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Design and Development of a Laboratory KIT Module for a DC-DC Converter

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Abstract: ***In AC circuits, the voltage from one level can be transformed into another level using transformers but in dc circuits, transformers cannot be used to change the voltage level. So, a special class of circuits called dc-dc converter is needed for voltage transformation. This paper focuses on the design and development of dc-dc converter. Compared to the classical dc-dc converters such as buck, boost and buck-boost types the Sepic converter provides isolation to the load via a high frequency transformer. In this paper implementation of laboratory kid module of buck converter is analyzed with simulated and hardware results. PSPICE simulation, mathematical analysis and hardware development are the contributions.***

Keywords: Buck converter, PWM controller, Pspice simulation

1. Introduction

A *DC*-to-*DC* converter is an electronic circuit which converts a source of direct current (*DC*) from one voltage level to another. It is a class of power converter.

DC to *DC* converters is important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different from that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage). Additionally, the battery voltage declines as its stored power is drained. Switched *DC* to *DC* converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing. Most *DC* to *DC* converters also regulate the output. Some exceptions include high-efficiency *LED* power sources, which are a kind of *DC* to *DC* converter that regulates the current through the *LED*s, and simple charge pumps which double or triple the input voltage.

SWITCH MODE: Electronic switch-mode *DC* to *DC* converters convert one *DC* voltage level to another, by storing the input energy temporarily and then releasing that energy to the output at a different voltage. The storage may be in either magnetic field storage components (inductors, transformers) or electric field storage components (capacitors). This conversion method is more power efficient (often 75% to 98%) than linear voltage regulation (which dissipates unwanted power as heat).

This efficiency is beneficial to increase the running time of battery operated devices. Another important innovation in *DC-DC* converters is the use of synchronous rectification replacing the flywheel diode with a power *FET* with low "On" resistance, thereby reducing switching losses. Most *DC* to *DC* converters are designed to move power in only one direction, from the input to the output. However, all switching regulator topologies can be made bi-directional by replacing all diodes with independently controlled active rectification. A bi-directional converter can move power in either direction, which is useful in applications requiring regenerative braking.

2. Analysis of Buck Converter

Step down or buck converters are a vital part to electronics today. They are capable of converting a voltage source into a lower regulated voltage source, through the use of switching mechanism, a diode, an inductor, and multiple capacitors. The buck converter is the type of converter whose output voltage is less than the input voltage. It is a class of switching-mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple

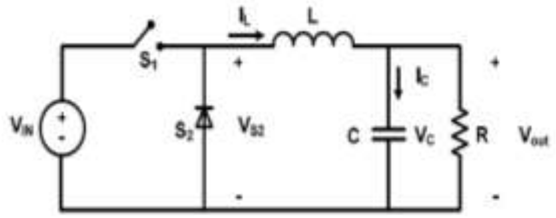

Figure 1: Buck Converter

The operation of the buck converter is fairly simple, with an inductor and two switches (usually a transistor and a diode) that control the inductor. It alternates between connecting the inductor to source voltage to store energy in the inductor and discharging the inductor into the load.

For the purposes of analysis it is useful to consider an idealised buck converter. In the idealised converter all the components are considered to be perfect. Specifically the switch and the diode have zero voltage drop when on and zero current flow when off and the inductor has zero series resistance. Further it is assumed that the input and output voltages do not change over the course of a cycle (this would imply the output capacitance being infinitely large).

Continuous Mode:

A buck converter operates in continuous mode if the current through the inductor (I_L) never falls to zero during the commutation cycle. When the switch pictured above is closed (On-state), the voltage across the inductor is $V_L = V_I - V_o$. The current through the inductor rises linearly. As the diode is reverse-biased by the voltage source V, no current flows through it; when the switch is opened (off state), the diode is forward biased. The voltage across the inductor is $V_L = -V_O$ (neglecting diode drop). Current I_L decreases. It can be seen that the energy stored in L increases during On-time (as I_L increases) and then decreases during the Off-state. L is used to transfer energy from the input to the output of the converter.

Discontinious Mode:

The current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle. Converter operates in steady state. Therefore, the energy in the inductor is the same at the beginning and at the end of the cycle (in the case of discontinuous mode, it is zero). This means that the average value of the inductor voltage (V_L) is zero.

