[Flyback transformer tutorial: function and design]

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The low cost, simplicity of design and intrinsic efficiency of flyback transformers have made them a popular solution for power supply designs of below 100W to 150W. Other advantages of the flyback transformer over circuits with similar topology include isolation between primary and secondary and the ability to provide multiple outputs and a choice of positive or negative voltage for the output.

This article discusses design parameters for the flyback or swinging choke type of transformer used in flyback converters. The latter has been used for many years and its topology is unique within the transformer-isolated family of regulators.

Flyback transformer function

When the switch is turned on, energy is stored in the primary (within the core material). As shown in Figure 1, the polarity dots on the transformer and the diode are arranged such that there is no energy transferred to the load when the switch is on. When the switch is turned off, the polarity of the transformer winding reverses due to the collapsing magnetic field, the output rectifier conducts and the energy stored in the core material is transferred to the load. This activity continues until the core is depleted of energy or the power switch is once again turned on.

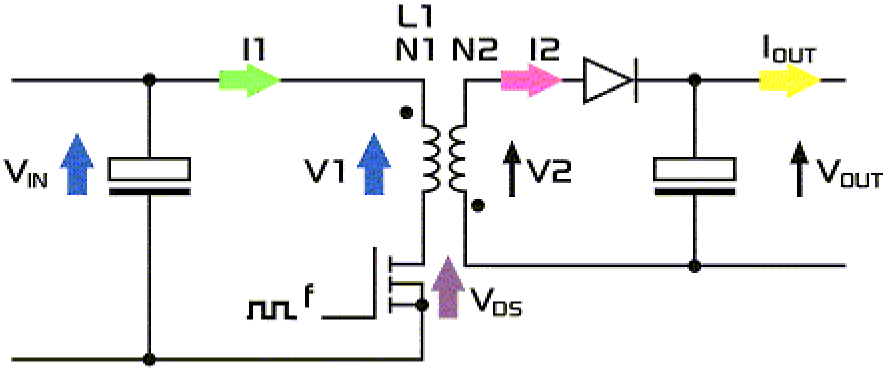

Figure 1. Typical flyback transformer circuit

The flyback regulator can operate in either discontinuous or continuous mode. In the discontinuous mode (see Figure 2), the energy stored in the core when the FET is on/off is completely emptied from the core during the flyback period. In the continuous mode, (see Figure 3) the FET is turned on before the core empties of flyback energy. A typical flyback transformer may operate in both modes depending on the load and input voltage.

Designers should consider the maximum load at low voltage, including all conditions within the operating range of the flyback, as it will simply shut down (discontinuous mode) between cycles and wait for the load demand to catch up with the power-delivery capability. This is one of the most dynamic characteristics of the flyback, regulated over a wide range of input voltage and load.

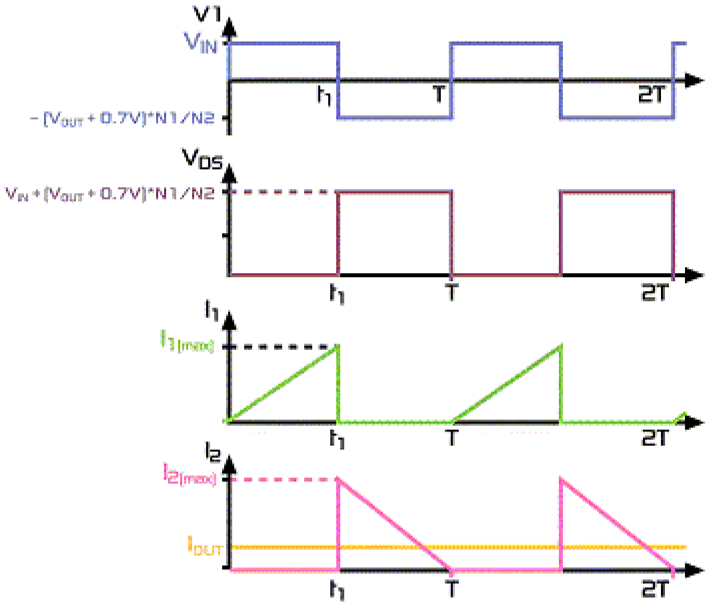

Figure 2. Flyback transformer in discontinuous mode

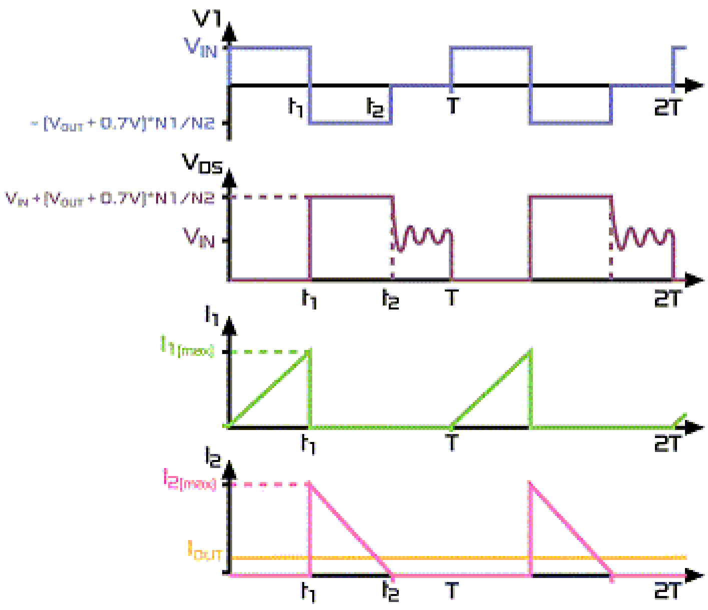

Figure 3. Flyback transformer in continuous mode

Flyback design parameters
Design parameters for a flyback transformer

The following equations are frequently used to specify a flyback transformer. They are followed by a typical design example.

