POWER ELECTRONICS LAB
Experiment-I
STUDY OF BASIC TRANSISTOR CONVERTERS

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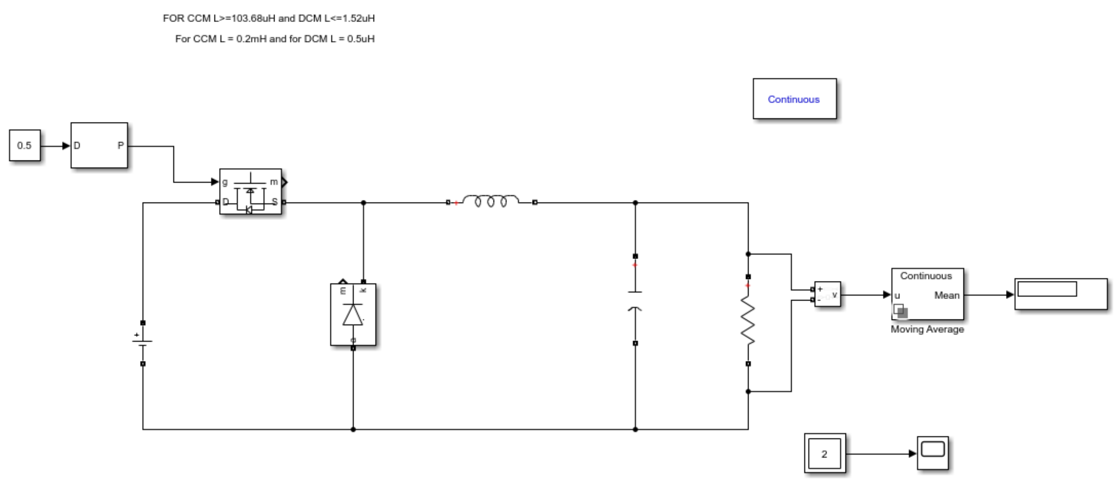
Part-A:

Simulate the buck converter in MATLAB/Simulink using following parameters:

Input Voltage (Vin) = 110V, Capacitance C = 4μF, Load resistance RL = 11.52Ω, Switching Frequency=50 kHz. Choose MOSFET and diode resistance as 1μΩ, and diode voltage drop as 0 V (to simulate close to an ideal converter).

I. Select the value of L such that the converter operates in CCM for the given condition. Change duty ratio in steps of 0.1 starting from 0.1 to 0.9, and tabulate calculated and measured value of the output voltage. Also, plot a graph of voltage gain (Vout/Vin) Vs duty ratio (in x-axis) for CCM operation. Note: change L value if required, but make sure that the converter operates in CCM always for the entire duty ratio(limiting inductor value for CCM and DCM at 0.1 duty ratio).



For the circuit to operate in CCM, we need

$$L \geq \frac{(1 - D_{min})R_L}{2f_{sw}}$$

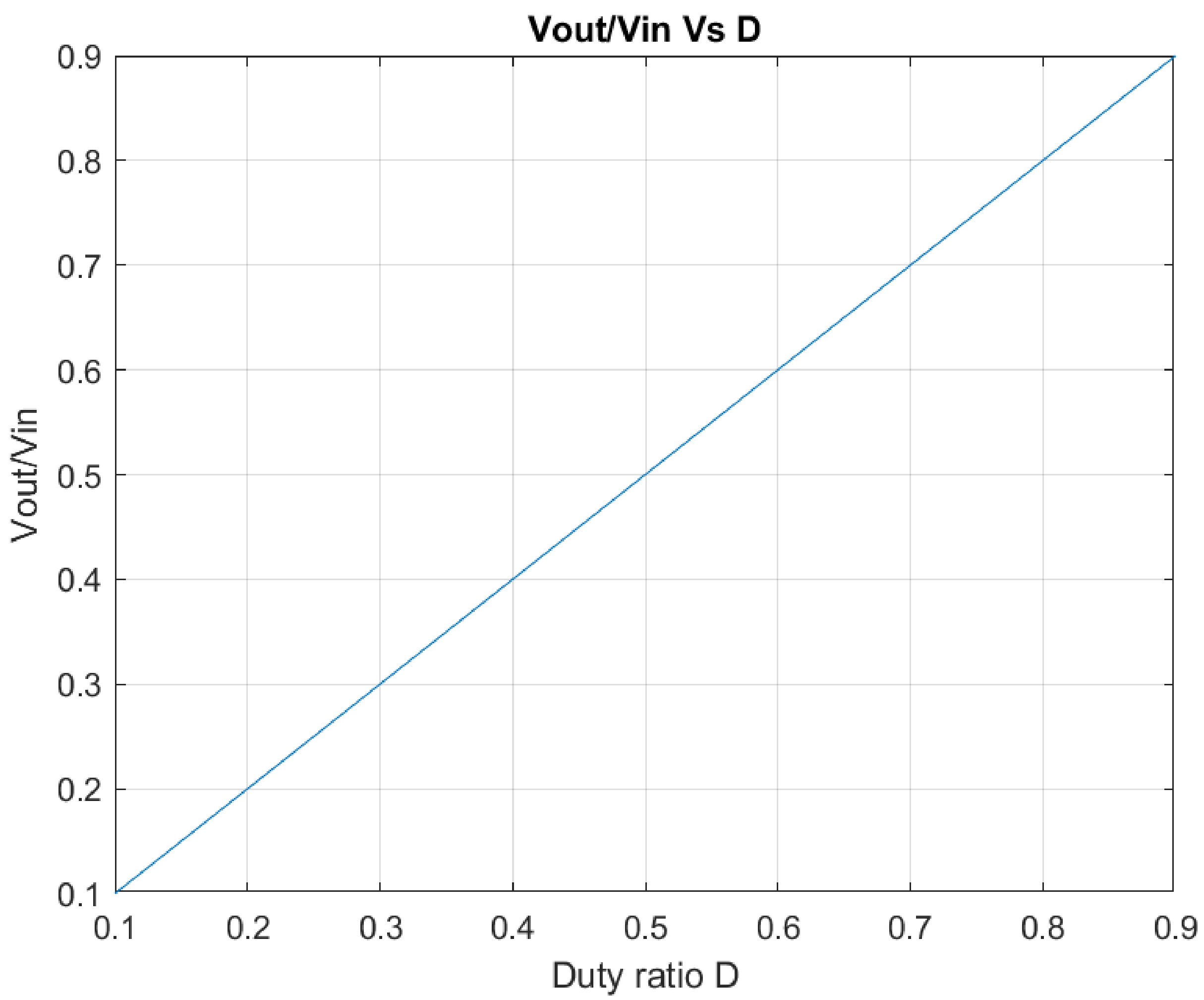
$$L \geq \frac{(1 - 0.1)11.52}{2 * 50k}$$

$$\boldsymbol{L \geq 103.68uH}$$

Choosing **L = 200uH**

D	Vout/Vin
0.1	0.1
0.2	0.2
0.3	0.3
0.4	0.4
0.5	0.5
0.6	0.6
0.7	0.7
0.8	0.8
0.9	0.9

Voltage Gain vs Duty Ratio plot:



II. Now select L such that the converter operates in DCM. For the duty ratio 0.5 compare the output voltage obtained in the CCM and DCM case.

Now we need to operate the converter in DCM at duty ratio 0.5

Vin = 110V, C = 4µF, R_L = 11.52Ω, f_{sw} = 50KHz

For the circuit to operate in CCM, we need

$$L \leq \frac{(1-D)R_L}{2f_{sw}}$$

$$L \leq \frac{(1-0.5)11.52}{2 * 50k}$$

$$\boldsymbol{L \leq 57.6uH}$$

Choosing **L = 0.5uH**

At **D = 0.5**

Vout = 91.71Volts

D = 0.5

For CCM L = 0.2mH **Vout = 55 Volts**

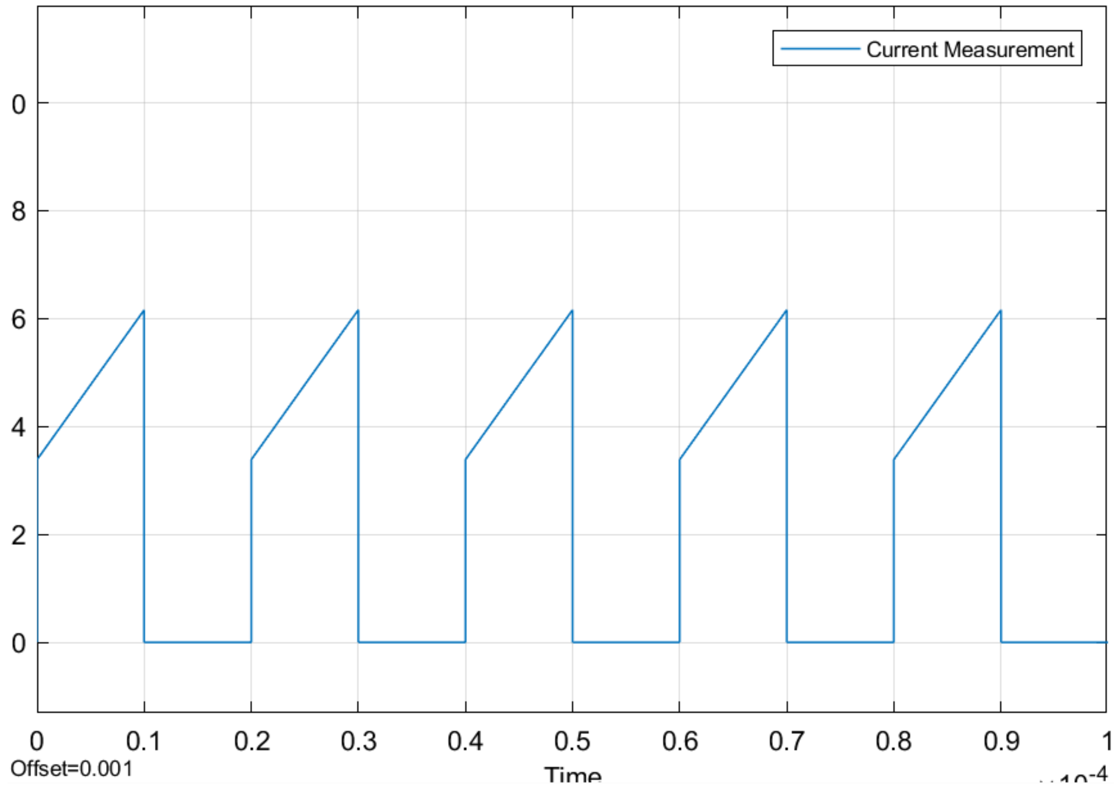
For DCM L = 0.5uH **Vout = 91.71 Volts**

III. For a given duty ratio (say 0.5) observe and save simulated waveforms for the following variables for both CCM and DCM case: current and voltage waveforms of MOSFET, inductor, diode, and output capacitor.

