An Introduction to Flyback Converters: Parameters, Topology, and Controllers

Introduction

Flyback converters are versatile power electronics devices used in applications such as medical devices and laptops. Also known as isolated buck-boost converters, these converters are simple circuits that can regulate a system's output voltage (V_{OUT}) while minimizing electromagnetic interference (EMI).

This article will introduce flyback converters, and explore their topology, useful parameters, and operation. It will also discuss MPS's AC/DC flyback controllers — the MPX2002 and MPX2003 — which provide both primary-side regulation (PSR) and secondary-side regulation (SSR).

Flyback Converter Parameters and Topology

For flyback converters, the inductor is split to form a coupled inductor, also called flyback transformer. This coupled inductor isolates the converter's input from its output. Figure 1 shows a schematic of a flyback converter, with the components described below:

- V_{IN}: The input voltage, which is the source of electrical power for the circuit.
- C_{IN} and C_{OUT}: The input and output capacitors, respectively. The capacitors are used to store and release electrical charge to the regulator V_{IN} and the output voltage (V_{OUT}).
- Control: A signal that comes from the IC controller that switches on the primary MOSFET. This process allows current to flow through L_P, and this current is transferred to the output.
- L_P and L_S: The primary and secondary inductors, respectively. The coupled inductors store and release energy, as well as determine V_{OUT} based on the number of individual turns in their winding.
- D: The diode, which rectifies V_{OUT} by converting the alternating current (AC) to direct current (DC) so that current can only flow in one direction.
- R_L: The load that emulates the power consumption of the flyback converter.

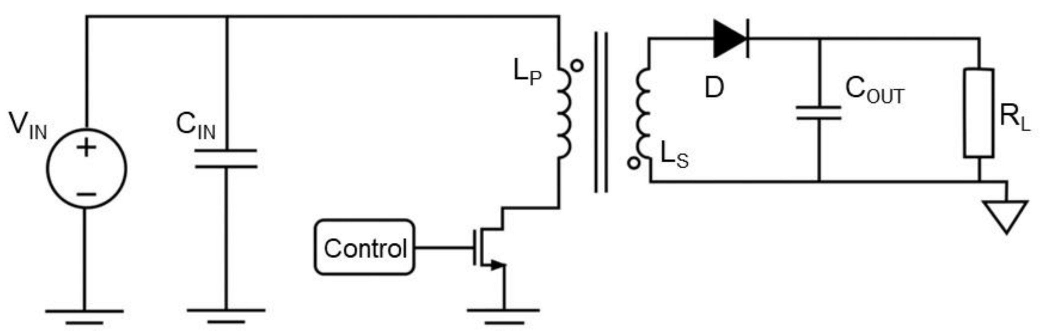

Figure 1: Flyback Converter Topology

Flyback Converter Considerations

When choosing a flyback converter, there are important considerations to make, including identifying some basic parameters, such as V_{IN}, V_{OUT}, L_P, and L_S. A few additional considerations are listed below:

- The transformer turns ratio, N_P:N_S (where N_P is the number of turns for the primary winding, and N_S for the secondary winding) directly affects V_{OUT}. If N_S increases, then V_{OUT} increases proportionally; if N_S decreases, V_{OUT} also decreases proportionally. By contrast, N_P is inversely proportional to V_{OUT}; if N_P increases, then V_{OUT} decreases proportionally, and vice versa.

- The duty cycle is the ratio of the on time compared to the total switching period (t_{ON} / τ_{SW}). The duty cycle determines V_{OUT} based on V_{IN} and the transformer's turns ratio, with a higher duty cycle resulting in a higher V_{OUT}.
- Protection mechanisms and isolation are vital for flyback converters to meet safety standards such as UL 1577 and IEC 62368. Protections can be optimized for EMI performance and to help ensure that the device does not operate under suboptimal conditions.

