International Journal of Scientific & Engineering Research, Volume 8, Issue 3, March 2017
ISSN 2229-5518

Hardware Development and Implementation of High Frequency Non-isolated DC/DC Converter for Switched Mode Power Supplies

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Abstract— A hardware prototype is developed in this research work for a DC/DC buck converter, which is one of the switched-mode power supply (SMPS) topology. DC/DC converters are the devices that are designed mainly for the purpose of changing voltage levels conveniently. Depending on the topology, an output voltage could either be greater than or less than the input voltage. A buck topology which is developed in this work has the output voltage less than its input voltage. The aim of this research work is to design and simulate such a buck converter, which has the variable input voltages and has a constant output voltage. The output voltage of a buck converter is controlled by using a controller LTC 3703 that changes its duty cycle. For the simulation of the designed buck converter, an LTSpice software is used, and for the hardware implementation a four layer printed circuit board (PCB) designed is carried out in CADSTAR 15 for a special purpose application.

Index Terms—DC/DC Converter, High Frequency, Design, MOSFET, Inductor, Capcitor, Diode, Controller, Simulation, LTSpice, Hardware, CADSTAR 15, PCB etc.

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1 Introduction

A Buck converter is the most basic SMPS topology that produces an output voltage that is less than its input voltage. Basically, they are widely used to convert an unregulated dc input voltage into a regulated dc output voltage at another voltage level [1]. The input current is discontinuous due to the power switch MOSFET current that pulses from zero to an output current every switching cycle. The output current is continuous because the current is supplied by the output inductor and capacitor combination. They are equipped in SMPS for computers and electronic systems as well in drives, e.g. to control the speed of dc mchines. DC/DC converters can be classified into non-galvanically isolated and galvanically isolated DC/DC converter. The isolated DC/DC is electrically separated between the input and the ouput terminals while the input and the output terminals of a non-isolated converter share the common ground [2]. In this paper, non-galvanically isolated buck converter is considered.

Buck converter operates in two modes of operation that is continuous conduction mode (CCM) and discontinuous conduction mode (DCM). It is also called, MOSFET fully ON state and MOSFET fully OFF state. The MOSFET fully ON state is when the switch (Q) is ON and the diode (D) is cut off as shown in Fig. 1. In CCM, current continuously flows through inductor (L) throughout the switching cycles [3].

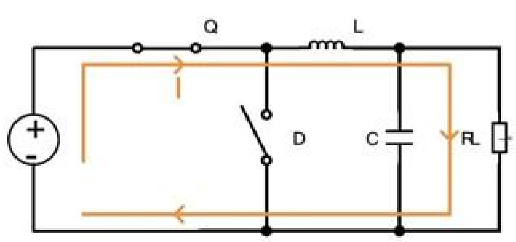

Fig. 1: MOSFET fully ON state [3]

The fully OFF state is when Q is OFF and D is ON with forward current flowing through L and resistor (R) as shown in Fig. 2. In DCM, current through inductor reaches zero before the end of a switching cycle [3].

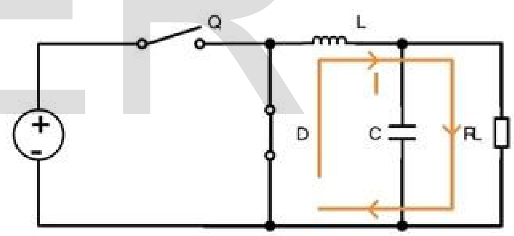

Fig. 2: MOSFET fully OFF state [3]

2 Design Overview

2.1 Definig Tasks

The first task is to convert the variable DC input voltage ranges from 30 V – 70 V into 24 V DC with an output current of 10 A and output power of 240 W. It is shown in Fig. 3.

