Technical Article

Isolated Switch-Mode Power Supplies: How to Choose a Forward vs. a Flyback Converter

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Abstract

In the world of power management, there are a range of applications that require isolated power conversion, such as in medical devices, communications equipment, and industrial systems. This is to protect the end user or to prevent interference from input to output (or both). This article will discuss isolated switch-mode power supplies (SMPS) in more detail and introduce the forward and flyback isolated conversion topologies that are commonly used in these applications. It will investigate the advantages/disadvantages of these devices and their suitability for different power levels. The article aims to provide a clear understanding of how to select the correct isolated topology for your application.

Introduction

Isolation is the ability of an electrical system to prevent direct current flow between two separate (isolated) sections of a design. This can be required in a range of different use cases; for example, when input-to-output isolation is necessary. Functional isolation is where the input and output grounds are separated, preventing a noisy supply from interfering with the output side—breaking the ground loop. Alternately, the downstream load may need to be isolated, which is being powered by the regulator, from the high voltage at the input side, which is considered basic isolation. Some systems then require an increased level of isolation to increase safety and reliability in the system.

Beyond the high level safety and isolation needs for this type of implementation, there are other reasons an isolated topology would be selected. In high step-up/step-down applications, an isolated topology is required since the smaller duty cycle and minimum on-/off-time requirements cannot be met with a standard buck or boost converter. In inverting applications, isolated devices are used to achieve a positive to negative voltage conversion.

Multi-output applications can employ an isolated topology to provide several outputs from a single power converter by using a multi-output transformer. These are just some of the areas where an isolated topology can be helpful.

Flyback Converter

A flyback converter is a type of isolated SMPS that uses a transformer to transfer energy from the input to the output. It can be configured in buck or boost mode. A switch, typically a transistor that is used to turn the energy transfer on and off, is connected in series with the primary winding of the transformer. When the switch is closed, energy is stored in the transformer's magnetic field. When the switch opens, the energy is transferred to the output through a rectifier circuit using a low loss Schottky diode or if higher efficiencies are required, an active switch. The article "How to Design a No-Opto Flyback Converter with Secondary-Side Synchronous Rectification" discusses the design of a flyback converter with an active secondary side switch. Since energy is stored in the transformer during the on-cycle and released to the output during the off-cycle, the amount of energy that can be transferred with a flyback design is limited. Due to physical limitations, the size of the transformer is limited. This, in turn, limits the current capability of the transformer—too much energy and the transformer core can saturate.

Another detail to bear in mind when looking at a flyback transformer is the polarity indicators—a simple dot indicates the polarity of each of the windings relative to one another. For a flyback topology, the primary and secondary windings are out of phase, so this is why you will see one dot at the top for the primary side and the dot at the bottom for the secondary side. This means that the primary and secondary currents and voltages will be 180° out of phase with one another.

The traditional flyback implementation (see Figure 1) uses an optocoupler to close the feedback loop and to maintain regulation. However, there are disadvantages with this approach. Optocouplers have limitations such as high power consumption, slow speed (loop response can be difficult to optimize), bulky, and prone to degradation over time. They also require biasing to operate, which results in additional circuitry at the secondary side of the circuit, increasing the board area. Optocouplers are LED-based, so they wear out over time. This wear can be accelerated by increased current and temperature. The wear out is defined in a performance graph showing the long-term current transfer ratio (CTR) of the

