Design, Analysis and Modifications of a Telecom Converter

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Abstract – **In this paper the straightforward design of a telecom DC/DC converter is presented. The converter was built and tested through lab measurements. Step by step changes are made in order to enhance efficiency. Every step is described and well documented with measurement results.**

Keywords – **DC/DC converter, forward, efficiency**

I. Introduction

The most frequently used DC/DC converter is a single switch forward converter, especially for telecom use with input voltage range from 36 to 72V. It is used in Central Offices, Private Branch Exchanges, Digital Radio Relay Systems, Radio Base Stations etc. Usual power range is from few watts to a couple hundred watts with one or multiple outputs. Very important requirements for these converters are high efficiency and high density. Unlike the flyback converter they have two magnetic components: the transformer and the output inductor.

II. Principle of forward converter

The basic forward converter circuit is shown in Fig. 1. During the time when the primary power switch (MOSFET Q) is on, the energy is transferred to secondary. Diode D1 is forward biased and the current flows through inductor L to the capacitor C and the load. When the power switch turns off, diode D1 is reverse biased and forward biased diode D2 provides freewheeling path for inductor current from input and stored in the transformer. Capacitor C acts as a reservoir and holds the output voltage nearly constant.

III. Design and improvements

The task is to design a 50W telecom forward converter using current mode control IC with careful choice of operating parameters and components. Achieving the efficiency as much as possible near 90% is the primary objective. The footprint size must be smaller than 100x50mm.

First we choose the switching frequency to be around 340 kHz, which is a compromise between the efficiency and size. Knowing that, a good choice of core for the transformer and the inductor is EFD20, N49 material from TDK-EPCOS.

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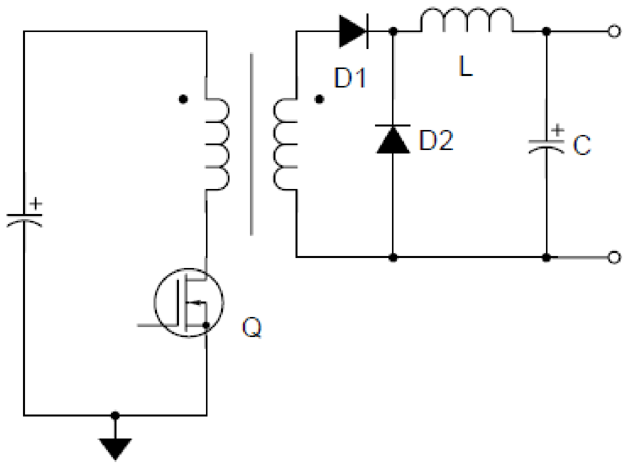

Fig. 1. Forward converter

Design specifications are given in Table I.

TABLE I
DESIGN SPECIFICATIONS

		Min	Typ	Max	
Input voltage	V_{IN}	36	48	72	V
Output voltage	V_O		5		V
Output current	I_O	1.3	10		A
Output current limit	I_{OCL}		12		A
Full load efficiency	η		85		%
Switching frequency	f_{SW}		340		kHz

The main contributors to power losses are transformer, output inductor, power switch, current sensing and secondary rectifiers.

Starting from design specifications we will now calculate basic parameters for the transformer and output inductor (Table II).

TABLE II
BASIC PARAMETERS

		Max	Typ	Min	
Duty cycle	D	0.42	0.31	0.21	
Number of primary turns	N_P		16		
Number of secondary turns	N_S		6		
Primary RMS current	I_{PRMS}	2.64	2.29	1.87	A
Secondary RMS current	I_{SRMS}	7.04	6.10	4.99	A
Output inductance	L		4.75		μH
Number of induct. turns	N		5		

There are several transformer reset methods: Resonant Reset, Active Clamp, RCD Clamp and Third Winding. For simplicity and smaller losses we will use a third winding reset scheme. Now it is time to wind the transformer and output inductor. We will use for the primary 5 parallel strands of 0.22mm copper wire and for the secondary 0.1mm thick copper foil, in order to minimize copper losses. For the output inductor we will use the same foil.

Knowing specific core losses we can now calculate the losses in both magnetic components (Table III). Total transformer power loss at 48V input voltage is 0.94W. This results in approximately 42 °C rise above ambient temperature. For the inductor temperature rise is 23 °C. If we are not satisfied with results, only way to further minimize losses is to change the core geometry.