Flyback Converter Operation

Flyback converters operate such that they store and transfer energy. Flyback converters have two periods: the on time (t_{ON}) and the off time (t_{OFF}), which are controlled by the MOSFET's switching states (see Figure 2). At t_{ON}, the MOSET is in the on state, and current flows from the input and through L_P to charge the coupled inductor. At t_{OFF}, the MOSFET is in the off state. The coupled inductor demagnetizes through the diode, and this current then charges C_{OUT} and powers the load. This process can be simplified into a few steps:

1. t_{ON} begins. When the MOSFET turns on, current flows through L_P and the energy is stored in the transformer's magnetic field.
2. t_{ON} ends.
3. t_{OFF} begins. When the MOSFET turns off, the stored energy is transferred to the output via the secondary diode/MOSFET, charging C_{OUT} and then increasing V_{OUT}.
4. t_{OFF} ends.

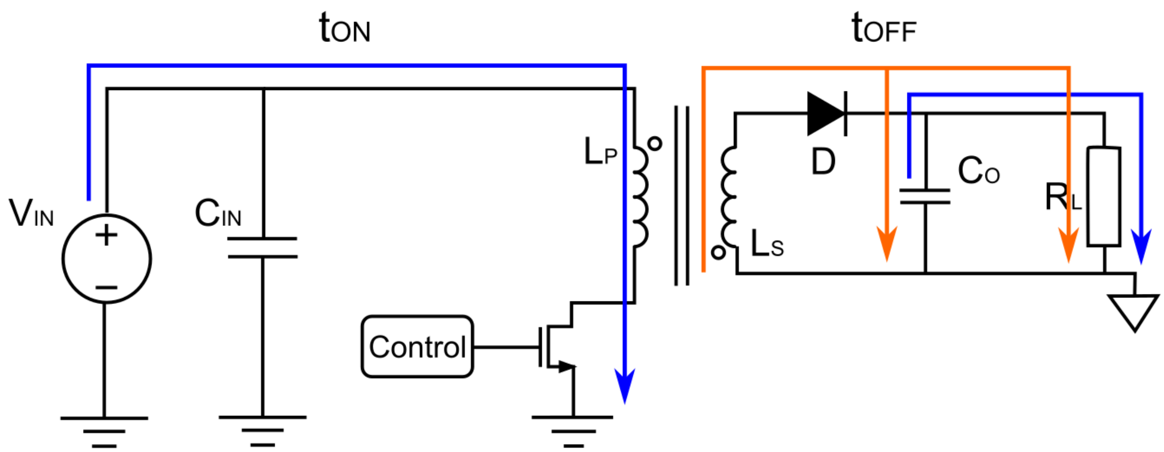

Figure 2: t_{ON} and t_{OFF}

The cycle repeats to regulate V_{OUT}. Although a flyback converter follows the overall process described above, there are additional processes and modes that can be selected to optimize efficiency.

Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM)

Flyback converters can operate in continuous conduction mode (CCM) or discontinuous conduction mode (DCM).

In CCM, the MOSFET switches from t_{OFF} to t_{ON} before the inductor completely discharges, which prevents the inductor current (I_L) from reaching zero. In DCM, the energy is completely discharged, meaning there is a time during which I_L is zero. When I_L is zero, both the diode and MOSFET are in an off state.

Because CCM has a constant current, this method is recommended for applications where the load varies, as it provides a more stable V_{OUT}. CCM is also typically beneficial for applications with moderate or heavy loads.

However, DCM is recommended for light loads. In DCM, the transient response is faster under light loads and even shows higher efficiency if the secondary diode/MOSFET has zero-current switching (ZCS) during t_{OFF}, which turns off the switching device as soon as the current reaches zero. ZCS reduces the power dissipation across the switching devices.

Table 1 shows a brief summary comparison of these two modes.

