Isolated Supply Overview and Design Trade-Offs

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Isolated Supply Overview and Design Trade-Offs

— By David Baba, Product Applications Engineer

Introduction

The design of the power architecture within the communications infrastructure market consists of many trade-offs and design considerations. Multiple factors such as input and output voltage, output current, space constraints, efficiency, as well as the priority the designer places on each of these needs, determine which topology should be used. This article addresses design considerations from a topology selection perspective, providing an overview of each topology's operation and the solution that is best implemented given the system's needs and the trade-offs involved.

Basic topology descriptions are provided along with waveforms. Equations are also provided which are useful for determining RMS ripple currents and losses in the pass elements. *Note: The equations have been derived using small ripple approximation; namely, all current slopes are approximated to zero.*

Isolated Supply Overview

Isolation is required primarily for safety. Isolated circuits are protected from potentially lethal transient voltages and currents present on the primary side of isolation. Isolation also removes ground loops that would otherwise be present in a non-isolated design. The removal of ground loops increases noise immunity of the secondary supply.

There are also proven benefits to isolation, such as the freedom to step down voltages from the primary to the secondary side. Isolation also makes it possible to create a negative supply from the primary to secondary side of the isolation transformer. Conversely, it is possible to generate a positive supply from a negative supply.

Flyback Converter Continuous Conduction Mode (CCM) Single-Ended Topology

Operation of a Flyback Converter

The flyback converter is a buck-boost derived topology. This means that the transfer function is of the form $V_{OUT}/V_{IN}= D/(1-D)$ where D is a fraction of the switching period during which the main switch is on. What appears to be a transformer is actually a coupled inductor or "flyback transformer"

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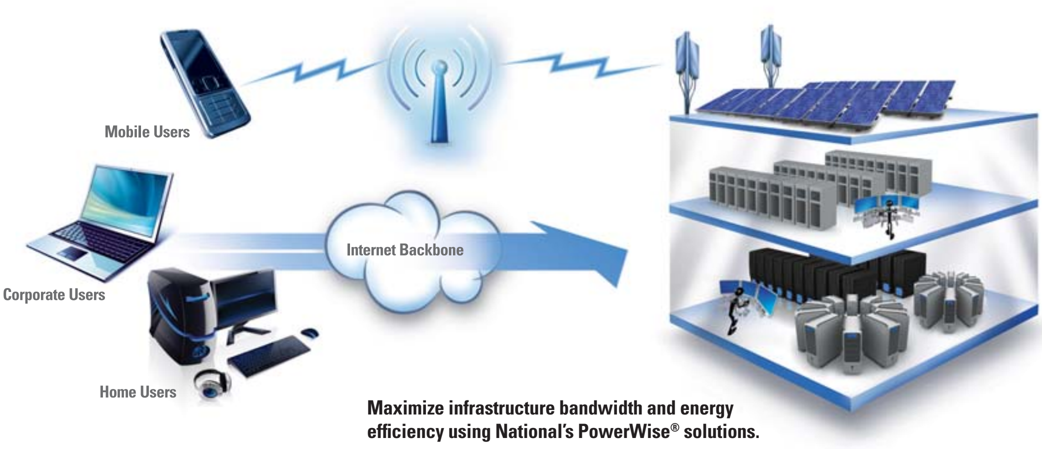

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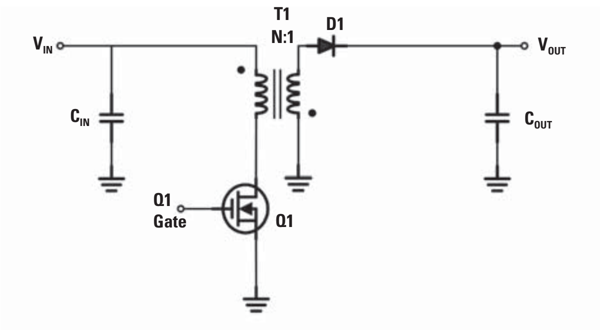

Figure 1. A Flyback Converter

since the current does not flow simultaneously in the primary and secondary. As in a traditional buck-boost topology, the output is inverted. For a positive voltage on the output, the dots are reversed as shown in *Figure 1*. When Q1 is turned on, then V_{IN} is applied across the primary of the transformer, and energy is stored in the primary winding. When Q1 turns off, this stored energy is transferred to the secondary and D1 conducts supplying energy to the load. The voltage and currents are scaled according to the turns ratio.