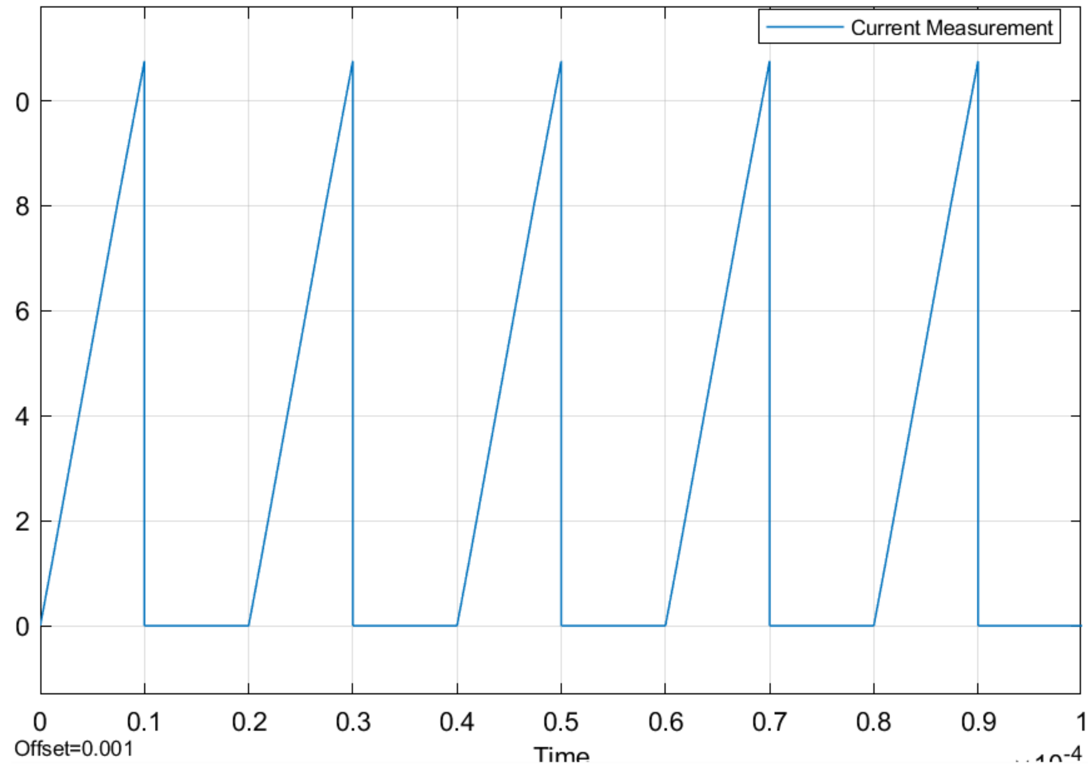
L = 200uH for CCM

L = 50uH for DCM

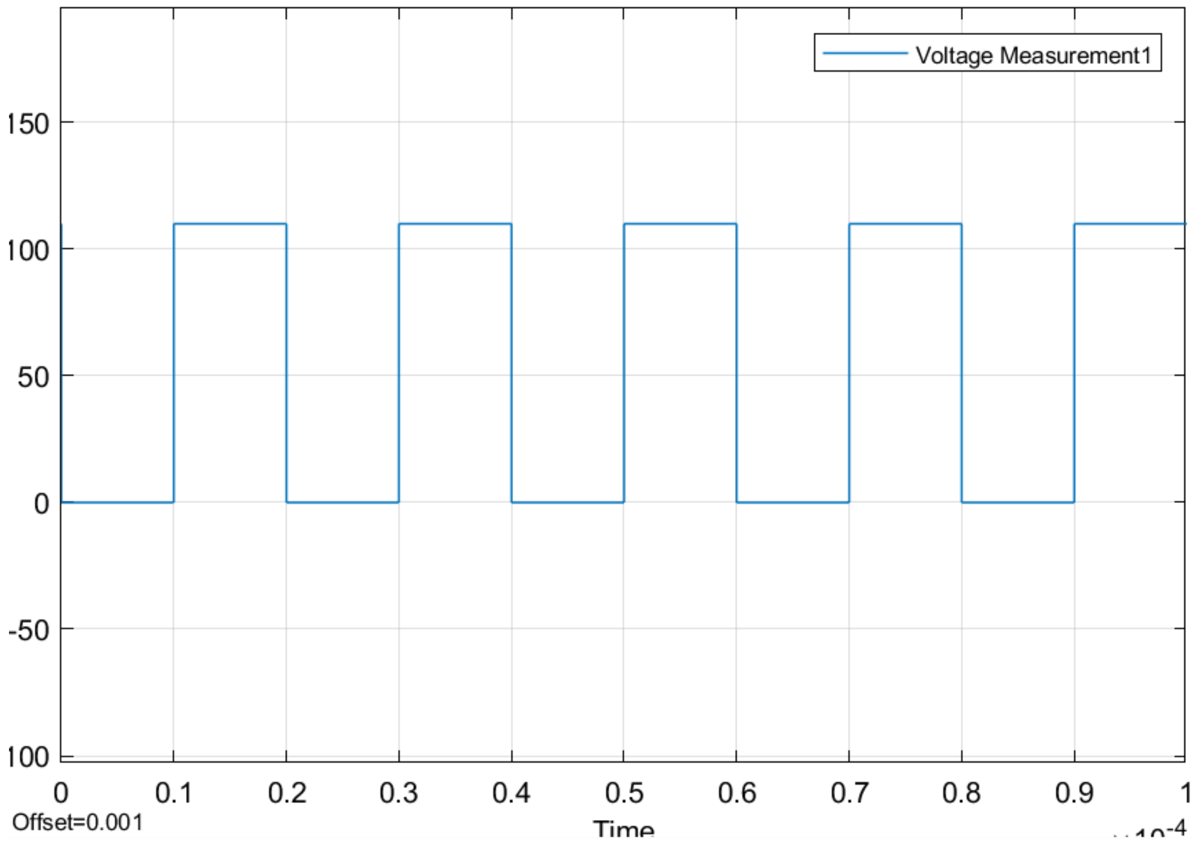
MOSFET CURRENT CCM



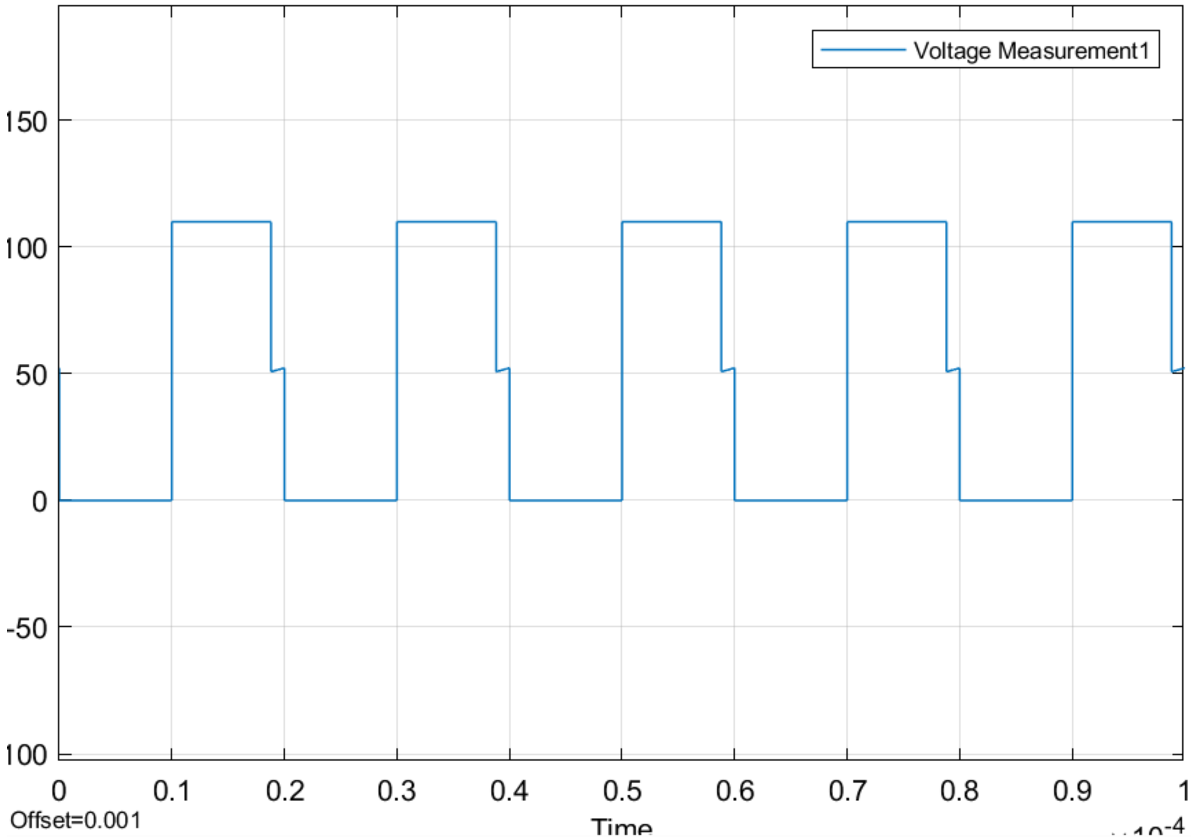
MOSFET CURRENT DCM



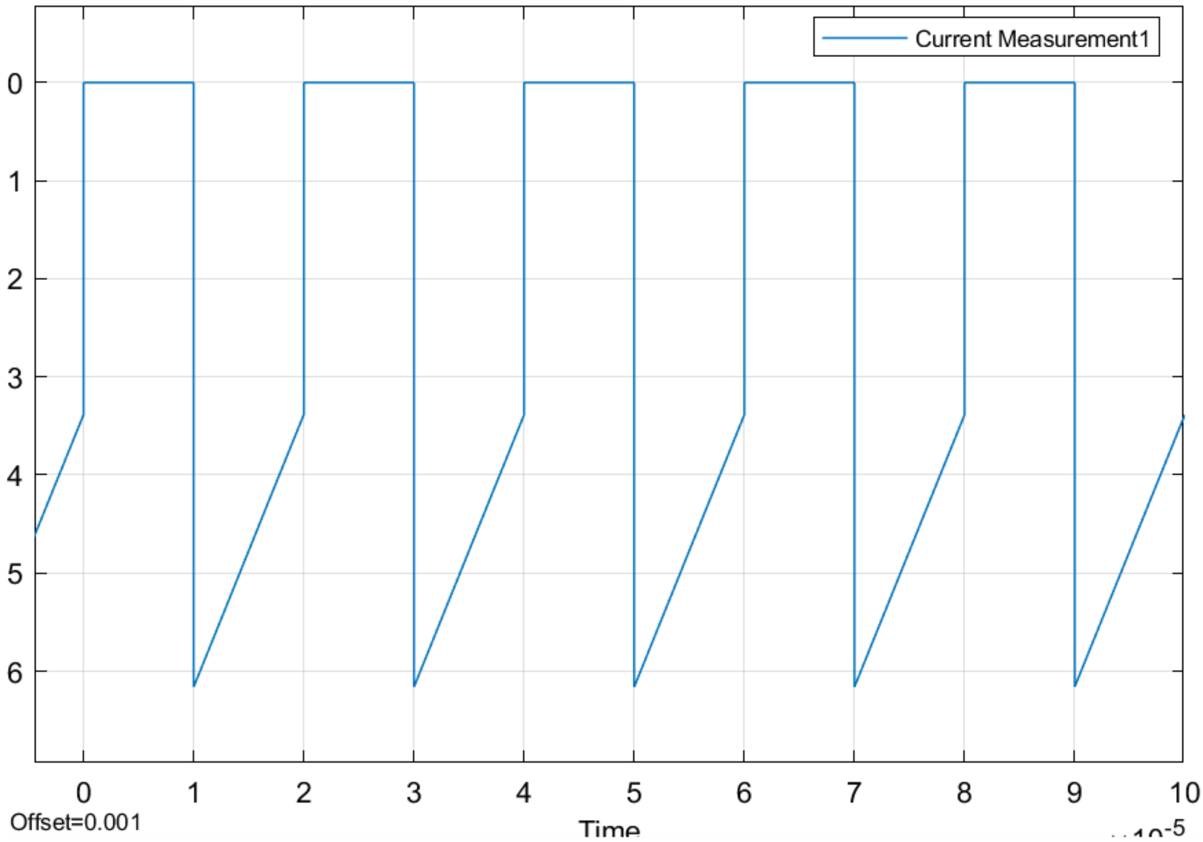
MOSFET VOLTAGE CCM



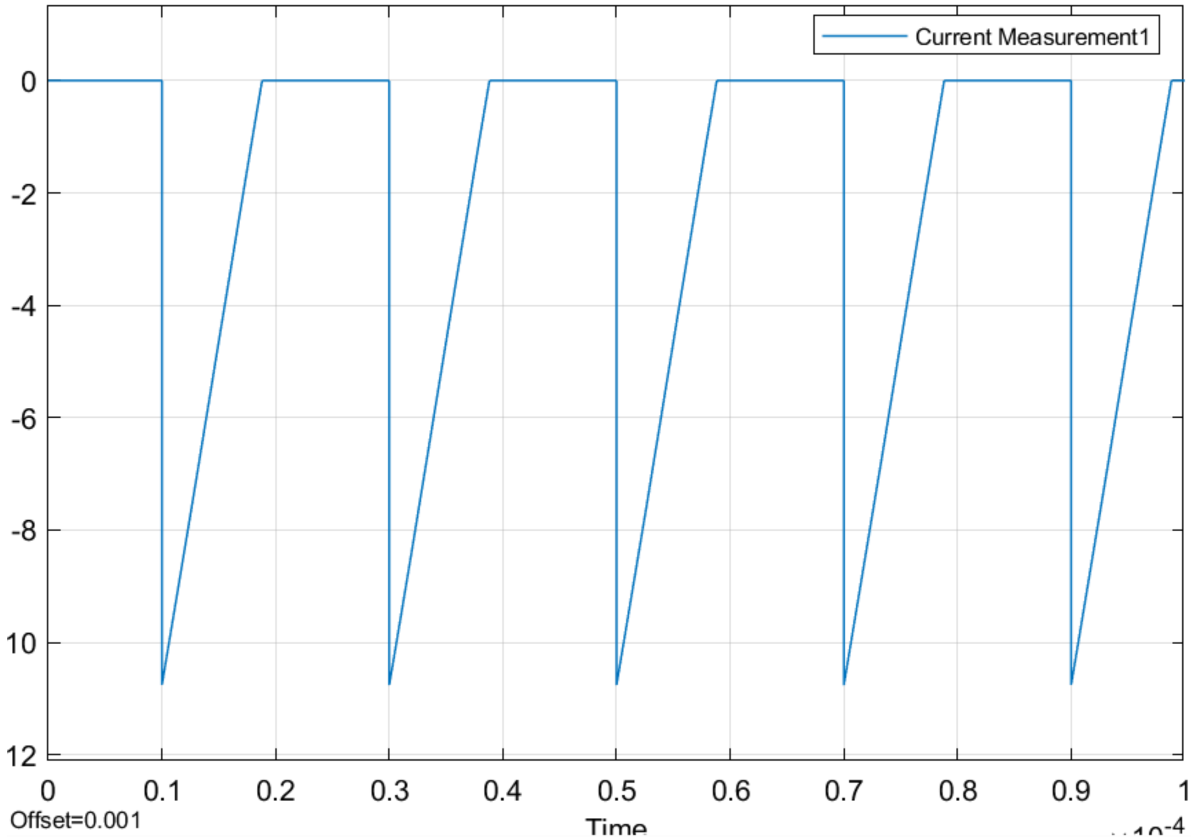
MOSFET VOLTAGE DCM



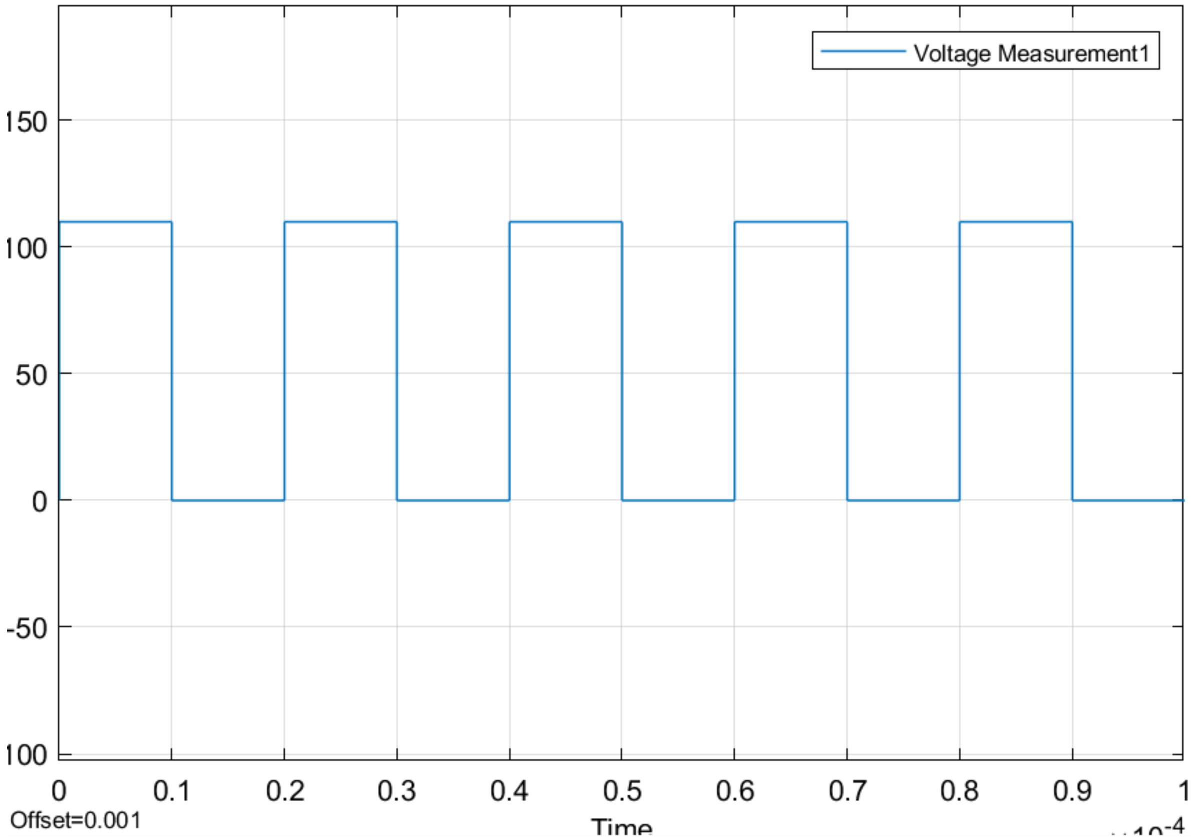
DIODE CURRENT CCM



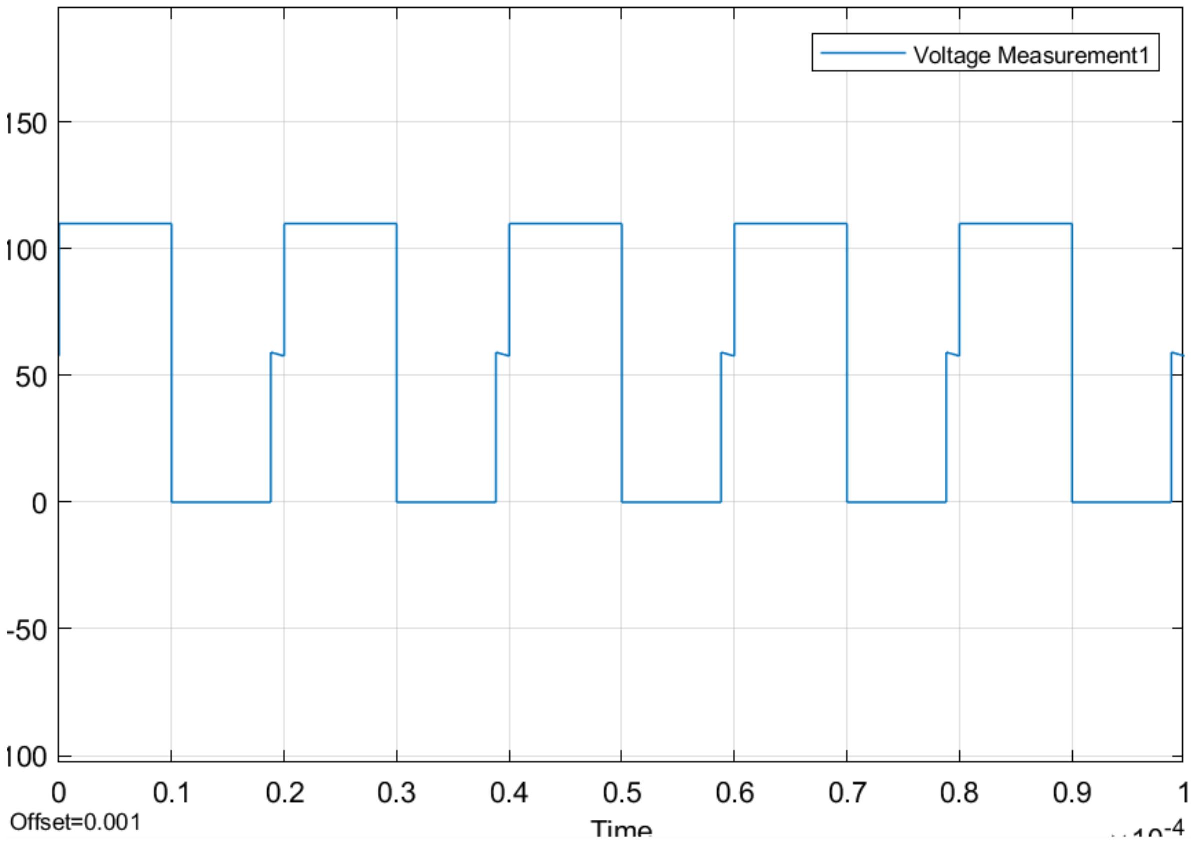
DIODE CURRENT DCM



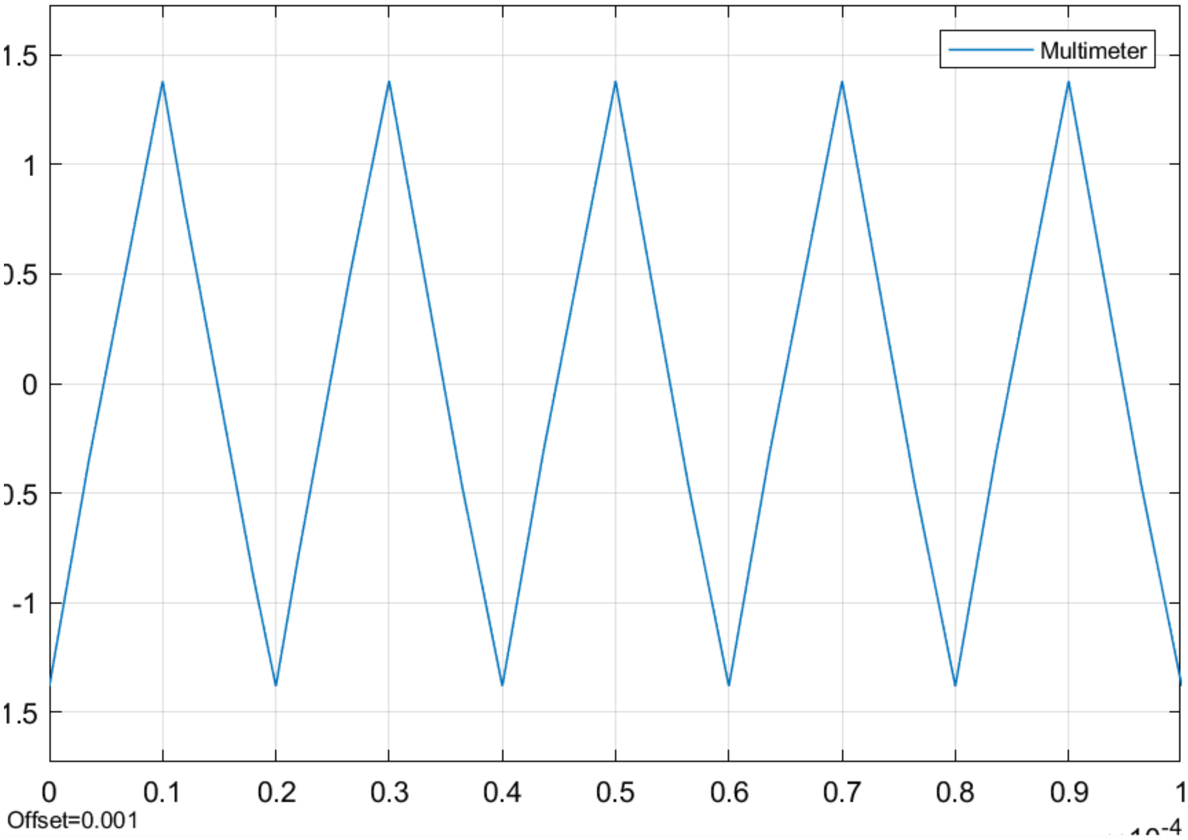
DIODE VOLTAGE CCM



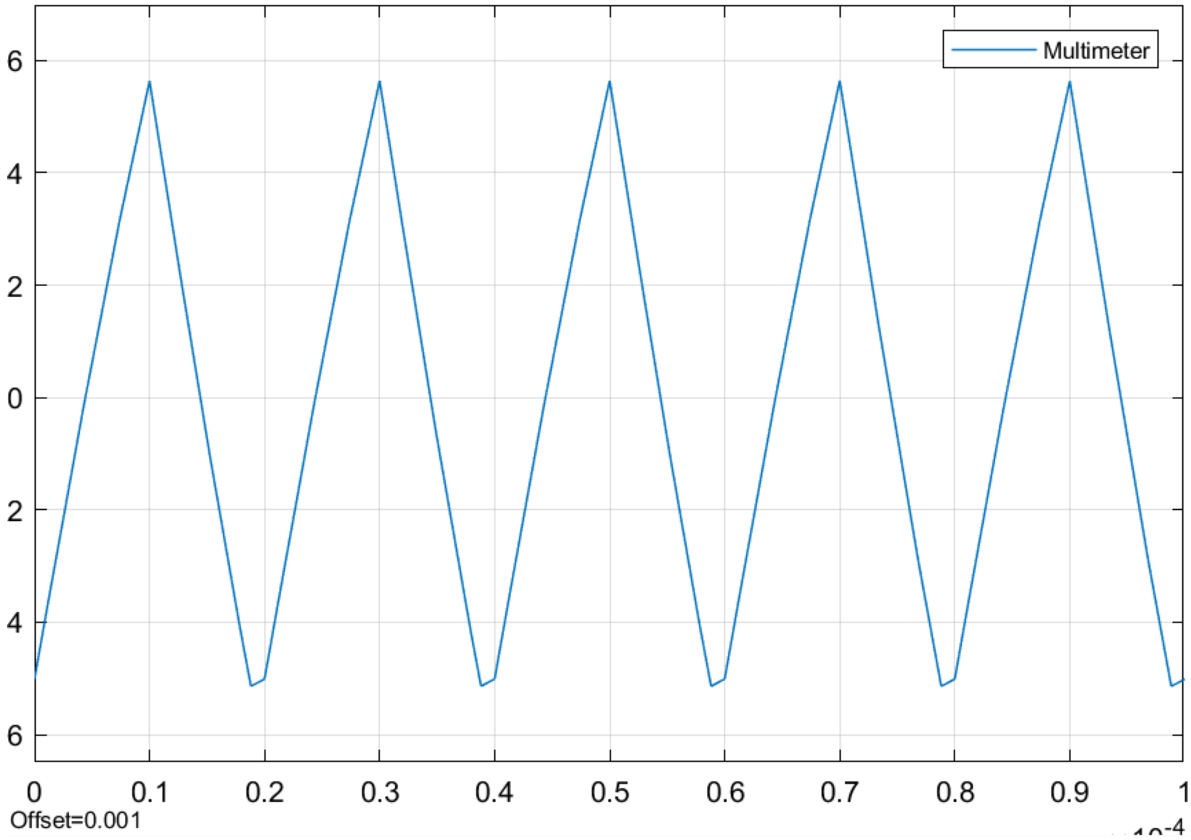
DIODE VOLTAGE DCM



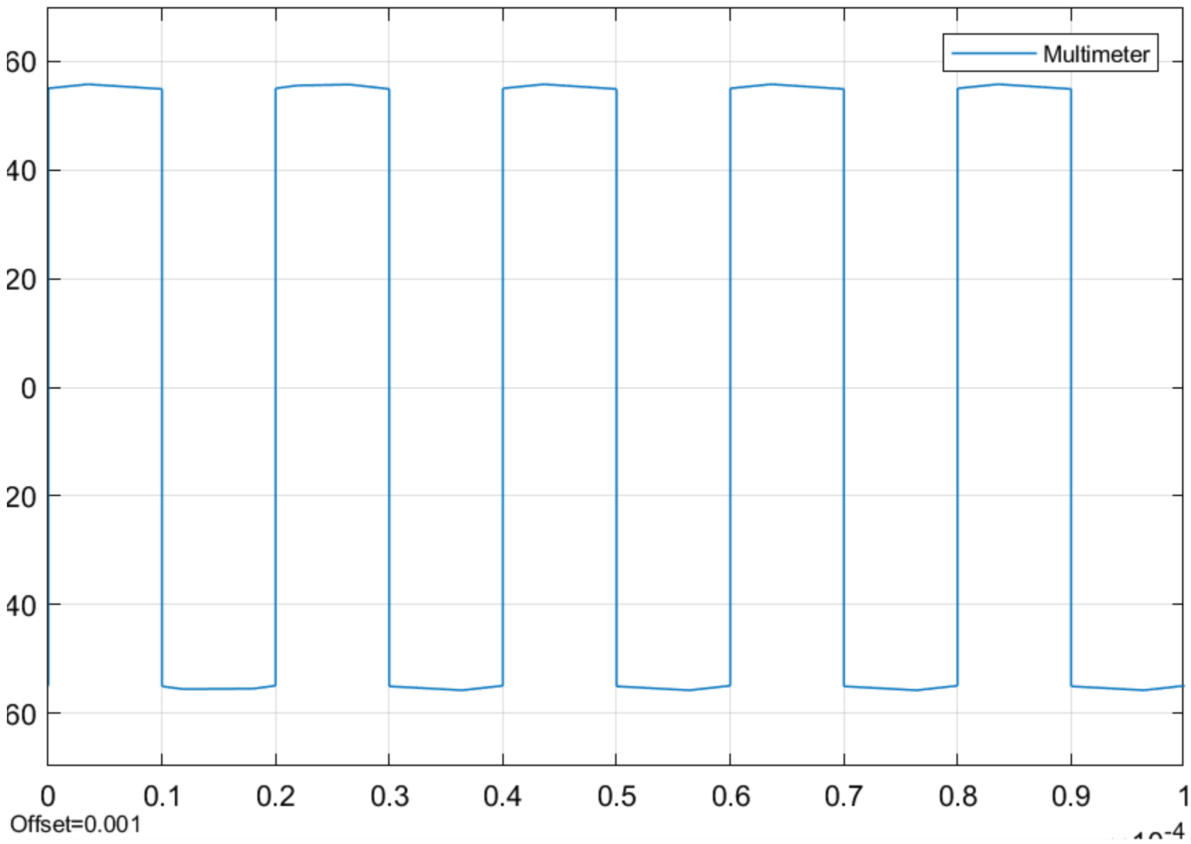