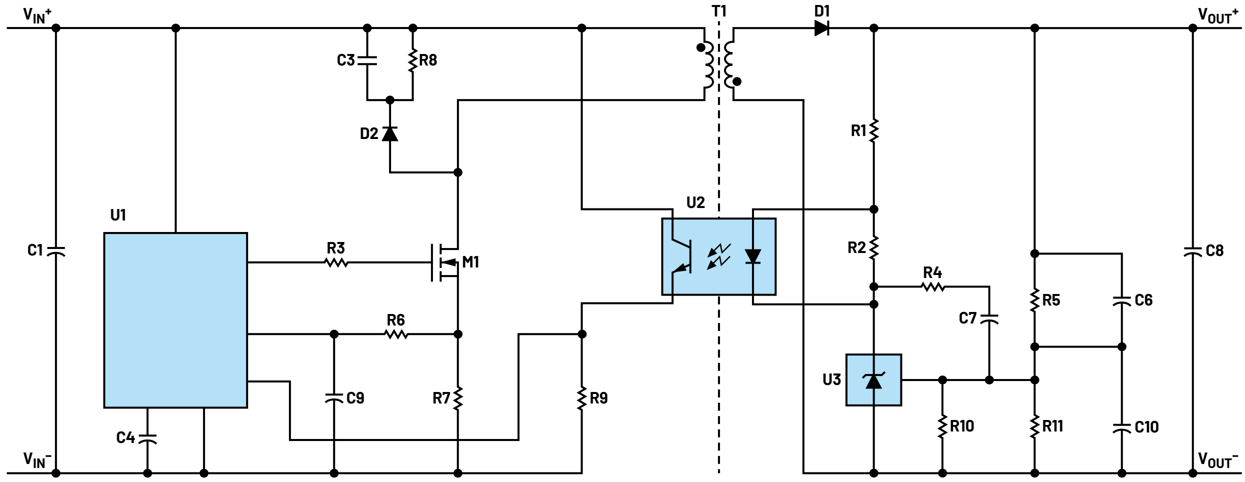

Figure 1. Traditional implementation 1.

optocoupler. The degradation will also vary from part to part, so these are not a reliable solution for critical applications.

Another flyback implementation (see Figure 2) uses a third winding to provide secondary side information to the control circuitry to maintain regulation. However, even though the bulky optocoupler has been removed as well as the associated biasing circuitry, this third winding adds to the physical size of the transformer and the response to output changes is slow. This can lead to poor transient response.

What Is a No-Opto Flyback Converter?

Another type of flyback converter is the no-opto flyback converter (see Figure 3). No-opto refers to the fact that the converter does not use an optocoupler

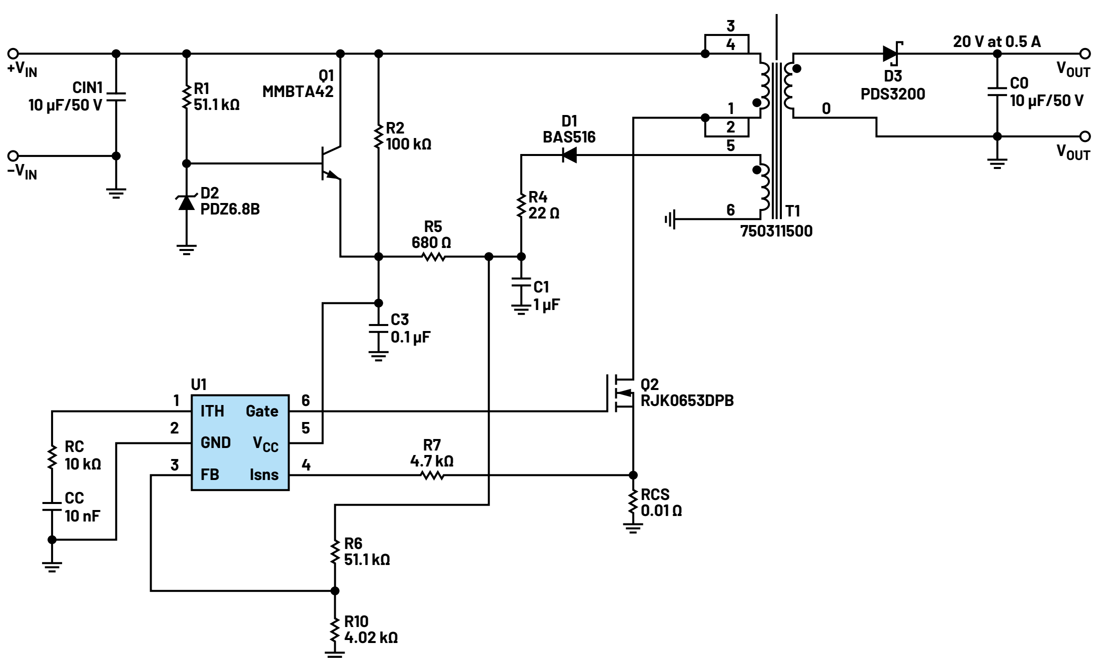

Figure 2. Traditional implementation 2.