It should be noted that the currents in the output and input are both pulsating, and therefore the ripple current ratings for the input and output capacitors are relatively high. Additional capacitors may be needed to handle this rating in higher-power designs.

Ideal Use of a Flyback Converter

A flyback topology is typically the first-choice topology for an isolated power supply when a simple low-cost solution is required. Flyback topologies are also very useful for generating multiple voltages. Only a single output is typically regulated, but it is straightforward to add windings to the transformer for additional voltage rails. A flyback converter is generally acceptable up to an output level no greater than 150W. Above this power level, other topologies more suitable for greater power levels should be considered. In comparison to all of the other isolated topologies, the flyback topology uses the least components and therefore typically has the smallest footprint, particularly at low power levels. The flyback converter uses a single FET to energize the transformer, utilizes a single-output diode, and does not need an output inductor. As a result, the current to the output is discontinuous and the output voltage ripple will be greater.

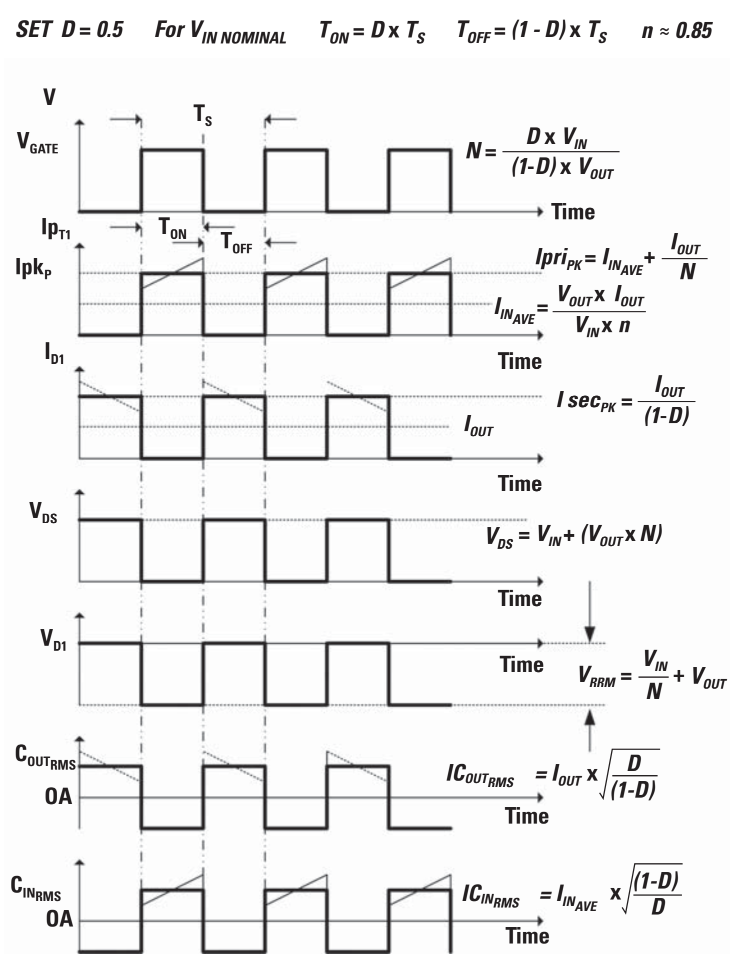

Figure 2. Flyback Converter Waveforms

Isolated Supply Overview and Design Trade-Offs

The transformer is automatically reset by the output voltage during the off period and therefore does not require a reset winding.

