Flyback Converter Design for Low Power Application

Ashraf A. Mohammed and Samah M. Nafie
Research and Development center
Sudanese Electricity Distribution Company
Khartoum, Sudan

ashraf.abubaker.mohammed@gmail.com, samah.nafie@gmail.com

***Abstract*— Flyback converters have been quite used for DC-DC conversion and electrical isolation since they are simple to operate, minimum component count and small size. Flyback converter like any other switch mode power supply (SMPS) has two modes of conduction, the best mode for the design is selected and implemented. Due to its operation in relatively high frequency in range of 100 KHz compared to 50 Hz transformer with hard switching, some noises appeared from parasitic and leakage elements in the converter. The sources of noises have been tracked to minimize its effect on performance. The practical results obtained from the design implement actions are shown in this paper.**

***Index terms*— Flyback Converter, Flyback Transformer, Power Electronics, DC-DC Converter and SMPS.**

I. INTRODUCTION

Flyback converter used for transforming DC power supply in the range of few Watts to 150 Watts efficiently and with few components counts. For our application that requires delivering an average power of 200 milliWatt, a choke filter is used instead of power transformer. The purpose we used the transformer is to provide electric isolation between primary side and secondary side, which is required by safety standards for electronic devices.

Unlike AC transformer which requires simultaneously energy transfer, Flyback converter has to store energy in magnetizing inductance when the switch is on and transfer it to the secondary side when the switch is off. Hence the transformer magnetizing inductance is designed to be more in this type of transformer, to be able to store some amount of energy.

Due to the requirements to reduce energy and cost of electronic devices, switch mode power supplies has to operate in high frequency in order to use smaller and cheaper magnetics inductors and transformers. Smaller transformer means less inductance and the core can easily goes into saturation and make a short circuit, but the high frequency increases the impedance of the magnetic inductance and core saturation is prohibited. High frequency hard switching uncover series of problems made by leakage inductance and parasitic elements in the converter.

Flyback converter topology is used excessively in different applications and many papers and notes have been published about it, nevertheless only few of them considered the secondary leakage inductance effects on primary side and on performance [6]. The effect on performance will be discussed later on this paper since it was critical to our application.

In this paper we will talk about steps we made in our design with emphasis on the following subjects:

- Selecting the conduction mode for our Flyback converter to meet performance requirements.
- Track Source of Noise and attempt to eliminate it as far as possible.
- Show the practical results for the converter we have implemented.

II. CONDUCTION MODE

The main supply that gives the power to our flyback converter is capable to deliver maximum current of 17mA and 22V. There is other loads connected with it, therefore the flyback converter has to be efficient and not to draw current that will not be transferred to the secondary or it will be dissipated in the protection diode Zener diode. As a result of that requirement the flyback converter has to work in discontinuous conduction mode DCM. In DCM all energy stored in the inductor –when the switch is on- is transferred to the secondary side of the transformer when the switch is off, shown in Fig. 1. On the other hand continuous conduction mode CCM has some current remain in magnetizing inductance, as shown in Fig. 2. Not all of the current drawn from the main supply, stored in magnetizing inductance is dissipated by the load, though the average current drawn from the main is increased, this reduce the utilization of the converter. The DCM has the following advantages:

a. Better efficiency as mentioned above.

b. Faster transient response.

c. Lower primary inductance, consequently smaller transformer.

d. The reverse recovery of secondary diode is not a big concern since the current is zero when it has to switch off.

But it has a disadvantage of higher peak currents results in higher peak voltages has to be blocked, since our design work in 20V this peaks are not very destructive. You can view more advantages and disadvantages in [1] and [2].

Conditions for the converter to work on DCM depend on magnetizing inductance L_M, switching frequency f_s, primary current i_p, load R, input voltage V_{in}, and duty cycle D [3]:

$$\frac{2L_M\, f_s}{R} < (1-D)^2 \tag{1}$$

978-1-4673-7869-7/15/$31.00 ©2015 IEEE

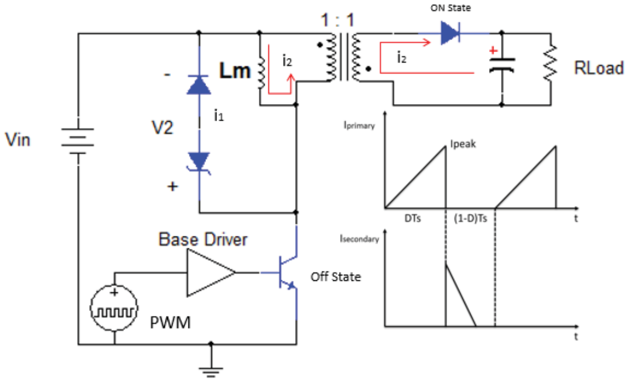

Fig. 1 DCM Current Waveform

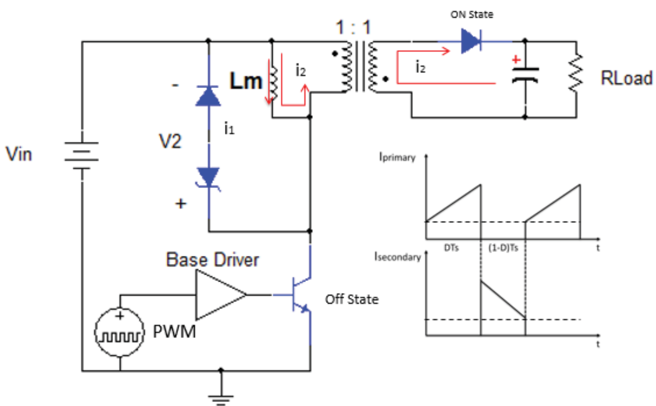

Fig. 2 CCM Current Waveform

$$f_s = {V_{in} D}\big/(2 L_M < i_p >) \tag{2}$$

$$L_M = \frac{R}{2\,f_s}(V_{in} D / V_o)^2 \tag{3}$$

From these three equations magnetizing inductance and the switching frequency can be obtained for the given load and input voltage and desired output voltage. Though some analysis shows that the peak current in DCM is constant and hence the average current in the primary is constant too, regardless the load, we have noticed that the primary peak current and its average increases with load. We refer this to the change in coupling coefficient and mutual inductance of the transformer which in term changes the magnetizing inductance by reducing it.

After obtaining the value for the inductance and have a transformer, it is very essential to measure the transformer values to get the value of primary, secondary, magnetizing and leakage inductances. Simple and straight forward steps in [4] have been used, but for more accurate results the measurement must be done when the transformer leads are welded to reduce measurement errors for leakage inductance as discussed in [5].

III. EMI Noise Sources

After getting the values for the design and setting up the circuit, when we were taking observation through oscilloscope we had seen the effects of leakage inductance and parasitic elements on the circuit. It is very difficult to have a good tradoff between cost, component count and performance when designing a flyback converter. The reason that the leakage and parasitic elements are uneasy to predict, measure and dealt with. The first source of noise and voltage spikes was the primary leakage inductance. When the switch turns off the current flows in the primary leakage inductance doesn't find a path therefore the magnetic field around the inductance collapses and make a voltage spike. This spike is very large and can damage the switch if it exceeds collector emitter breakdown voltage of the transistor. We have used Zener diode to limit the spike and the reflected voltage from secondary winding. Though the spike is limited by the Zener but the energy previously stored in the leakage inductance has to be dissipated in some element. This energy is stored in parasitic capacitance of the transformer circuit and pushed back to the leakage inductance and back again to the capacitances, this forms ringing or EMI wave as shown in Fig. 3. The major components of this ringing is the primary peak current, leakage inductance and parasitic capacitance. The first two components are easy to predict and measure but the third component-parasitic capacitance-is complicated. This capacitance is formed from multiple capacitance; capacitance between transformer windings, testing board capacitance, Zener protection diode capacitance, capacitance to the ground and switching transistor capacitance as shown in Fig. 4. Equation (4) shows the relation between the peak voltage, peak current, inductance and capacitance:

$$V_{peak} = I_{peak}\sqrt{l_{leakage}/C_{total}} + V_{in} + V_{out} \tag{4}$$

$$Z_c = \sqrt{\frac{l_{leakage}}{C_{total}}} \tag{5}$$

Where Z_c denote the characteristic impedance.

As suggested in [6] transistor collector emitter capacitance is the dominant capacitance, hence it is better to have transistor with bigger capacitance. Unfortunately this comes in price and add more complexity to the base driver of transistor, the transistor has more capacitance will not switch on and off very quick as needed to operate the transformer, therefore a complex gate driver is needed to make it fast. The good thing about this noise, we have very low energy stored in it because our design is for low power application, so this noise will not be very dangerous, though it must be reduced and filtered as we will mention later.