to provide feedback from the isolated side to the converter to maintain regulation. Instead, the no-opto flyback samples the isolated output voltage at the primary side by looking at the flyback pulse waveform.

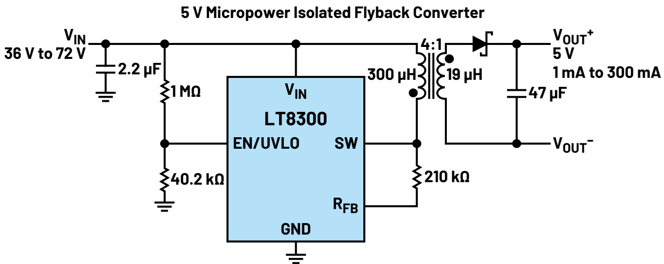

Figure 3. The LT8300 no-opto flyback application circuit (36 V to 72 V V_{IN}, 5 V V_{OUT}).

This type of design has many advantages in terms of board area and reliability. The lack of an optocoupler means that this space and the secondary side feedback components are not required. Relative to designs that use a third winding, the transformer size is also smaller. This board area reduction can be especially important in applications where space is at a premium, such as portable devices or compact electronics.

When the power switch turns on, the transformer primary current will increase up to the peak current limit (different for each IC) at which point the switch is turned off. The voltage at the switch node rises to the output voltage (V_{OUT}) multiplied by the primary-secondary turns ratio (Nps) plus the input voltage (V_{IN}).

$$SW\ Voltage = V_{OUT} \times Nps + V_{IN} \quad (1)$$

The rated switch voltage is important as it is on nonisolated switching regulators. However, more care is required with this type of converter since the switch node sees a voltage that is equal to the output voltage times the transformer turns ratio plus the maximum input voltage. In addition, there is a leakage inductance spike, so the design needs to ensure that the switch voltage is not exceeded when all these conditions aggregate.

What Is Leakage Inductance?

Leakage inductance is a type of parasitic inductance that is present in all transformer-based circuits, including the flyback and forward converters discussed here. It is seen as the inductance that is not directly connected to the intended circuit, but is coupled through the magnetic field of the transformer. It is a parasitic component. This means that it is not directly included in the circuit design, but is present due to the physical properties of the transformer. It can be thought of as the leakage of the transformer's magnetic field from the primary winding to the secondary winding or vice versa.

This leakage inductance can impact both forward and flyback converters in different ways because of how the energy is transferred. For a flyback converter, the leakage inductance causes a voltage spike across the primary switch when it turns off and can be more prominent with larger load currents. Circuit designers need to ensure there is adequate margin for any worst-case leakage voltage spikes. This means that the reflected output voltage on the primary needs to remain below the max switch voltage, which is the abs max rating of the primary MOSFET (which can be integrated into the flyback or a separate component depending on the power level).

Transformer design is very important when it comes to leakage inductance, so working with the transformer manufacturer to minimize this or selecting a transformer with minimal leakage is important. If that is not possible, then there are some snubber circuits that can be added across the primary side of the transformer to dampen the voltage spikes. More information on the design of these circuits can be found in the flyback data sheets. Analog Devices' LT8300 micropower isolated flyback converter data sheet discusses this in more detail.