Forward Converter, Single-Ended Topology

Operation of a Forward Converter

The forward converter is a buck-derived topology and, as such, it has a non-pulsating output current due to the usage of an output inductor. This topology uses a reset winding (Nr) on the transformer to reset it. When Q1 is turned on, D1 is forward biased, the voltage across the secondary is equal to V_{IN}/N, and D2 and D3 are reverse biased. V_{IN} is applied to the primary winding and the magnetizing current increases at a rate of V_{IN}/LM, where LM is the magnetizing inductance.

The maximum duty cycle is set to less than 50% if Np = Nr. The transformer is reset during the Q1 off interval (1-D).

During the (1-D) period, Q1 is turned off but the magnetizing current must continue to flow, causing the voltage across Np to reverse. The current commutates through D3, decreasing the magnetizing current in Np and resetting it to zero. During this period, D1 is reverse biased and the output current then flows through D2. D2, as in a buck converter, acts as a free-wheeling diode.

Ideal Use of a Forward Converter

The forward converter is relatively simple compared to the bridge topologies, making it a popular choice for isolated supplies up to 200W of output power. Like the flyback converter, it uses a single FET to magnetize the primary of the transformer. However, because a forward is buck derived, the output inductor ensures continuous current flow to the output capacitor, which reduces the RMS ripple currents in it.

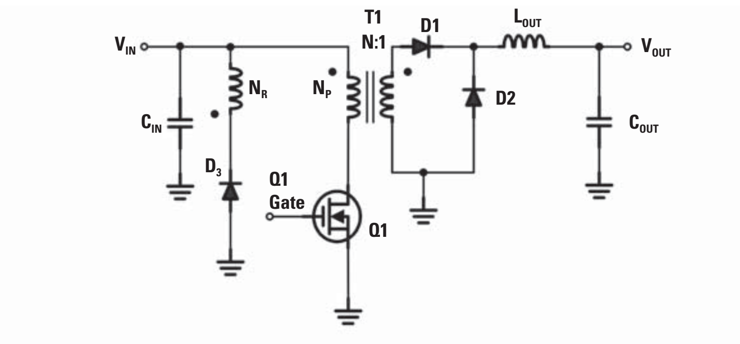

Figure 3. A Forward Converter

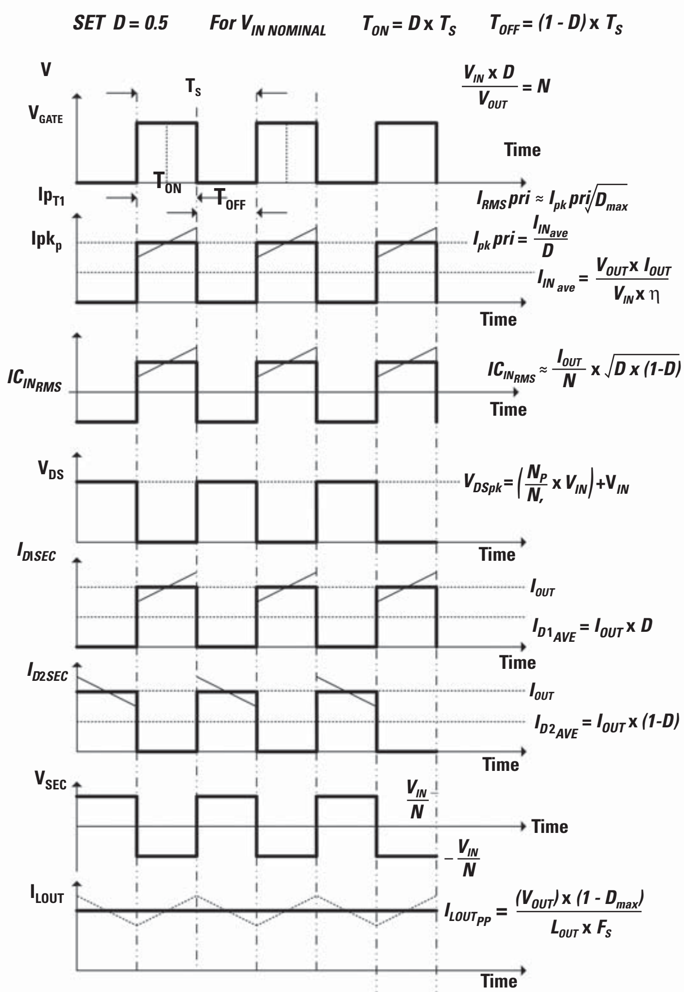

Figure 4. Forward Converter Waveforms

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Active-Clamp Forward Converter