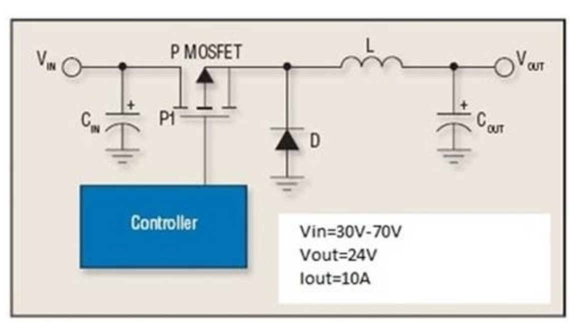

Fig. 3: Basic stepdown buck converter with operating parameters

For this purpose, LTSpice software is used. It is a computer software implementing a SPICE simulator of electronic circuits produced by semiconductor manufacturer Linear Technology [5]. Fig. 3 shows the basic configuration of a buck converter where the switch is integrated in the selected integrated circuit (IC). Buck converter has the filter inductor on the output side, which provides a smooth continuous output current waveform to the load [4].

2.2 Design Parameters

The following table 1 shows the design input parameters of the CCM buck converter.

Table 1: Design parameters

Input Voltage	30 V – 70 V (DC)
Output Voltage	24 V (DC)
Output Current	10 A
Switching Frequency	250 KHz
Inductor Ripple Current	30% of the Output Current
Output Ripple Voltage	300 mV

3 Componet Selection and Design Equation [1]

3.1 Inductor Selection

The range of the inductor value is often given in the data sheet. When selecting an inductor for a buck converter if the value of an inductor in the data sheet is not given, the following eq. 1 gives us a good estimation for a choice of the right inductor.

$$L = \frac{V_{out}}{f_s \times \Delta I_L \times I_{out}}\left(1 - \frac{V_{out}}{V_{in}}\right) \quad (1)$$

Hence, the value of the inductance after calculation is:

$L = 15\ \mu H$

If the value of an inductor is higher, then the output current is also higher. Moreover, the size of a buck converter can be smaller by keeping the lower value of an inductor.

3.2 Diode Selection

In order to reduce losses, two schottky diodes were used. Eq. 2 gives us the forward current rating of a schottky diode. Whereas, eq. 3 is the power dissipation of the diode.

$$I_f = I_{out(max)} \times (1 - D) \quad (2)$$

Where, I_f is the forward current of the diode which is 0.3 for schottky diode and $I_{out(max)}$ is the maximum output current of the buck converter.
By putting the values in eq. 2,

$I_f = 7$ A

Power dissipation of diode is equal to:

$$P_f = V_f \times I_f \quad (3)$$

Where, V_f is the forward voltage drop across schottky diode and its ranges from 0.2 to 0.4. After putting the values in eq. 3, the value of the power dissipation (P_f) is equal to:

$P_f = 2.1\ W$

3.3 Input Capacitor Selection

The value of an input capacitor is normally given in the data sheet. The best practice is to use low equivalent series resistance (ESR) ceramic capacitors. The dielectric material must be X5R or better. As X5R dielectric is a Class II type dielectric that is suitable for the higher capacitance applications. The value can be increased if the input is noisy. The minimum value of the input capacitor is necessary to stabilize the input voltage due to peak current requirement of the switching supply.

3.4 Output Capacitor Selection

It is desirable to use low ESR capacitors to minimize the ripple on the output Voltage. The ceramic capacitors are suitable choice if the dielectric material is X5R or better.

The following equations can be used to caliberate the output capacitor values for a better output voltage ripple.

$$C_{out} = L\frac{\left(I_{out(max)} + \frac{\Delta I_L}{2}\right)^2}{(\Delta V + V_{out})^2 - (V_{out})^2} \quad (4)$$

By calculating eq. 4 the value of the output capacitance is:

$C_{out} = 136\ \mu F$

By adding 20% capaciatance tolerance value, the total value of the output capacitance is now:

$C_{out} = 150\ \mu F$

3.5 MOSFET Selection

For selecting the MOSFET, two external N channel MOSFETs are used. Since drain of an each MOSFET will see the fully supply voltage 70 V (Max), choose a 100V MOSFET to provide a margin of safety.

