NAMAL INSTITUTE

Department of Electrical Engineering

Power Electronics Lab

EE 312L

LAB PROJECT

Design of DC-DC Converter

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Date Performed		
Instructors		
Signature		

Document History

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Introduction

In this lab session, we are going to design a DC-DC Converter. A DC-DC converter is used to convert the DC input voltage to a DC output voltage having a large or smaller magnitude as required by the load. In this project specifications, we are going to design a step down converter that will convert high voltage by input to low voltage at output (also known as Buck Converter). These converters are used in many applications including desktop, laptops, mobile solar, UPS etc. and designed for articular application depending on given load specifications.

Environment and Equipment:

- OrCad Capture CIS (Theoretical Design + Simulation)
- Power Electronics Lab (Final Hardware Testing)
- Gate Driver IC
- MOSFET IRF540N
- Inductor
- Capacitor
- Diode D1N4001
- Resistor

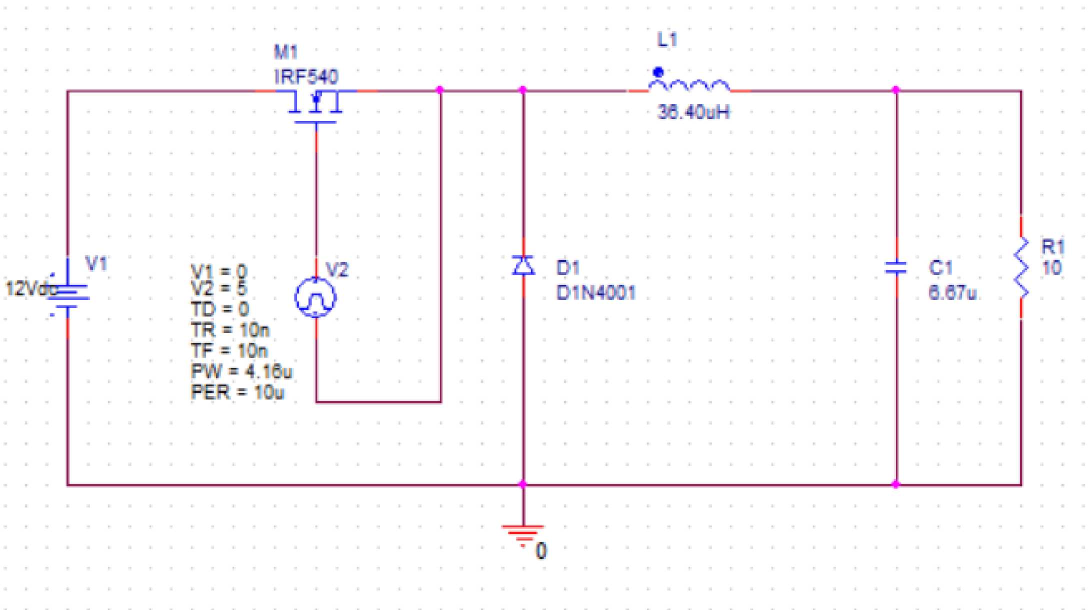
Purpose:

“To design a DC-DC Converter of 5V Output in continuous conduction mode from a 12V DC power supply with ripple factor less than 3% of the output voltage.”

Procedure:

As we know that a Buck Converter is a step down converter that convert large voltage magnitude to a smaller one, so basically we are going to design a converter with 5V DC output from 12V DC source voltage. This is a generic DC-DC Buck converter system that can be used for different applications.

Circuit Diagram:



DC-DC Buck Converter Circuit Diagram Figure (1)

Description:

In this circuit diagram, we have used a 12V Dc power supply and given voltage at the Drain terminal of MOSFET. At the Gate terminal, we have given gate signal to control the electronic switch. The Source terminal is connected with rest of the circuit is a low-pass or average-pass filter that includes diode, inductor, capacitor and load resistor. The circuit works on MOSFET switching which help us to control output voltage value.

When Duty Cycle is decreased, the output voltage is decreased because large area is chopped in OFF state of the switch and in smaller area gives power in ON stage of the switch so the average output value is decreased.

