Design and Realization of a Flexible Mains Switching Power Supply

Zoran Zivanovic[1] and Vladimir Smiljakovic[2]

Abstract – **In this paper the design of mains power supply is presented. The basic theory of FLYBACK converter is also given. The converter was built and tested through lab measurements. Design steps are described and well documented with measurement results.**

Keywords – **CCM, DCM, ESR, flyback, LC filter, MOSFET**

I. Introduction

The most frequently used AC/DC converter is a single switch flyback converter. From few watts to a couple hundred watts, with one or multiple outputs, they need to have high efficiency and high power density. Unlike the forward converter they have only one magnetic component - the transformer.

II. Principle of a Flyback Converter

The basic flyback converter circuit is shown in Fig. 1. While the primary power switch (MOSFET) is on, the energy is taken from input and stored in the transformer. Actually it is a coupled inductor, because the current does not flow at the same time in the primary and secondary side. At the secondary the diode is reverse biased and the load takes energy from the output capacitor. When the power switch turns off, the output diode is forward biased and the energy is transferred to the output capacitor and the load. There are two basic modes of operation. The first mode is the discontinuous conduction mode (DCM) in which all of the stored energy is transferred to secondary during the time the power switch is OFF and the current has a triangular shape. The second mode is the continuous conduction mode (CCM) in which the part of the stored energy remains in the transformer when the power switch turns on again and the current has a trapezoidal shape (Figs.2 and 3).

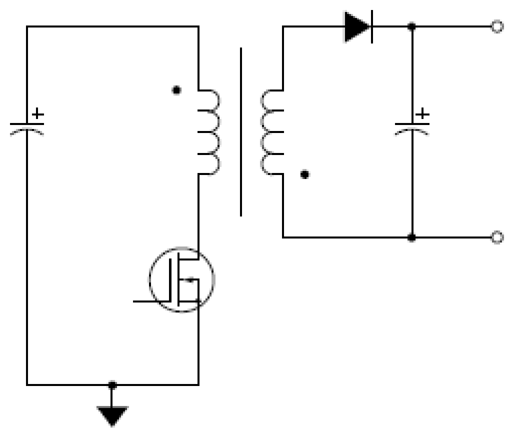

Fig.1. Flyback converter

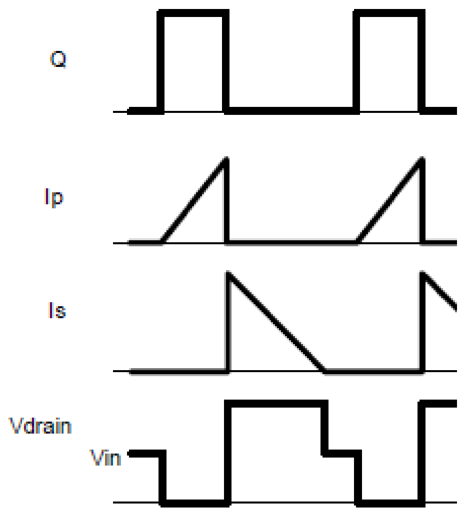

Fig.2. DCM Waveforms

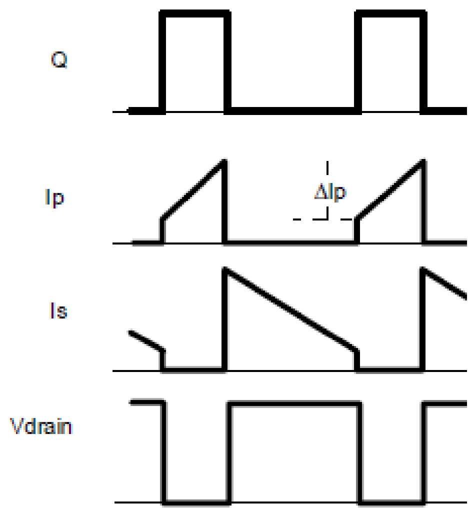

Fig.3. CCM Waveforms

[1]Zoran Zivanovic is with the IMTEL KOMUNIKACIJE AD, Bul. Mihajla Pupina165b, 11070 Belgrade, Serbia, E-mail: zoki@insimtel.com.

[2]Vladimir Smiljakovic is with the IMTEL KOMUNIKACIJE AD, Bul. Mihajla Pupina165b, 11070 Belgrade, Serbia, E-mail: smiljac@insimtel.com.

A DCM converter requires a transistor and diode with higher current rating and bigger capacitors with low ESR (equivalent series resistance) and vice versa. For a given converter the operating mode depends on the switching frequency, input voltage and output load.

III. Design and Analysis

The task is to design a 40W CCM flyback converter using current mode control IC with careful choice of operating parameters and components. Achieving the maximum flexibility is the primary objective. The footprint size must be around 160x100mm. A block schematic of the converter is given in Fig. 4.

