LINEAR TECHNOLOGY

Journal of Analog Innovation

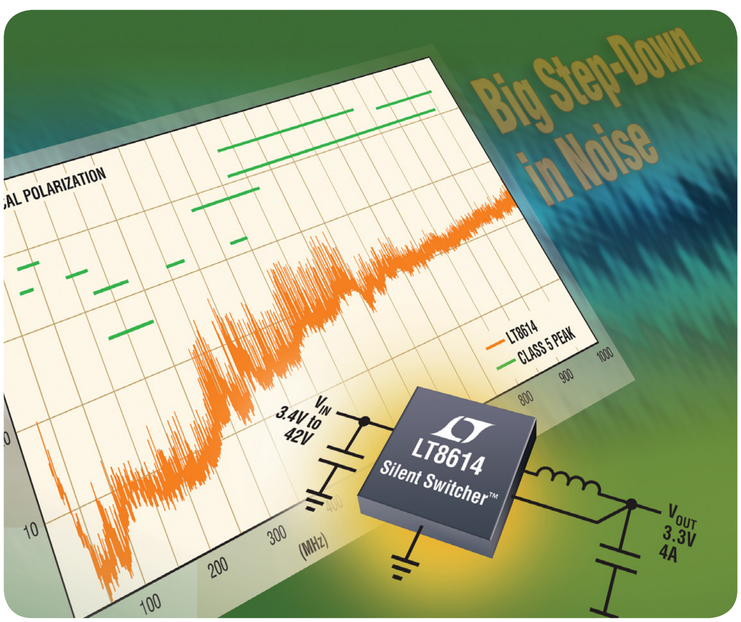
April 2014 Volume 24 Number 1

IN THIS ISSUE

Active Clamp Synchronous Controllers for Forward Converters with 6.5V to 100V+ Inputs

Wei Gu, Randyco Prasetyo and Fei Guo

The LT3752, LT3752-1 and LT3753 are highly integrated, high performance active clamp forward controllers that minimize external component count, solution size and cost. Two of these controllers, the LT3752 and LT3753, are designed for inputs up to 100V, while the LT3752-1 is designed for applications with input voltages greater than 100V—suitable for HV car battery and offline isolated power supplies, industrial, automotive and military systems. All produce compact, versatile and efficient solutions for single-IC output power levels up to 400W. Higher power levels are supported by stacking converter outputs in series. See Table 1 (on page 4) for a feature comparison of these devices.



The LT8614 Silent Switcher™ selected for *EDN* & *EE Times* ACE Award (page 3)

NO-OPTO MODE OPERATION REGULATES WITH ACCURATE PROGRAMMABLE VOLT-SECOND CLAMP

Figure 1 shows a complete 150W forward converter that requires no opto-couplers thanks to the LT®3752's accurate, programmable volt-second clamp. For a forward converter operating in continuous conduction mode, the output voltage is $V_{OUT} = V_{IN} \bullet N \bullet D$, where V_{IN} is the input voltage, N is the secondary to primary turns ratio and D is the duty cycle. The duty cycle clamp on the OUT pin of the LT3752, LT3752-1 and LT3753 inversely tracks V_{IN} to maintain constant V_{OUT} over the input voltage range.

(continued on page 4)

LINEAR TECHNOLOGY

Table 1. Feature comparison of LT3752, LT3752-1 and LT3753

PART	INPUT RANGE	ACTIVE CLAMP DRIVER	HOUSEKEEPING FLYBACK CONTROLLER
LT3753	8.5V–100V	Lo-Side	No
LT3752	6.5V–100V	Lo-Side	Yes
LT3752-1	100V–400V+	Hi-Side	Yes

(LT375x) continued from page 1)

In an active volt-second clamp scheme, the accuracy of V_{OUT} depends heavily on the accuracy of the volt-second clamp. Competing volt-clamp solutions use an external RC network connected from the system input to trip an internal comparator threshold. Accuracy of the RC method suffers from external capacitor error, part-to-part mismatch between the RC time constant and the IC's switching period, the error of the internal comparator threshold and the nonlinearity of charging at low input voltages.

To ensure accurate regulation part to part, the LT3752, LT3752-1 and LT3753 feature trimmed timing capacitor and comparator thresholds. Figure 2 shows V_{OUT} versus load current for various input voltages.

