Experiment No.1

DC-Dc Buck Converter

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1. Introduction

The DC–DC Buck Converter is one of the most common types of switching converters used to step down a higher DC voltage to a lower DC voltage efficiently. Unlike linear regulators, the buck converter operates by rapidly switching a transistor (acting as a chopper) on and off, controlling the energy transferred to the output through an inductor and smoothing it with a capacitor. This switching operation allows for high efficiency and precise voltage regulation, making buck converters essential in modern power electronics applications such as power supplies, battery chargers, and embedded systems.

2. Objectives

- Understand the working principle of a buck converter.
- Analyze the relationship between input voltage, output voltage, and duty cycle.
- Observe and interpret voltage and current waveforms using Multisim simulation tools.
- Evaluate the converter's efficiency and steady-state operation.

3. Theory

The step-down dc-dc converter, commonly known as a buck converter, is shown in Figure below. It consists of dc input voltage source VS, controlled switch S, diode D, filter inductor L, filter capacitor C, and load resistance R. The state of the converter in which the inductor current is never zero for any period is called the continuous conduction mode (CCM).

It can be seen from the circuit that when the switch S is commanded to the on state, the diode D is reverse-biased. When the switch S is off, the diode conducts to support an uninterrupted current in the inductor.

$$(V_s - V_o)\,DT = V_o(1 - D)T$$

The output voltage and current are:

$$V_o = D\,V_s$$

And $$I_s = DI_o$$

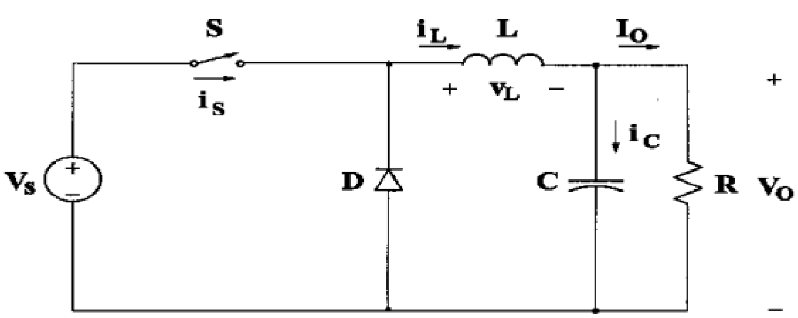
The ripple inductor current ΔI is:

$$\Delta I = \frac{DV_s(1-D)}{fL}$$

The ripple capacitor voltage is:

$$\Delta V_c = \frac{DV_s(1-D)}{8CLf^2}$$

In order to generate a purely DC output at the load, a low-pass filter can be applied to the basic switching converter as shown in Figure 3. If we could generate an ideal low-pass filter, the output measured across V would naturally become Vs (D) as indicated above. However, since we know we cannot create an ideal low-pass filter, the following theory will introduce sizing considerations for the inductor and capacitor based primarily on the load and PWM input frequency.



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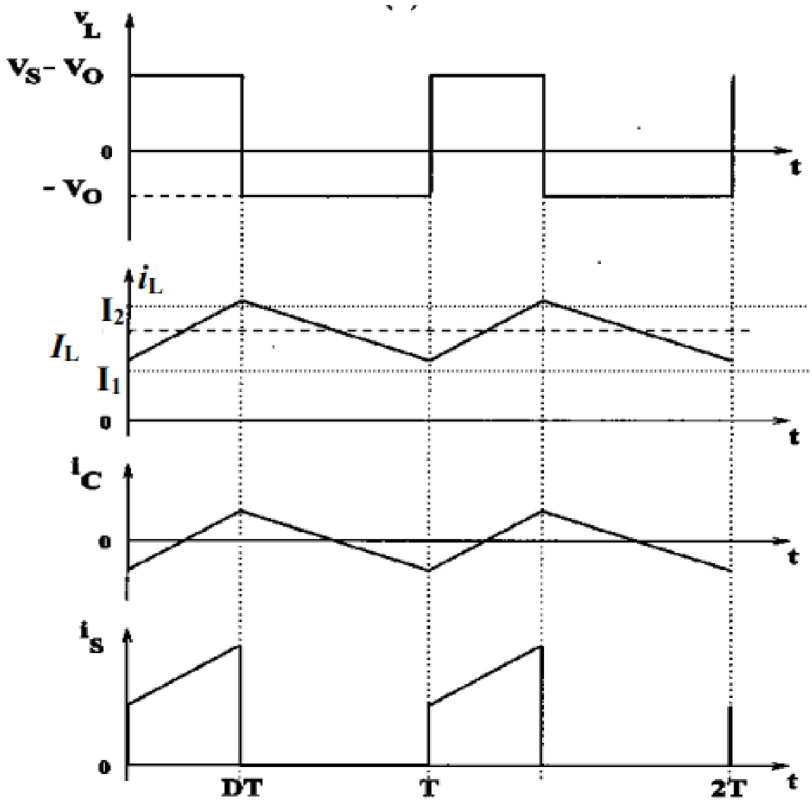