Table 1: CCM vs. DCM

Parameter	CCM	DCM
Efficiency	Less efficient	More efficient
Transient Response	Slower response	Faster response
EMI	Worse performance	Better performance
Transformer	Larger transformer	Smaller transformer
Inductor RMS Current and Ripple	Lower	Higher

Primary-Side Regulation (PSR) and Secondary-Side Regulation (SSR)

One of the most significant challenges with flyback converters is maintaining isolation between the input and output, which divides the converter into a primary side and a secondary side.

With primary-side regulation (PSR), the output can be regulated using very few components. The auxiliary winding shares the same ground reference as the input voltage, so there is no need for an external optocoupler (see Figure 3). Because the auxiliary transformer is related to V_{OUT}, it is possible to use the transformer's turns ratio to control the system.

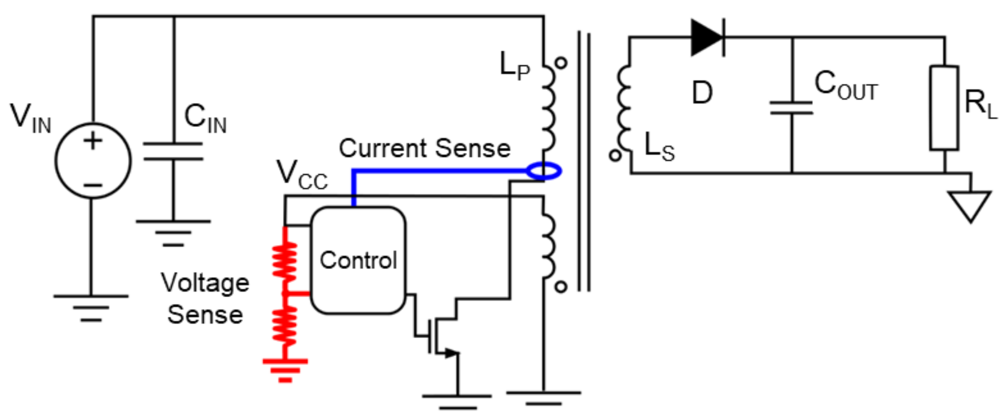

Figure 3: Primary-Side Regulation

PSR is recommended for high-voltage applications because it reduces the isolation voltage requirements, which also reduces the total cost. However, PSR samples the voltage when I_L is at its lowest, which does not provide constant monitoring and means that regulation takes longer.

Secondary-side regulation (SSR) is able to provide more accurate regulation. In SSR, V_{OUT} is directly sensed, and this signal is sent to the converter through an optocoupler that transmits the signal without breaking the isolation barrier (see Figure 4). SSR allows designers to utilize other methods to further optimize regulation, such as using escalated windings or weighted feedback.

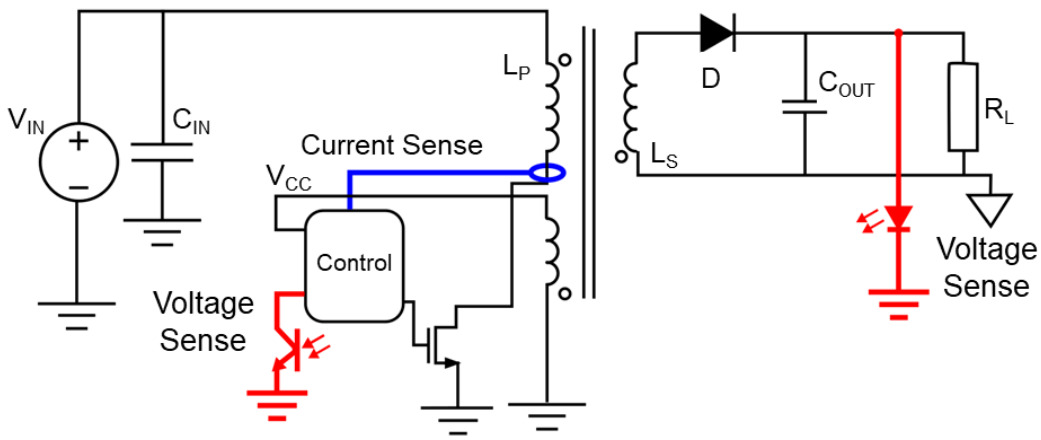

Figure 4: Secondary-Side Regulation

However, SSR requires additional external components. This increases the solution size and cost, and can also make the system less reliable since there are more components that can break down or experience a failure.