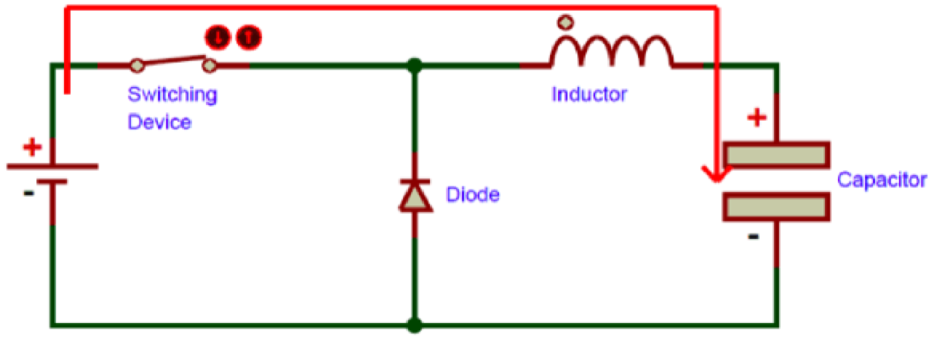
Now we will explain the working of the circuit with each part explained in detail.

Working:

The working of a Buck converter can be divided in two steps i.e. Closed Switch and Opened Switch.

1. When Switch is Closed:

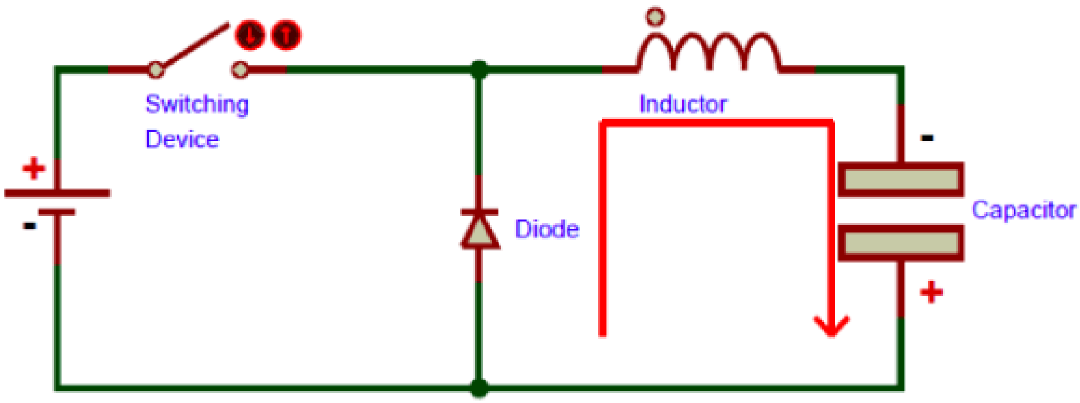
When the switch is closed, the diode becomes **reversed biased** and the **inductor** starts storing energy because the current starts conduction through capacitor and resistor. The stored energy of inductor and capacitor is transferred to the load and so the output voltage is almost constant. The capacitor is used to constant and smooth the voltage while inductor keeps current flow constant based on their fundamental properties.



Closed Switch Circuit Diagram (2) Reference ***[1]***

2. When Switch is Open:

When the switch is opened, the conduction is stopped but inductor current cannot be zero directly as it opposes the sudden change in current. So the stored energy of inductor makes diode forward biased and continue the flow of current through diode. So the output voltage and current is maintained when switch is open.



Open Switch Circuit Diagram (2) Reference ***[1]***

So at the end the, the flow of current and voltage is maintained at the output and average value of DC voltage is obtained through a complete cycle.

Data (Performance Parameters):

Now we will take a look at the data we have measured and calculated. Basically we need the ripple factor that must be less than 3% of output voltage as in our design specifications. So we will calculate the values of Capacitor and Inductor to calculate the output voltage.

Note that the ripple voltage value is dependent on the value of capacitor, so higher value of capacitor will reduce the ripple voltage and we will achieve our design specification.

Let us now calculate the Inductor and Capacitor values for the given ripple voltage and output voltage.

The required ripple voltage must be less than 3% of the output voltage 5V Dc. So:

$$\boldsymbol{\Delta Vc = \frac{3}{100} * 5V = 0.15}$$

For the given ripple voltage value and output voltage value we can design our circuit.

Design of Buck Converter:

Design of DC - DC Converter

Given:-

Input Voltage = V_{in} = 12V

Output voltage = V_o = 5V

Switching frepuency = f_s = 100kHz

Ripple Factor = 3% of output Voltage

$\Delta V_c = 0.03 \times 5 = 0.15V$

$R = 10\,\Omega$ (Assumption)

As $V_{in} > V_o$, So we'll do calculations as buck converter.

Calculations:-

We know That

- $V_o = D V_{in}$

$$D = \frac{V_o}{V_{in}} = \frac{5}{12} = 0.416667$$

Duty cycle $= D = 41.67\%$

- Inductance.