TABLE III
TRANSFORMER AND INDUCTOR LOSSES

		Max	Typ	Min	
Core effect. volume	V_E		1.46		cm^3
Specific core losses	P_V		0.2		W/cm^3
Primary resistance	R_P		60		mΩ
Secondary resistance	R_S		3.5		mΩ
Core loss	P_{CORE}		0.29		W
Primary loss	P_{PRI}	0.42	0.31	0.21	W
Secondary loss	P_{SEC}	0.17	0.13	0.087	W
Inductor loss	P_{IND}		0.5		W

As a next step we will compare the power losses for two power switches BUZ30A (Table IV) and IRF640 (Table V).

TABLE IV
BUZ30A POWER LOSSES

BUZ30A			Typ		
ON resistance	R_{DS}		0.1		Ω
Reverse transfer capac.	C_{RSS}		130		pF
Conduction loss	P_{CON}	0.69	0.52	0.35	W
Switching loss	P_{SW}	0.31	0.55	1.20	W
Total loss	P_{TOT}	1.00	1.07	1.55	W

TABLE V
IRF640 POWER LOSSES

IRF640			Typ		
ON resistance	R_{DS}		0.1		Ω
Reverse transfer capac.	C_{RSS}		53		pF
Conduction loss	P_{CON}	0.69	0.52	0.35	W
Switching loss	P_{SW}	0.13	0.22	0.49	W
Total loss	P_{TOT}	0.82	0.74	0.84	W

Obviously MOSFET IRF640 is a better choice because of lower switching losses.

For current sensing we can use a current sense resistor or a current transformer. Power dissipated in current sense resistor is given in Table VI.

TABLE VI
CURRENT SENSE RESISTOR POWER LOSSES

		Max	Typ	Min	
Current sense resistance	R_{CS}		0.2		Ω
CS resistance loss	P_{CS}	1.39	1.05	0.7	W

Losses associated with current sense transformer are a little more complex to calculate because dissipation is distributed to the transformer, diode and resistor. The calculation results are given in Table VII.

TABLE VII
CURRENT TRANSFORMER POWER LOSSES

		Max	Typ	Min	
Current sense resistance	R_{CS}		8.2		Ω
Primary resistance	R_{CPRI}		6		mΩ
Secondary resistance	R_{CSEC}		1.14		Ω
Turns ratio	n		40		
CS resistance loss	P_{CST}	36	27	18	mW
Primary loss	P_{CPRI}	42	32	21	mW
Secondary loss	P_{CSEC}	5.8	4.5	2.9	mW
Diode loss	P_D	39	34	28	mW
Total loss	P_{CTOT}	122.8	97.5	69.9	mW

Dissipation of 1.39W on simple current resistor reduce efficiency significantly (near 3%), so that we will use current sensing transformer with dissipation an order of magnitude smaller.

At the end we will compare the power losses for two secondary rectifiers – Schottky diodes MBR2060CT and MBR2535CT (Table VIII).

TABLE VIII
RECTIFIERS POWER LOSSES

		Min	Typ	Max	
MBR2060CT	P_{RECT1}		4		W
MBR2535CT	P_{RECT2}		6.2		W

Comparing to the other losses it is obvious that the choice of secondary rectifier is critical for the converter efficiency. We will use MBR2535CT.

IV. REALISATION

DC/DC converter was built on FR-4 substrate with 70µm copper with footprint 85x40mm. Printed circuit board was mounted on the aluminum cooling plate. The transformer and the output inductor are wounded on thorough hole coil formers according to calculations. Current sensing transformer (of the shelf P8204 from PULSE) is adopted for primary current sensing.

The first step was measuring full load efficiency with BUZ30A and MBR2060CT on board at various input voltages. The results are given in Table IX. The efficiency is around 83%, not so bad for the start.

TABLE IX
EFFICIENCY-FIRST STEP

			Typ		
Input voltage	V_{IN}	36	48	72	V
Input current	I_{IN}	1.657	1.242	0.827	A
Input power	P_{IN}	59.65	59.61	59.54	W
Efficiency	η	83.00	83.00	83.30	%

The next step is to replace BUZ30A with IRF640 and repeat the measurements. The results are given in Table X.