INDUCTOR CURRENT CCM



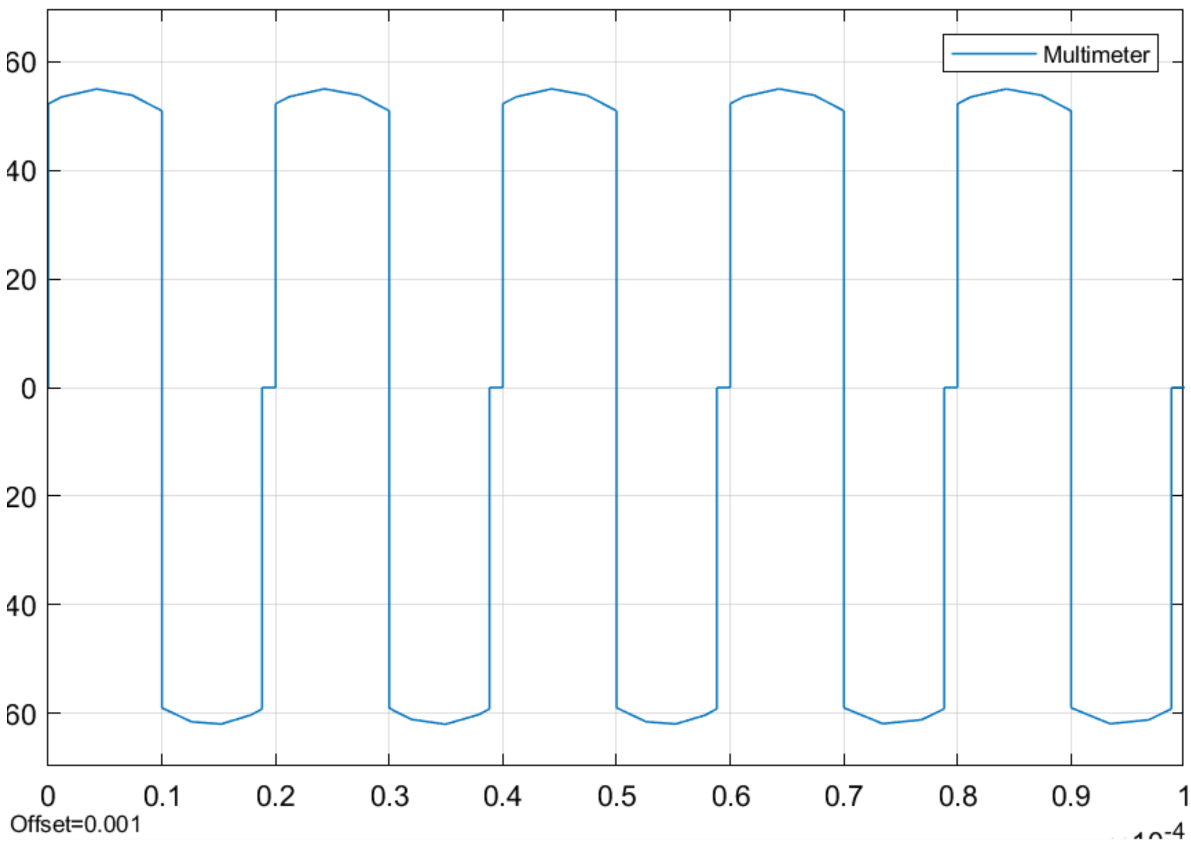
INDUCTOR CURRENT DCM



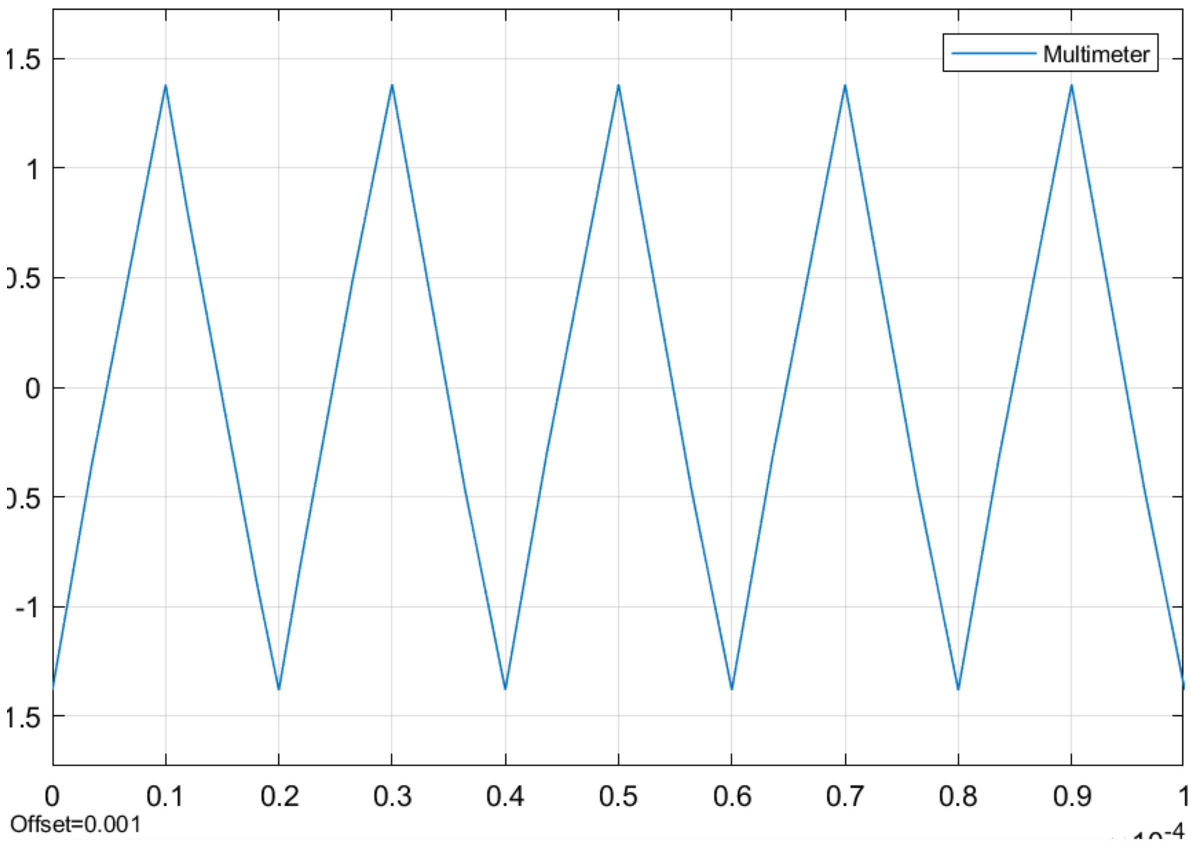
INDUCTOR VOLTAGE CCM



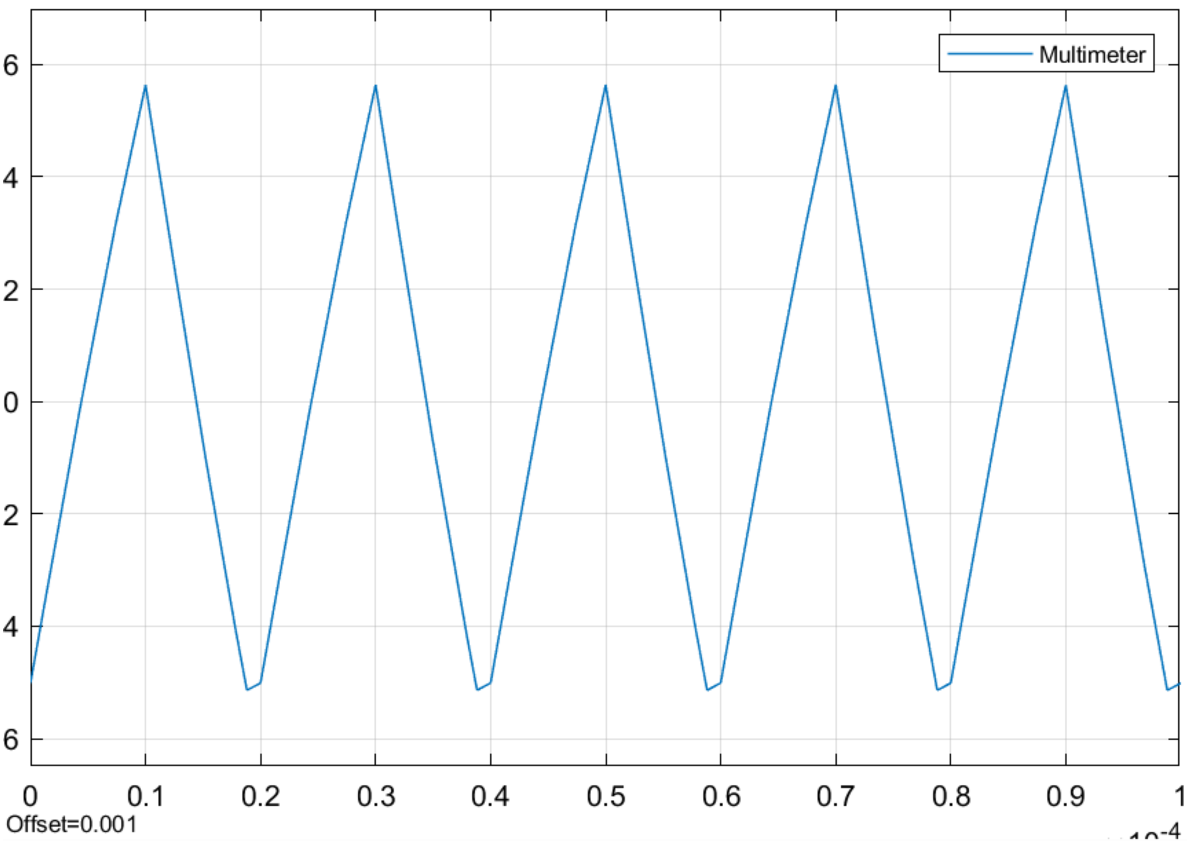
INDUCTOR VOLTAGE DCM



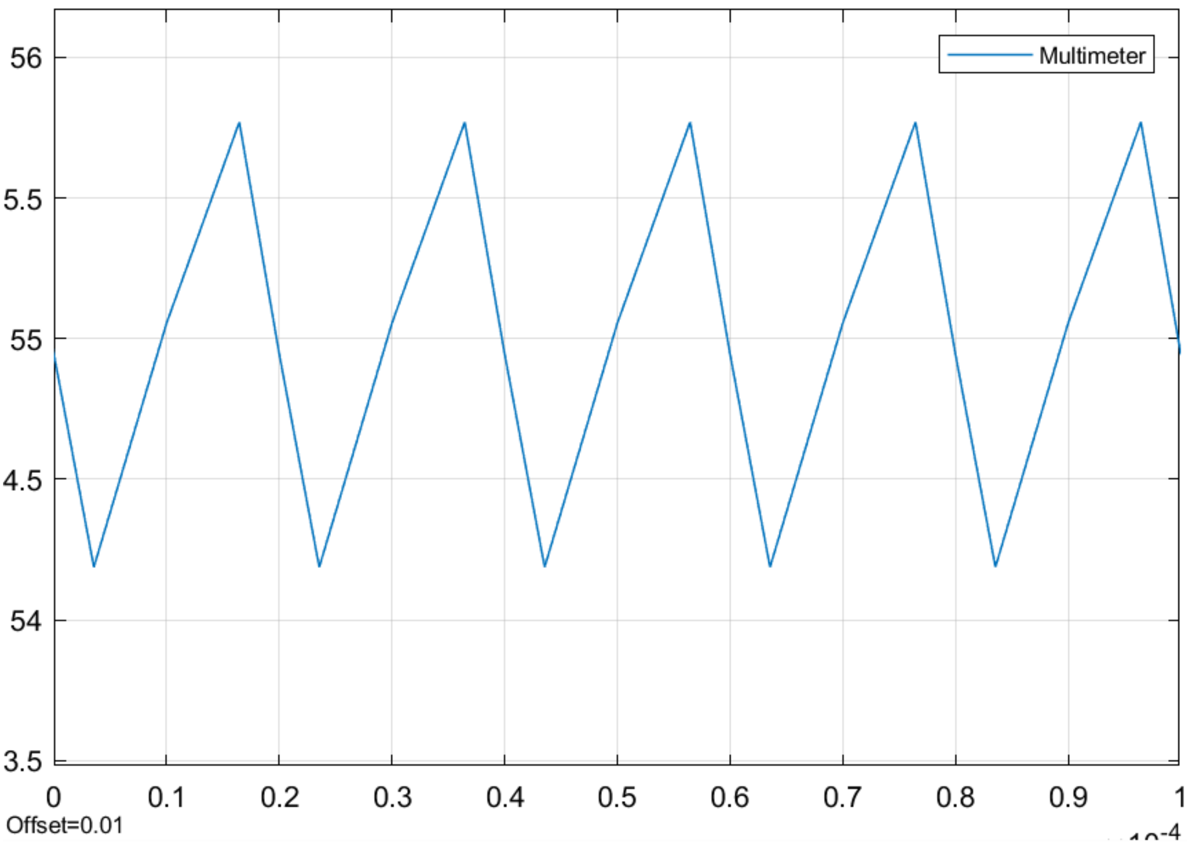
CAPACITOR CURRENT CCM



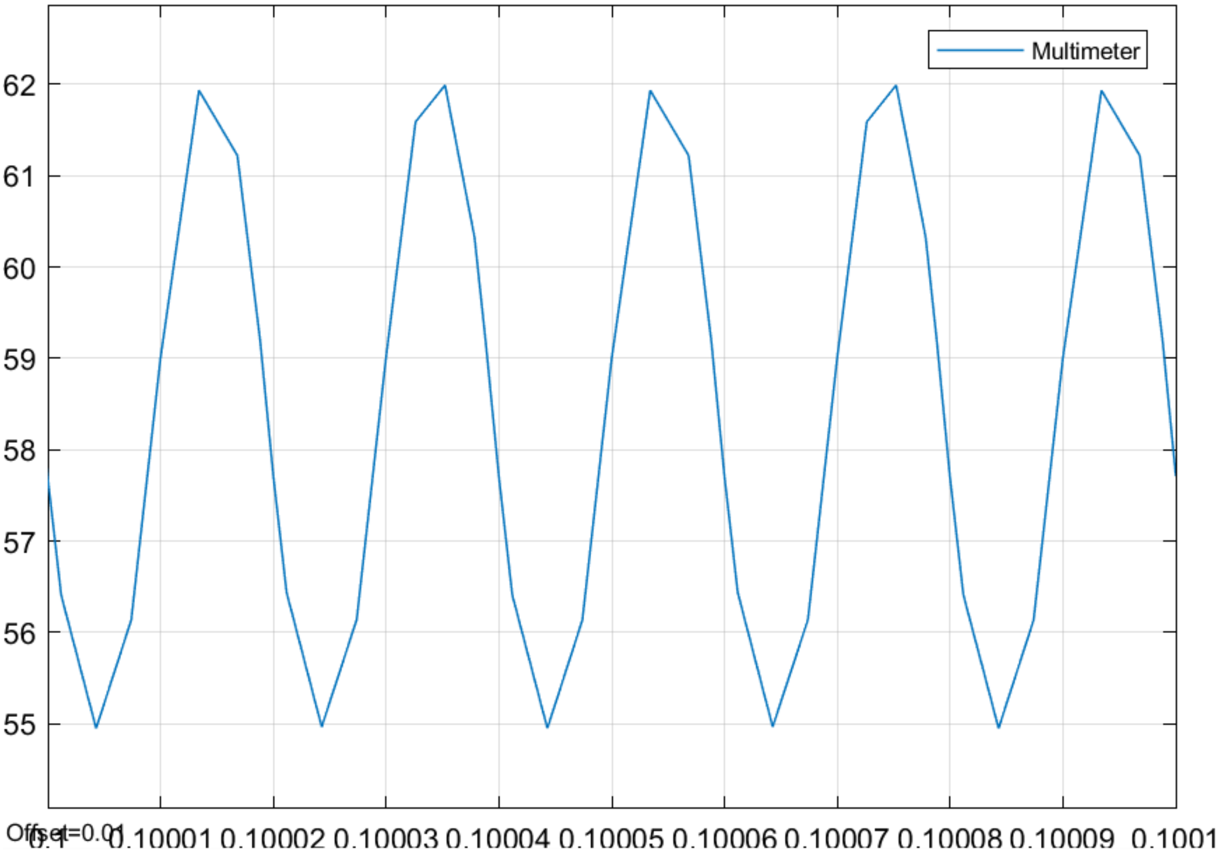
CAPACITOR CURRENT DCM



CAPACITOR VOLTAGE CCM



CAPACITOR VOLTAGE DCM

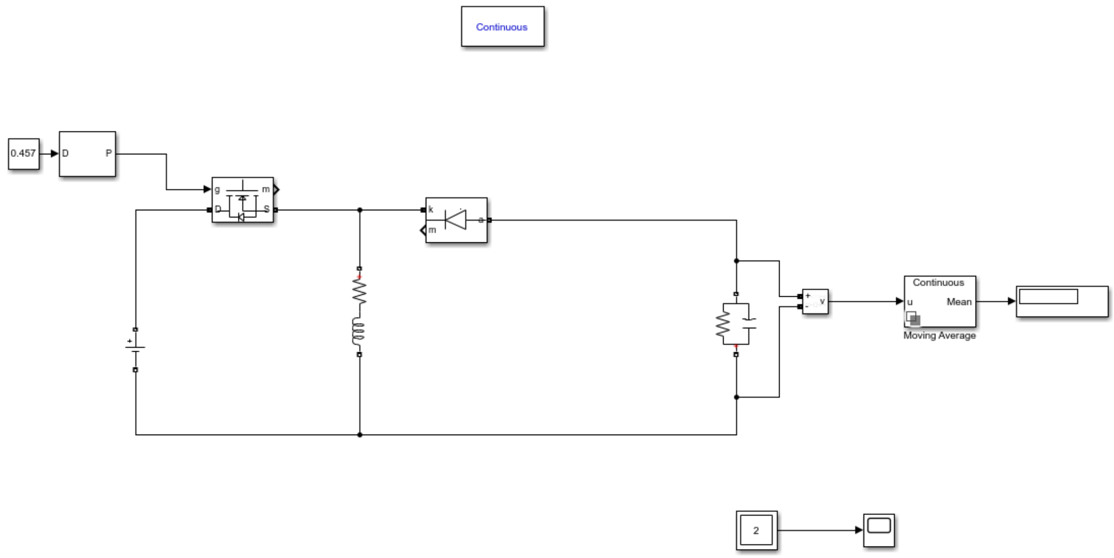


Part-B: Simulate the **buck-boost converter** in MATLAB/Simulink using following parameters: Input Voltage **(Vin)=57V,** Inductor **L = 226µH**, Capacitance **C = 