Forward Converter

The forward converter also uses a transformer to transfer energy from the input to the output, with a switch connected in series with the primary winding of the transformer, like a flyback. The difference here, however, is that it does not rely on the transformer as an energy storage element, but rather transfers the energy

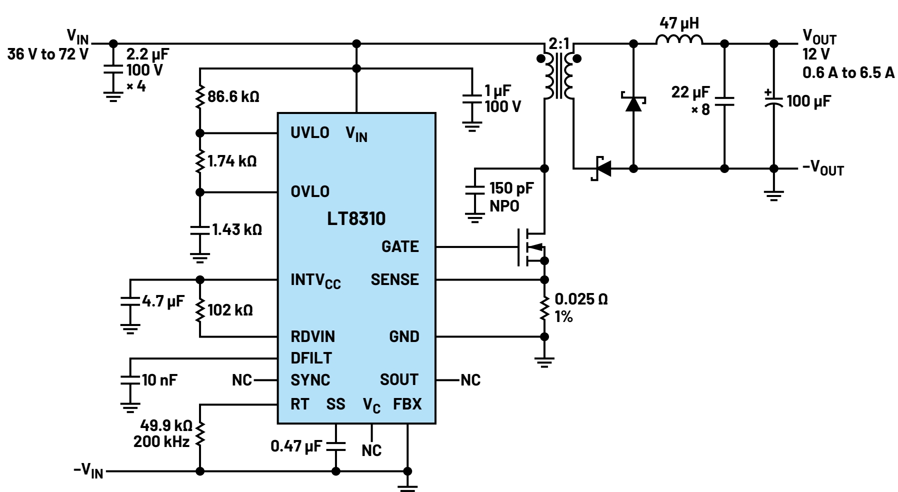

Figure 4. The LT8310, 12 V output forward converter.

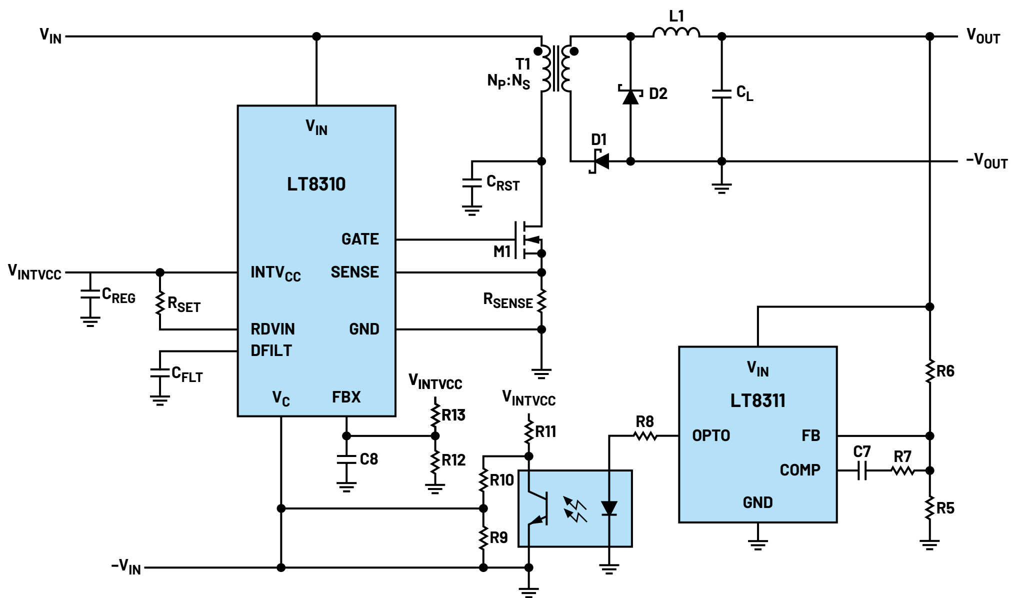

Figure 5. The LT8310, optocoupler feedback.

immediately to the secondary side where it is rectified and filtered to provide a regulated isolated output, which is higher or lower than the input voltage (by varying the transformer turns ratio). The topology is easily identified by looking at the dot indicator on the transformer. Both the primary and secondary side phase indicators are aligned meaning that there is a 0° phase shift of the current and voltage between the primary and secondary side.