If the resistor that programs the duty cycle clamp goes open circuit, the part immediately stops switching, preventing the device from running without the volt-second clamp in place.

INTEGRATED HOUSEKEEPING FLYBACK CONTROLLER

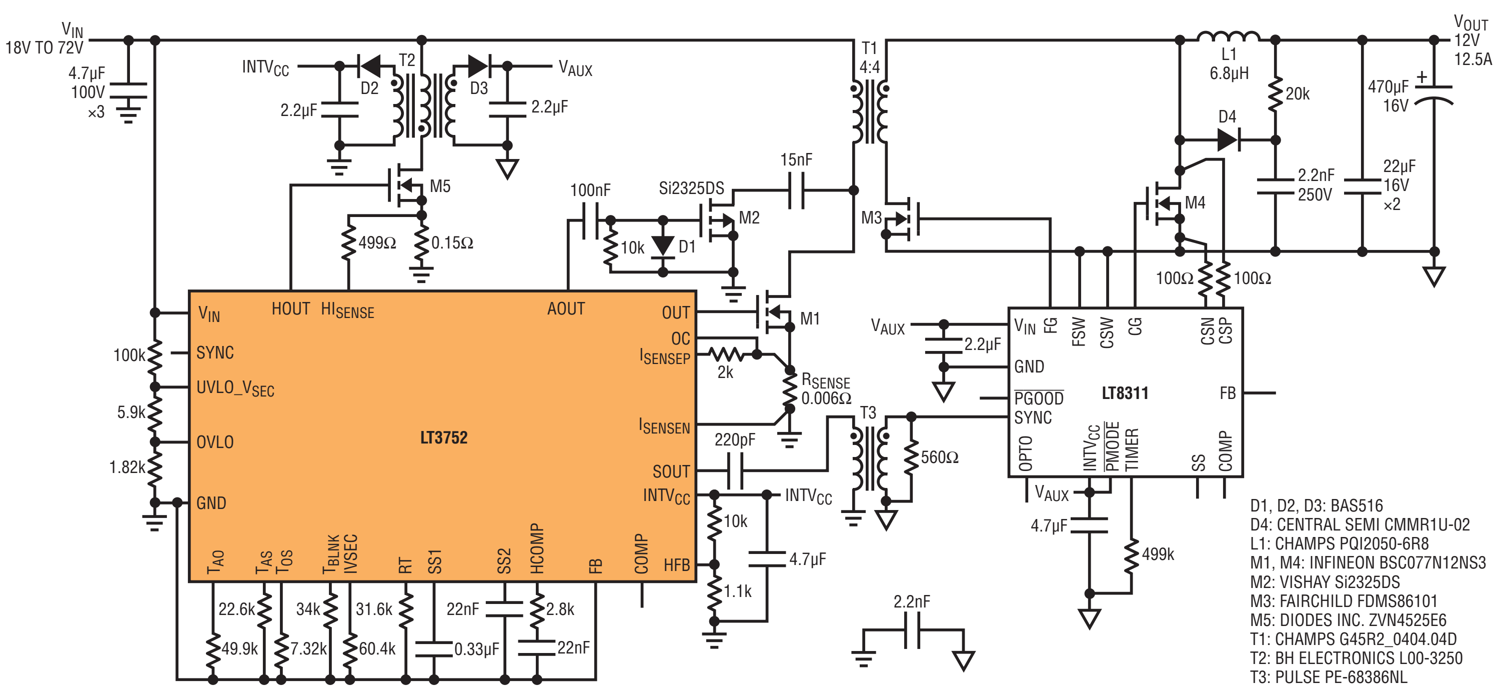
The LT3752/LT3752-1 includes an internal constant frequency flyback controller for generating a housekeeping supply. The housekeeping supply can efficiently provide bias for both primary and secondary ICs, eliminating the need to generate bias supplies from auxiliary windings in the main forward transformer, significantly reducing transformer complexity, size and cost.

The housekeeping supply can be used to overdrive the $INTV_{CC}$ pin to take power outside of the part, improve efficiency, provide additional drive current and optimize the $INTV_{CC}$ level. The housekeeping supply also allows bias to any secondary side IC before the main forward converter starts switching. This removes the need for external start-up circuitry on the secondary side.

