The Flyback Converter

Course Project
Power Electronics
Design and Implementation Report

by
Kamran Ali 13100174
Muhammad Asad Lodhi 13100175
Ovais bin Usman 13100026
Syed Bilal Ali 13100026

Advisor
Nauman Zaffar
[nauman.zaffar@lums.edu.pk@lums.edu.pk]

Reader

January 13, 2013
Department of Electrical Engineering
Syed Babar Ali School of Science and Engineering
Lahore University of Management Sciences, Pakistan
1 Introduction and Derivation

The flyback converter is based on the buck-boost converter. It is a transformer-isolated version of the buck-boost converter. Figures 1 to 4 show how a flyback converter can be derived from the basic buck-boost converter.

The basic function of the inductor is unchanged, and the parallel windings are equivalent to a single winding constructed of larger wire. Although the two-winding magnetic device is represented using the same symbol as the transformer, a more descriptive name is “two-winding inductor”. This device is sometimes also called a flyback transformer. Unlike the ideal transformer, current does not flow simultaneously in both windings of the flyback transformer. Figure 4 illustrates the usual configuration of the flyback converter. The MOSFET source is connected to the primary-side ground, simplifying the gate drive circuit. The transformer polarity marks are reversed, to obtain a positive output voltage. A 1:n turns ratio is introduced; this allows better converter optimization.

2 Analysis of the flyback converter

The behavior of most transformer-isolated converters can be adequately understood by modeling the physical transformer with a simple equivalent circuit consisting of an ideal transformer in parallel with the magnetizing inductance.

The magnetizing inductance must then follow all of the usual rules for inductors; in particular, volt-second balance must hold.

Figure 1: Buck-boost converter

Figure 2: Inductor L is wound with two parallel wires

Figure 3: Inductor windings are isolated, leading to the flyback converter
when the circuit operates in steady-state. This implies that the average voltage applied across every winding of the transformer must be zero.

Application of the principle of volt-second balance to the primary-side magnetizing inductance yields

$$\langle v_L \rangle = D(V_g) + D'(\frac{-V}{n})$$

$$M(D) = \frac{n_2D}{n_1(1 - D)}$$

where we have taken transformer’s turn ratio $n = \frac{n_1}{n_2}$.

Similarly, application of the principle of charge balance to the output capacitor $C$ leads to

$$\langle i_C \rangle = D(\frac{-V}{R}) + D'(\frac{I}{n} - \frac{V}{R})$$

$$I_m = \frac{n_2V}{n_1RD'}$$

where $I_m$ represents the dc component of the magnetizing current, referred to the primary. The dc component of the source current $i_g$ is

$$I_g = DI$$

Figures 5-8 show the process through which we arrived to above results. Figure 9 shows the equivalent circuit which models the dc components of the flyback converter waveforms can be constructed. It contains a $1:D$ buck-type conversion ratio, followed by a $(1 - D):1$ boost-type conversion ratio, and an added factor of $1:n$, arising from the flyback transformer turns ratio.

After taking the stress on the transistor (the active switching component) and $P_{load}$ into account, the Utilization factor of this
The flyback converter is commonly used at the 50–100W power range, as well as in high voltage power supplies for televisions and computer monitors. It has the advantage of very low parts count. Multiple outputs can be obtained using a minimum number of parts: each additional output requires only an additional winding, diode, and capacitor. The peak transistor voltage is equal to the dc input voltage $V_g$ plus the reflected load voltage $V_n$; in practice, additional voltage is observed due to ringing associated with the transformer leakage inductance. A snubber circuit may be required to clamp the magnitude of this ringing voltage to a safe level that is within the peak voltage rating of the transistor [1].

3 Design Specifications

Following are our design specifications
1) Output voltage ($V_{out}$) = 12 Volts
2) Input Voltage ($V_{in}$) = 332 Volts
3) Max Output Power = 50 Watts
4) Output Voltage ripple ($\Delta V_{out}$) = 0.1 Volts
5) Switching frequency ($f_s$) = 40 KHz