4. Example Configuration

Let us assume we have the following configuration:

V_s = 12 V

R_L = 100 Ohms

f = 50 kHz

P_{max} = 1.44 W

P_{min} = 0.36 W

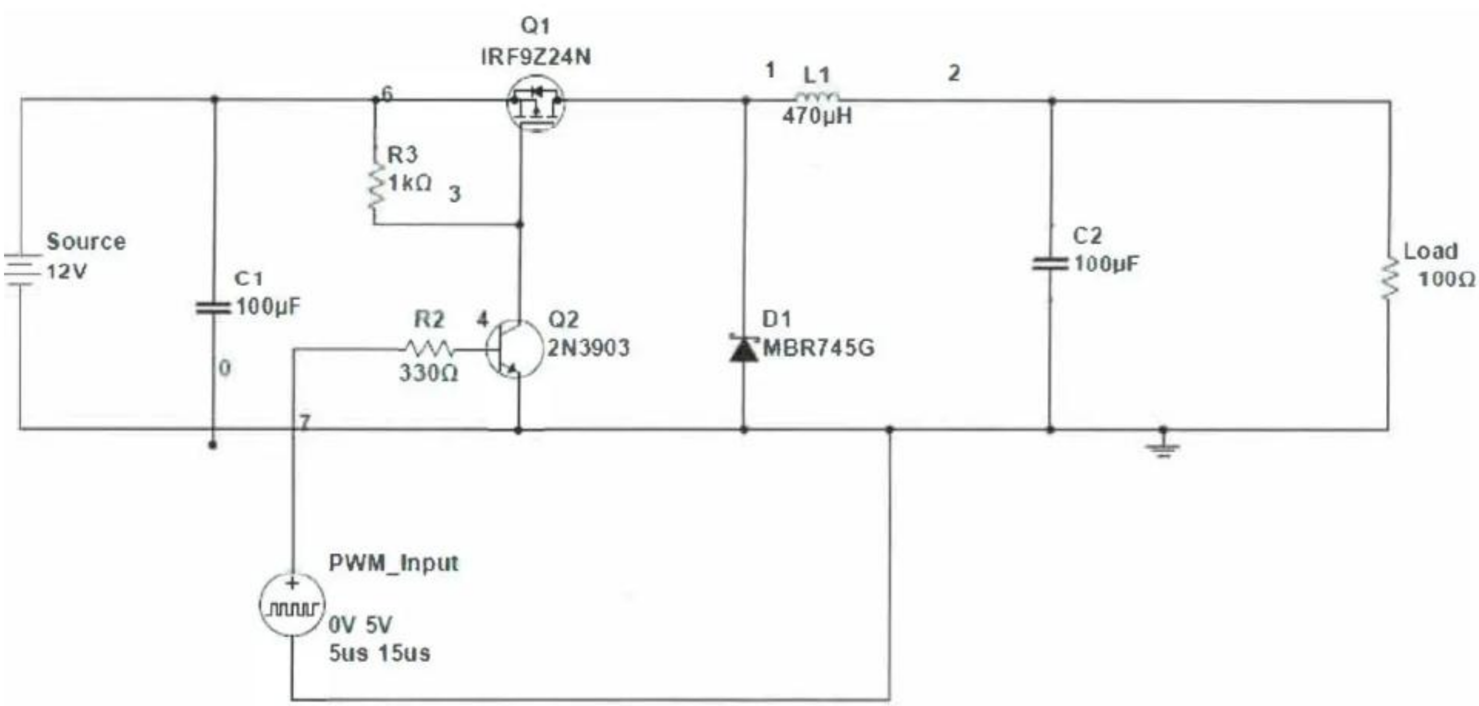
Ripple Voltage <= 3 mV

L_{min}= 500µH

C_{min}= 100 µF

5. Switch Design

The left half of the circuit in Figure was an over simplification of reality. In order to properly account for various voltage levels at the input and differing levels between the PWM input and the source voltage, an increase in complexity is warranted.



Duty Cycle	V_o	I_{load}	P_{Source}	P_{load}	Efficiency
100%					
90%					
80%					
70%					
60%					
50%					
40%					

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6. Discussion

1. What is the main function of a DC–DC buck converter, and how does it differ from a linear voltage regulator?
2. Explain how the **duty cycle (D)** of the switching signal affects the **output voltage** of the buck converter.
3. What is the role of the **inductor** and **capacitor** in the buck converter circuit?
4. Describe what happens to the inductor current and output voltage when the **switch (transistor)** is turned ON and OFF.
5. How does changing the **switching frequency** affect the performance and output ripple of the converter?
6. Compare the **theoretical output voltage** (calculated using $Vo=D\times Vs$) with the **simulated value** obtained in Multisim. What could cause any differences?
7. Why is it important to use **PWM (Pulse Width Modulation)** to control the converter instead of varying the input voltage directly?
8. Discuss the **efficiency** of the buck converter. What are the main factors that can reduce its efficiency in a real circuit?

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