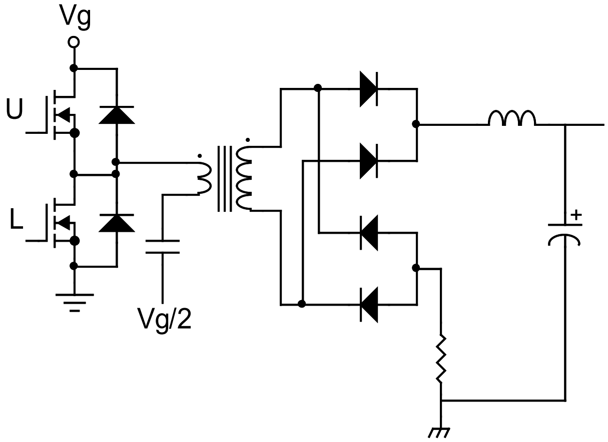
Half-Bridge Circuit Behavior

by Dennis L Feucht

Of the various forward-switching converter circuits, the half-bridge can be one of the most difficult to design correctly. It is often the optimal choice of converter in a power range between series-forward and full-bridge circuits. It uses the same number of power switches as the series-forward converter, yet provides full-wave flux drive to the transformer, halving its core size. It uses two active switches as a half-bridge and two series capacitors to provide a voltage midway between the power rails. These capacitors can complicate behavior. This article explains a different complication, the transformer secondary currents. Once secondary circuit behavior is understood, yet another problem -- that of transformer-diode resonances -- can be addressed. Despite the problems with the conventional half-bridge, elegant solutions can transform it into one of the most attractive and reliable converter topologies.

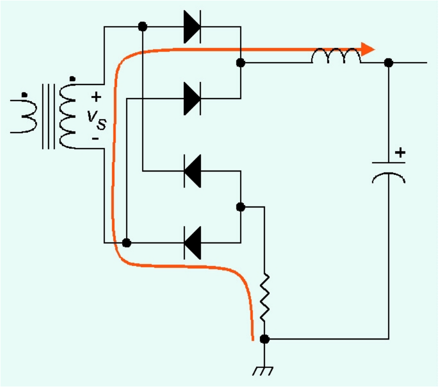
Half-Bridge Circuit

A half-bridge circuit is used as the primary-side driver of a common-passive (CP) or buck-derived *forward* converter, as shown below:



On successive half-cycles of the drive (corresponding to the on-times of active switches U and L), the transformer flux is driven with opposing polarities, resulting in full core utilization. A full-wave diode bridge circuit also allows full utilization of the transformer secondary winding, delivering power to the output on both half-cycles. The diode bridge drives an inductor followed by a capacitor with the output voltage across it of V_o.

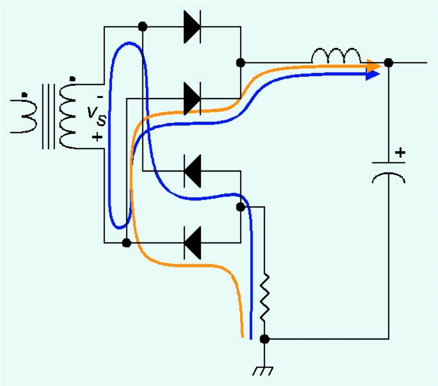
The full switching cycle starts when switch U turns on, starting time interval t_{on+}. A voltage of $V_g/2$ is applied to the primary winding and current quickly ramps up across the leakage inductance, delivering secondary current, as shown below. When $v_s > V_o$, the top and bottom diodes conduct. Inductor current,



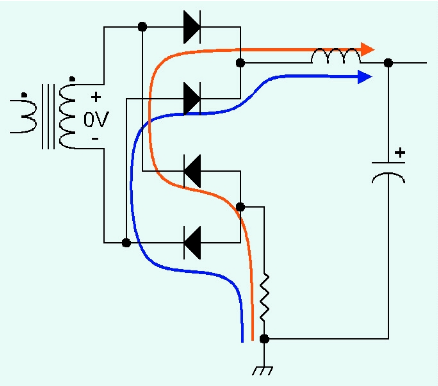
i_L, ramps up.