PRECISION UNDERVOLTAGE LOCKOUT AND SOFT-START

The precision LT3752/LT3752-1 undervoltage lockout (UVLO) feature can be used for supply sequencing or start-up overcurrent protection—simply apply a resistor divider to the UVLO pin from the V_{IN} supply.

Figure 1. 150W forward converter in No-Opto mode



In an active volt-second clamp scheme, the accuracy of V_{OUT} depends heavily on the accuracy of the volt-second clamp. Competing volt-clamp solutions use an external RC network which suffers from a number of error sources. To ensure accurate regulation part to part, the LT3752, LT3752-1 and LT3753 feature trimmed timing capacitor and comparator thresholds.

The UVLO pin features adjustable input hysteresis, allowing the IC to resist input supply droop before engaging soft-stop. During soft-stop the converter continues to switch as it folds back the switching frequency, volt-second clamp and COMP pin voltage. The LT3752, LT3752-1 and LT3753 have a micropower shutdown threshold of approximately 400mV at the UVLO pin—V_{IN} quiescent current drops to 40µA, or lower.

Adding capacitors to the soft-start pins, (SS1 and SS2) implements the soft-start feature, which reduces the peak input current and prevents output voltage overshoot during start-up or recovery from a fault condition. The SS1/2 pins reduce the inrush current by lowering the current limit and reducing the switching frequency, allowing the output capacitor to gradually charge toward its final value.

SHUTDOWN WITH SOFT-STOP

In a reversal of soft-start start-up, the LT3752/LT3752-1 and LT3753 can gradually discharge the SS1 pin (soft-stop) during shutdown. Figure 3 shows shutdown waveforms of the converter shown in Figure 5. Without soft-stop, the self-driven synchronous rectifier feedback transfers capacitor energy to the primary, potentially causing shutdown oscillation and damaging components on the primary side.

Figure 4 shows shutdown waveforms with soft-stop. The converter continues to switch as it folds back switching frequency, volt-second clamp and COMP pin voltage, resulting in clean shutdown.

CURRENT MODE CONTROL

The LT3752/LT3752-1 and LT3753 use a current mode control architecture to increase supply bandwidth and response to line and load transients over voltage mode controllers. Current mode control requires fewer compensation components than voltage mode control architectures, making it much easier to compensate a broad range of operating conditions. For operation in continuous mode and above 50% duty cycle, required slope compensation can be programmed by a single resistor.

PROGRAMMABLE FEATURES SIMPLIFY OPTIMIZATION

The LT3752/LT3752-1 and LT3753 include a number of programmable features that allow the designer to optimize them for a particular application. For instance, programmable delays between various gate signals can be used to prevent cross-conduction and to optimize efficiency. Each delay can be set with a single resistor.

Programmable turn-on current spike blanking (adaptive leading edge blanking plus programmable extended blanking) of the main MOSFET greatly improves the converter's noise immunity. During gate rise time, and sometime thereafter,

Figure 2. Output voltage vs load current at various input voltages

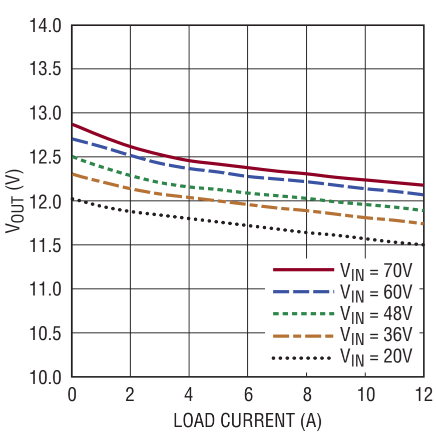


Figure 3. Shutdown waveforms of circuit in Figure 5 without soft-stop show oscillations.