4 Design

- First we find that value of ‘D’, the duty cycle which maximizes the Utilization factor. Utilization factor for flyback converter is $U = \sqrt{D(1 - D)}$, from this equation we find the value of ‘D’ which maximizes the utilization, which comes out to be $D = \frac{1}{3}$.
- Next we find the desired turns ratio using $M(D)$. Plugging in $V_{out} = 12$ Volts, $V_{in} = 332$ Volts and $D = 1/3$ we get:
  \[ n = \frac{6}{83} \]
  - Finding the Load resistance value. Plugging in the $V_{out} = 12$ Volts and $P_{out} = 50$ Watts,
  \[ R = \frac{V_{out}^2}{P_{out}} \]
  \[ R = 2.88 \Omega \]
- Finding the Value of Capacitance. Plugging in the $V_{out} = 12$ Volts, $D = 1/3$, $T_a = 1/f_s$, $R = 2.88 \Omega$, and $\Delta V_{out} = 0.1$ Volts we get,
  \[ C = \frac{V_{out}DT_a}{2R\Delta V_{out}} \]
  \[ C = 69.4 \mu F \]
  We can use a value greater than this too but not smaller.
- Finding the value of Inductance (L): For the calculation of inductance, we first need to calculate a couple of things which are: $I_m$, $\Delta i_m$, $I_{m,max}$, $I_1$, $I_2$, and $I_{tot}$.

  The $I_m$ is calculated as:
  \[ I_m = \frac{n_2V}{n_1RD} \]
  Plugging the values in the above formula, we get:
  \[ I_m = 5/12 = 0.4167 \ A \]
  $\Delta i_m$ is kept to be 20% of $I_m$. So, the value of $\Delta i_m$ we get is:
  \[ \Delta i_m = 1/12 \ A \]
  $I_{m,max}$ is the sum of $I_m$ and $\Delta i_m$.
  $I_1$ is calculated by the formula
  \[ I_1 = I_m\sqrt{D}\sqrt{1 + \frac{1}{3}\left(\frac{\Delta i_m}{I_m}\right)^2} \]
  Plugging in the required values in the above formula, we get:
  \[ I_1 = 0.242 \ A \]
  $I_2$ is calculated by the formula
  \[ I_2 = \frac{n_1}{n_2}I_m\sqrt{D}\sqrt{1 + \frac{1}{3}\left(\frac{\Delta i_m}{I_m}\right)^2} \]
  Plugging the values in the above formula, we get:
  \[ I_2 = 5.137 \ A \]
  $I_{tot}$ is calculated by:
  \[ I_{total} = I_1 + \frac{n_2}{n_1}I_1 \]
  Plugging the values in the above formula, we get:
  \[ I_{tot} = 0.5846 \ A \]
• Finding the value of core parameters: We now need to find some of the parameters of the core:
1) Mean Length per turn (MLT)
2) Cross-Sectional area of wire
3) Winding area
4) Length of the air gap
5) Number of turns of the primary winding
6) Number of turns of the secondary winding
7) Fraction of window area allocation
8) Window area of a specific winding

The mean length per turn is calculated by finding the circumference of the core on which the windings are to be wound. In our case, it came out to be:

\[ \text{MLT} = 2(1.245 + 1.535) \text{ cm} \]
\[ \text{MLT} = 5.56 \text{ cm} \]

The cross sectional area is the area of the core on which the winding is to be wound. In our case, it came out to be:

\[ A_c = (0.97 \times 1.26) \text{ cm}^2 \]
\[ A_c = 1.22 \text{ cm}^2 \]

The winding area is the total area in which the windings will be placed. We are using EI-core, thus the total winding area is:

\[ W_A = 2(1.965 \times 0.795) \text{ cm}^2 \]
\[ W_A = 3.124 \text{ cm}^2 \]

The air gap is found by formula:

\[ l_g = \frac{\mu_0 L_m I_{m,\text{max}}^2}{A_c B_{\text{max}}^2} 	imes 10^4 \]
\[ l_g = 0.683 \text{ mm} \]

The number of primary windings is calculated as:

\[ n_1 = \frac{L_m I_{m,\text{max}}}{A_c B_{\text{max}}} \times 10^4 \]
\[ n_1 = 271.64 \]

The number of secondary windings is calculated as:

\[ n_2 = \frac{n_2}{n_1} \]
\[ n_2 = 19.63 \]

The fraction of window allocation is calculated by the following formula:

\[ \alpha_j = \frac{n_j I_j}{n_1 I_{\text{tot}}} \]
\[ \alpha_1 = 41.4\% \]
\[ \alpha_2 = 58.6\% \]

5 Implementation

Figure 10 shows the PCB we designed. It includes the Rectifier, Gate Derive Circuit and the main Flyback converter components. Moreover, figures 11 to 21 show implemented circuits and oscilloscope outputs (showing significant characteristics of the converter e.g. voltage across the active switch Q1 IGBT)
Figure 20: Voltage blocked by IGBT

Figure 21: Ringing effect due to the leakage inductance of transformer

References

[1] ecee.colorado.edu/ecen4517/materials/flyback.pdf