Operation of an Active-Clamp Forward Converter

During the on (D) period, V_{IN} is applied to the primary of the transformer. The voltage on the secondary is V_{IN}/N and the magnetizing current increases at a rate of V_{IN}/LM.

During the (1-D) interval, Q1 turns off and Q2 turns on. The magnetizing current continues to flow in the same direction, but now it flows through Q2. Due to the volt-second balance of the transformer, $V_{IN}/(1\text{-}D)$ is seen across the C-clamp capacitor (also referred to as the reset voltage). The voltage across the primary and the magnetizing inductance is now reversed and the magnetizing current in the primary now ramps down to a negative value since $V_{IN}/(1\text{-}D)$ is larger than V_{IN}. Due to the volt-second balance of the flux, this completely resets the magnetizing current to where it was at the start of the switching period.

It is important to note that synchronous FETs replace the diodes in the forward configuration. This highlights one advantage of the active clamp forward; namely, it lends itself well to self-driven synchronous rectification. Unlike a typical forward, the active clamp drives the sync FETs over the complete switching period, yielding greater efficiencies.

As a cautionary note, the benefits of synchronous rectification diminishes as the V_{OUT} increases beyond 12V due to switching losses, thereby increasing total FET losses.

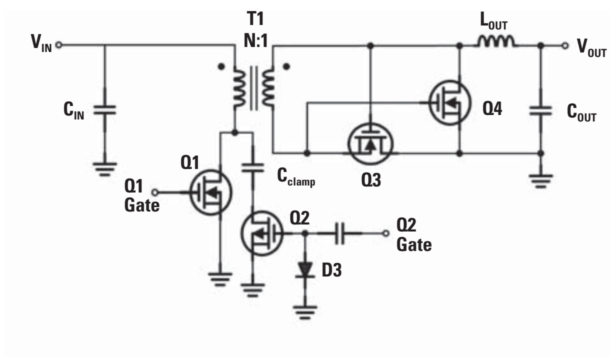

Figure 5. An Active-Clamp Forward Converter

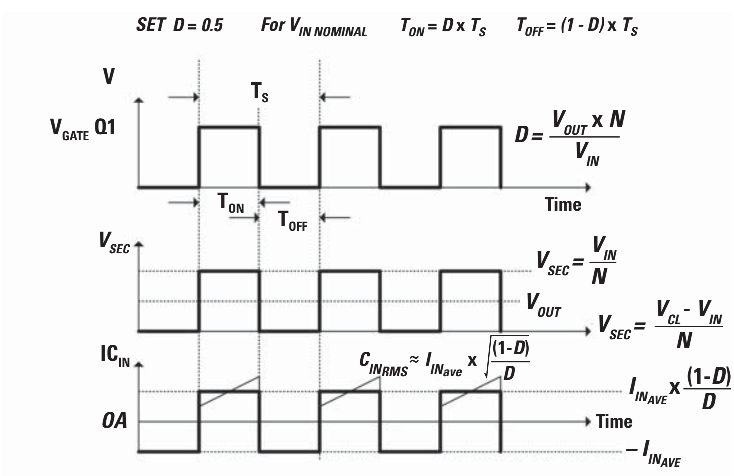

Figure 6. Active-Clamp Forward Converter Waveforms

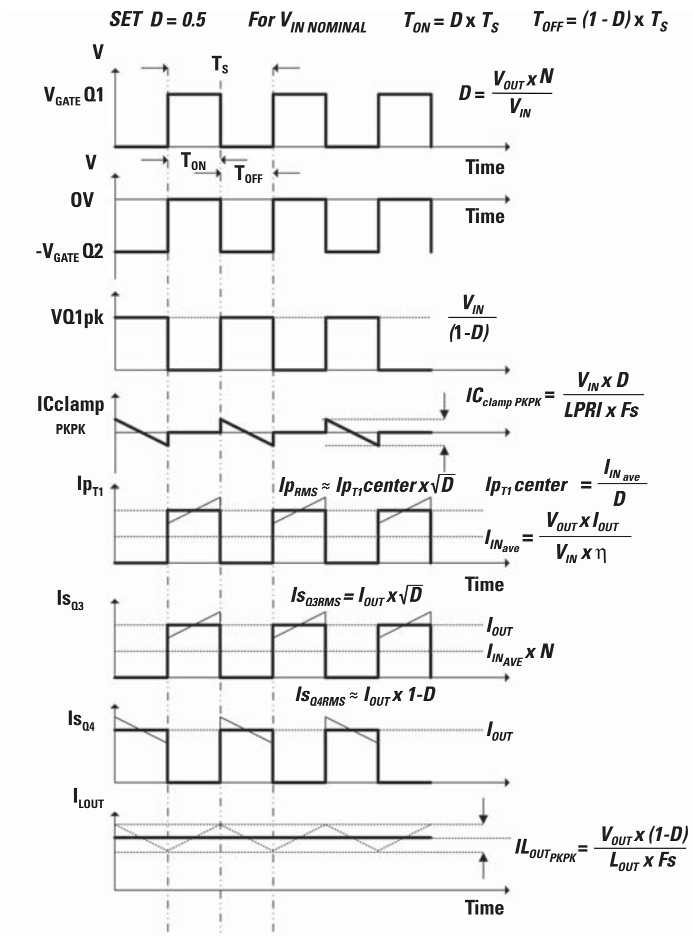

Figure 7. Active-Clamp Forward Converter Waveforms (Continued)

Ideal Use of an Active-Clamp Forward Converter

The addition of the active clamp to the forward converter allows the realization of greater efficiencies through the use of synchronous FETs, the elimination of switching losses in the primary FET due to zero voltage switching (ZVS), and the non-dissipative reset of the transformer recycling the leakage inductive energy back to the input. Another benefit is lower EMI due to soft switching which makes this topology an ideal choice for low-noise applications.

