The Fundamentals of Flyback Power Supply Design

The development of small, light, low cost, and highly efficient switching power supplies is one of the major contributors to the reduction in power consumed by modern electronic products and has enabled the introduction of ever tighter industry standards for efficiency and standby power consumption.

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Of the many possible topologies for a switch-mode power supply (SMPS), the most popular in the sub-150 W category, is the flyback converter. This, in spite of the fact that it places high stresses (voltage and current) on the primary side switch and secondary diode. However, the flyback converter does offer major advantages. It can operate over a wide input voltage range and provide multiple isolated regulated output voltages from a single switching element.

The flyback topology

Figure 1 illustrates the basic implementation. The flyback converter is derived from buck-boost topology with a mutually-coupled inductor that forms the transformer. The transformer provides a voltage ratio from input to output and the advantage of galvanic isolation.

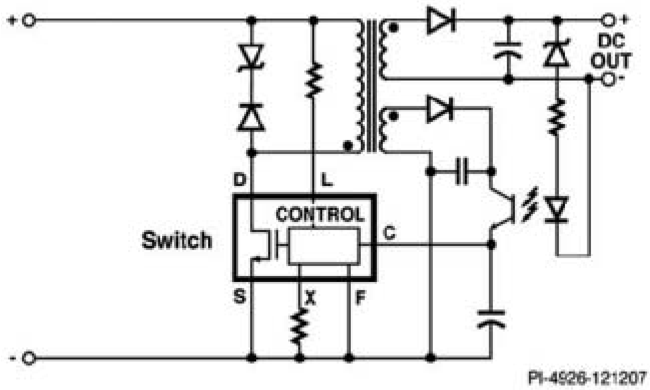

Figure 1: Implementation of a flyback converter

In Figure 1, the control IC incorporates a high-voltage MOSFET switch that switches the input (normally rectified AC mains) via the transformer primary. Figure 2 shows the resulting voltages and currents seen by the MOSFET switch and output rectifier diode.

In the ON state, the voltage across the switch falls to zero and the current ramps linearly in the primary winding. During this time, the magnetizing inductance of the transformer accumulates energy from the input. Meanwhile, the output diode is off (reverse biased) and energy is supplied to the load from the output capacitor.

When the MOSFET turns off, the energy stored in the magnetizing inductance transfers to the secondary winding. The voltage across the secondary winding reverses, the diode turns on (forward biased), and the magnetizing energy transfers to the output capacitor and load.

To maintain isolation from input to output, an isolated feedback circuit is required to provide either voltage or current mode control. In Figure 1, an optocoupler is used to provide the feedback control path.

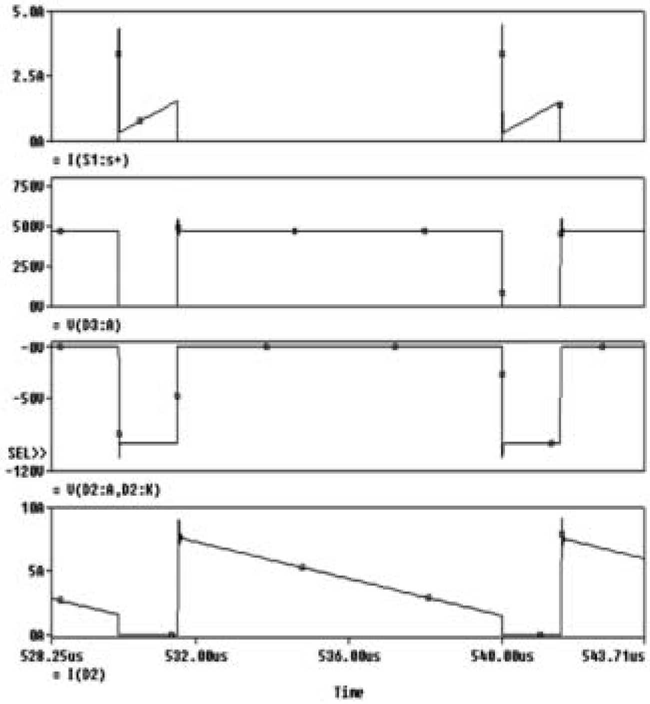

Figure 2: Operation of a flyback converter (from top to bottom, MOSFET current, MOSFET voltage, Output Diode Voltage and Output Diode Current

There are two main operating modes for the flyback converter: continuous conduction mode (CCM) and discontinuous conduction mode (DCM) (see Figure 3).

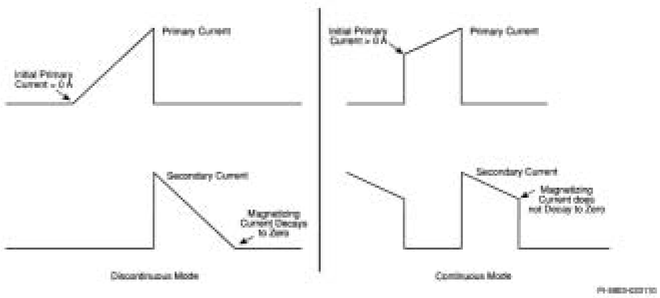

Figure 3: Continuous and discontinuous conduction modes

With DCM, the energy stored in the transformer is delivered to the load before the next switching cycle commences. With CCM, the next switching cycle commences while magnetizing energy is still stored in the transformer. DCM has the advantage that a lower inductance transformer is required for a given output power, but at the cost of higher peak primary and secondary currents, hence higher conduction losses and lower overall efficiency.