So, for this case Si7456DP MOSFET has been choosen which has 100 V drain to source voltage (BV_{DSS}).

$$P_{main} = \frac{V_{out}}{V_{in(max)}}(I_{out})^2\lfloor 1 + 0.009(T_{Jmax} - 25)\rfloor(R_{DS(on)}) + (V_{out})^2\left(\frac{I_{out}}{2}\right)(2)(C_{Miller})\left(\frac{1}{10 - 4.7} + \frac{1}{4.7}\right)(f_s) \quad (5)$$

(6)

International Journal of Scientific & Engineering Research, Volume 8, Issue 3, March 2017
ISSN 2229-5518

$$P_{sync} = \left(\frac{V_{in} - V_{out}}{V_{in}}\right)(I_{out})^2[1 + 0.009(T_J - 25)](\frac{R_{DS(on)}}{2})$$

After inserting the values from the data sheet in eq. 5 and 6:

P_{main} = 2.37 W and P_{sync} = *1.37 W*

4 Simulation and Results

4.1 Simulation using LTspice

For the simulation of a step down buck converter, an LTspice IV is used. It is a computer implementing a SPICE simulator of electronic circuits, produced by semiconductor manufacturer Linear Technology. All the values which are calculated section 3 along with LTC3703 controller are used in the designed process. The designed step down buck converter is shown below. The following fig. 4 shows the simulation of step down DC/DC buck conveter using LTspice IV.

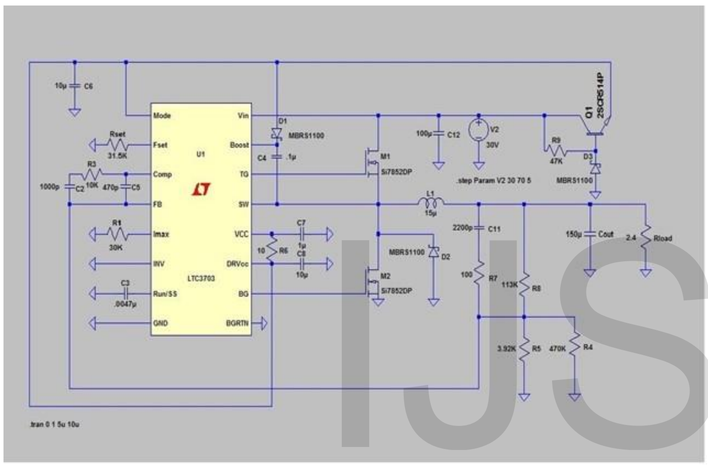

Fig. 4: Simulation of a buck converter

4.2 Simulation Results

Fig. 5, 6 and 7 are the simulation results, when the input voltages of 30 V, 50 V and 70 V respectively applied to a buck converter. It shows the same results for all the three different input voltages. Hence, the simulation results show that any voltage applied to a buck converter, which ranges from 30 – 70 V will always give a constant output voltage of 24 V and a constant output current of 10 A. The green line in the figures that are given below, indicates the applied voltage. Whereas, red line indicates output current and the blue line indicates the output voltage. Furthermore, the results are also illustrated in table 2.

Tabel 2: Simulation results

Input Voltage	Output Voltage	Output Current
30 V	24 V	10 A
50 V	24 V	10 A
70 V	24 V	10 A