TABLE X
EFFICIENCY-SECOND STEP

			Typ		
Input voltage	V_{IN}	36	48	72	V
Input current	I_{IN}	1.637	1.220	0.813	A
Input power	P_{IN}	58.93	58.56	58.54	W
Efficiency	η	84.00	84.53	84.56	%

Simple change of primary power switch give us the efficiency rise of over 1%. Now we will change the secondary rectifier MBR2060CT with more efficient MBR2535CT. We do the measurements again and the results are in Table XI.

TABLE XI
EFFICIENCY-THIRD STEP

			Typ		
Input voltage	V_{IN}	36	48	72	V
Input current	I_{IN}	1.575	1.170	0.780	A
Input power	P_{IN}	56.70	56.16	56.16	W
Efficiency	η	87.30	88.14	88.14	%

Now we have an efficiency rise of about 3.5% that is expected according to calculations. Full load efficiency is now around 88% - a good result.

Simultaneously with efficiency measurements we have recorded the waveforms at the point of interest.

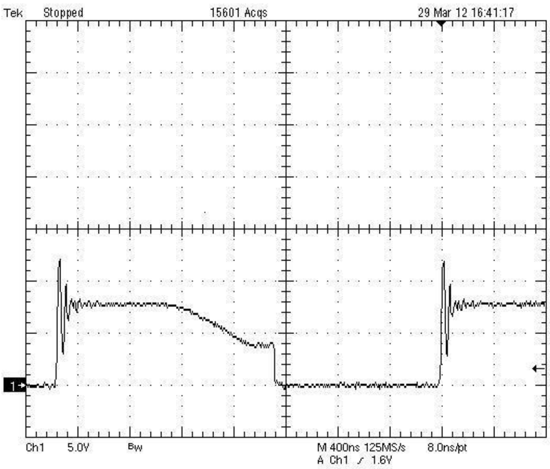

Fig. 2. Drain waveform at 36V

The drain waveforms of primary power switch at full load and input voltages of 36, 48 and 72V are given in Figs. 2, 3 and 4 respectively