Irrespective of the operating mode employed, when the MOSFET turns off, an extremely high voltage is generated across the device (as shown in Figure 4). The voltage sustain capability of the MOSFET is the most critical parameter to consider in flyback power supply design because it affects the selection of all other major components.

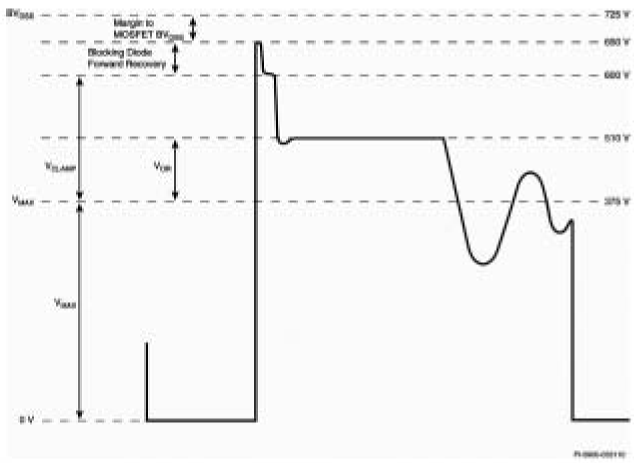

Figure 4: Reflected output voltage

When the MOSFET turns off, the output voltage across the secondary is reflected back through the transformer and multiplied by the turns ratio (VOR). This voltage appears in series with the (maximum) input voltage VMAX. In addition, there is a spike due to the effect of parasitic leakage inductance which appears also in series with the input voltage VMAX and the VOR. This requires the inclusion of a voltage limiting clamp network to prevent the voltage rating of the MOSFET being exceeded.

Maximizing VOR enables a higher turns ratio to be used in the transformer. This provides the advantages of lower primary side peak and RMS currents and lower peak inverse voltages across the secondary diode. Higher VOR values are especially suited for higher output voltages (12 V) where the corresponding turns ratio does not get too large. Lower values of VOR are better suited for lower output voltages (e.g., 5 V) or in multiple-output power supplies.

Minimizing the peak and RMS currents clearly reduces conduction losses within the primary side switch. Another factor to consider is switching losses within the MOSFET resulting from the charge and discharge of parasitic capacitances. Power Integrations (PI) implements the integrated MOSFET using a technology that results in much lower parasitic capacitances. Hence, the switching losses are much lower . The technology enables 132 kHz designs to run as efficiently as 66 kHz designs, providing the opportunity for significant savings in the transformer design by reducing the core size required for a given output power or increasing efficiency for the same core size.

Magnetics design

After the controller/MOSFET device, the most critical component in a flyback converter is the transformer.

The transformer in a flyback converter is always custom made for the specific application. The design of a transformer involves the consideration several variables – many of them obscure magnetics parameters. Fortunately, smart design tools are available to assist the design engineer, such as PI Expert? from Power Integrations.

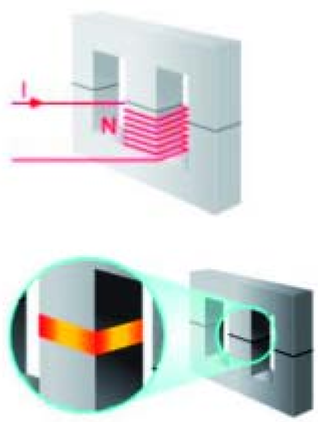

Figure 5: Flyback transformer construction

The flyback transformer is different than a conventional iron-cored line frequency transformer, being more like two coupled inductors. A conventional transformer is not designed to store energy, whereas energy storage is fundamental to the operation of a flyback transformer. A flyback transformer operates at frequencies above 50 kHz vs 50/60 Hz for an iron-cored transformer. For these reasons, the core is commonly made of ferrite rather than iron and includes a non-magnetic air gap. Virtually all the energy is stored across this gap.

The design of the windings must take account of DC losses and current density, as well as AC effects such as the skin effect (where the current tends to flow along the surface of the conductor) and the proximity effect (where the current crowds to one side of the wire).

Key component considerations
Figure 6 is the schematic for a complete single-output power supply employed as an example to illustrate key component choices.

U1 is a member of the TOPSwitch-JX? controller family from PI, incorporating a MOSFET rated at 725 V with low drain-to-source capacitance (COSS). The low COSS enables the circuit to operate efficiently at 132 kHz, allowing a smaller, lower cost transformer core to be used.

The use of high VOR allows the use of 60 V Schottky diodes (D8, D9) instead of 80 V or 100 V types. The 60 V diodes are more efficient and less expensive because of their lower forward voltage drop.