3. Pspice simulation

A Buck converter has the following given values as Vs = 110V, R = 5Ω, L = 681.82μH, C = 8.33μF, IC = 3V, K = 0.42, Fr = 25 KHz

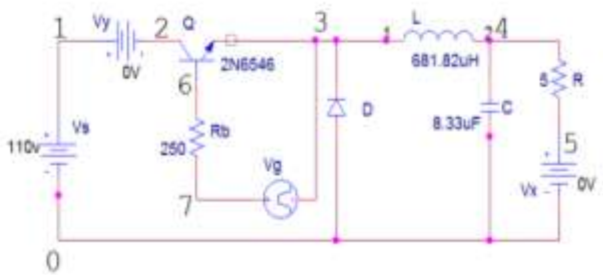

Figure 2: Pspice simulation of Buck converter

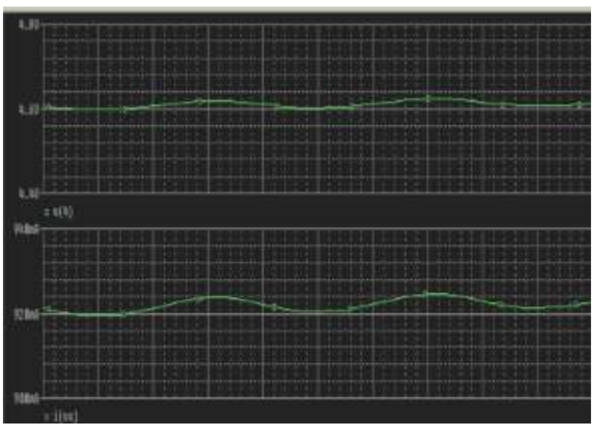

Figure 3: Buck converter output

4. Hardware Implementation

PULSE WIDTH MODULATION: Pulse width modulation (PWM) is a very efficient way of providing intermediate amounts of electrical power between fully on and fully off .A simple power switch with a typical power source provides full power only when switched on.PWM is a comparatively recent technique, made practical by modern electronics power switches.

The term duty cycle describes the proportion of on time to the regular interval or period of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on. PWM works well with digital controls, because of their on/off nature, can easily set the needed duty cycle.

PWM of a signal or power source involves the modulation of its duty cycle, to either convey information over a communication channel or control the amount of power sent to a load.

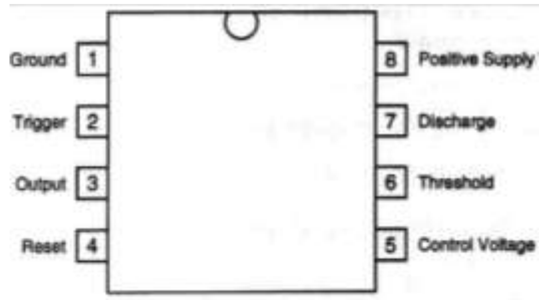

Figure 4: 555 Timers

To generate PWM pulses we make use of 555 TIMER.

The 555 timer is an integrated chip (circuit) used in a variety of timer, pulse generation and oscillator applications. The 555 can be used to provide time delays as an oscillator, and as a flip – flop element.

It operates from a wide range of power supplies ranging from +5V to +18V supply voltage. Sinking or sourcing 20mA of load current

The external components should be selected properly so there the time intervals can be made into several minutes proper selection of only a few external components allows timing intervals of several minutes along with frequencies exceeding several hundred Kilo Hertz

It has a high current output, the output can drive TTL.

It has a temperature stability of 50 parts per million per degree Celsius change in temperature or equivalently 0.005%/deg Celsius

The duty cycle of the timer is adjustable with the maximum power dissipation per package is 600mW and its trigger and rest inputs are logic compatible.

Applications of 555:

Monostable:

- Timers
- Missing pulse detection
- Bounce free switches
- Touch switches

- Frequency divider
- Capacitance measurement
- PWM

Astable
- LED
- Lamp flashers
- Pulse generation
- Logic clocks
- Tone generation
- Security alarms
- Pulse position modulation