The secondary side has two rectifier diodes (nonsynchronous implementation) and also an output filter formed by the inductor and capacitor to reduce the output ripple. The LT8310 is capable of operating in a no-opto configuration similar to the no-opto flybacks, but also with optocoupler feedback if required. It can also be implemented as a synchronous rectified forward by using the SOUT pin to drive secondary side MOSFETs, which helps to optimize the efficiency.

There are some key differences between flyback and forward converters—efficiency, load current capability, size, and cost.

Efficiency: In general, forward converters tend to be more efficient than flyback converters, as they have less losses due to core saturation and leakage inductance. However, the efficiency of a converter also depends on the specific design of the circuit and the components used. For example, power level is an important element in this part of the discussion, so it is not always an apples-to-apples comparison. Historically, the gap between the two topologies would have been greater, but with more efficient components available they are much closer in efficiency achieved.

Load current capability: Forward converters tend to handle higher load currents than flyback converters because the transformer design allows for a larger current to flow through the primary winding. Energy is transferred in the same cycle (forward) rather than stored (flyback) so the transformer size is what limits the load current capability. Flybacks are generally used in applications up to 60 W to 70 W due to transformer limitations, and beyond this a forward converter is a more optimal solution that is capable of providing hundreds of watts of power.

Size: Flyback converters tend to be smaller than forward converters due to the transformer design and the smaller number of components required to enable this conversion topology (less FETs and a simpler filter). The smaller size of the flyback converters can be an important consideration for applications where size is a critical factor, such as portable devices.

Cost: Flyback converters tend to be less expensive than forward converters due to the simpler transformer design, but also because of the lower component count to enable the circuit. Table 1 shows a simplified comparison between both topologies and the number of components required to enable the circuit. As shown, the flyback is a simpler implementation. Even when complicating the designs further with synchronous rectification or the need for an optocoupler for feedback, the forward is still a more involved design from a component perspective, so this results in a larger cost but also a larger board area to implement.

Table 1. Component Count Comparison: Forward vs. Flyback

Component Count	Forward	Flyback
Controller	1	1
FETs	2	1
Transformer	1	1
Inductor	1	0
Rectifier diodes	2	1
Output caps	1	1
Total	8	5