Many notes ignore the secondary leakage inductance and its effect on performance and noise in the output voltage. We faced many interesting problems with it. We were using 1N4007 diode and it was have more capacitance and slow reverse recovery time. Slow reverse recovery time was a trouble if the flyback is working

Fig. 3 Voltage waveform across transistor collector emitter

in the CCM mode, but since it is not and it works in the DCM mode and no current flows through the diode when it revers biased, the reverse recovery is not a concern. Though the diode has more junction capacitance (15 pico farads typical) and as expected from (3), the characteristic impedance must be decreased as a result the peak voltage also decreases. Contrary we have found the spike is very large (130 volts) as shown in Fig. 5.

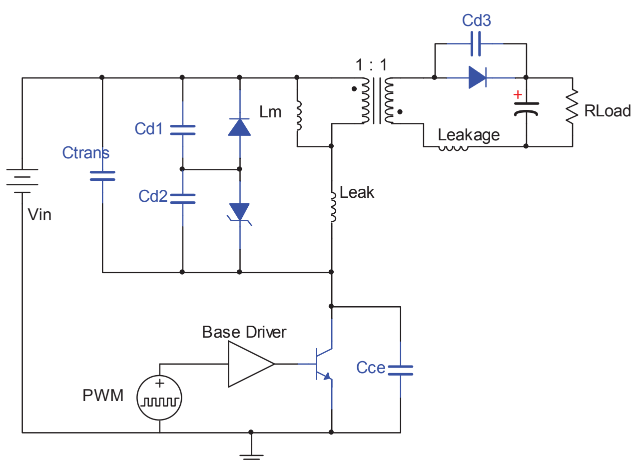

Fig. 4 Leakage inductance and parasitic capacitance

The cause of this large spike is reverse recovered charge in diode that has to be removed as to turn off the diode. This charge has to be removed in the reverse direction of leakage induction current, so a large spike occur if the charge was large compared to energy stored in leakage inductance.

Although there is no current going throw diode when it turns of the depletion region charge doesn't find a path to be removed and the reverse recovery current is very large (52 milliamp) for very short time as seen in Fig. 6. This current goes throw into secondary winding dot and consequently goes out primary winding dot and form a very large drawn current from the source. It draws a current with peak of 590 milliamp and its average is

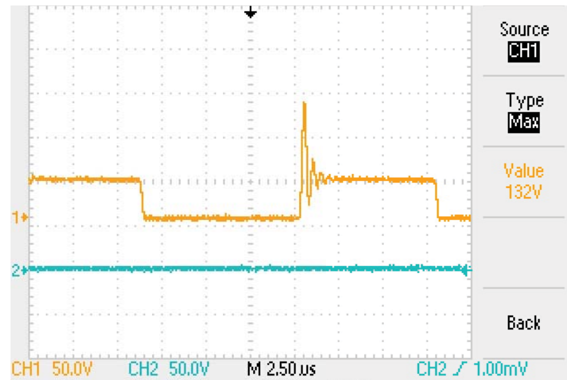

Fig. 5 Voltage spike across Secondary diode during turn off

59 milliamp only for reverse recovery as shown in Fig. 7. This was a huge degradation in performance of Flyback converter.

Therefore we use another diode 1N4938 have less threshold voltage and minimize the spike voltage and faster recover time to minimize current spike. Fig. 8 indicates the voltage across the diode in the secondary side of the converter and the spike is reduced to 59 Volts. Fig. 9 shows the corresponding current wave form in the primary, obviously the effect of reverse recovery current in secondary is vanished. This can be reduced more if we use Schottky diodes that has no charge to recover but care must be taken because of the reverse voltage can damage the diode since it has less reverse breakdown voltage.

