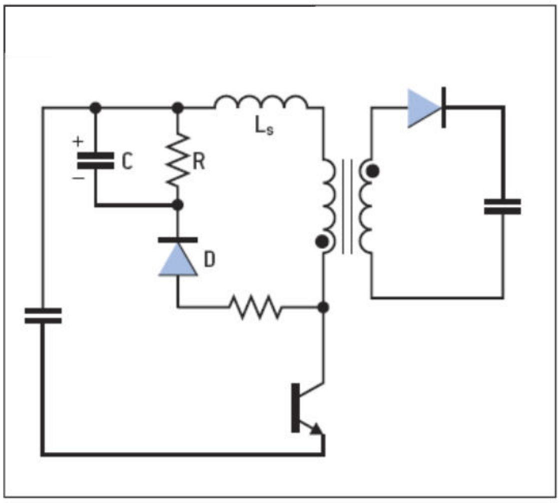

The Flyback Converter

Course Project
Power Electronics
Design and Implementation Report

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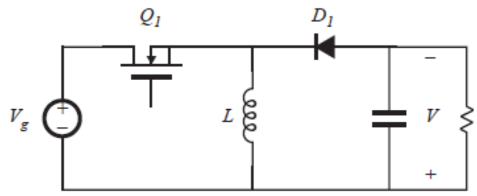

Figure 1: Buck-boost converter

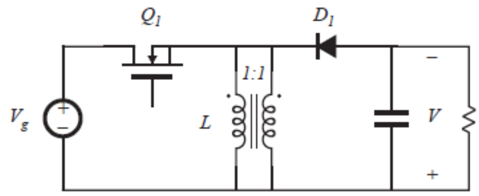

Figure 2: Inductor L is wound with two parallel wires

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

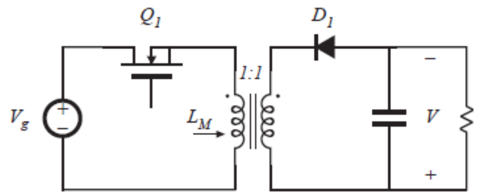

Figure 3: Inductor windings are isolated, leading to the flyback converter

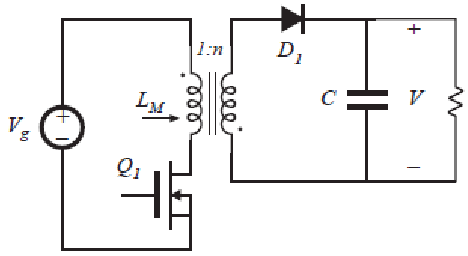

Figure 4: With a 1:n turns ratio and positive output

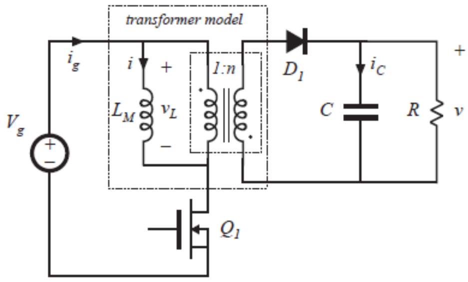

Figure 5: With transformer equivalent circuit models

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

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

$$M(D) = \frac{n_2 D}{n_1(1-D)}$$

where we have taken transformer's turn ratio n = n_1/n_2.

