Flyback Transformer Leakage Inductance, Part 2

Primary-to-Secondary Current Transfer

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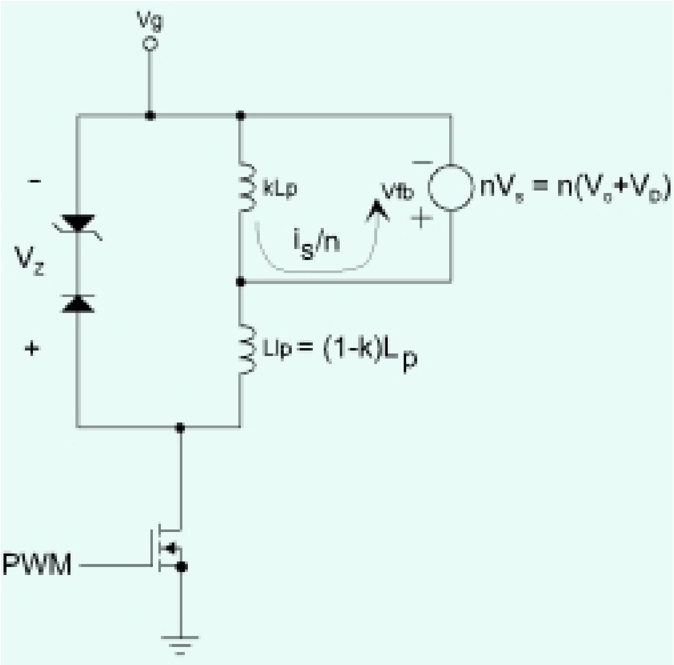
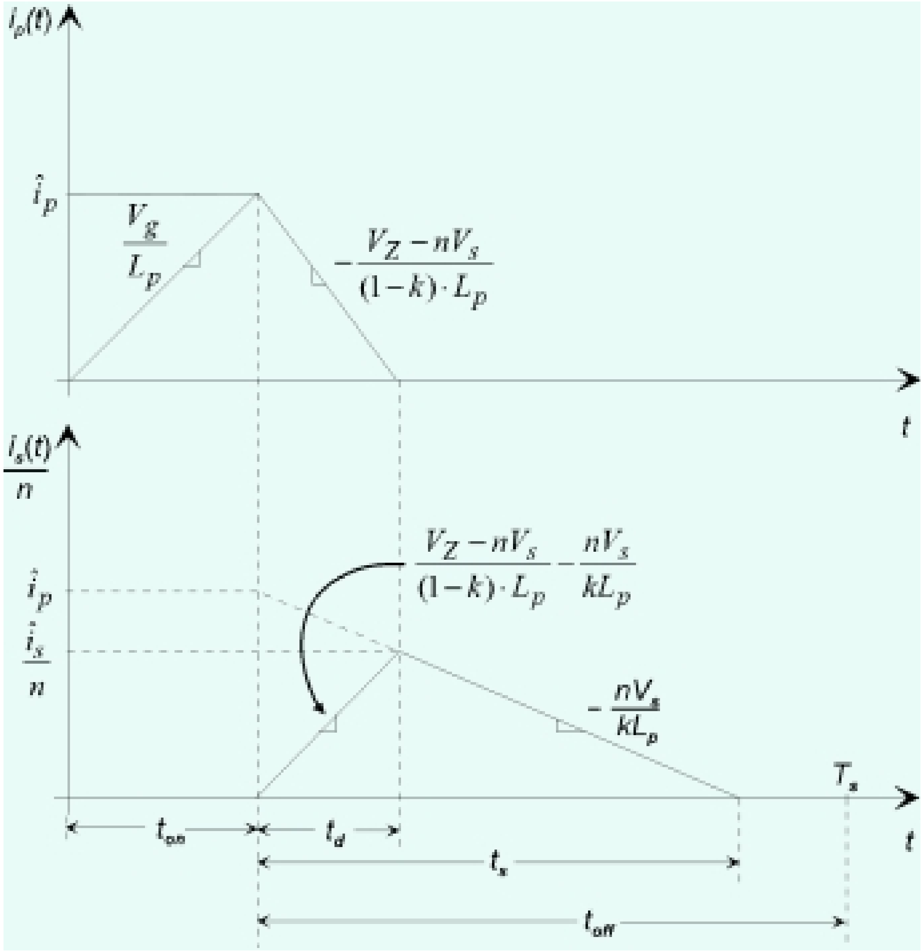
When a flyback converter's primary power switch turns off, current is transferred from the primary to the secondary winding. This does not occur instantaneously and the transfer delay depends on the primary-side clamp voltage. This current-transfer phenomenon is examined here.