Let V= L d_j/d_t, and $V_{in,min}$ =
$(L_p I_{pp} f)/(\delta_{max})$
Where V_{in} = input voltage, V
L_p = primary inductance, mH
I_{pp} = peak current, A
δ_{max} = maximum duty cycle, μs
f = operating switching frequency, kHz

For discontinuous mode,
Power out = $\frac{1}{2} * L_p * I_{pp} * f$
$I_{pp} = (2P_{out})/(V_{in,min} * \delta_{max})$

In the flyback transformer, as mentioned above, regulation is accomplished by PWM. If the transformer V_{in} varies from $V_{in,min}$ to $V_{in,max}$, then
$\delta min = (\delta max) / ((1- \delta max)C + \delta max)$
where $C = V_{in,max} / V_{in,min}$

Since I_{pp} is known,
$L_p = (V_{in,min} * \delta_{max}) / (I_{pp} * f)$

Although designers may rely on experience for core selection, that can only result in an approximation. The following formula is recommended for a better estimate.

$A_c * A_e = (((6.33*4)*L_p*I_{pp}*D)*10^8) / B_{max}$.
Where A_c = winding area, cm
A_e = core effective area, cm
$B_{max} = B_{sat}/2$, Gauss. Consult core manufacturers for material and loss vs. frequency
D = diameter of wire, inch

Air gap must be calculated for the flyback transformer, since it is operating single-ended and uses only half the flux capacity. This may create potential for driving the core into saturation.

Gap (cm) = $l_g = ((0.4*\Pi*L_p*I_{pp})*10^8) / (A_e*B_{max})$

After the air gap length is determined, the primary and secondary number of turns can be found.

$N_{pri} = (B_{max}*l_g) / (.4*\Pi*I_{pp})$
$N_{sec} = (N_p(V_p + V_d)(1-\delta_{max})) / (V_{in,mi} n * \delta_{max})$

The following example demonstrates the design of a flyback transformer in the discontinuous mode. Modern designs utilize PFC (power factor correction), positioned immediately after rectification. Boost topology is frequently used for its dynamic characteristic and wide range of input voltage. PFC will not be covered in this example.

Design parameters

V_{input} = 85 to 132 VAC
V_{output} = 5VDC @ 10A = 50Watts
Frequency = 100kHz
Assume δ_{max} = .45

Discontinuous Mode

1) Calculate the peak I_{pp}
Since $V_{in,min}$ = 85VAC, then $V_{in,min}$ = 85*1.4-20V for ripple and diode drop gives about 100VDC.
Thus, $I_{pp} = 2P_{out} / (V_{in,min} * \delta_{max}) = 100 / (100*.45) = 2.22$ A

2) Calculate the δ_{min}
$V_{in,max}$ = 132VAC*1.4 = 185VDC
Allowing a 10% margin, $V_{in,max}$ = 203VDC, say 200VDC
Allowing a 10% margin for $V_{in,min}$ = 90VDC
This gives us an input voltage ratio C = 200/90 = 2.22
Therefore $\delta_{min} = .45 / ((1-.45)*2.22+ .45) = .27$
As is evident from these results, the transformer will operate over the duty ratio of 0.27 to 0.45 for the V_{in} range of 200VDC to 90VDC.

3) Calculate primary inductance
L_p = 90*.45 / (2.22*100kHz) = .18mH

4) Select core
In this example we will use a current density of about 300 cm/A. Since I_{pp} = 2.22A, a total centimeters will be 300*2.22 = 666 cm. From wire chart, 22 AWG has diameter of 0.028 inch. We chose Magnetics, Inc material type “P” and from their catalog selected B_{max} = 500 Gauss. This will give us about 100mW/cm.
Therefore,
$A_cA_e = (6.33*4) *(.00018Hy)*2.22*(.028)*(10^8) / (500) = 1.59$ cm^4.
From the catalog PQ43230 (PQ3230) size has A_cA_e = 1.60 cm^4.

5) Calculate the air gap length
$L_g = (.4*\Pi*.00018*(2.22)*10^8) / (1.37*(500)) = .30$ cm (approx) at center leg of the core.

6) Calculate primary and secondary number of turns
N_{pri} = 500*.30 / (.4*3.14*2.22) = 54 turns
N_{sec} = 54*(5 + 1) (1 - .45) / (90*.45) = 4.4 turns.
We will use 5 turns because there will be losses from winding, PCB and other parasitic losses which we did not include. Next select wire for the output. For 10A, a wire of 10*300 = 3000cm, we choose 16AWG for the secondary. To minimize copper losses due to skin effect, we propose using multiple strands of thinner wires (4 strands of 22 AWG is equivalent of single 16 AWG).

Design engineers must also check for bobbin fill factor and temperature rise calculations, as implementation of safety requirements will increase the size of the flyback transformer.

Custom flyback transformers

CoEv Magnetics offers a wide range of SMPS transformers to meet customer needs and requirements. Designed to optimize size, cost and performance for specific applications, custom transformer packages are developed using a wide range of parameters, including: - Turns ratio - Current Handling Capability
- Drive Levels - Inductance
- Leakage inductance - Self Resonant Frequency
- DC Resistance - Mounting Configuration
- Isolation Voltage

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