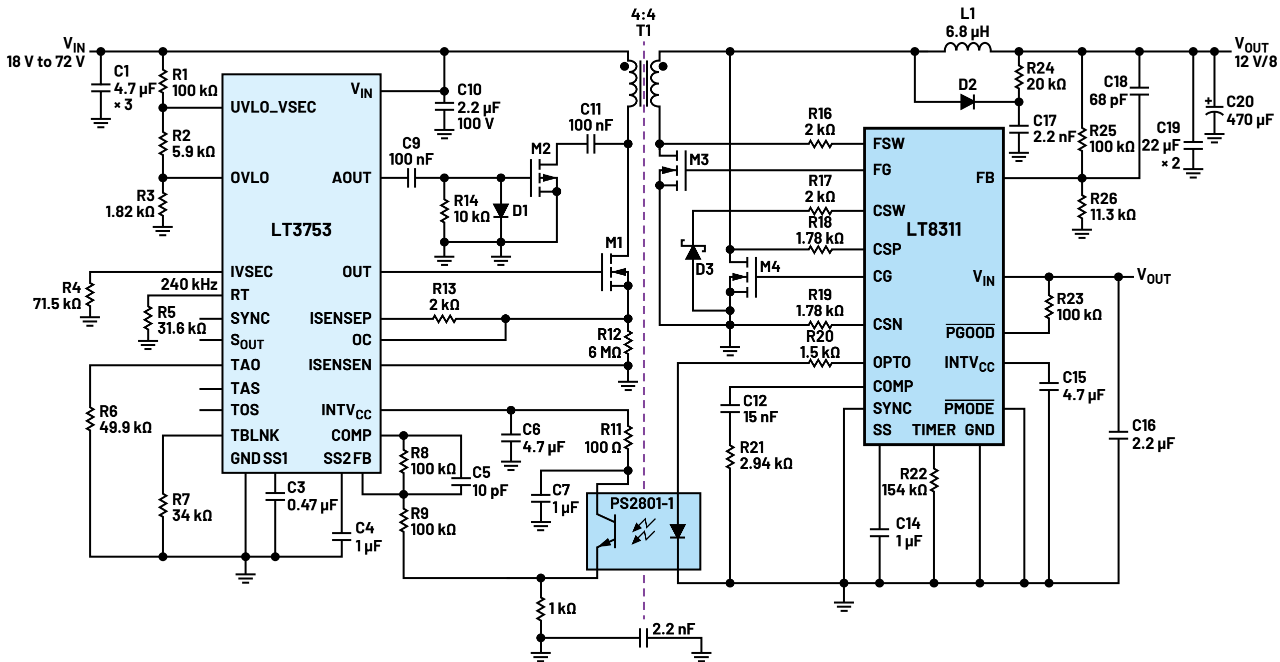

Figure 6. The LT8311 used in a forward application as a secondary side controller.

What Is a Secondary Side Controller and Is it Needed?

Both forward and flyback converters work without a secondary side controller by utilizing a diode (two for a forward converter) at the secondary side (isolated side of the transformer). However, this isn't always the most efficient method. Another way of doing this is to replace the diodes with low loss MOSFETs, which requires a secondary side controller. It is a switching controller to control the turn on and off of the MOSFETs at the secondary side of the isolation barrier. Some of these devices, such as the LT8311, can include circuitry to monitor the output voltage and provide this information to the primary side of the isolation barrier. It does this via an optocoupler signal. Figure 6 is an application circuit showing the LT3753 forward converter paired with the LT8311 in a secondary side control implementation with optocoupler feedback.

So, back to the question of whether a secondary side controller is needed in the design? The answer is, as with everything power related, it depends. It depends on the system requirements, accuracy, efficiency, project timeline, costs, etc. Ultimately, there are several benefits to having a secondary side controller that might help in the decision.

Increased efficiency: The secondary side controller allows for the control of low $R_{DS(ON)}$ MOSFETs instead of diodes, which helps to reduce the power dissipation at the secondary side, thereby increasing the efficiency of the system.

Improved regulation: it can monitor the output voltage and current and provide feedback to the primary side to help maintain a stable and accurate output voltage. This allows for tighter voltage regulation and improved output voltage stability.

Flexibility: Some secondary side controllers can include a range of additional features, which can make the converter more versatile and useful in a variety of different applications.

Example Applications That Can Require Isolated Power Conversion:

- Medical equipment: Isolation is often used in medical equipment to prevent electrical shocks to patients and medical staff. Isolation also prevents interference between the patient's electrical signals and the equipment, which can lead to more accurate diagnoses and treatments.
- Industrial control: Isolated power is required for many of the systems such as the communication interface power supply, industrial automation supply. Isolation is commonly used in industrial control systems to protect sensitive electronic equipment from high voltage transients and electrical noise.
- Automotive systems: Isolation is also used in automotive systems to prevent electrical interference between different subsystems and to protect electronic systems from voltage spikes and transients.
- Communication systems: Isolation is used in communication systems, such as telecom and datacom high power density power supply (PSU).
- Renewable energy systems: Isolation is also used in the power conversion of renewable energy systems such as solar, wind, or hydroelectric power plants for safety reasons, and to prevent interference between different parts of the system.
- Battery-based systems: Isolation is also important in battery-based systems, particularly when charging and discharging the battery, to protect sensitive electronic components from high voltage transients and to ensure safety.

Conclusion

Overall, isolation is used in a wide range of applications where the need to separate the input and output sides of a power converter is necessary for safety, accuracy, and reliability. Both flyback and forward converters are types of isolated SMPS topologies that can be used in these isolated applications. The choice between these two topologies depends on the specific requirements of the application and the trade-offs that need to be made in terms of efficiency, isolation, size, load current capability, and cost.

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