Table 2 shows a comparison between PSR and SSR.

Table 2: PSR vs. SSR

	Primary-Side Regulation	Secondary-Side Regulation
Cost	Lower cost	Higher cost
Complexity	Less complex	More complex
V_{OUT} Regulation	Worse regulation	Better regulation
Transient Response	Slower response	Faster response
Reliability	More reliable	Less reliable
Cross-Regulation	Worse regulation	Better regulation

Synchronous Rectification (SR)

A synchronous rectifier (SR) can be used in place of a diode. Synchronous rectification uses an actively controlled switch, such as power MOSFETs. Because MOSFETs have a low on resistance ($R_{DS(ON)}$), they have a smaller voltage drop than diodes, which reduces power loss and improves efficiency.

Synchronous rectification uses comparators that sense the voltage and open the transistors at certain times to allow current to flow in the right direction. Although this makes the system more complex with the addition of external components, it increases efficiency; since there is less power loss, it also results in a lower overall PCB temperature.

MPS's Flyback Controllers

A flyback converter is the block power supply, consisting of the flyback controller and all the power switches and transformer necessary to achieve the desired performance.

Meanwhile, a flyback controller is the IC used to control the power supply. It is designed by microelectronic circuits placed in a single die and encapsulated inside a typical plastic package (e.g. SOIC-8, SOICW-16, and TSOICW16-15). It features many functionalities, such as all the control circuitry, voltage and current regulators, and drivers to turn the power semiconductors on and off.

The MPX2002 is an all-in-one flyback controller that integrates a primary driving circuit, secondary controller, SR driver, and safety-compliant feedback in either an SOIC-W16 or TSOICW16-15 package (see Figure 5).

The MPX2002 offers the benefits of both PSR and SSR. The device has an SR that can match the signal of the primary-side MOSFET, and the integrated SR controller regulates the SR MOSFET for increased flexibility.

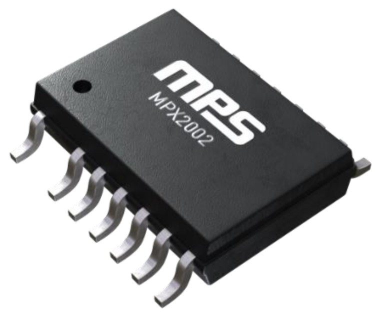

Figure 5: The MPX2002

This device operates in CCM under heavy loads, but switches to quasi-resonant (QR) mode when the load decreases. By switching between operation modes depending on the load, the MPX2002 can maintain high efficiency across a wide load range.

The MPX2002 provides incredibly robust protections for both the primary side and the secondary side. The primary-side protections are summarized below:

- Short-circuit protection (SCP): SCP is designed to protect the MPX2002 from over-current (OC) conditions. SCP is a surge-proof approach, which means that the device does not turn off after the first trigger. If SCP is triggered twice within 8 switching cycles, the primary side stops switching, then resumes normal operation once the condition is removed.
- CS short protection (SSP): If the CS pin's voltage does not reach a set value within a set timeframe, SSP is initiated to prevent the primary current from being overstressed. This protection only works within the first few switching cycles.
- Over-voltage protection (OVP): The IC can initiate OVP to prevent components from breaking down due to stress from an OV condition.
- Brownout protection (BOP): BOP is triggered to ensure that the device does not experience power supply concerns from an insufficient V_{IN}.
- Primary over-temperature protection (POTP): The primary side provides POTP to prevent damage due to overheating. There is a primary junction temperature; if it exceeds the POTP threshold (about 150°C), switching stops immediately until the junction temperature drops by about 40°C.
- Primary over-current protection (POCP): The primary side monitors to secondary side during start-up. If the primary side does not start up within the OCP time (t_{OCP}), then a fault condition occurs. During this fault condition, the POCP flag it set and the primary side runs in a protection operation.
- Primary external protection (PEP): The MPX2002 has a general-purpose protection pin (PEP). The MPX2002 monitors the voltage on PEP every 100μs to 200μs. If the PEP pin's voltage falls below the set protection threshold of 0.5 V, the PEP flag is pulled high. This pin can be used to indicate OTP for external components, or it can be used for OVP (see Figure 6).