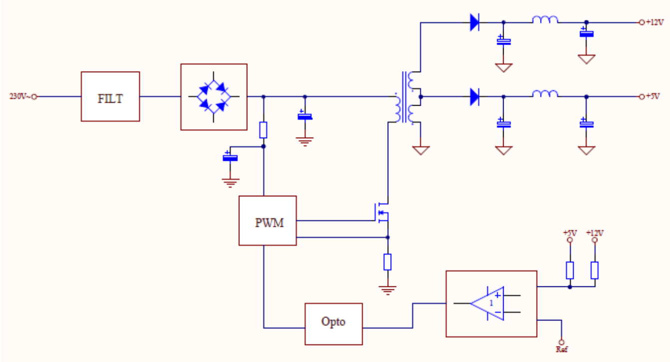

Fig.4. Block schematic of the converter

First we choose the switching frequency to be around 100 kHz, which is a compromise between the efficiency and size of the magnetics. Knowing that, a good choice of core for the transformer is ETD34, N87 material from TDK-EPCOS.

Design specifications are given in Table I.

TABLE I
DESIGN SPECIFICATIONS

		Min	Typ	Max	
Input voltage	V_{IN}	90	220	270	V_{AC}
Output voltage 1	V_{O1}		+5		V
Output voltage 2	V_{O2}		+12		V
Output voltage 3	V_{O3}		-12		V
Output power	P		40		W
Full load efficiency	η		80		%
Switching frequency	f_{SW}		100		kHz

We will now calculate the basic parameters for the transformer, using the following equations:

$$N = \frac{N_p}{N_s} = \frac{V_{DC}}{V_o + V_D} * \frac{D_{max}}{1 - D_{max}} \quad (1)$$

$$I_p = \frac{I_o}{N} * \frac{1}{1 - D_{max}} + \frac{\Delta I_p}{2} \quad (2)$$

$$L_p = V_{DC} * \frac{D_{max} T}{\Delta I_p} \quad (3)$$

$$N_p = \frac{L_p I_p}{B_{max} A_e} \quad (4)$$

$$I_{PRMS} = \sqrt{D_{max}\left(I_p^2 - \Delta I_p I_p + \frac{\Delta I_p^2}{3}\right)} \quad (5)$$

The results are given in Table II.

TABLE II
BASIC PARAMETERS

		Max	Typ	Min	
Duty cycle	D	0.40	0.17	0.14	
Number of prim. turns	N_P		38		
Number of sec. turns 5V	N_{S5V}		4		
Number of sec. turns 12V	N_{S12V}		7		
Primary RMS current	I_{PRMS}	0.65	0.41	0.37	A

Now it is time to wind the transformer. We will use a bundle of 7 twisted wires - 0.2 mm enamelled copper wire for the primary and a triple bundle of 0.3 mm for the secondary, in order to minimize copper losses taking into account the skin effect.

Knowing specific core losses we can now calculate the loss in magnetic component (Table III). Total transformer power loss at 220V_{AC} input voltage is 1.738W. This results in approximately 35°C rise above ambient temperature. Satisfied with the results, we will keep the chosen core geometry.

TABLE III
TRANSFORMER LOSSES

		Max	Typ	Min	
Core effect. volume	V_E		7.63		cm^3
Specific core losses	P_V		0.104		W/cm^3
Core loss	P_{CORE}		793		mW
Primary loss	P_{PRI}		435		mW
Secondary loss	P_{SEC}		510		mW

IV. Realisation

AC/DC converter was built on two layer FR-4 substrate with 35µm copper with a footprint of 160x100mm. The transformer is wounded on through hole coil former according to calculations. Current sense resistor is adopted for primary current sensing because of its small power dissipation (less than 100mW). Output voltage is further filtered out by the added LC filter. All electrolytic capacitors are low ESR aluminum electrolytic capacitors.

Furthermore we have measured full load efficiency at various input voltages. For practical reasons we have used input voltages from 120 to 370V_{DC}. This measure gives a slightly better result than the actual value. The results are given in Table IV. The efficiency is over 81%, which is good.

Using variable isolation mains transformer and resistive load we have recorded the waveforms at the point of interest.

TABLE IV
EFFICIENCY

		Min	Typ	Max	
Input voltage	V_{IN}	120	300	370	V_{DC}
Input current	I_{IN}	0. 41	0.158	0.131	A
Input power	P_{IN}	49.20	47.34	48.47	W
Efficiency	η	81.30	84.50	82.50	%

The drain waveforms of the primary power switch at full load and input voltages of 90, 220 and 270V_{AC} are given in Figs. 5, 6 and 7 respectively. As seen on the waveforms the converter is working in CCM mode. Ringing in the drain waveform of the power switch is not a problem because a maximum drain voltage is well within specifications of used IRFBC40.

