings a new level of simplicity, low part count and flexibility to high reliability applications. And finally, they are also easy to build.