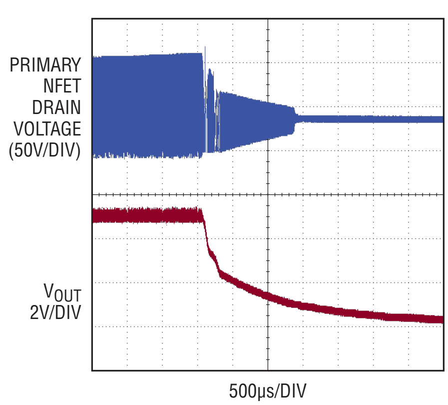
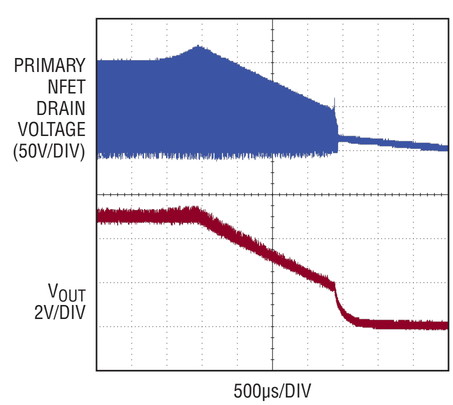


Figure 4. Shutdown waveforms of circuit in Figure 5 showing soft-stop in action



The LT3752/LT3752-1 and LT3753 include a number of programmable features that enable optimization for particular applications. For instance, programmable delays between various gate signals can be used to prevent cross-conduction and to optimize efficiency.