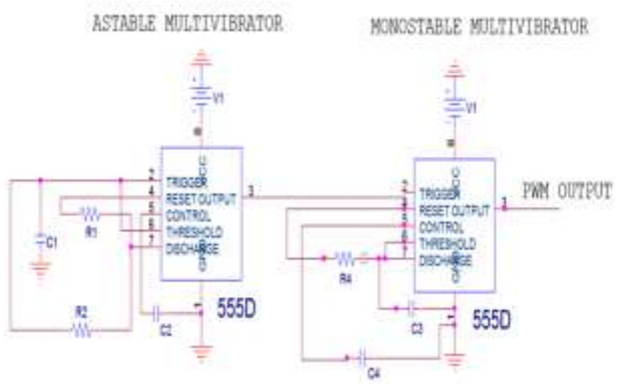

Figure 5: PWM Circuit

Figure 6: PWM Output

Design of Buck Converter

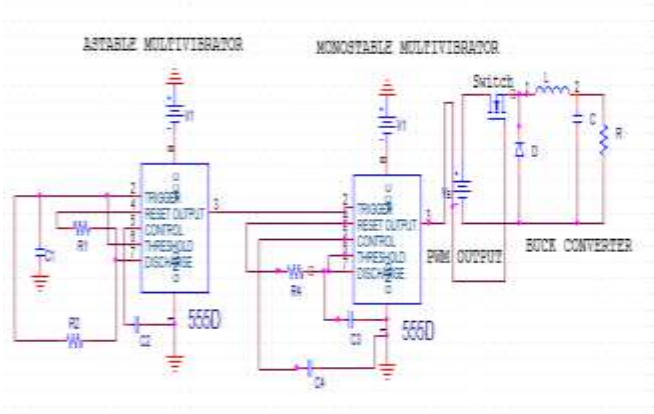

Figure 7: Hardware implementation of Buck converter

Choice of Operating Frequency
There is no definite rule to determine the operating frequency but the minimum frequency should be above 20 KHz to avoid the possibility of audio noise.

Advantages of the high frequency operation-reduced weight, volume and cost of the filter elements is less but high frequency leads to the increase in ESR above the capacitive reactance which is undesirable. So, the range of the operating frequency is determined by the capacitor ESR and the allowable ripple voltage at the output.

Another limiting factor is the switching losses of power switching transistors and free wheel diode at high operating frequency causing the reduction in the efficiency. So the optimum frequency range should be selected.

Choice of the Input Voltage
The choice of the input DC voltage is not very critical. The choice of input DC voltage should be such that the output voltage should not be greater than 90% of the minimum instantaneous input voltage since ON times greater than the 0.9T can result in the problems because of the storage time delay.

Choice of the Free Wheeling Diode
The recovery time of the diode it should be small since operating frequency is high. If the recovery time is high short circuit current may persist for most of the ON period of the transistor and may prove fatal to it.

The rating of the free wheel diode should be such that it can withstand the average diode current given by
I_d = (1-duty cycle)*maximum output current.

Choice of the Switching Power Devices

The reliability of the regulator and the overall performance of the circuit depend mostly on the choice of switching power devices. At high frequency the switching losses of power switching transistors are high resulting in the lowering the efficiency of the regulator.

In order to increase the efficiency of the regulator, fast switching semiconductors like MOSFET which has low switching losses is used.

Calculation Parameters

- Input voltage = 9V, F = 10 kHz, Output voltage = 3.8V, I_{LOAD} = 2A
- Duty cycle = 3.8/9 = 0.4222
- L = 10µH, C = 100µF, R = 100Ω

Figure 8: Hardware kit of Buck converter

5. Results & Analysis

Table 1: Comparison of Practical and Simulation results (Buck converter)

Vin (Input voltage)	K (duty cycle)	V_{0S} (Simulation output voltage)	V_{OP} (Practical output voltage)
9	0	0	0
9	0.2	1.8	1.6
9	0.4	3.6	3.8
9	0.6	5.4	5.2
9	0.8	7.2	7

V_{OS} – Simulation output voltage
V_{OP} – Practical output voltage

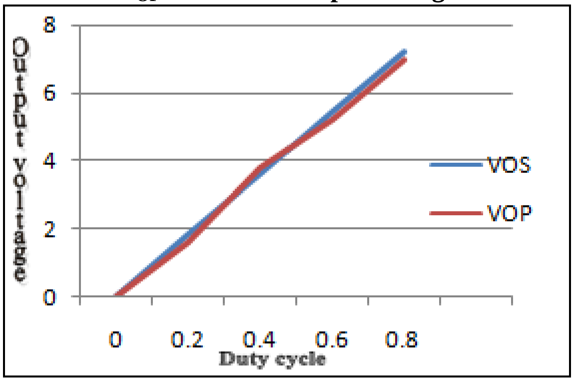

Figure 9: Graph of output vs duty cycle

6. Conclusion

Since, *DC-DC* converter is most important class of a power converter which has a wide range of application. Hence our main motive of our paper is to bridge the theoretical knowledge with practical knowledge while studying power electronics. So that, for the further modification of the converter will be easy with basic knowledge.

A *DC-DC* converter has two modes i.e. linear and switched mode. Since, linear mode cannot be used for large-drop high-current application and it is inefficient we have switched over to the switched mode.

Switched mode *DC-DC* converter has high efficiency and hence low heat generation. Its efficiency is beneficial to increase the running time of battery operated devices since, it convert the voltage level by storing input energy temporarily and releasing the output at different level. It is small in size and light in weight and also useful in regenerative braking.

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