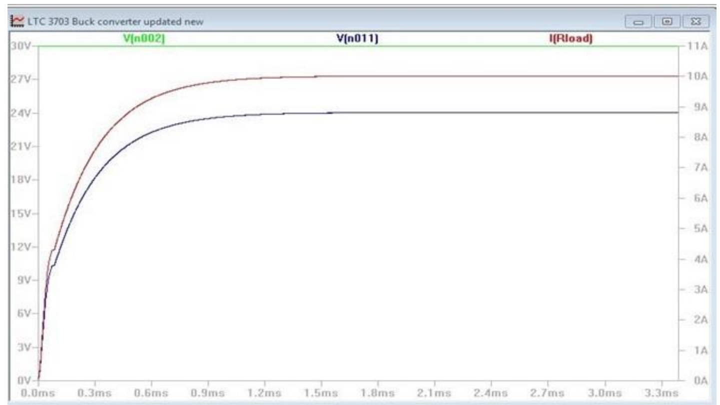

Fig. 5: Output current and output voltage waveform for 30 V

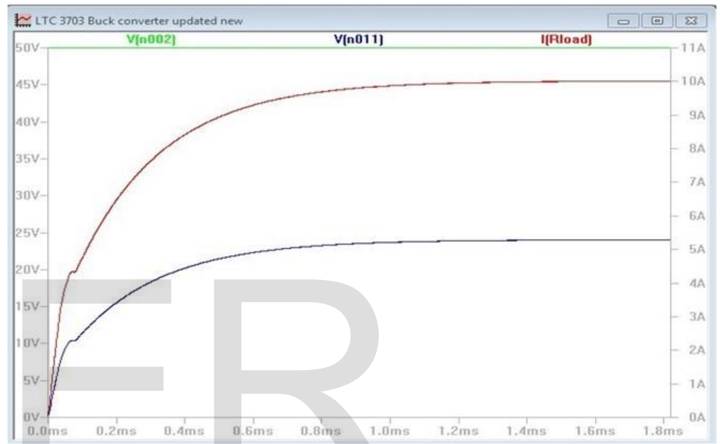

Fig. 6: Output current and output voltage waveform for 50 V

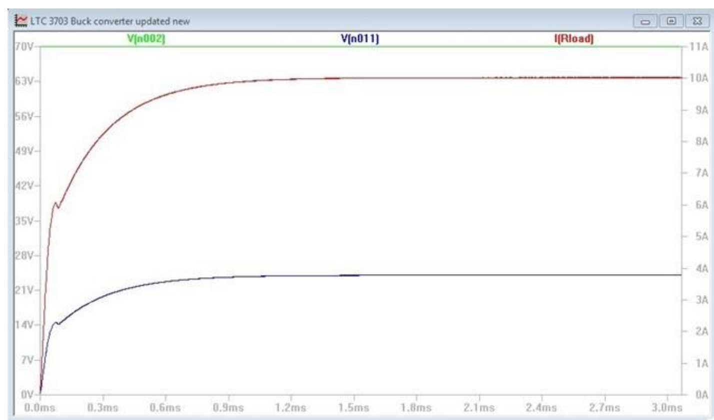

Fig. 7: Output current and output voltage waveform for 70 V

5 Hardware Development

5.1 Printed Circuit Board (PCB)

Virtually every electronic product is constructed with one or more PCBs. A PCB hold an IC and other components and implement the interconnections between them and it is created in abundance for portable electronics, computers, and entertainment equipments [6]. They are also made for test equipment, manufacturing, and spacecraft.

When laying out a PCB, it is important that the correct footprints are used in terms of electrical connections as well as in physical dimensions. If a footprint with a too small hole is used, then the component will not fit properly. In the same way, the components are hard to solder if the pads are too big. Surface-mount device (SMD) components were used in this research work. It is important to check the pad sizes and allow plenty of space for SMD components in order to solder the components by hand on PCB. Furthermore, the parasitic/stray capacitances and inductances formed by the PCB tracks are considered at high frequencies [7].

A PCB can be a single layer for simple electronic devices. For complex hardware, such as computer graphics cards and motherboards, it may have upto twelve layers. They are often green but it may come in any colour. In this research work, the four layers PCB has been designed by using a software called CADSTAR 15.

5.2 CADSTAR Software

CADSTAR is a window based electronic design automation (EDA) software tool for designing and creating schematic diagrams and PCBs. It provides engineers with a tool for designing simple or complex multi layers PCB. A uniform suit of applications that enable design engineers, layout professionals and high speed design specialists to define, implement and verify their ideas. The software is developed at Zuken's Technology Centre, ZTC in Bristol, United Kingdom [8].

5.3 Schematic Design

First, the schematic is designed by considering its correct footprint and then it is transformed into PCB. Different layers were used to make it compact and consist of the following four layers:

- Top Electrical
- Ground
- Voltage Supply
- Bottom Electrical

In fig. 8, schematic of a buck converter is shown.

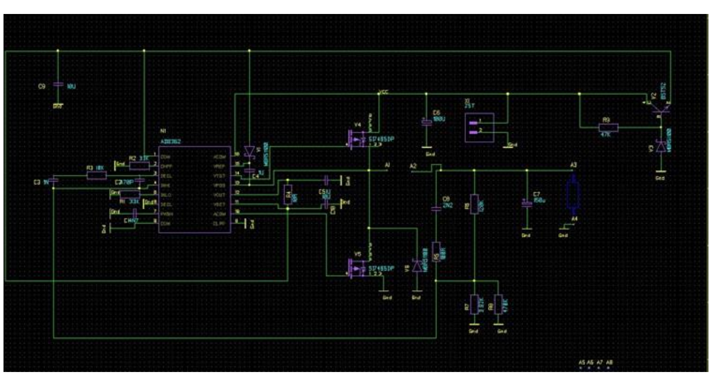

Fig. 8: Schematic of a buck converter

Final complete view of a PCB design using CADSTAR 15 software is shown in fig. 9.