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

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

$$I_m = \frac{n_2 V}{n_1 R D'}$$

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

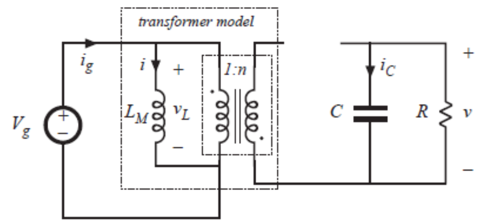

Figure 6: During subinterval 1

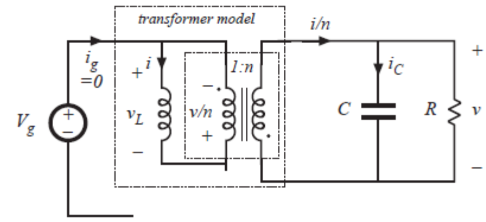

Figure 7: During subinterval 2

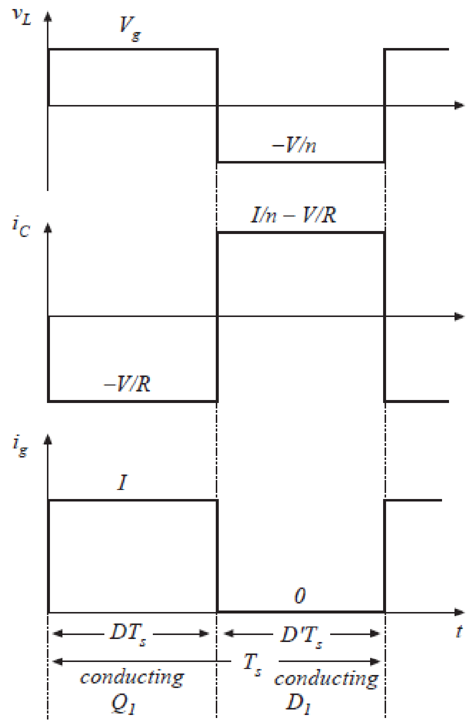

Figure 8: Flyback converter waveforms, continuous conduction mode

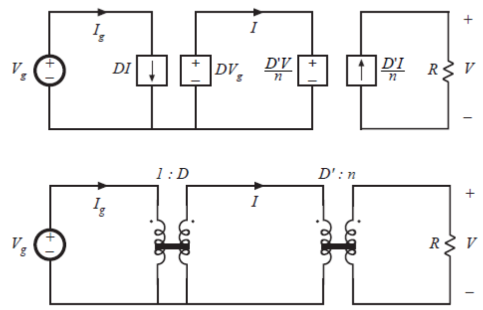

Figure 9: Flyback converter equivalent circuit models

converter comes out to be

$$U = \frac{P_{load}}{S_{total}}$$

$$U_{flyback} = \sqrt{D}(1-D)$$

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 (Vout) =12 Volts
2) Input Voltage (Vin) =332 Volts
3) Max Output Power = 50 Watts
4) Output Voltage ripple (ΔVout) = 0.1 Volts
5) Switching frequency (fs) = 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 Vout =12 Volts , Vin = 332 Volts and D=1/3 we get

$$n = \frac{6}{83}$$

- Finding the Load resistance value.

$$P_{out} = \frac{V_{out}^2}{R}$$

Plugging in the Vout = 12 Volts and Pout = 50 Watts,

$$R = \frac{V_{out}^2}{P_{out}}$$

$$R = 2.88\ \Omega$$

- Finding the Value of Capacitance. Plugging in the Vout = 12 Volts, D = 1/3, $T_s = 1/f_s$, R= 2.88 Ω, and ΔVout = 0.1 Volts we get,

$$C = \frac{V_{out} D T_s}{2R\Delta v_{out}}$$

$$C = 69.4\ uF$$

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, Δi_m, $I_{m,max}$, I_1, I_2, and I_{tot}.

The I_m is calculated as:

$$I_m = \frac{n_2 V}{n_1 R D'}$$

Plugging the values in the above formula, we get:

$$I_m = 5/12 = 0.4167\ A$$

Δi_m is kept to be 20% of I_m. So, the value of Δi_m we get is:

$$\Delta i_m = 1/12\ A$$

$I_{m,max}$ is the sum of I_m and Δi_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:

$$I_{tot} = 0.5846\ A$$

- inding 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:

$$MLT = 2(1.245 + 1.535)\ cm$$

$$MLT = 5.56\ cm$$

  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:

$$A_c = (0.97 \times 1.26)\ cm^2$$

$$A_c = 1.22\ cm^2$$

  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:

$$W_A = 2(1.965 \times 0.795)\ cm^2$$

$$W_A = 3.124\ cm^2$$

  The *air gap* is found by formula:

$$l_g = \frac{\mu_0 L_m I^2_{m,max}}{A_c B^2_{max}} 10^4$$

$$l_g = 0.683\ mm$$

  The *number of primary windings* is calculated as:

$$n_1 = \frac{L_m I_{m,max}}{A_c B_{max}} 10^4$$

$$n_1 = 271.64$$

  The *number of secondary windings* is calculated as:

$$n_2 = \frac{n_2}{n_1} n_1$$

$$n_2 = 19.63$$

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

$$\alpha_j = \frac{n_j I_j}{n_1 I_{tot}}$$

$$\alpha_1 = 41.4\%$$

$$\alpha_2 = 58.6\%$$

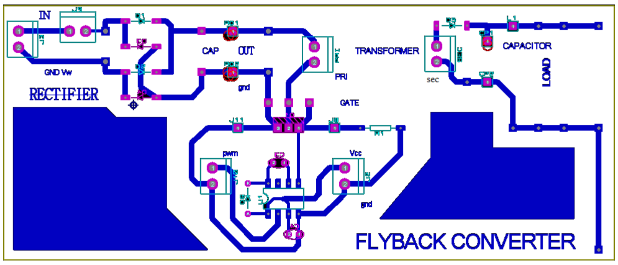

Figure 10: PCB Design

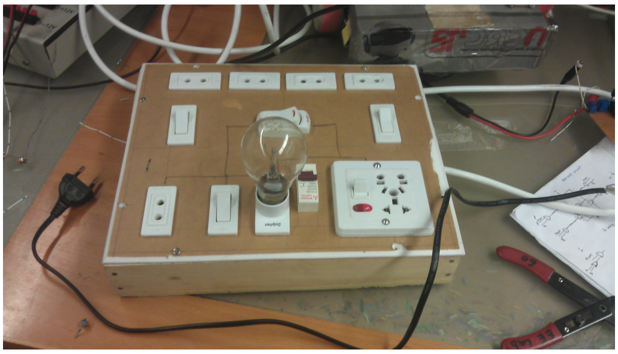

Figure 11: Protection Circuit with breaker and bulb

- The *wire sizes* are calculated as:

$$A_{w,k} = \frac{\alpha k K_\mu W_A}{nk}$$

$$A_{w,1} \leq 1.4285 \times 10^{-3}$$

$$A_{w,2} \leq 19.7 \times 10^{-3}$$

  The A'_ws are then matched from a *table to get the gauge of the wire* to be used.

$$Gauge_1 \geq 26$$

$$Gauge_2 \geq 15$$

  We used following gauge wires available in the lab. They meet the above requirements.

$$Gauge_1 = 28$$

$$Gauge_2 = 18$$

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)