Push-Pull Converter

Operation of a Push-Pull Converter

The push-pull converter is essentially an interleaved forward converter whose primary winding is made up of a center-tapped transformer. The push-pull converter is prone to flux imbalance problems and therefore current-mode control, rather than voltage-mode control, is recommended. The transformer for a given output power is smaller than that of a forward converter since the core is utilized in Quadrant 1 and 3 of the BH-loop curve.

Q1 conducts during the D period followed by Q2 conducting for an identical length of time during another D period, attaining volt-second balance on the primary winding. During the 1-D period, both FETs are off. The 1-D period follows each of the respective D periods. During the two D periods, V_{IN} is seen from the center tap to the drain of its respective FET. The non-conducting winding will see a reversal in voltage to maintain volt-second balancing, yielding twice the input voltage across the total primary-side winding and as seen by the drain of the non-conducting FET. The same voltage is seen on each half of the secondary, during each D period - scaled by a factor of N. The diodes provide rectification of each of the two D periods, producing a 2 x F_{SW} pulsating voltage waveform at the left side of L_{OUT}, from 0V to V_{IN} x D/N. The diode D1 conducts during the same D period that Q2 conducts. The diode D2 conducts during the same D period that Q1 conducts. It should be noted that during the two 1-D periods, neither Q1 nor Q2 is on, and diodes D1 and D2 both conduct to maintain current flowing into L_{OUT}. As is the case with the buck converter during the (1-D) period, D1 and D2 conduct simultaneously and act as the free-wheeling pass element.