54µF**, Load resistance **RL = 11.52Ω**, Switching Frequency = **50 kHz**, **Duty Cycle =0.457**. Choose MOSFET and diode resistance as 1µΩ, and diode voltage drop as 0.

Select parasitic resistance of inductor RL = 0 Ω in case (i) and RL = 5% of RL in case (ii).

Vary Duty ratio from 0.1 to 0.9 in steps of 0.1

I. Plot the voltage gain Vs duty ratio in case(i) and case(ii), and comment on the same.



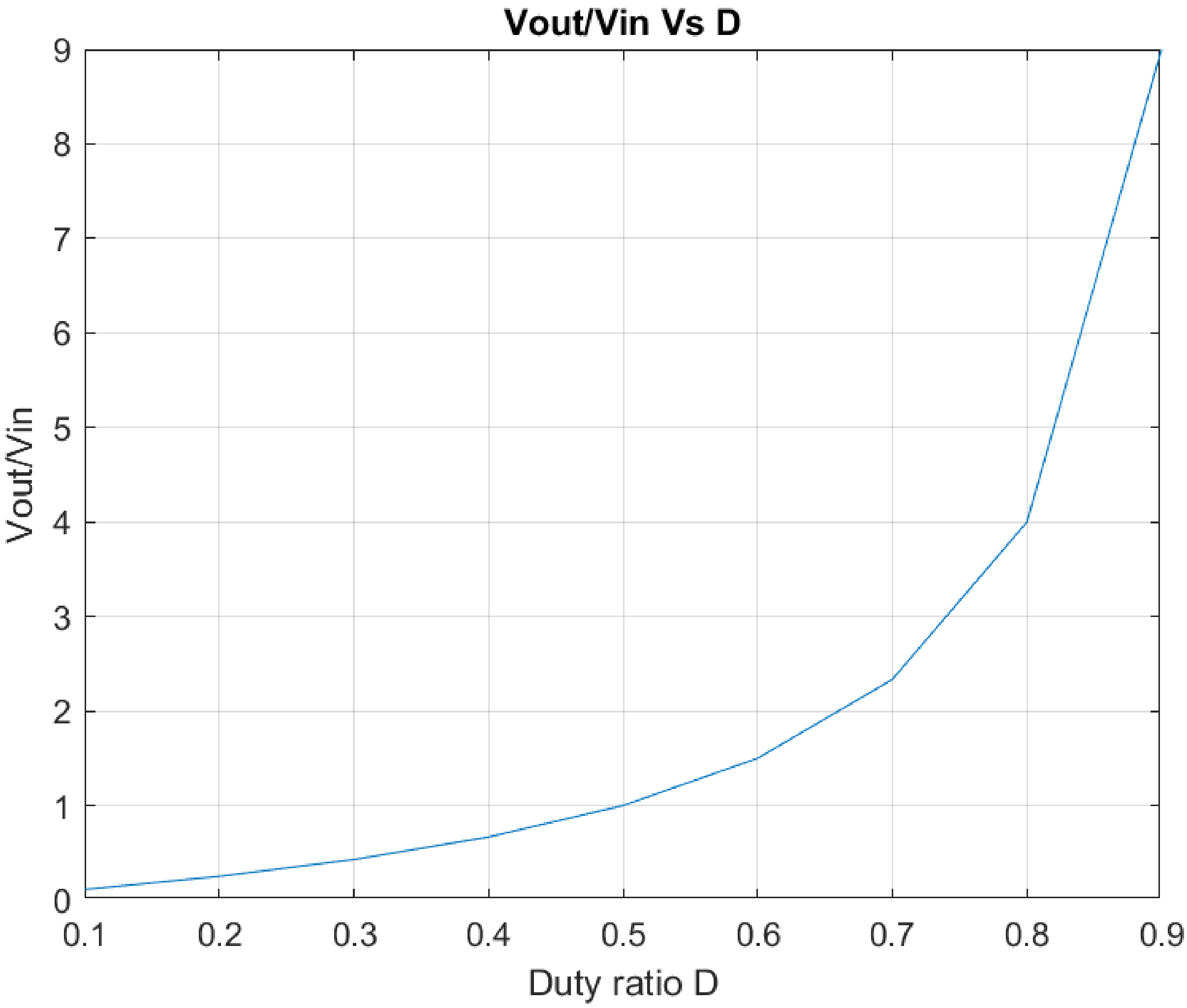
Case i)

Parasitic resistance RL= 0Ω

So, in CCM condition, gain(Vout/Vin) =$\frac{D}{1-D}$

Vin = 57V, C = 54µF, RLoad = 11.52Ω, fsw = 50KHz, L=226µH

D	Vout	Vout/Vin