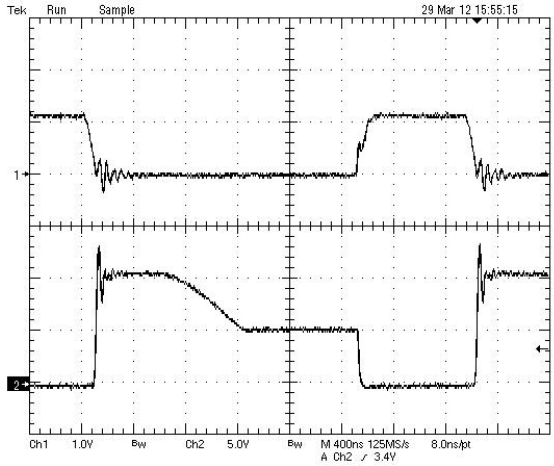

Fig. 3. Drain waveform at 48V with gate waveform above

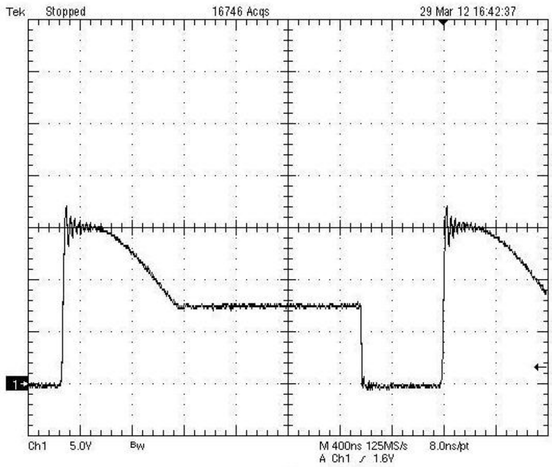

Fig. 4. Drain waveform at 72V

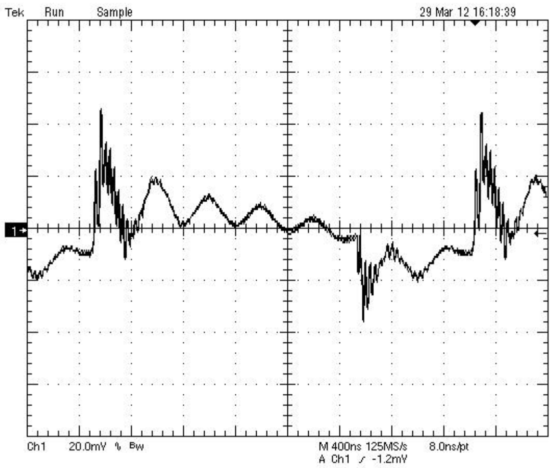

Fig. 5. Output voltage ripple at full load

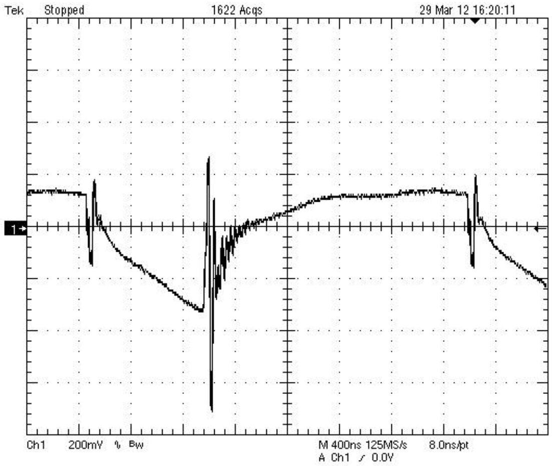

Fig. 6. Input voltage ripple at full load

Output and input ripple voltages are given in Figs. 5 and 6 respectively.

Output voltage rise into full load at 48V input is given in Fig. 7

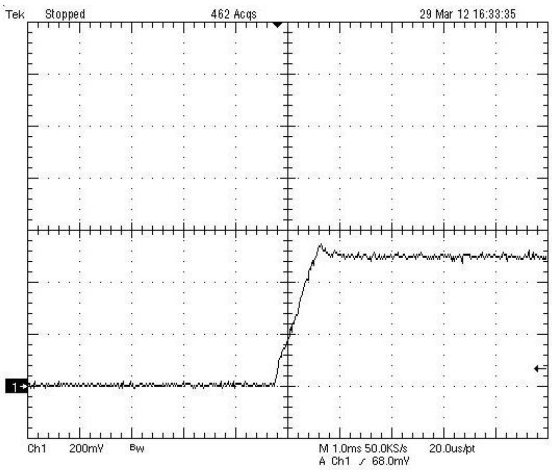

Fig. 7. Output voltage rise into full load at 48V input

The picture of converter prototype is given in Fig.8.

V. Conclusion

In this paper the design and analysis of 50W forward converter are presented.

The prototype was built and tested. The results verified that the full load efficiency is about 88%.

Further improvements are possible thorough Active Clamp Reset with controller change and Synchronous Rectifier in the secondary. The efficiency will go over 90%.

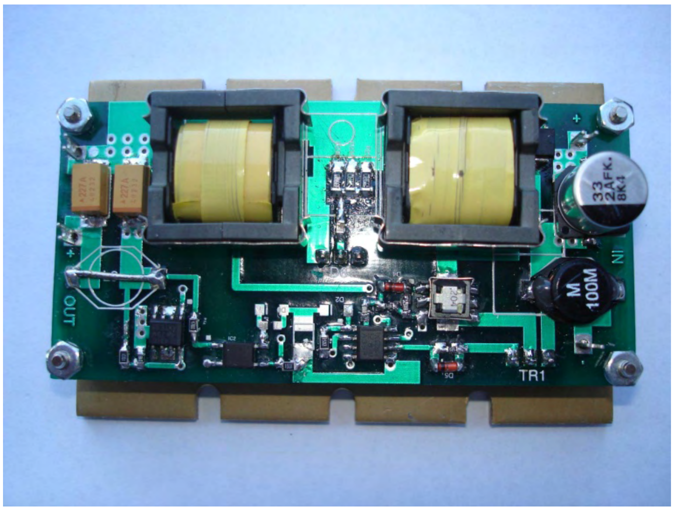

Fig. 8. The converter prototype

Acknowledgement

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