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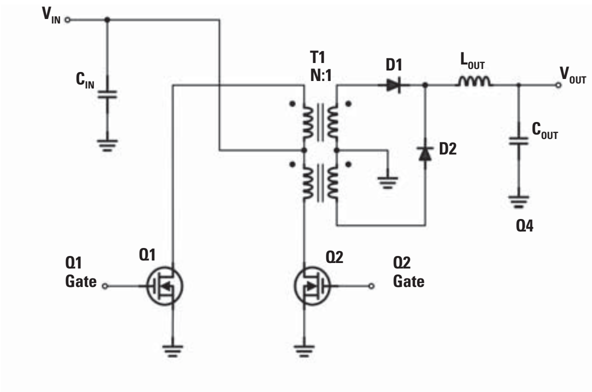

Figure 8. A Push-Pull Converter

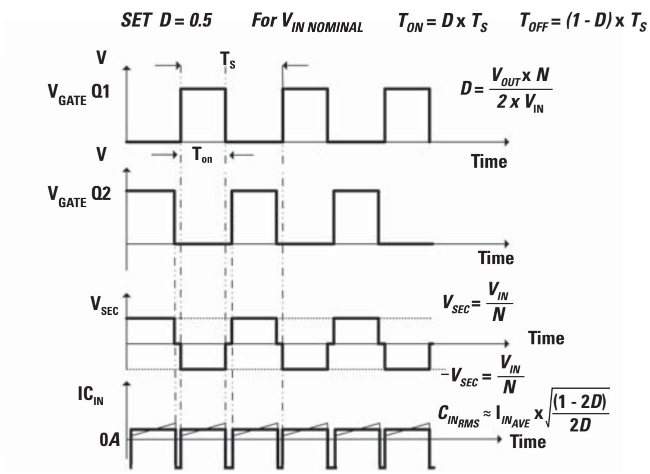

Figure 9. Push-Pull Converter Waveforms

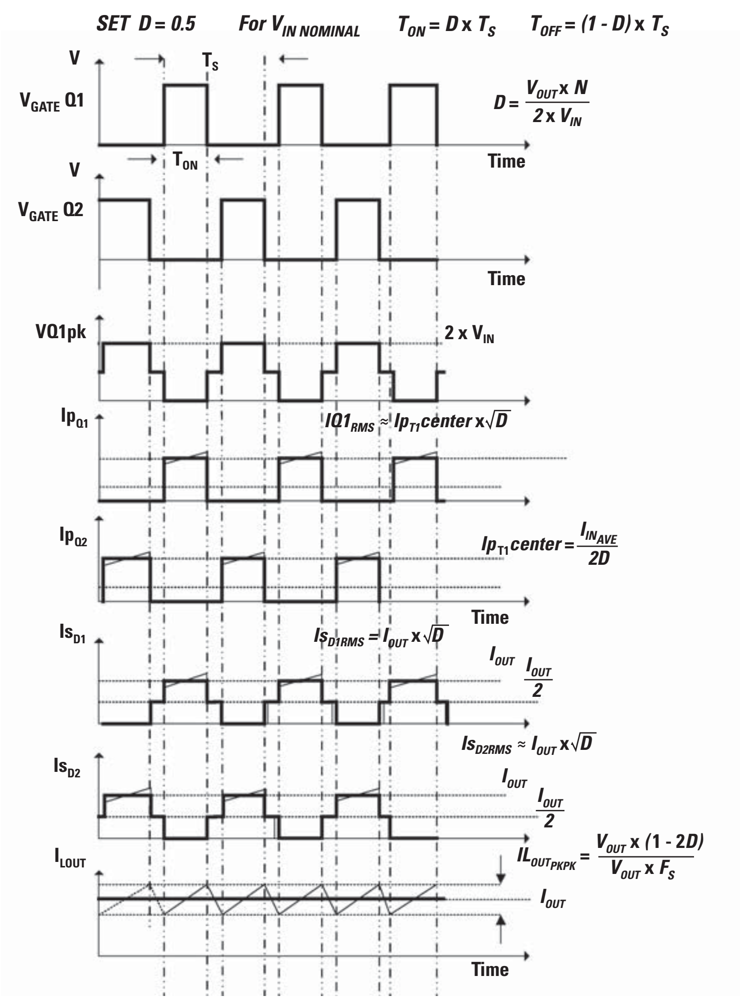

Figure 10. Push-Pull Converter Waveforms

Isolated Supply Overview and Design Trade-Offs

Ideal Use of a Push-Pull Converter

A push-pull converter operates as an interleaved forward converter and is ideal for higher-power designs above 200W. The push-pull converter has all the benefits of a forward converter while exhibiting lower input and output ripple currents compared to the forward, thus having smaller filter components. The push-pull converter can operate over the full duty cycle from zero to one. The FETs of a push-pull converter need to be rated at 2 x V_{IN}. The push-pull converter typically has flux imbalances in the transformer and, as a result, magnetizing current is not reset to zero. Over consecutive cycles, the flux density in the core accumulates to higher and higher levels, eventually driving the core into saturation. Therefore, current-mode control should be used to ensure proper and complete reset of the transformer.