0.1	-6.332	-0.11109
0.2	-14.25	-0.25
0.3	-24.42	-0.42842
0.4	-37.99	-0.66649
0.5	-56.97	-0.99947
0.6	-85.48	-1.49965
0.7	-133	-2.33333
0.8	-228	-4
0.9	-513	-9



The plot follows the formula $Gain = \frac{D}{1-D}$ as there is no parasitic resistance in the inductor, the gain increases exponentially as we increase duty ratio.

Case II)

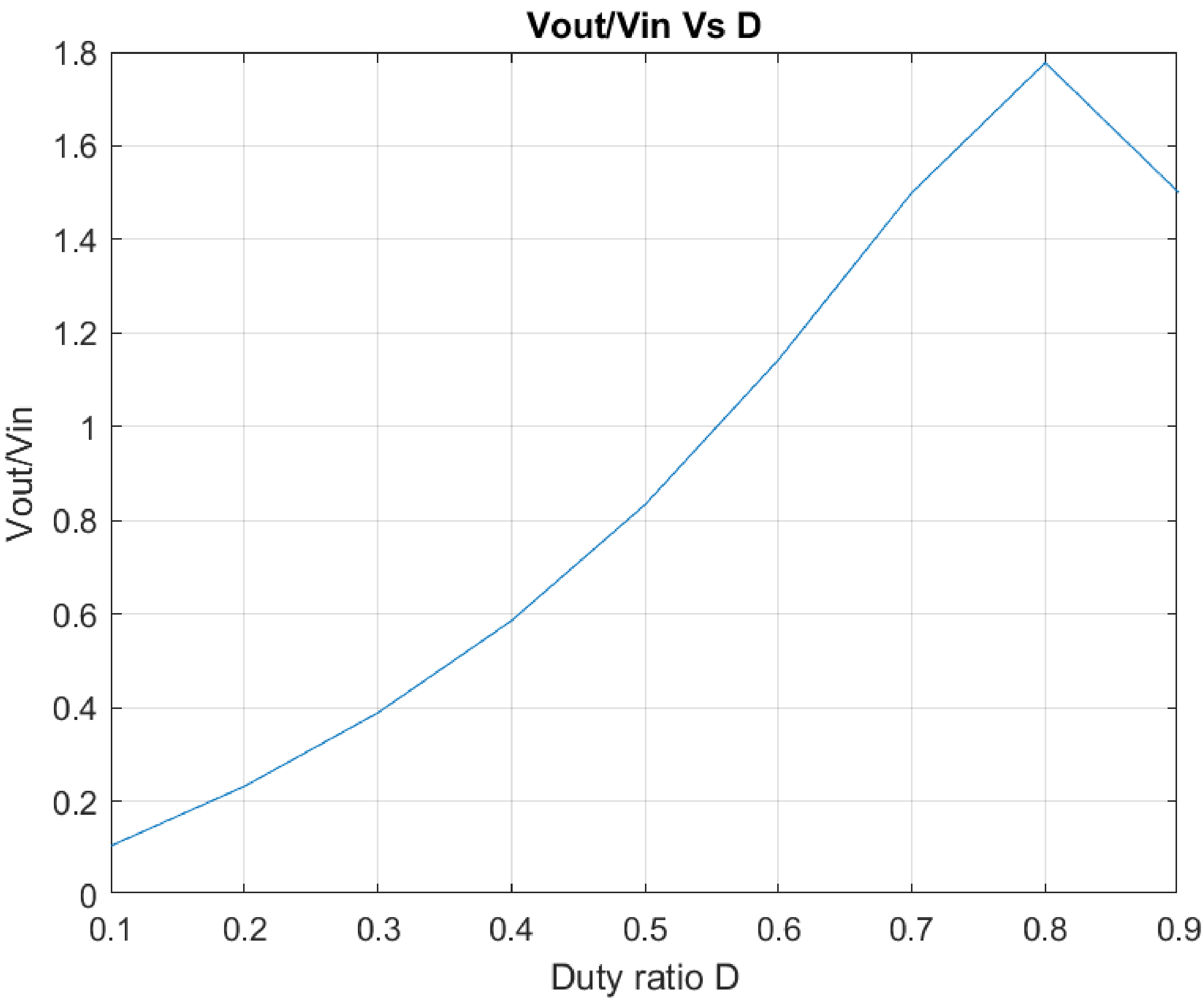
Parasitic resistance RL= 5% of RLoad = 0.576Ω

So, in CCM condition, gain(Vout/Vin) = $\frac{D}{1-D+\frac{R}{R_{Load}(1-D)}}$

Vin = 57V, C = 54µF, RLoad = 11.52Ω, fsw = 50KHz, L=226µH

D	Vout	Vout/Vin
0.1	-5.964	-0.10463
0.2	-13.21	-0.23175

0.3	-22.16	-0.38877
0.4	-33.36	-0.58526
0.5	-47.47	-0.83281
0.6	-65.12	-1.14246
0.7	-85.48	-1.49965
0.8	-101.3	-1.77719
0.9	-85.5	-1.5



Due to parasitic resistance, power is dissipated through the inductor, so gain doesn't increase exponentially in this case. Also ,for high duty ratio gain eventually decreases as inductor current is inversely proportional to (1-D) so it dissipates an increasing amount of power.

II. Keeping all other parameters the same, vary the switching frequency and check at what frequency the system will be on the verge of CCM and DCM conditions for case(i) and case(ii) for D=0.457?