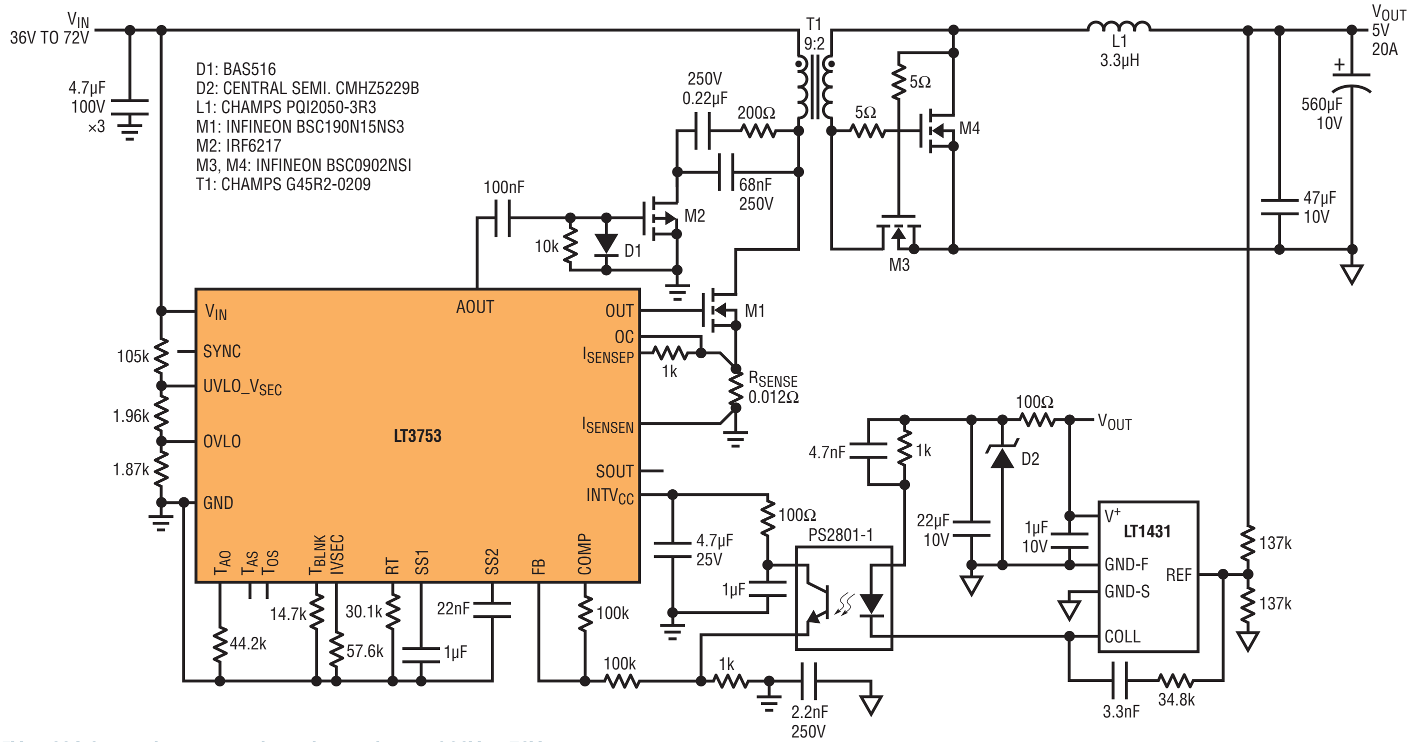


Figure 5. 5V at 20A forward converter that takes an input of 36V to 72V

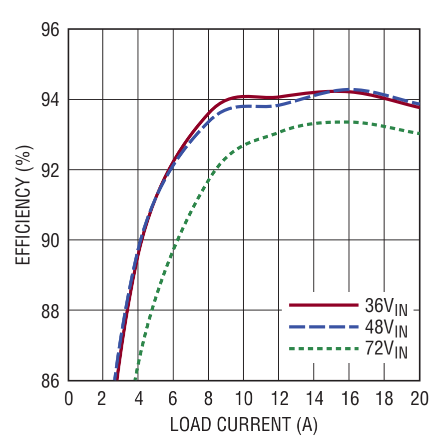
noise can be generated in the current sensing resistor connected to the source of the MOSFET. This noise can false trip the sensing comparators, resulting in early switch turnoff. One solution to this problem is to use an oversized RC filter to prevent false trips, but programmable turn-on spike blanking can eliminate the need for additional RC filtering.

The operating frequency can be programmed from 100kHz to 500kHz range with a single resistor from the RT pin to ground, or synchronized to an external clock via the SYNC pin. The adjustable operating frequency allows it to be set outside certain frequency bands to fit applications that are sensitive to spectral noise.

36V–72V INPUT, 5V/20A FORWARD CONVERTER

Figure 5 shows a 5V, 20A output converter that takes a 36V–72V input. The

Figure 6. Efficiency of the converter in Figure 5



active reset circuit consists of a small P-channel MOSFET M2 and a reset capacitor. The MOSFET M2 is used to connect the reset capacitor across the transformer T1 primary winding during the reset period when M1 MOSFET is off. The voltage across the reset capacitor automatically adjusts with the duty cycle to provide complete transformer reset under all operating conditions.

Also the active reset circuit shapes the reset voltage into a square waveform that is suitable for driving the secondary synchronous MOSFET rectifier M4. The MOSFETs are on the secondary side and are driven by the secondary winding voltage. Figure 6 shows the efficiency for this converter.

The LT3752/LT3752-1 and LT3753 use a current mode control architecture to increase supply bandwidth and response to line and load transients when compared to voltage mode controllers. Current mode control requires fewer compensation components than voltage mode control architectures, making it easier to compensate a broad range of operating conditions.