Half-Bridge Converter

Operation of a Half-Bridge Converter

The half-bridge converter is also buck derived and uses a center-tapped secondary and the turns ratio can be considered as N: 1:1, where the 1s are each of the center-tapped secondary windings.

During the D period, Q1 turns on and $V_{IN}/2$ is seen across the primary winding. During this same period, half of the V_{IN} voltage is transferred to the secondary, forward biasing D1 by a voltage equal to $V_{IN}/2N$.

During the following D period, Q2 turns on and Q1 is off. And $-V_{IN}/2$ is seen across the primary, resetting the magnetizing current in the core. Diode D2 is forward biased by $–V_{IN}/2N$ and diode D1 is reversed.

The voltage seen at the left side of L_{OUT} is identical to the push-pull converter; namely, switching at twice the primary side frequency and traversing from 0V to $V_{IN}/2N$.

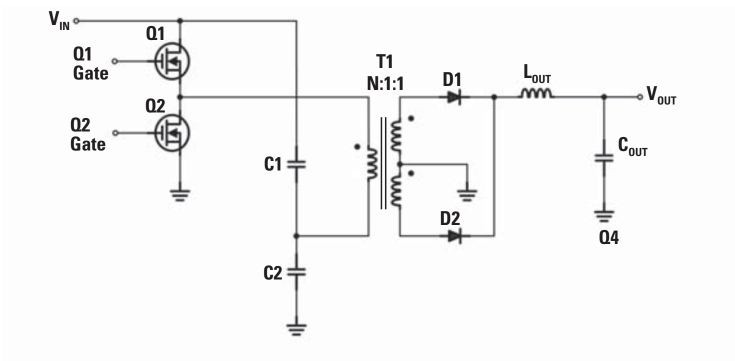

Figure 11. A Half-Bridge Converter

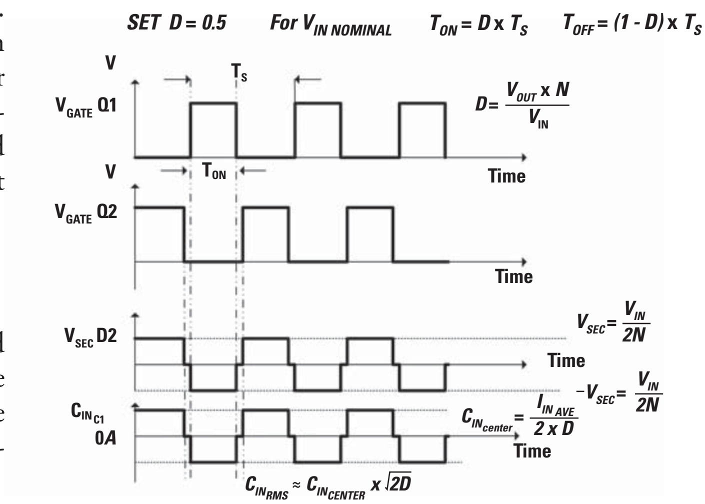

Figure 12. Half-Bridge Converter Waveforms

As is the case with the push-pull converter during the two (1-D) periods, neither Q1 nor Q2 is on and diodes D1 and D2 both conduct to maintain current flowing into L_{OUT}.