Gate voltage waveform can be seen in Fig. 8 and 9.

Current waveform, typical for the continuous conduction mode is given in Fig.10. An ugly spike at the beginning of each pulse is a result of parasitic reactance. Leading edge blanking circuit of the PWM controller removes them easily.

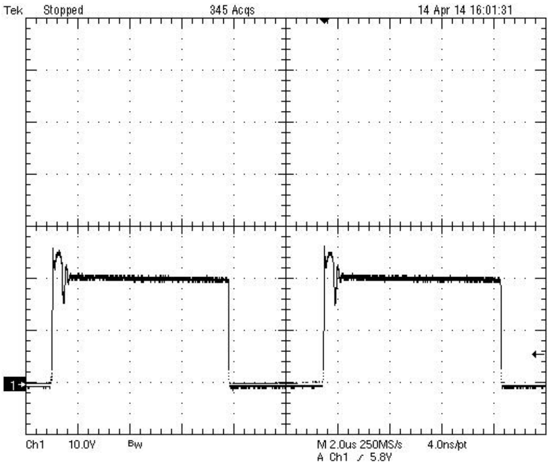

Fig.5. Drain voltage waveform at 90V_{AC}

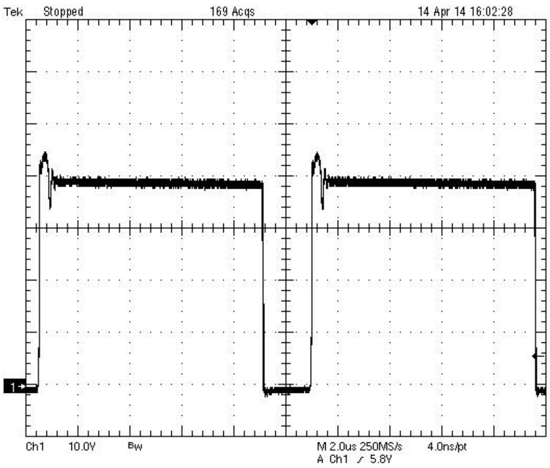

Fig.6. Drain voltage waveform at 220V_{AC}

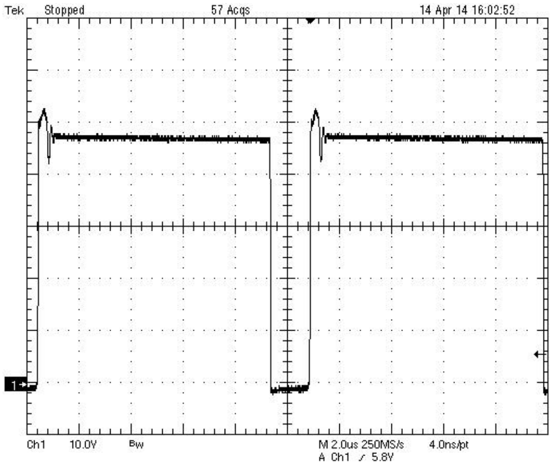

Fig.7. Drain voltage waveform at 270V_{AC}

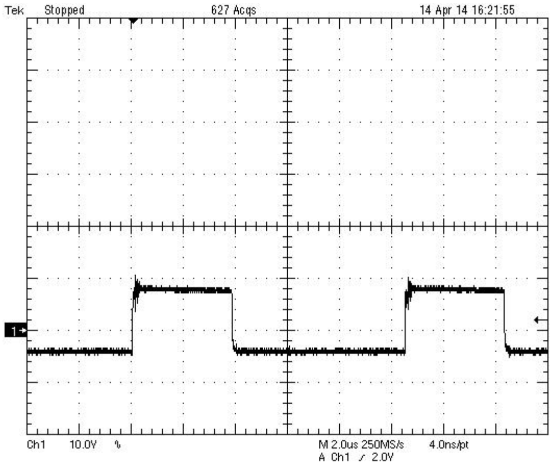

Fig.8. Gate voltage waveform at 90V_{AC}

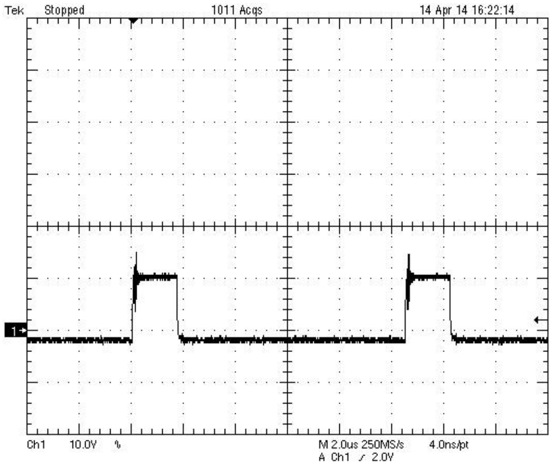

Fig.9. Gate voltage waveform at 220V_{AC}

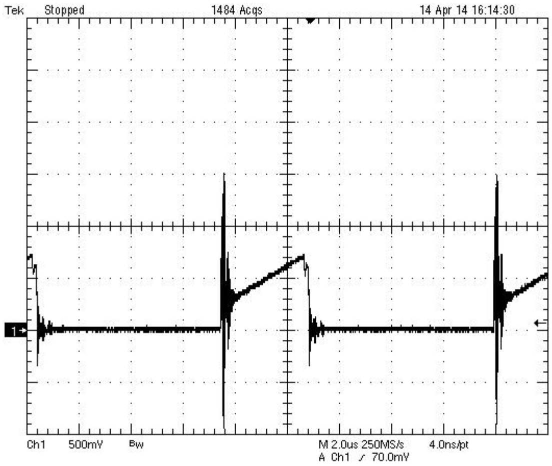

Fig.10. Drain current waveform at $90V_{AC}$