We know That

$$L_{critical} = \frac{D(V_{in} - V_o)R}{2 f_s V_o}$$

$$L_{critical} = \frac{0.4167 \times (12-5) \times 10}{2 \times 100 \times 10^3 \times 5}$$

$$L_{critical} = 29.12 \times 10^{-6} = 29.12\,\mu H$$

We know

$L > L_{critical}$

$L = 1.25\, L_{critical}$

$L = 1.25 \times 29.12\,\mu H$

$L = 36.40\,\mu H$

$L = 36.40\,\mu H$

- **Capacitor:-**

We know that

$$C = \frac{D(V_{in} - V_o)}{8 f_s^2 L \Delta V_c}$$

$$C = \frac{0.4167(12-5)}{8 \times (100 \times 10^3)^2 \times 36.40 \times 10^{-6} \times 0.15}$$

$$C = 6.67 \mu F$$

- **Output power.**

$$P_o = \frac{V_o^2}{R} = \frac{(5)^2}{10} = 2.5W$$

So at the end we have;

C = 6.67 uF

L = 36.40 uH

D = 41.67%

$\Delta \boldsymbol{Vc} = \mathbf{0.15}$

Theoretical Maximum Voltage Rating:

MOSFET IRF540N➔ Drain-Source Voltage = 100V and Gate-Source Voltage = 20V
Diode D1N4001 ➔ 50 V

Theoretical Average Voltage Rating:

MOSFET IRF540N ➔ N/A
Diode D1N4001 ➔ 35V

Theoretical Maximum Peak Current Rating:

MOSFET IRF540N ➔ Drain Current = 33 A
Diode D1N4001 ➔ 30 A (Forward)

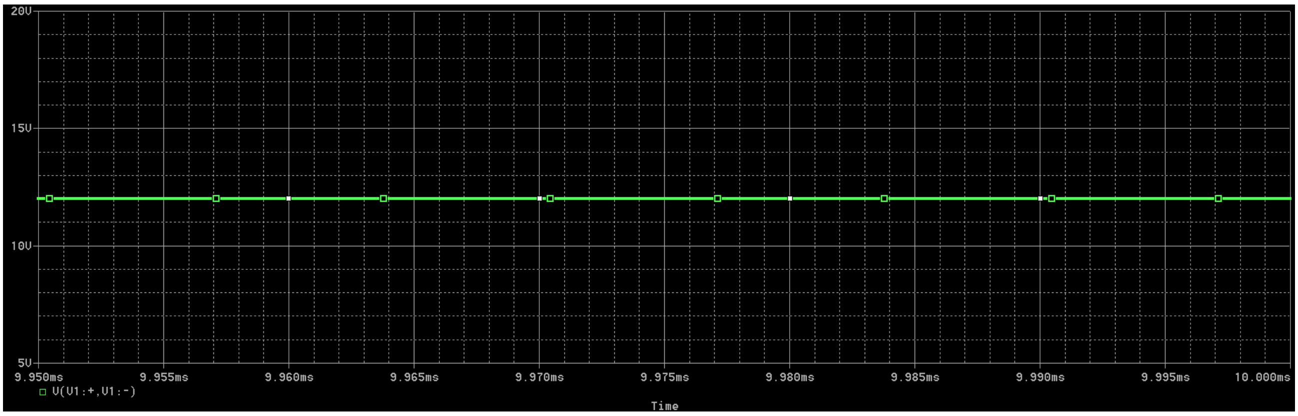
Theoretical RMS Current Rating:

MOSFET IRF540N ➔ N/A
Diode D1N4001 ➔ 1.0 A (Forward)

Data Analysis and Discussion:

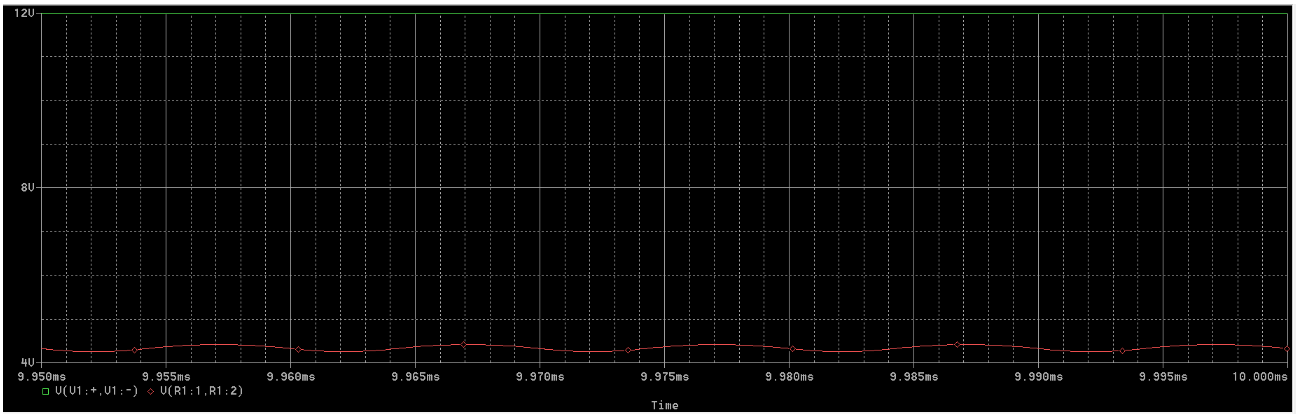
Here are the graphs of our results by using the above design calculations:

Input Voltage:



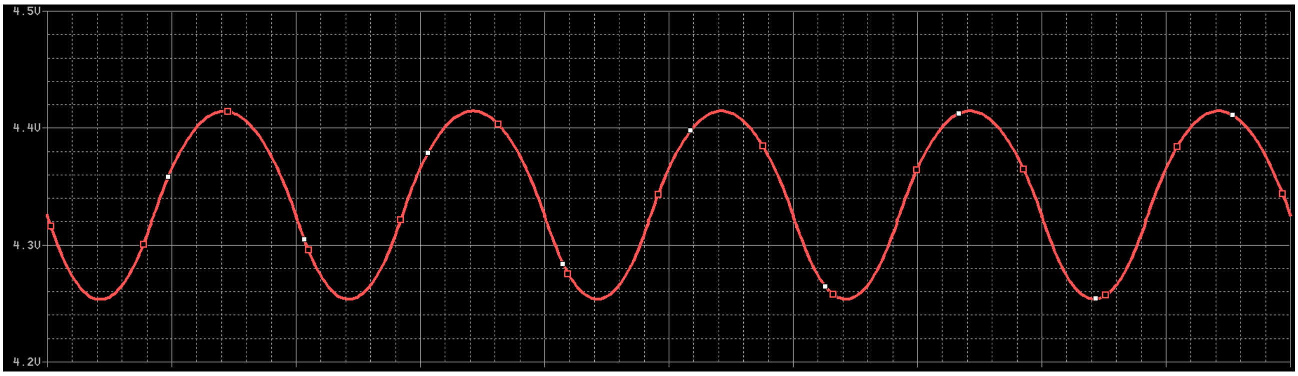
Vin = 12 V DC

Output Voltage:



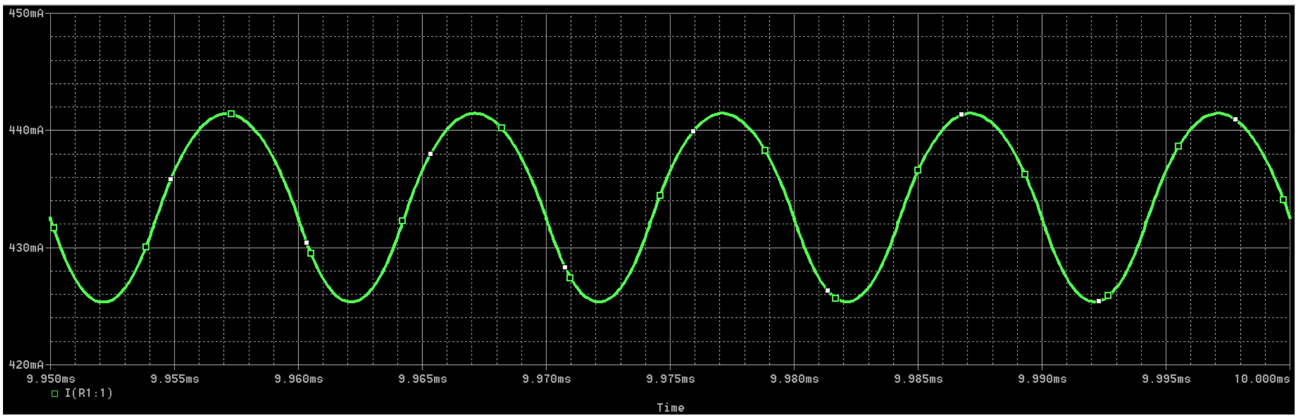
Vo = 4.425

Output Voltage Alone:



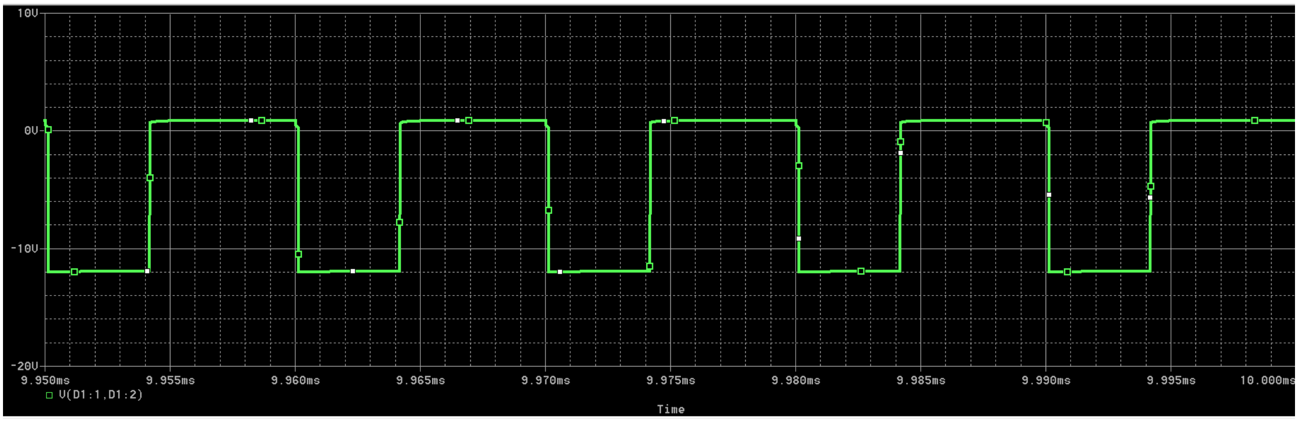
Vo = 4.425

Output Current:

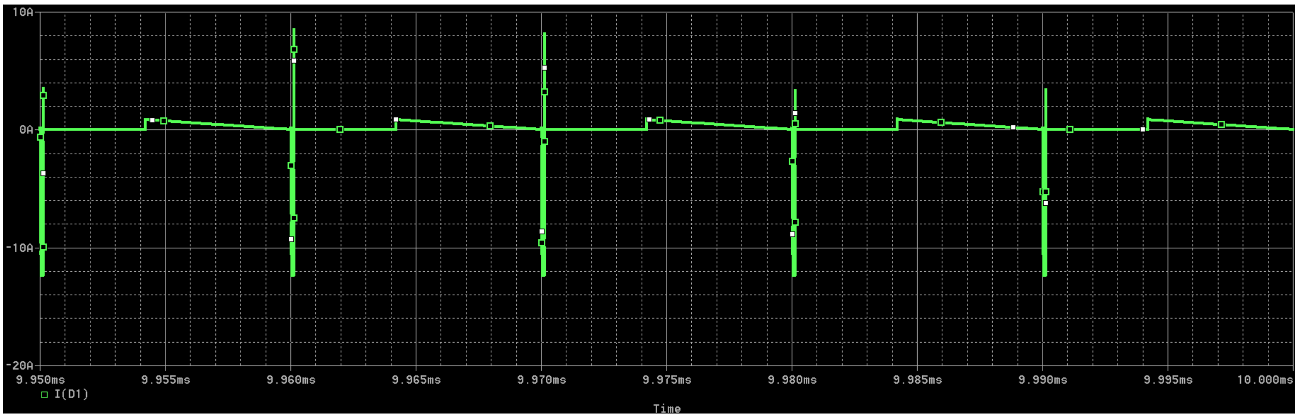


As the load is resistive, so output current is same as voltage.

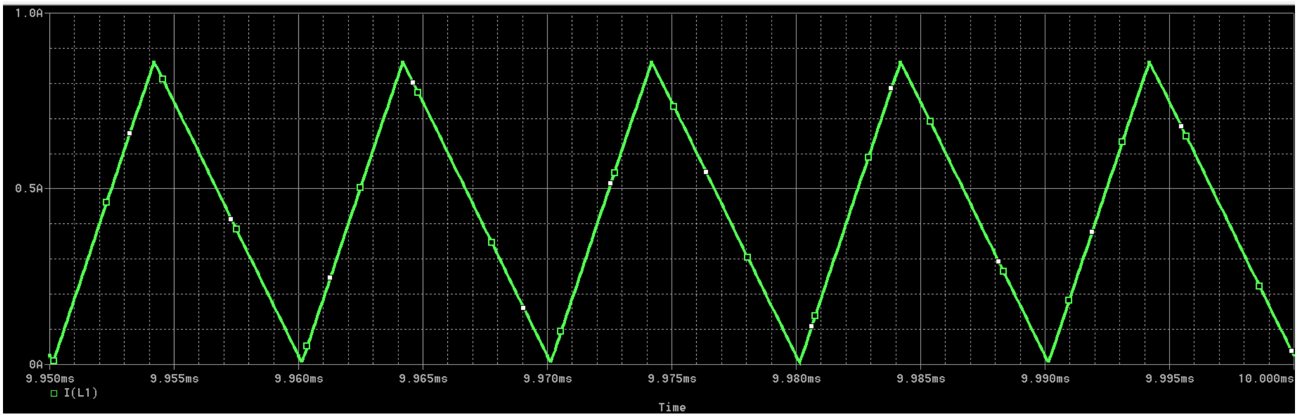
Diode Voltage:



Diode Current:

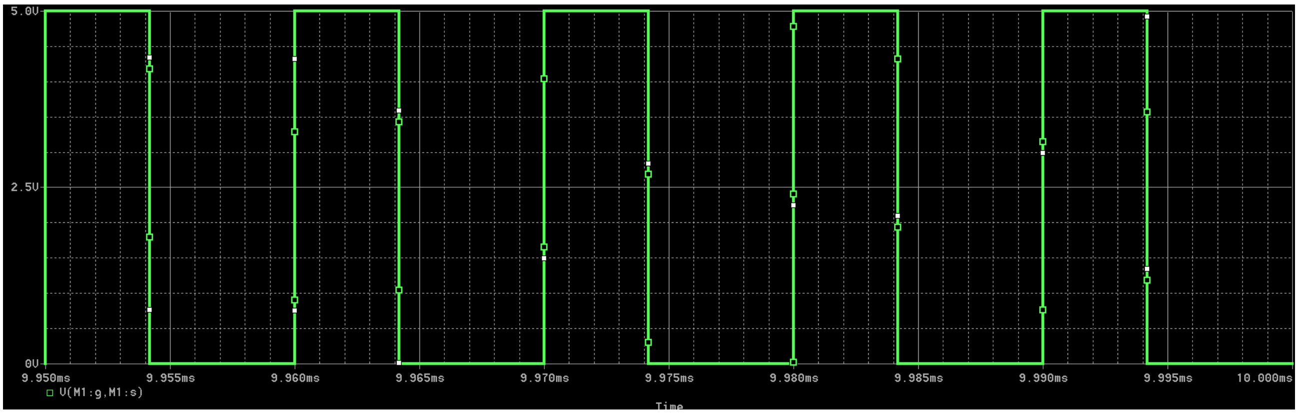


Inductor Current:



Here we can see that the inductor is continuously conducting current keeps charging and discharging. We can see the boundary condition when inductor current approaches zero but never become zero and starts charging cycle again. So the continuous conduction mode is achieved where inductor current is not zero exactly.

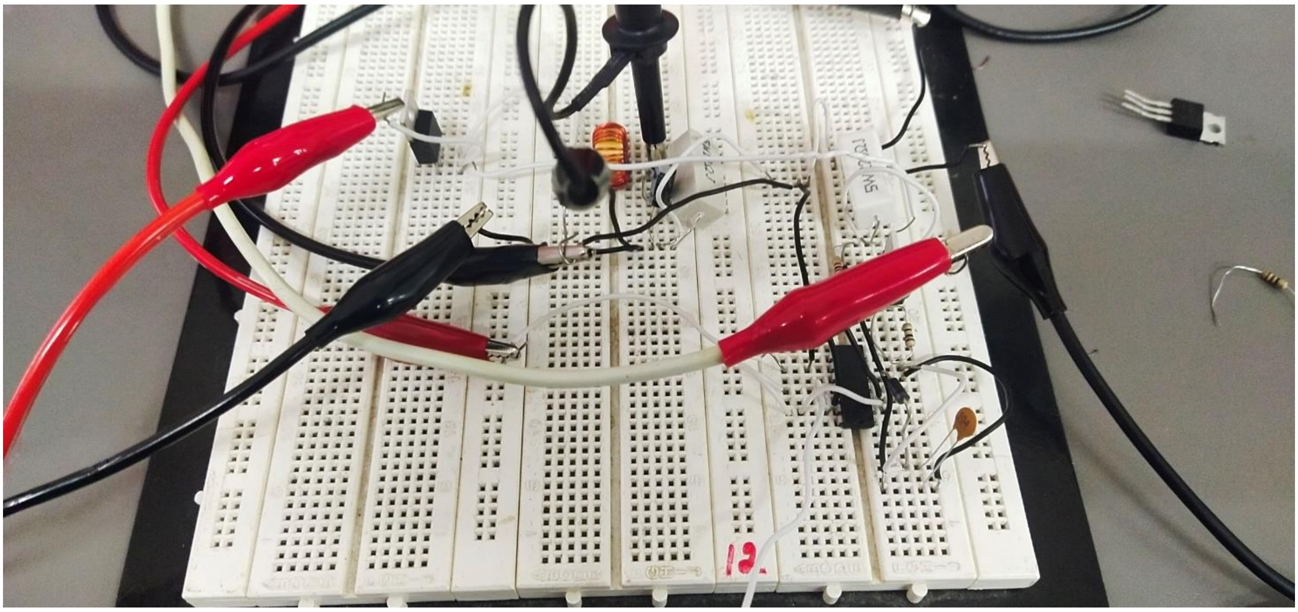
Gate to Source Voltage:



Here is the Duty cycle at Gate signal is 41.67%. This is less than the 50% duty cycle because we are designing a step down converter for which decreasing Duty Cycle, decrease the output voltage because large area is chopped in OFF state of the switch and in smaller area gives power in ON stage of the switch so the average output value is decreased.

Hardware Implementation:

Circuit:

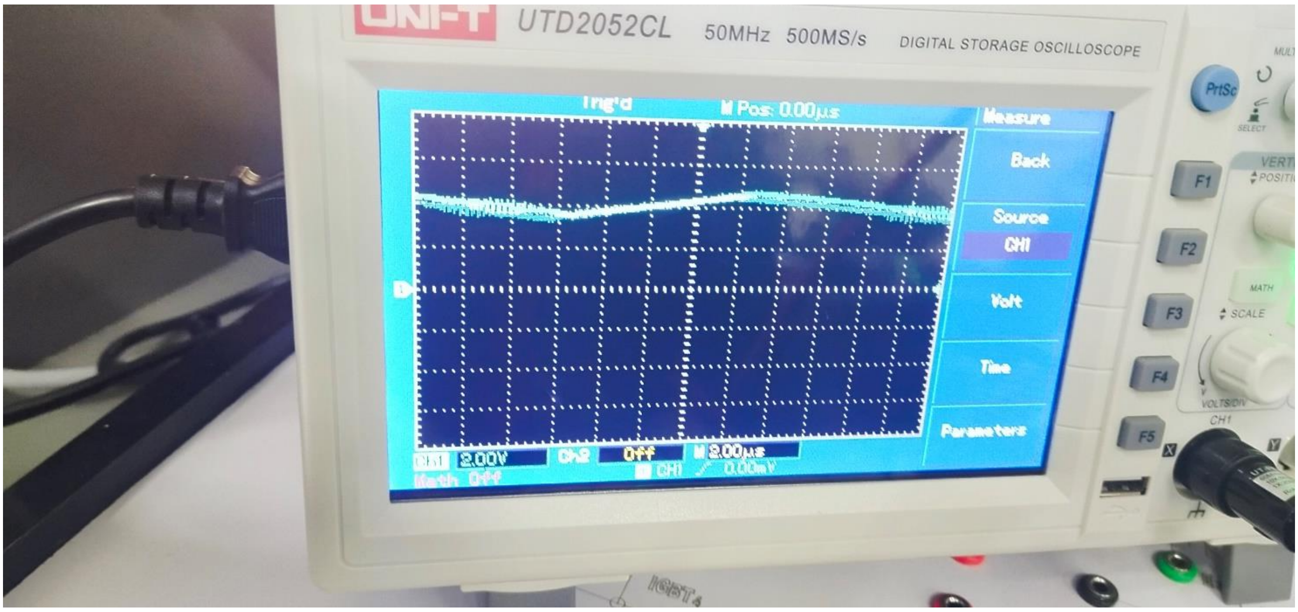


Description:

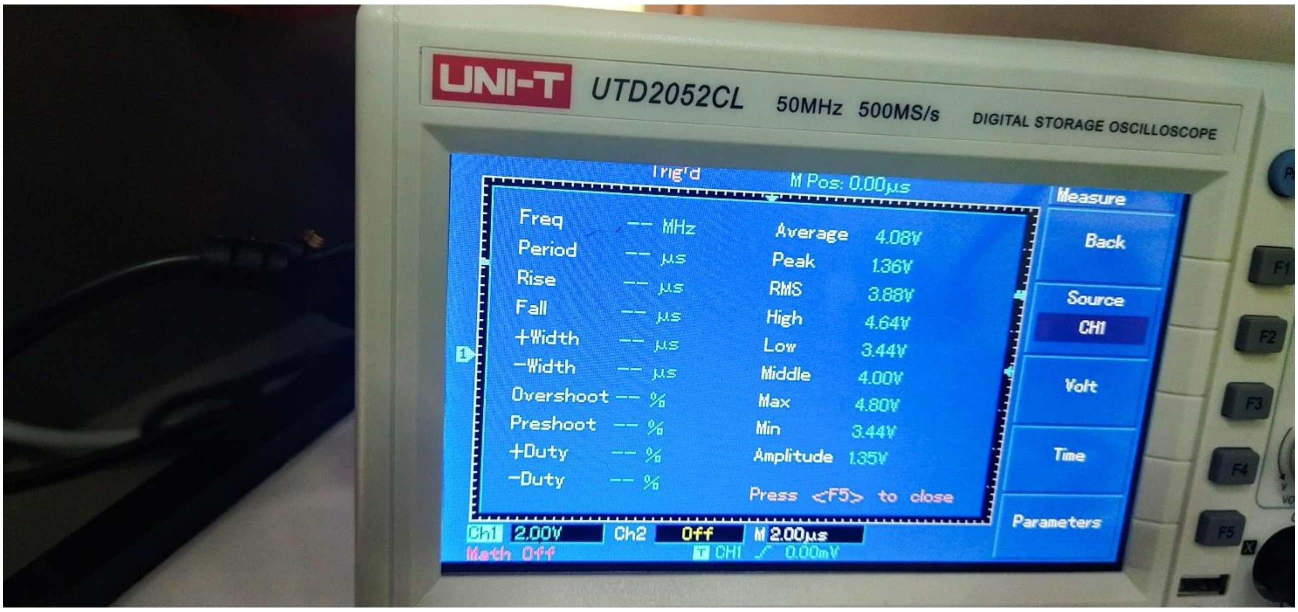
This circuit works exactly same as we have discussed earlier. However, in hardware part we have used a High-Side Fate Driver additionally using Bootstrap circuit.

In a buck converter based on an N-channel MOSFET, the source terminal of the MOSFET is not connected to the circuit ground (not ground-referenced) and is floating. The N-channel MOSFET of a buck converter is a high-side switch. Drive circuits for the high-side switches are called high-side drivers and are more complicated than low-side drivers because it is more difficult to turn off a floating switch **[2]**. To turn the MOSFET on, the gate driver needs to create an effective gate voltage that is higher than the input voltage. So we used bootstrap circuit to solve this problem. Using IR2110 IC.

Output Voltage Waveform:



Output Voltage Data:



Comments:

In the above figure, we can see that the output voltage is 4.64 V which is nearly equal to the 5V design specification. Hence, we have designed a DC-DC Converter that steps down the output voltage to ~ 5V from a 12V DC input having ripple voltage less than 3% of the output voltage.

Conclusion:

At the end of this lab session, we conclude that using a semiconductor switch (MOSFET or BJT) and a low pass/average-pass filter we can design a complete DC-DC step down converter that is also known as Buck Converter. We have observed that the converter design is universal but the component values depend on the specific design criteria for which the circuit is designed. We have achieved ~5 V DC output with a ripple factor less than 3% specification for our design. The efficiency of our design is also good which can be increased by increasing inductance value or switching frequency. This also depends on the type of application to whether use a high value inductance and switching frequency or not. There are also some specifications of discrete components and ICs used in the circuit which affect the output voltage. However, overall results were satisfactory.

References:

[1] *Buck Converter: Basics, Working, Design and Operation. [Online]. Available:* Buck Converter: Basics, Working, Design and Operation (components101.com)

[2] *Bootstrap Circuit in the Buck Converter. [Online]. Available:* Bootstrap Circuit in the Buck Converter (rohm.com)

CLO's	Assessment Type	Excellent 5	Good 4	Average 3	Unsatisfactory 2	Poor 1	Marks
CLO1/2/3	**Circuit Implementation**	Successfully completed in time with complete understanding	Successfully performed but not with clear understanding	Had difficulty in completing the tasks	Not completed about half of the tasks	Task not completed	
CLO1/2/3	**Report**	Clean and clear without any match with fellow students	Clean and clear but slight overlap with other students	Not very clear and clean and partial overlap with fellow students	Not very clear and clean and most of content overlapping with fellow students	Report not submitted	
CLO1/2/3	**Timeline**	Report received with in due time	Report was 1 day late	Report was 3 days late	Report was late for 1 week	Report not submitted	