The input capacitor C3 must be chosen to provide the minimum DC voltage to maintain regulation at the lowest specified input voltage and maximum input power. The high DCMAX limit and optimized dual slope line feed forward for ripple rejection enable a capacitance of only 82 µF to be used in this 30 W design.

A primary clamp is necessary to limit the peak source-drain voltage across the MOSFET integrated in U1. An RCDZ (Zener bleed) clamp (VR1, C4, R5, D5) is used to give higher load efficiency and lower no-load consumption. The RCDZ clamp provides a tighter tolerance than a simple Zener clamp and allows a VOR as high as 150 V.

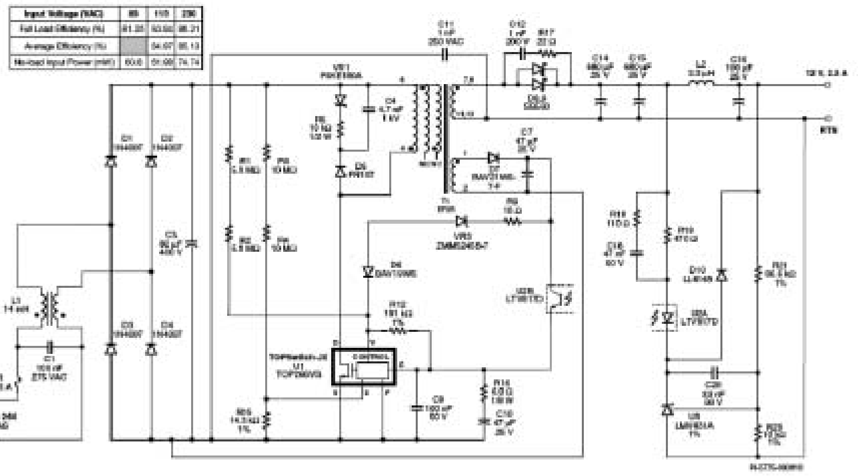

Figure 6. Schematic of high efficiency 12 V, 30 W, universal input flyback supply with very low no-load

The secondary snubber (C12, R17) attenuates ringing generated by parasitics on the secondary side. If not controlled, this ringing would generate radiated EMI and could damage the secondary diodes by exceeding their voltage rating.

A post filter formed by inductor L2 and capacitor C16 is often placed at the output of a switching power supply. This second stage LC filter reduces high frequency switching ripple at the output of the power supply. For lowest ripple, low ESR capacitors should be used.

Multiple output designs
The flyback topology lends itself well to the design of multiple output power supplies. Figure 7 illustrates one example.

The primary choice to be made in designing a multiple-output supply is whether to use independent or stacked secondary transformer windings. In Figure 7, the -12 V winding is independent but the others are stacked. The use of stacked windings ensures better cross regulation, but a disadvantage is that the current of all three outputs passes through the lowest winding. In this design, optimum cross regulation is achieved on the 3.3 V and 5 V outputs by the use of foil windings and by sum regulating (obtaining feedback from both outputs).

With multiple outputs, the design of the transformer takes on an extra level of complexity, and compromises often have to be made in the selection of turns ratios. Fortunately, PI Expert provides full support for multiple output designs.

Conclusion
The flyback converter has become ubiquitous in low-power switch-mode power supplies and in low-cost multiple-output supplies for a huge range of applications. The availability of sophisticated controller ICs, together with high-voltage MOSFETs and design support software, enable flyback supplies to meet the most demanding performance and environmental standards. It is anticipated that further developments will push the boundaries of performance and power consumption even further in the years to come.

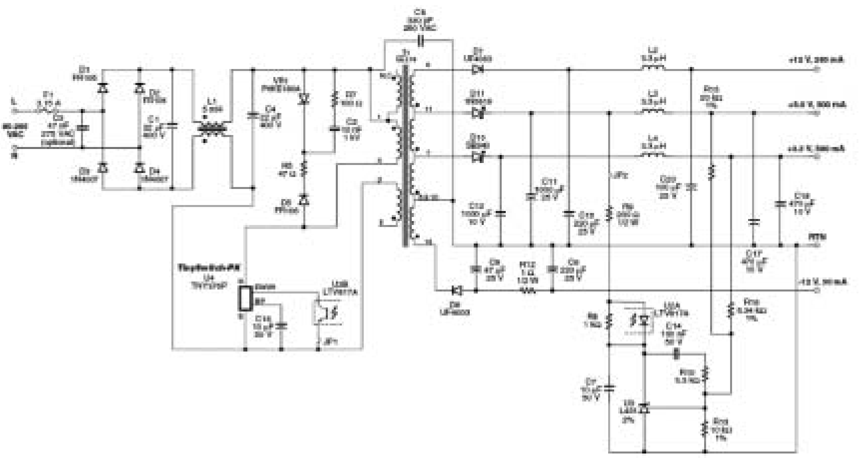

Figure 7: Schematic of a universal input, multiple-output DVD player power supply

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