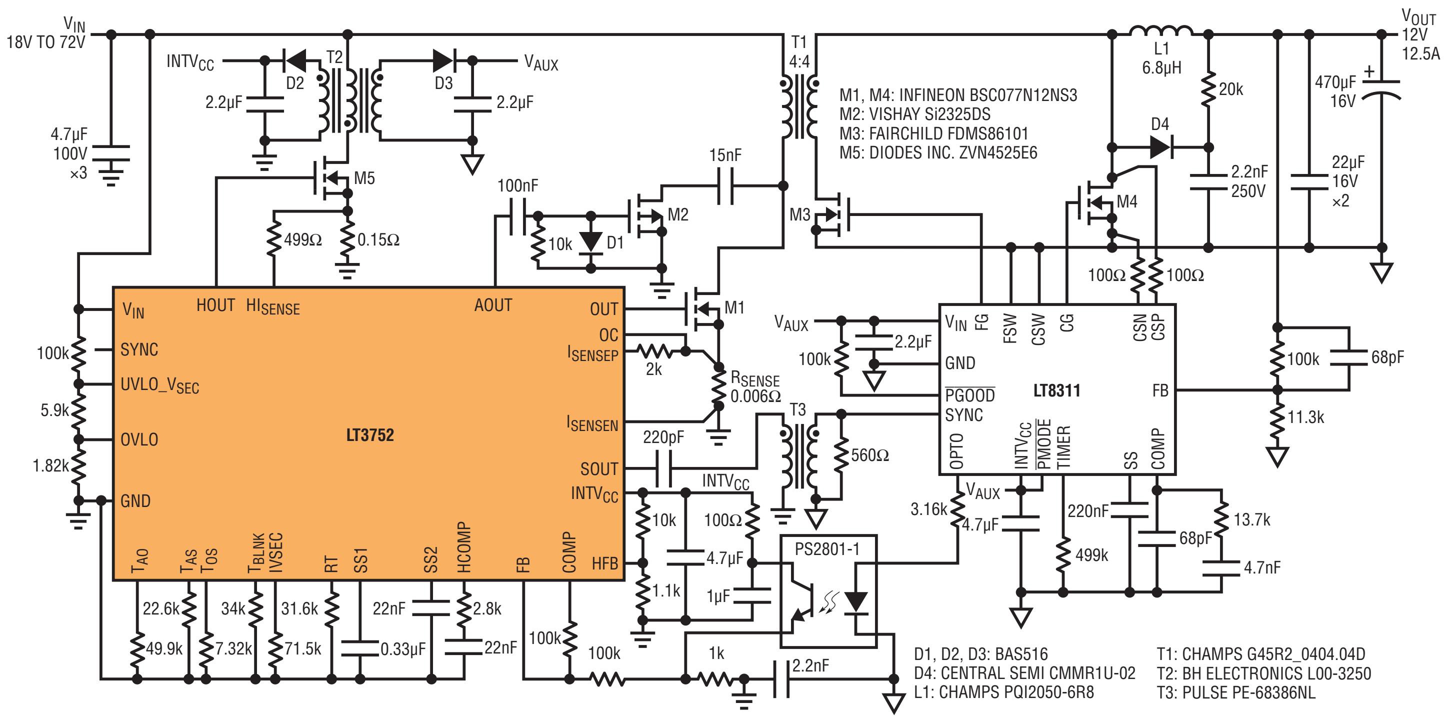


Figure 7. 18V–72V input, 12V at 12.5A output forward converter

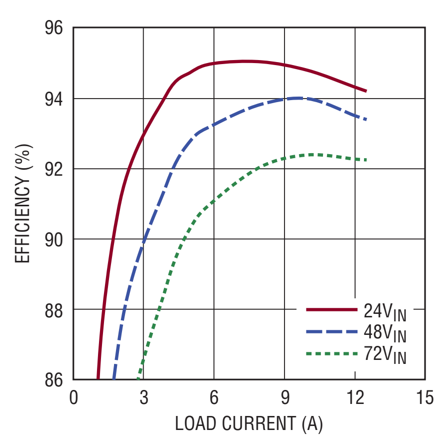
18V–72V INPUT, 12V/12.5A FORWARD CONVERTER

Figure 7 shows an 18V–72V input, 12V/12.5A output forward converter. The LT8311 is used on the secondary side of forward converters to provide synchronous MOSFET control and output voltage feedback through an opto-coupler. A pulse transformer (see T3 in Figure 7) is required to allow the LT8311 to receive synchronization control signals from the primary-side IC. These control signals are interpreted digitally (high or low) by the LT8311 to turn on/off the catch and forward MOSFETs. Figure 8 shows the efficiency for this converter.

150V–400V INPUT, 12V/16.7A FORWARD CONVERTER

Figure 9 shows a 150V–400V input, 12V/16.7A output isolated flyback converter. For high input voltage applications, the voltage rating of the available P-channel MOSFETs may not be high enough to be used as the active clamp switch in the low side active clamp topology. An N-channel approach using the high side active clamp topology should be used. This topology requires a high side gate driver or a gate transformer to drive the N-channel MOSFET to switch in the active clamp capacitor. Figure 10 shows the efficiency for this converter.

Figure 8. Efficiency for the converter in Figure 7



The LT3752/LT3752-1 includes an internal constant frequency flyback controller for generating a housekeeping supply. The housekeeping supply can efficiently provide bias for both primary and secondary ICs, eliminating the need to generate bias supplies from auxiliary windings in the main forward transformer, significantly reducing transformer complexity, size and cost.