As we can see in Figs.11 and 12 input voltage ripple is 24 V_{PP} at $90V_{AC}$ and 10V at $220V_{AC}$. It is easily compensated by the action of current mode power controller.

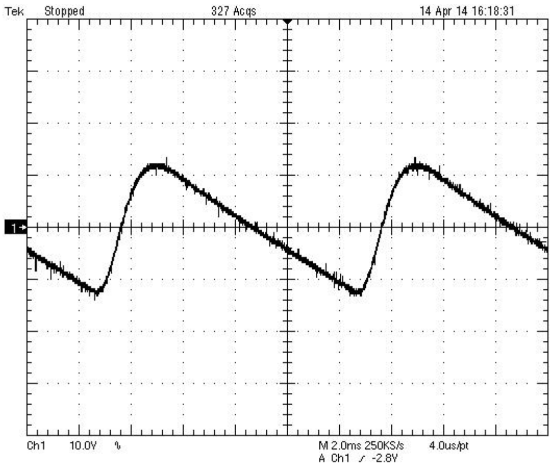

Fig.11. 100Hz input voltage ripple at $90V_{AC}$

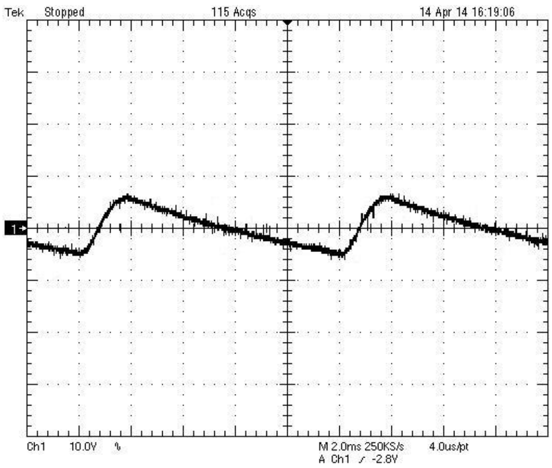

Fig.12. 100Hz input voltage ripple at $220V_{AC}$

The picture of converter prototype is given in Fig.13.

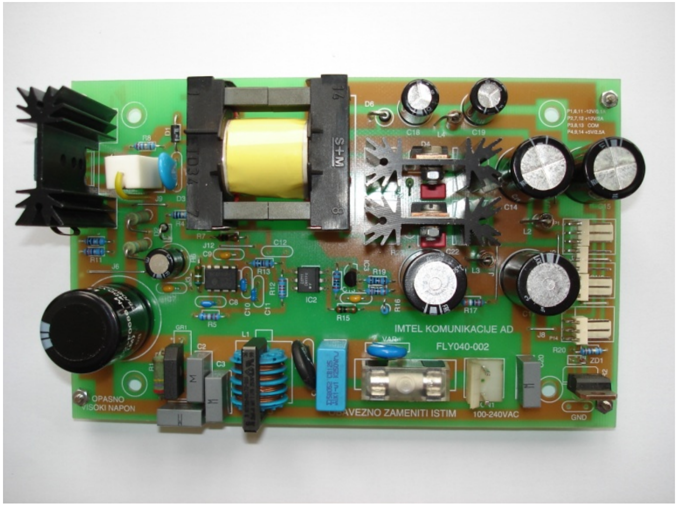

Fig.13. Converter prototype

V. CONCLUSION

In this paper the design and analysis of 40W flyback converter are presented. The prototype was built and tested. The results verified that the full load efficiency is over 81%. The converter is cheap and easy to manufacture. With minor changes we can make different versions of this power supply.

ACKNOWLEDGEMENT

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