Due to the differences in capacitances in C1 and C2, the voltage across them will not be identical and current-mode control will worsen the voltage imbalance causing one capacitor to discharge to zero and causing the half- bridge converter to stop working.

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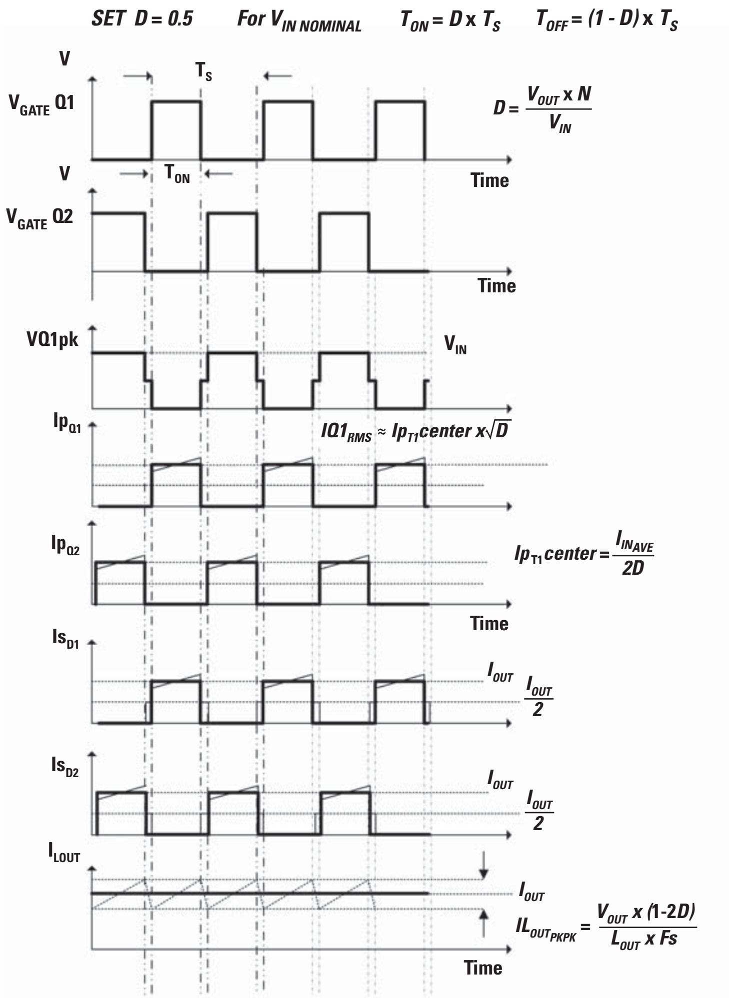

Figure 13. Half-Bridge Converter Waveforms (Continued)

Ideal Use of a Half-Bridge Converter

A half-bridge converter is ideal for higher-power designs such as 200W and above. The half-bridge converter competes with the push-pull converter in these applications.

A half-bridge converter exhibits lower input and output ripple currents compared to the forward and flyback converter, thus having smaller filter components. The half-bridge converter exhibits voltage differences across the input capacitors and as a precaution, current-mode control should be avoided.

Summary

The flyback converter is the smallest and simplest of the isolated topologies and is recommended for low-power applications up to 150W. The forward converter has improved performance over the flyback and should be considered for low-power applications up to 200W. The active-clamp forward converter has higher efficiencies than the forward converter and is the first choice for low-noise applications. For power levels over and above the limitations of flyback, forward, and active-clamp forward converters, push-pull and half-bridge converters should be considered.

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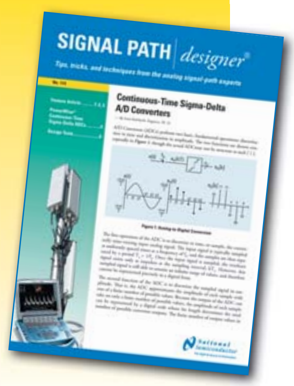

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