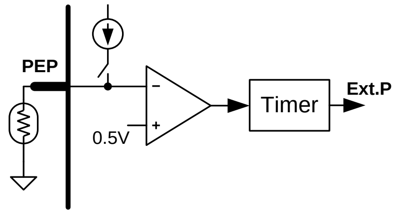

Figure 6: Primary External Protection

The secondary-side protections are summarized below:

- Secondary under-voltage lockout (SUVLO): To prevent the secondary side from operating at an insufficient voltage, the secondary side does not operate until the supply voltage (V_{DD}) exceeds its rising threshold. If V_{DD} falls below the falling threshold, the secondary side shuts down.
- Secondary overload protection (SOLP): The MPX2002's IS pin senses the output current with current-sense resistors. If the IS voltage exceeds the overload threshold for longer than the delay time, SOLP is triggered and the device stops switching.
- Secondary OVP (SOVP): The secondary side also features OVP to protect the MPX2002 from overstress.
- FB open-loop protection (FBOLP): If a fault condition occurs, the MPX2002 may lose its feedback loop, and V_{OUT} may go out of regulation. To protect the circuit from protection, the MPX2002 checks V_{OUT} and the FB pin's voltage. If the FB pin's voltage falls below its threshold for a set time, the secondary side initiates FBOLP to protect the device.
- SR gate open/short protection (SGOP/SGSP): The SR driver has SGOP to protect the circuit from being damaged when the SR is unable to turn on successfully. The secondary side does not start up until the primary side starts up again.
- SRD abnormal protection (SRDP): If the secondary side starts up and there are 7 consecutive primary switching pulses, but the SR gate does not reach the threshold set by the SRD pin, then the secondary side does not recover until the primary side or secondary side triggers under-voltage lockout (UVLO).
- Secondary over-temperature protection (SOTP): Similar to POTP, SOTP features a protection threshold and sets the SOTP flag until secondary side's junction temperature falls below the hysteresis threshold.

The MPX2003 is an all-in-one flyback controller that can also operate with CCM, DCM, and QR. The device integrates a controller, secondary-side SR, and sensing and driving circuity. It provides 100% production HIPOT compliance testing. Like the MPX2002, the MPX2003 is also available in SOICW-16 and TSOICW16-15 packages.

The MPX2003 provides the same protections as the MPX2002 and supports the same safety guidelines, with DIN VDE V 0884-17 in progress. Furthermore, MPX2003 can achieve a significantly higher switching frequency (f_{SW}), up to 140kHz.

Conclusion

Flyback converters use a coupled inductor that splits the converter into two segments — the primary side and the secondary side — to regulate V_{OUT} across a wide V_{IN} range. These converters can operate in CCM for varying loads, or can improve efficiency by operating in DCM at low output power. A flyback controller is within the flyback converter's block power supply. The controller can be used to control circuitry for optimization.

The MPX2002 is an all-in-one-flyback controller that provides all of the standards benefits of flyback converters (e.g. high efficiency, excellent V_{OUT} regulation, and simple design), and also features extensive protections designed to protect both sides of the converter from fault conditions. The MPX2003 is a similar part being approved for additional safety features, and can achieve an even higher switching frequency. MPS offers flyback controllers with PSR, SSR, and both. To see more of MPS's flyback controllers, check out the MPS website and find the solution to meet your application needs.