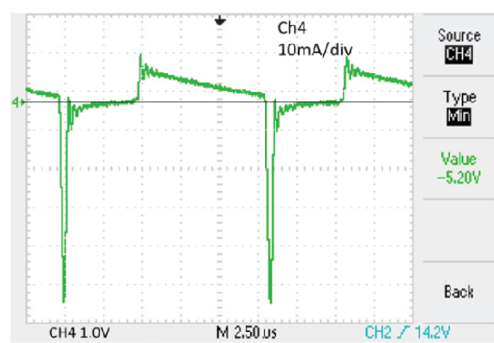

Fig. 6 Reverse recovery current on Secondary diode

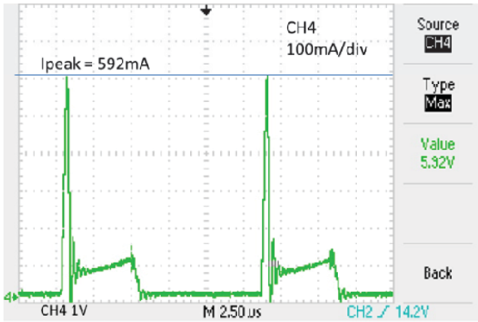

Fig. 7 Current spike in primary due to reverse recovery current in Secondary

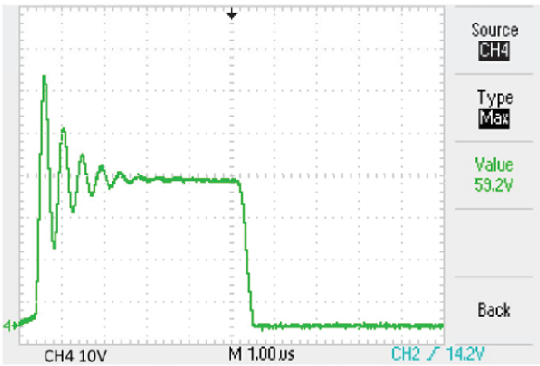

Fig. 8 Peak Voltage with 1N4938

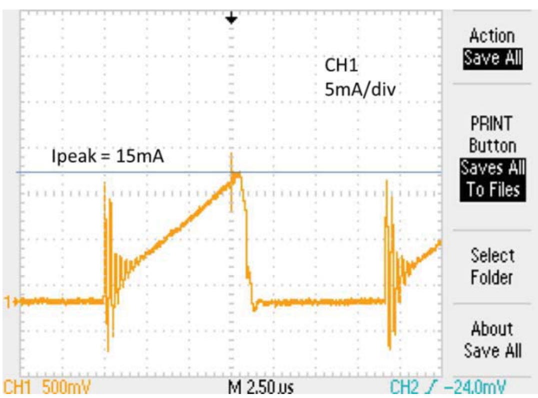

Fig. 9 Current waveform in primary side

IV. Snubber and EMI filter

We had a strategy, prior to filter EMI and adding snubber to reduce the ringing frequency, we have to track down the sources of this EMI and ringing on the circuit and minimize it. Other ways to reduce the effect of this noise is by having good layout in circuit, the lines that carry fast switching signal must put close to each other, leads of capacitors must be shorted to reduce leakages and not radiate this EMI noise [7]. The snubber used to minimize the peak and frequency of ringing is well discussed in [6] and [8].

Our next step in the design is to measure accurately the EMI noise energy over frequency by Line Impedance Stabilization Network LISN to design filter. This is a requirement by EMC standards (e.g. CISPR22, FCC15 etc.). EMI has to be filtered as not harm other electronic devices nearby [9].

V. Conclusion

A discontinues conduction mode Flyback converter was designed, built and tested. The Flyback features electrical isolation between input and output as required by safety standards. Minimum number of components was use to implement the converter. The sources of noise and other effects that reduces the performance was reduced to minimum.

References

[1] M. Sclocchi, "Step-by-step for an optimized flyback supply design (Pt 1 of 2)," 25 10 2011. [Online]. Available: http://www.eetimes.com/document.asp?doc_id=1279175.

[2] R. Patel and G. Frutz, "Switching ower supply design review - 60 Watt Flyback Regulator," Texas Instruments, Dallas, 2001.

[3] R. W. Erickson and D. Maksimovic, "Converter Circuits," in *Fundamentals of Power Electronics*, Second ed., Springer US, 2001, pp. 161-165.

[4] C. Basso, "How to deal with leakage elements in Flyback Converters," On Semiconductor Application Note AN1679/D, 2005.

[5] "Measureing leakage inductance," Voltech Notes VPN 104-105/3 , 2001.

[6] R. Ridely, "Flyback converter snubber design," 2005. [Online]. Available: http://www.ridleyengineering.com/dc1/54-11-flyback-converter-snubbers-design.html?showall=&limitstart=. [Accessed 20 1 2015].

[7] M. H. Chew, "Handling EMI in switch mode power supply design," On Semiconductor Application Note AN1695, 1999.

[8] M. Milanovic, J. Korelic, A. Hren, F. Mihalic and P. Slibar, "Reduction of ringing losses in Flyback converter by using the RC-RCD Clamp circuit," *AUTOMATIKA* , pp. 31-37, 30 2 2006.

[9] C. Basso, "Conducted EMI filter design for the NCP1200," On Semiconductor Application Note AND8032/D , 2001.