When switch U turns off, starting t_{off+}, the primary winding is clamped by the diode shunting switch L. This causes v_s to reverse polarity, and the transferred current quickly ramps down, as the primary winding voltage opposes it across the leakage inductance. The magnetizing current, i_m, concurrently transfers to the secondary (as $n \cdot i_m$, shown below in blue), where it is opposed by V_o and decreases.

If $n \cdot i_m < i_L$ it is then part of the inductor current. The remaining i_L flows through bridge diodes as clamp current (in red). Only the top diode is off because v_s opposes its conduction.



If $n \cdot i_m$ decreases to zero during the off-time, then v_s collapses to zero and all four bridge diodes conduct, as shown below:

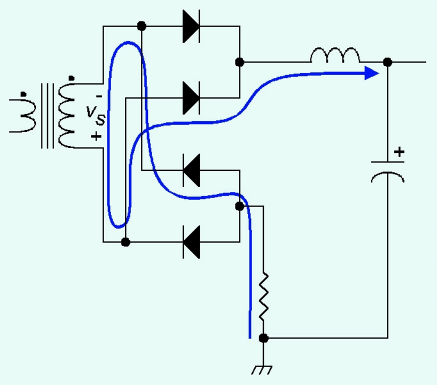


During off-time, the bridge is shorting the secondary winding while delivering inductor current. The inductor current splits between the shunt series-diode branches. This short refers back to the primary winding as 0 V.

At the beginning of t_{on+}, the secondary clamp diodes turn off. During turn-off, the secondary current through top and bottom diodes delivers turn-off (diffusion) current to the other diodes, which can be a large current pulse during their reverse recovery. After the inner diodes shown above are off, conduction occurs through top and bottom diodes during t_{on+}.

When t_{on+} begins, the magnetizing current adds to the secondary current, and transfers back to the primary winding when it changes polarity. As secondary current quickly increases with $V_g/2$ applied to the leakage inductance, the secondary clamp diodes begin reverse recovery only when the secondary current equals i_L, causing the clamp-diode current to go to zero. When the clamping diodes turn off, the capacitance at the input-terminal node of the inductor has been discharged (by the clamping action) to near-0 V, and the full secondary current flows into it, exciting a resonance with the secondary leakage inductance. This resonance typically requires a series RC damping network.

For the negative half-cycle, switch L turns on and t_{on-} commences, as shown below. The behavior is symmetrical with the positive half-cycle.



During t_{off-}, primary current flows in the upper diode shunting switch U. And for $n \cdot i_m < i_L$, $n \cdot i_m$ contributes to i_L and the remaining inductor current flows through the third and top diodes so that only the bottom diode is off. If $n \cdot i_m$ decreases to zero during t_{off-}, then inductor current splits between the diode branches from ground.

During diode turn-off, the reverse (turn-off) current increases at some *di/dt* (smaller with faster diodes) as diode diffusion charge flows out of the forward-biased junction and the forward voltage collapses. At peak reverse (recovery) current, the reverse voltage across the diode then quickly increases as *di/dt* changes polarity. The remaining reverse current charges the reverse-biased diode junction capacitance.

Closure

The secondary turn-on resonance can be problematic in that the resulting oscillatory waveforms can exceed component voltage ratings. A series RC damping network can be applied across the secondary, but the power dissipation in this network makes it unattractive. In an Innovatia 750-W charger design, this problem is solved by taking one of the elements of the problem -- the transformer leakage inductance (which resonates with the secondary diode capacitances) -- and turning it into an advantage. The resonance is modified to become a desirable aspect of the overall behavior. For more on this new zero-power-switching half-bridge converter topology and the problem with series capacitances in the primary, get the e-booklet on the 750-W converter from www.innovatia.com

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