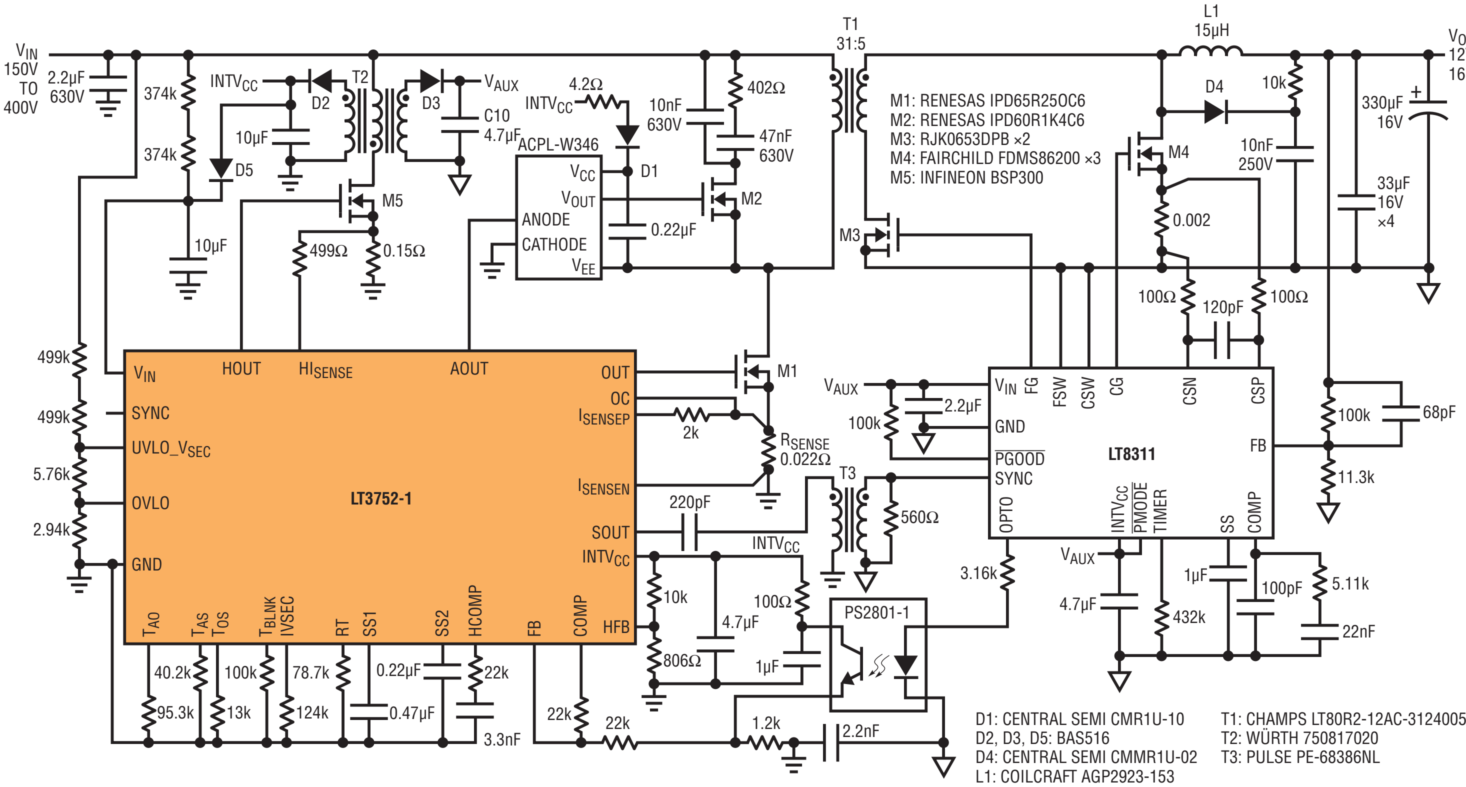


Figure 9. 150V–400V input, 12V/16.7A output isolated forward converter

CONCLUSION

The LT3752, LT3752-1 and LT3753 simplify the design and improve performance to isolated power supplies with a volt-second clamp architecture that produces accurate regulation. An integrated flyback controller can be used to produce a housekeeping supply, simplifying the magnetics. Current mode control improves bandwidth and allows compensation for a broad range of operating conditions. Soft-stop features protect the supply and other components from potentially damaging voltage and current spikes. ■

Figure 10. Efficiency for the converter in Figure 9