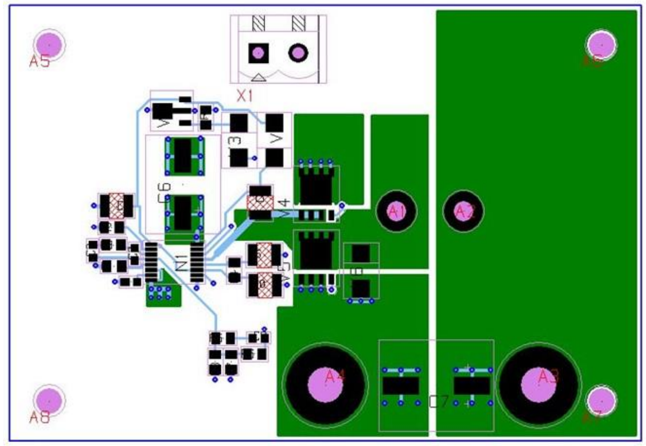

Fig. 9 Final silk view of a PCB design

5.4 List of Components

Following components were used in the designed procedure:

- Capacitors
- Resistors
- Inductor
- LTC 3703 Controller
- Schottky Diodes
- N-Channel Mosfets
- Darlington NPN Transistor
- High Voltage swithching Diode
- Zener Voltage regulator

5.6 Final PCB Design

The final form of a hardware PCB design is shown in fig. 9. All the SMD components were properly soldered by hand on PCB and then tested for the final results which are 24 V dc output voltage and 10 A output current of a DC/DC buck converter.

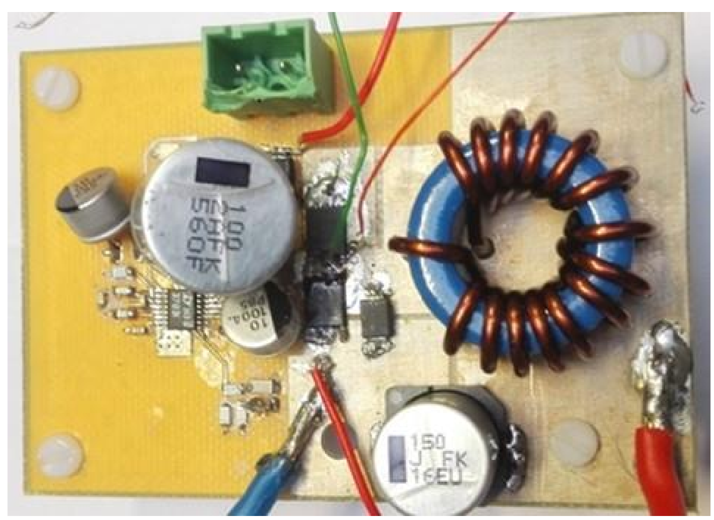

Fig. 10: Final Hardware PCB design

6 Conclusion

The objective of this research work is the simulation and hardware implementation of a non-isolated high-frequency DC/DC buck converter. For this purpose, the buck converter was designed and simulated in LTSpice. Accordingly, hardware was developed, by first designing PCB using CADSTAR 15. One of the aim of this work was also to make the hardware of a buck converter as compact as possible. In order to achieve this goal, a multi-layer design approach was used and the four layers PCB was designed. Different components like inductor, capacitors, resistors, diodes, MOSFETs, and controller were selected according to their calculated values. The components were manually soldered on PCB. This hardware is used to give a constant output voltage of 24 V DC to the Power Control System from a variable source input voltage which ranges from 30 V DC to 70 V DC. The input voltage is variable as it is supplied by a battery in which the voltage level is not constant. Finally, the hardware prototype of the buck converter was tested and it was found that it works properly for that special purpose application.

Acknowledgment

The authors wish to thank Dr.-Ing. Seyed-Mohsen Hosseini for his guidance.

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