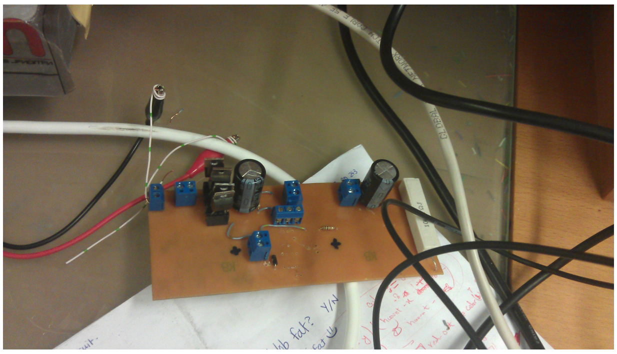

Figure 12: PCB Implementation

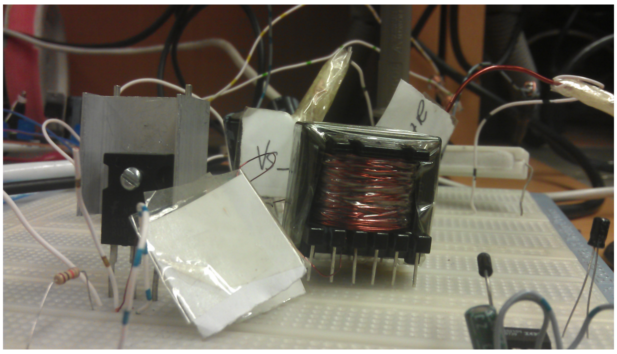

Figure 13: Flyback Transformer and IGBT

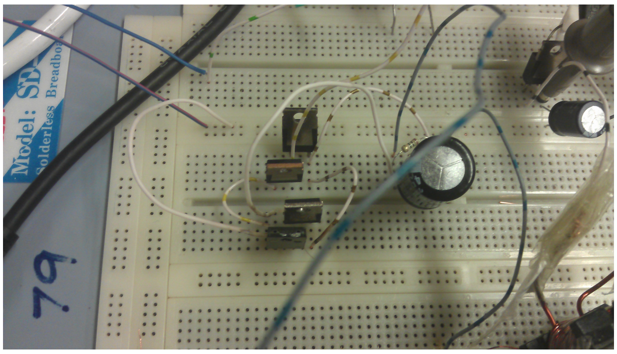

Figure 14: Rectifier

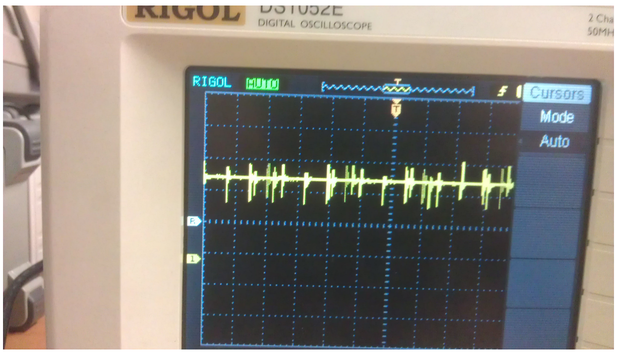

Figure 15: 12V-DC Output with ripple

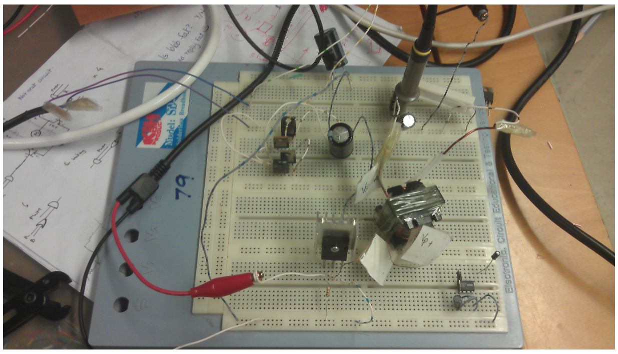

Figure 16: Breadboard Implementation

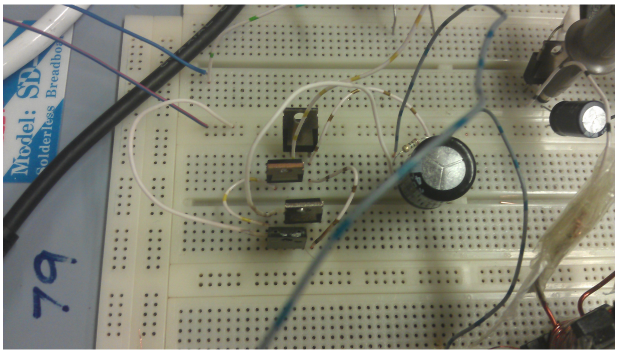

Figure 17: Rectifier

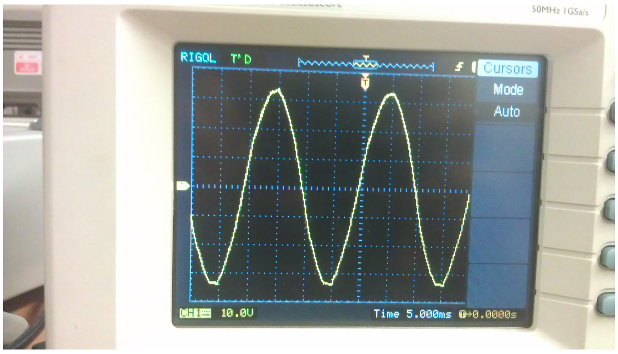

Figure 18: Input from mains

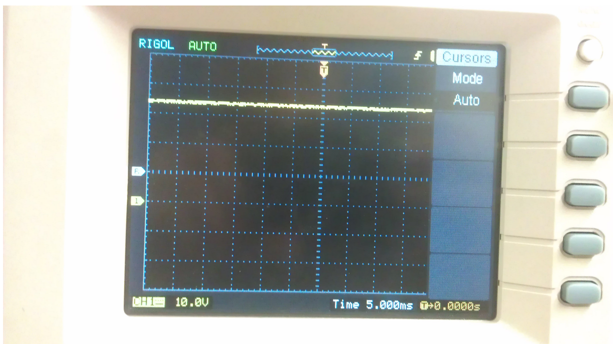

Figure 19: Rectified Output

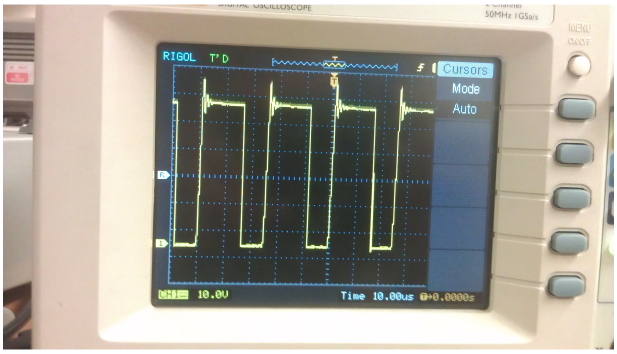

Figure 20: Voltage blocked by IGBT

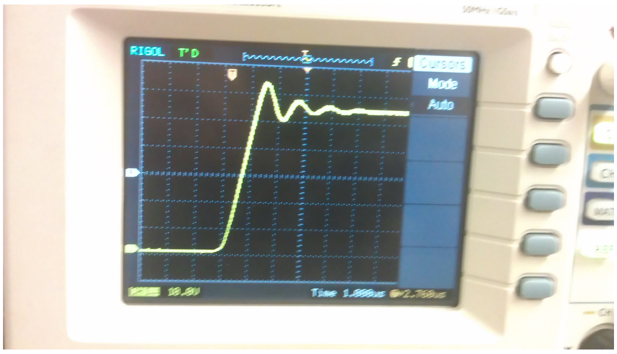

Figure 21: Ringing effect due to the leakage inductance of transformer

References

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

[2] R. W. Erickson: *Fundamentals of Power Electronics*