Case(i): Vin = 57V, C = 54µF, RLoad = 11.52Ω, L=226µH, RL= 0Ω, Duty ratio(D) = 0.457

$$GAINccm = \frac{D}{1-D}$$

$$GAINdcm = \frac{V_{in}D^2}{2LI_o f_{sw}}$$

In Limiting condition at both the gains will be same

So theoretically DCM to CCM transition happens at **fsw=7.515KHz** for no parasitic resistance

CHECKING INDUCTOR CURRENT AT VARIOUS FREQUENCY

fsw	I_L
5KHz	-0.058
6KHz	-0.054
7KHz	-0.049
8KHz	0.5528
7.2Khz	-0.042
7.4Khz	-0.008
7.6Khz	0.1528

So It is observable that Fsw is between 7.4Khz and 7.6Khz

Case(ii): Vin = 57V, C = 54µF, RLoad = 11.52Ω, L=226µH, RL=0.576Ω, Duty ratio(D) = 0.457

fsw	I_L
5KHz	-0.037
6KHz	-0.032
7KHz	-0.031
8KHz	-0.0087
9KHz	0.6599
10KHz	1.255
8.1Khz	0.01
8.2Khz	0.0771

So It is observable that Fsw is between 8Khz and 8.1Khz

III. For case (i) tabulate the steady-state input and output currents for various duty ratios.

Duty ratio	Input Current	Output Current
0.1	0.147	-5.486
0.2	0.5	-1.235
0.3	0.9	-2.115

0.4	1.817	-3.292
0.5	2.47	-4.92
0.6	4.192	-7.363
0.7	8.566	-11.45
0.8	22.44	-19.62
0.9	107.77	-44.27

Part-C

For following operating condition(i.e. Input Voltage(Vin) = 110V, Load voltage =**48V**, Inductance = **115µH** Capacitance C =**50µF,** Load resistance RL=**11.52Ω**, Switching Frequency =**50kHz**, CCM and steady-state operation) compare the following between buck and buck-boost converter: voltage and current stress of switch and diode, inductor current ripple, output voltage ripple (save waveforms).

Given operating condition:

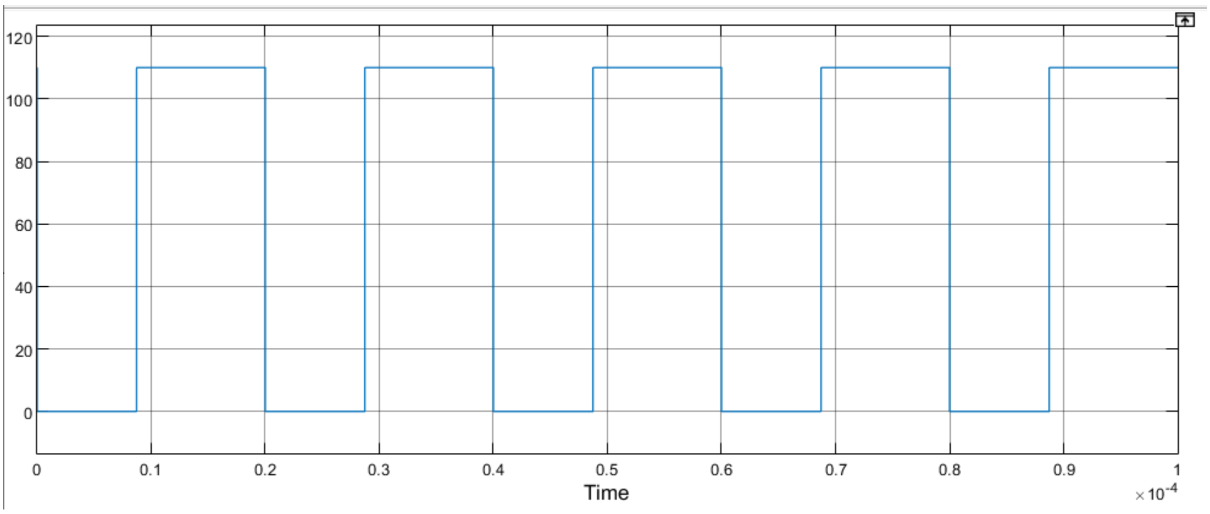
Vin = 110V, RLoad = 11.52Ω, L = 115µH, C=50µF, fsw = 50KHz, Vout = 48V

$$D_{buck} = \frac{V_o}{V_{in}} = \frac{48}{110}$$

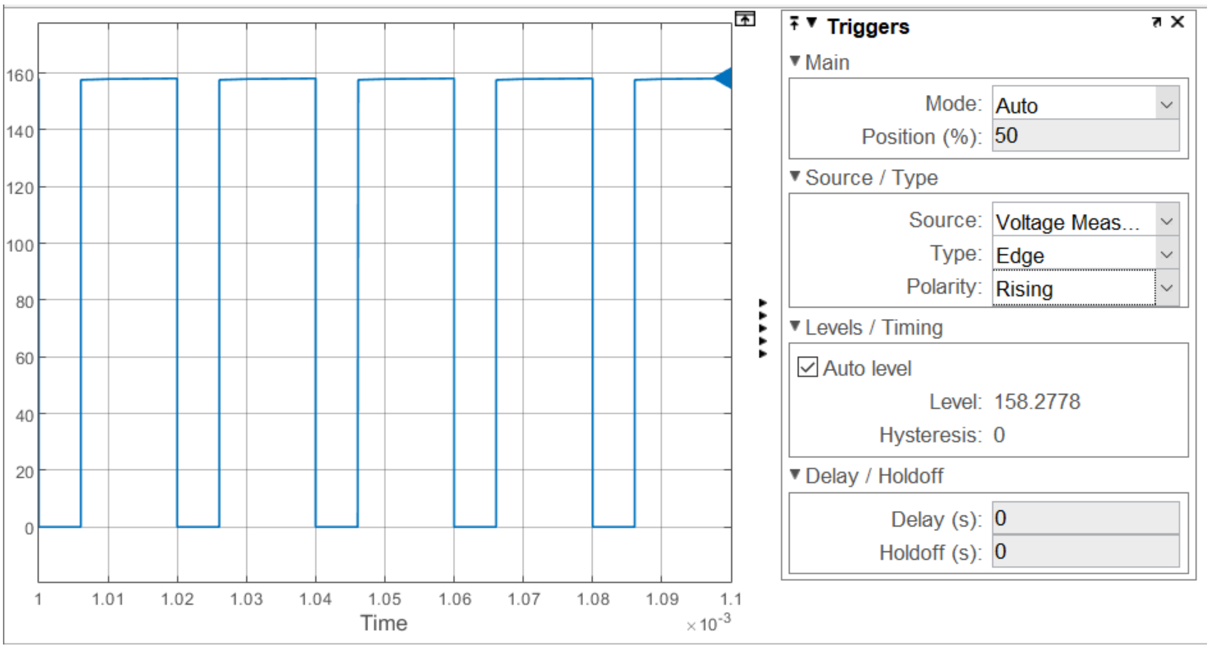
$$D_{buck-boost} = \frac{V_o}{V_o + V_{in}} = \frac{48}{158}$$

MOSFET VOLTAGE STRESS

Buck Convertor (110V)



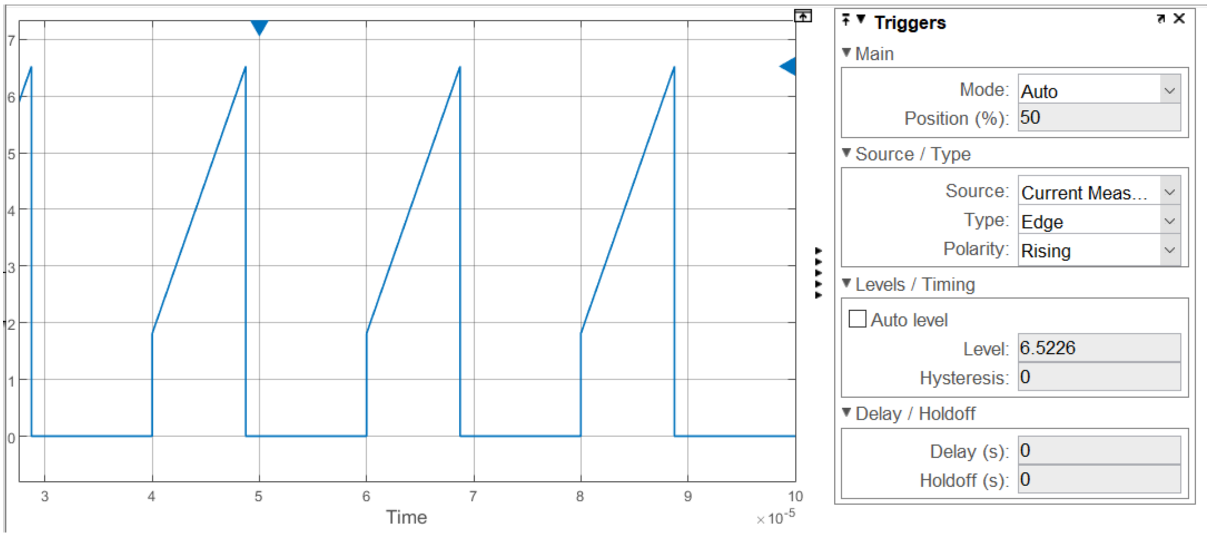
Buck Boost Convertor (158.2V)



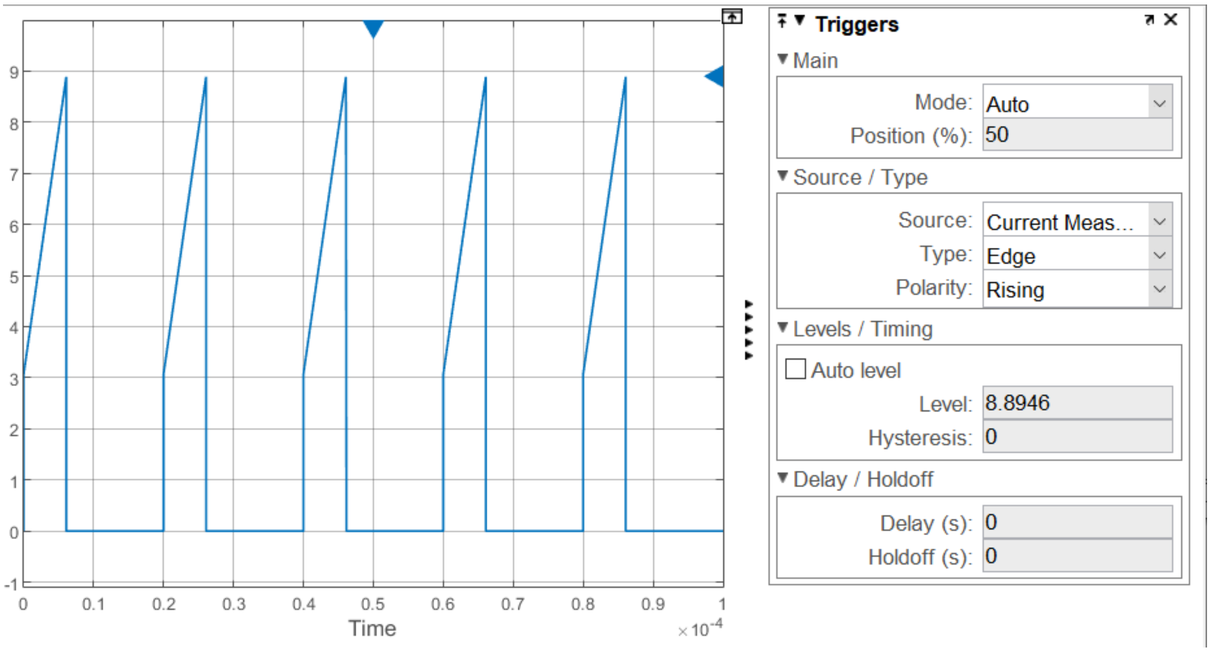
So a buck-boost converter switch has higher voltage stress than a buck converter in given operating condition.

