POWER CONVERTERS

Understand two-switch forward/flyback converters

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The forward and flyback converters are two popular topologies widely used in isolated DC-DC power converters. These topologies are favoured by designers for their simplicity, ability to handle multiple isolated outputs, and ease to optimise the duty cycle by selecting the transformer turns ratio.

Simplicity is partially based on the fact that conventional forward and flyback converters employ a single MOSFET switch, which is primary ground referenced for convenient gate drive implementation. However, the drawback to this single switch approach is that the voltage stress on the switch is the sum of the input voltage, the reflected transformer voltage and the turnoff voltage spike caused by leakage inductance.

Adding a second MOSFET switch on the high side results in the two-switch forward or flyback topology, of which the voltage stress on each MOSFET is clamped to the input voltage. The leakage inductance energy is also clamped and recycled back to the input to improve efficiency.

The dissipative snubber circuit that is often required in the single switch approach is no longer required. MOSFET switches with a rated voltage slightly higher than the input voltage can be employed in the two-switch topology, while a rating of greater than twice the input voltage is required for the single-switch topology.

For many applications the added complexity and part count of two-switch forward and flyback converters can be a small price to pay for the benefits received.

Two-switch forward converter

Figure 1 shows the two-switch forward converter topology, which consists of the input capacitor CIN, two MOSFET switches Q1 and Q1, the power transformer T1, two clamp diodes D3 and D4, two rectifier diodes D1 and D2, and the output filter consisting of L0 and C0.

Figures 2a and 2b depict the operation of the two-switch forward converter. Both Q1 and Q2 are turned on and off simultaneously. When they are on (Figure 2a), power is delivered to the load through the transformer and the output filter.

When the MOSFETs are turned off (Figure 2b), power flow in the primary circuit is cut off, and the voltage on the primary winding will reverse until the dot end is clamped to return by D3 and the non-dot end is clamped to VIN by D4. Therefore, each MOSFET will see a turnoff voltage stress magnitude of VIN.

Not only is the energy from the transformer magnetizing inductance clamped but more importantly the leakage inductance energy is also clamped and returned to the input power bus through diodes D3 and D4. Energy stored in the leakage inductance during the on-time does not have to be dissipated in a resistive snubber or the MOSFETs themselves.

This advantage over a single switch approach reduces system power losses and reduces system noise, since the ringing normally associated with the release of the inductive energy is now clamped. Consequently, there is no need for snubber circuit and the EMI signature of the converter is greatly reduced.

Transformer core reset in a single switch forward converter
is normally accomplished with a tertiary reset winding. Generally the reset winding has the same number of turns as the primary winding. Thus, the core will always reset with a reset time equal to the on-time of the transistor. The voltage stress on the MOSFET switch will be twice the input voltage plus the spike caused by the leakage energy.

By limiting the duty cycle of the MOSFET switch to less than 50 per cent the transformer core will always reset each cycle. The two-switch forward converter resets the transformer in exactly the same way without the additional reset winding, because the conduction of D3 and D4 effectively applies the input voltage in reversed polarity to the power transformer primary winding to reset the core.

Since the maximum drain to source voltage across the MOSFETs is clamped to VIN, there is no uncertainty as to what the peak voltage stress will be. This benefit can not be overstated. Peak voltage stress in a single switch approach is proportional to the value of leakage inductance, switching speed and circuit layout. Leakage inductance is difficult to control and can often vary even after the design goes into production.

At first glance, the series conduction loss of the high side MOSFET appears to be additional power dissipation. However, a study of MOSFET process characteristics reveals that the two-switch topology can actually result in a reduction of conduction losses. For a single-switch forward converter with a 36V to 75V input application, a 200V MOSFET is often required provided the leakage inductance spike is controlled.

The die size, and hence the cost of a MOSFET, are proportional to both the on-resistance (Rds(ON)) and the voltage rating. While the two-switch approach requires two MOSFETs in series, the total resistance of the two MOSFETs usually can be smaller than a single switch with twice the voltage capability, for a given die size.

Gate drive losses are obviously higher with two switches, but with the lower Rds(ON) and the elimination of leakage inductance loss often results in a gain of conversion efficiency. The elimination of snubber components and control of the leakage inductance effects are big benefits of the two-switch topology especially at higher input voltages.

Higher input voltage applications often have more primary turns which tend to increase leakage inductance and loss. The benefits of the two-switch approach increase with increasing input voltage, but lower input voltage applications can often benefit as well.

Historically, driving the high side MOSFET has been a challenge for the two-switch topology since the high side MOSFET requires a floating gate driver. New monolithic IC regulators eliminate the headache of the high side MOSFET gate drive through the use of a boot-strap capacitor technique controlled by a high speed level shift circuit. Figure 3 shows the block diagram of the high side gate drive implementation.

The advantages of two-switch forward become more remarkable in an integrated solution where the complete control circuit, gate drive for both high side and low side switches, and even the two high voltage MOSFETs, can all be integrated in the same IC.

By clamping voltage stress on the MOSFETs, the maximum input voltage range of the power converter can approach the rated voltage of the MOSFETs, making...
full use of the MOSFET process capability. In contrast, the maximum input voltage range for a single-switch forward converter is limited to less than half the rated voltage of the MOSFET.

A typical example of the fully integrated Two-Switch DC-DC regulator is National Semiconductor’s LM5015, which provides a high performance low cost DC-DC regulator solution capable of a very wide input voltage range from 4.25V to 75V.

**Two-switch flyback converter**

Figure 4 shows a Two-Switch Flyback converter topology, which consists of two MOSFET switches Q1 and Q2, the power transformer T1, two clamp diodes D1 and D2, the secondary rectifier diode D0, the input filter capacitor CIN and the output filter capacitor CO. Both MOSFET switches are turned on and off simultaneously, as in the two-switch forward converter. The operation of the Flyback transformer is best described as two-winding coupled inductor. Energy is supplied to the inductor in the primary circuit when the primary MOSFETs are active, then the energy is released to the secondary when the primary MOSFETs turn off.

The coupling between the primary and secondary windings is never perfect; this leakage inductance can destroy the primary MOSFET in a single switch approach if left unchecked. The clamp diodes in the Two-Switch Flyback are used to recover the leakage energy back to the input, and to clamp the turn-off peak voltage across each MOSFET at VIN.

All of the same benefits are realised in the two-switch flyback as in the two-switch forward. The voltage stresses on the MOSFET switches are clamped to VIN, and the leakage inductance energy is returned to the input instead of being dissipated in snubbers that are normally required in the single switch approach.

The same techniques as shown in Fig. 3 can be used for the high side MOSFET gate drive. The Two-Switch Flyback can be operated in either discontinuous or continuous conduction mode just like the Single-Switch Flyback converter.

**Conclusion**

By adding a high side MOSFET switch, the two-switch forward or flyback topology clamps the voltage stress on each MOSFET switch to the input voltage. With the two-switch approach, the leakage energy is recycled back to the input to improve efficiency and there is no need for dissipative snubber circuit that is often required in the single switch converters.

The added complexity and part count of the two-switch forward and flyback converters can be a small price to pay for the benefits received. The advantages of two-switch approach become more remarkable in an integrated solution in which the gate drive for both switches, and even the two MOSFET switches can be integrated in the same IC with the control circuit. The integrated solution allows the input voltage range to approach the rating of the MOSFET process capability providing a small form factor, high performance solution.