Flyback Circuit Current Transfer

Continuing from Part 2, a Zener diode clamp, with its simplified constant-voltage clamping characteristic, is shown in the flyback circuit below.



The associated current waveforms are shown below.



Current transfers from the primary to the secondary winding during the period t_d, as shown. The slopes of the current ramps of the two waveforms are derived as follows.

The primary supply voltage, V_g, is applied to the primary winding of inductance L_p during t_{on}, the time the power switch (the MOSFET in the circuit above) conducts. For a flyback circuit the secondary circuit diode is reverse-biased and no secondary current flows. Then the switch turns off, and clamp and secondary current conduct. The secondary circuit refers its output voltage plus diode drop, $(V_o + V_D) = V_s$, as the secondary winding voltage to the primary by turns ratio, n, as $n{\cdot}V_s$. This is the *flyback voltage*,

$$V_{fb} = n \cdot V_s\ ,$$

that occurs across the mutually-coupled part of the primary winding ($k{\cdot}L_p$), as shown in the schematic. The secondary current referred to the primary, is i_s/n, and is plotted as a function of time in the lower graph.

The primary-side current (which is the clamp current) ramps down at a rate determined by the voltage across the primary leakage inductance, L_{lp}. This voltage is the difference between the clamp voltage, V_Z, and the flyback voltage, V_{fb}. It decreases by the peak primary current in time t_d, which can now be expressed as the change in current over the slope:

$$t_d = \frac{-\hat{i}_p}{-\frac{V_Z - nV_s}{(1-k)\cdot L_p}} = \frac{(1-k)\cdot L_p}{V_Z - nV_s} \cdot \hat{i}_p$$

In the lower plot the secondary current is referred to the primary circuit. It ramps up at the clamp-current rate (from the upper plot) minus the rate of $V_{fb}/k\cdot L_p$, which is the decay rate of the secondary current. The two slopes combine as terms shown by the arrow on the lower plot.

The finite transfer time causes the peak secondary current to be less than it would be for instantaneous transfer. In that case, primary current is $\hat{i}_p$ at turn-off, and secondary current would commence instantaneously with a peak value of $\hat{i}_p \cdot n$. This lost current is, in effect, retained on the primary side and the associated power dissipated in the clamp. In other words, by the time the secondary current ramps up to its peak, the secondary-current decay rate has reduced it to less than $\hat{i}_p \cdot n$. The actual peak secondary current (referred to the primary) is expressed as follows:

$$\frac{\hat{i}_s}{n} = \left(\frac{V_Z - nV_s}{(1-k)\cdot L_p} - \frac{nV_s}{kL_p}\right)\cdot t_d = \hat{i}_p \cdot \left[1 - \left(\frac{1-k}{k}\right)\cdot\left(\frac{nV_s}{V_Z - nV_s}\right)\right] = \hat{i}_p \cdot (1-\alpha)$$

The loss term for $\hat{i}_p$ is α..It depends on coupling coefficient, k, V_{fb}, turns ratio, and V_Z. Usually, $k \cong 1$, and V_{fb} is determined by converter design. Consequently, V_Z is the controlling variable for peak secondary current. By minimizing t_d, which is equivalent to maximizing V_Z given all else, current transfer efficiency is maximized.

Closure

A finite time is required for flyback current to transfer completely from primary to secondary winding. This time is affected mainly by the one design variable free to be chosen, the clamp voltage V_Z. The higher V_Z is, the higher the secondary peak current. The transfer efficiency can be assessed either as transfer time, t_d, which must be short relative to the switching period, T_s, or by the loss factor, α. Expressions for both were derived above and are the key clamp design equations.