<u>MOSFET CURRENT STRESS</u>

Buck Convertor (6.5226A)



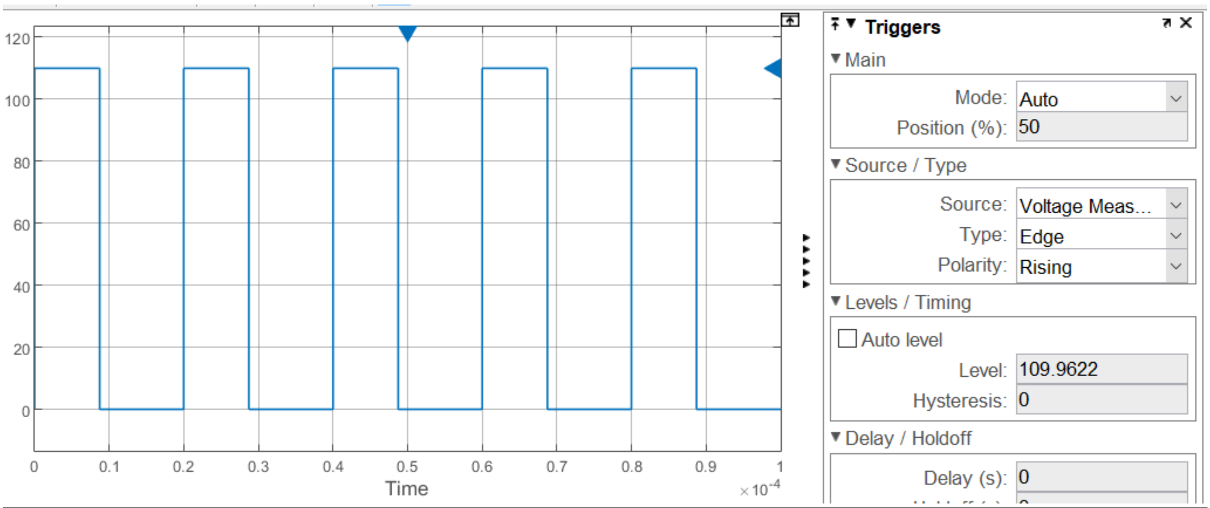
Buck Boost Convertor (8.8946A)



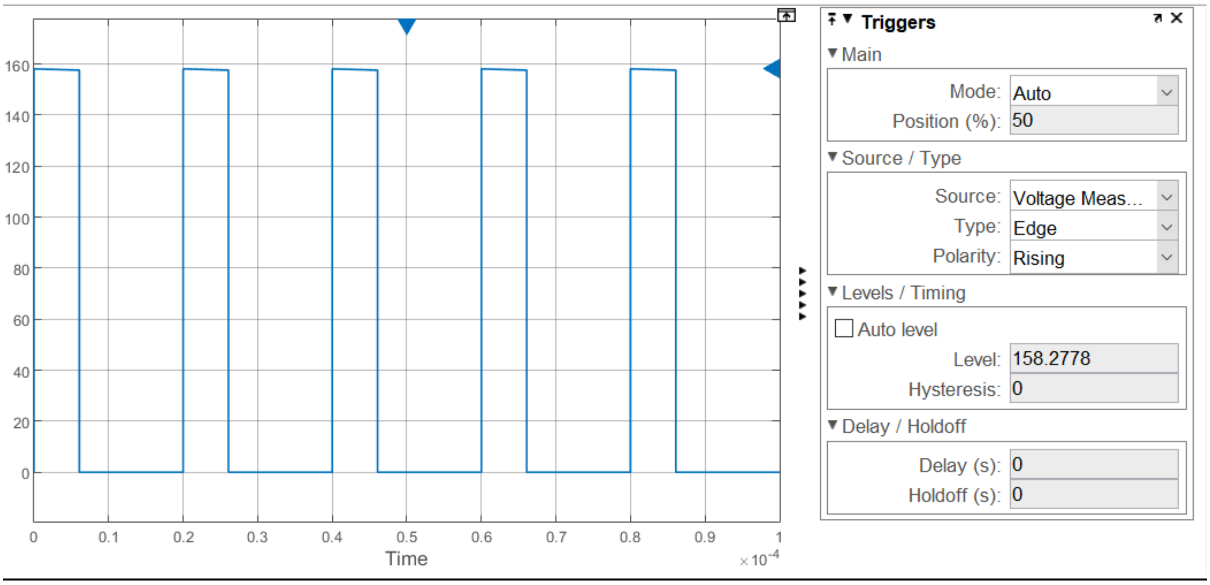
So a buck-boost converter switch has higher current stress than a buck converter in given operating condition.

Diode Voltage Stress

Buck Convertor (110V)

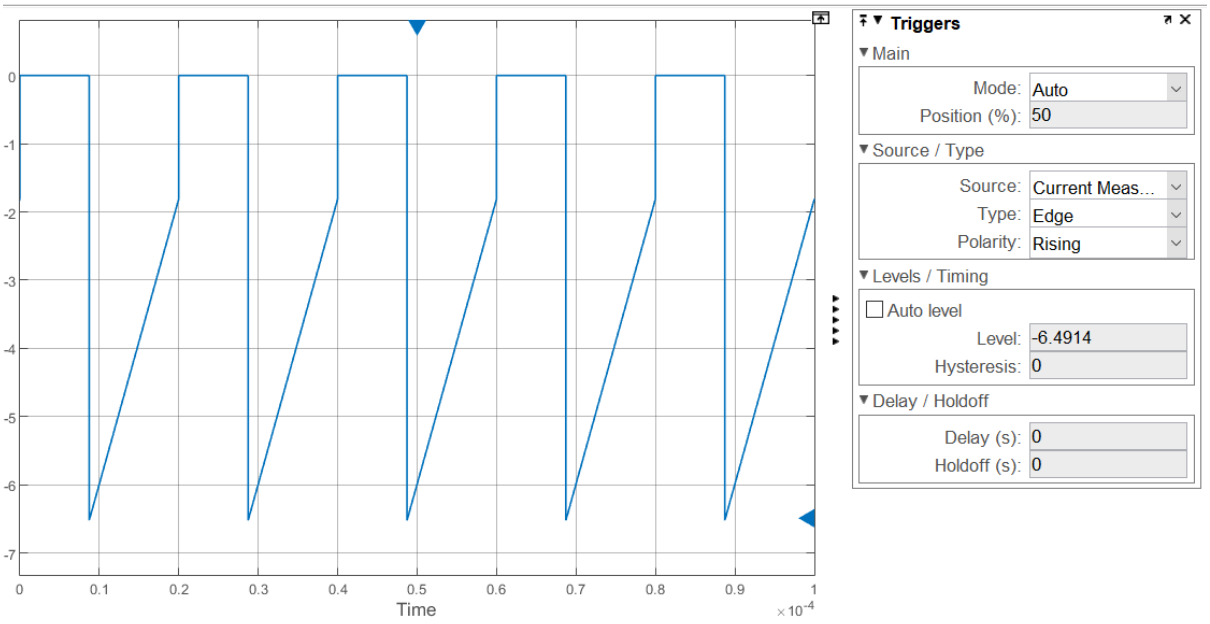


Buck Boost Convertor (158.27V)

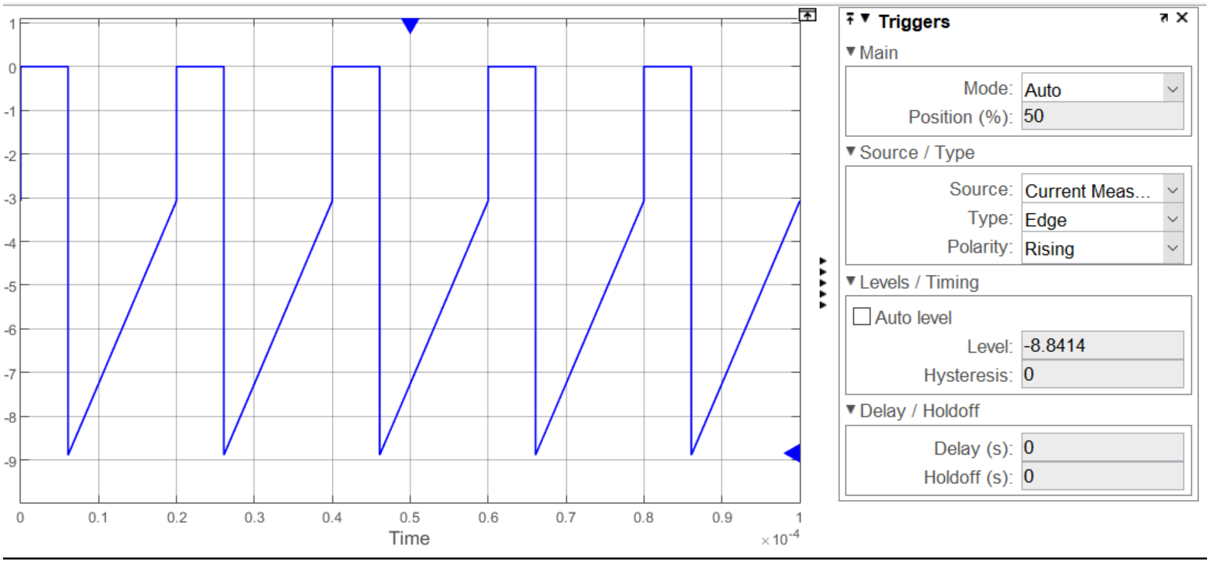


Diode Current Stress

Buck Convertor (6.49A)



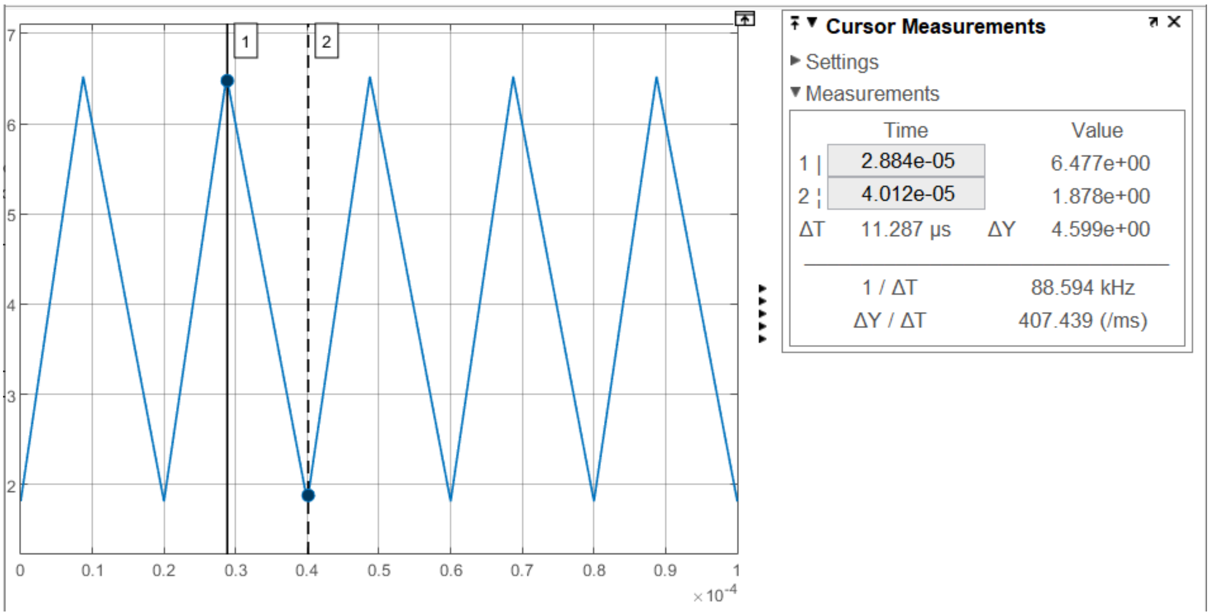
Buck Boost Convertor(8.84A)



So a buck-boost converter diode has higher current stress than a buck converter in given operating condition.

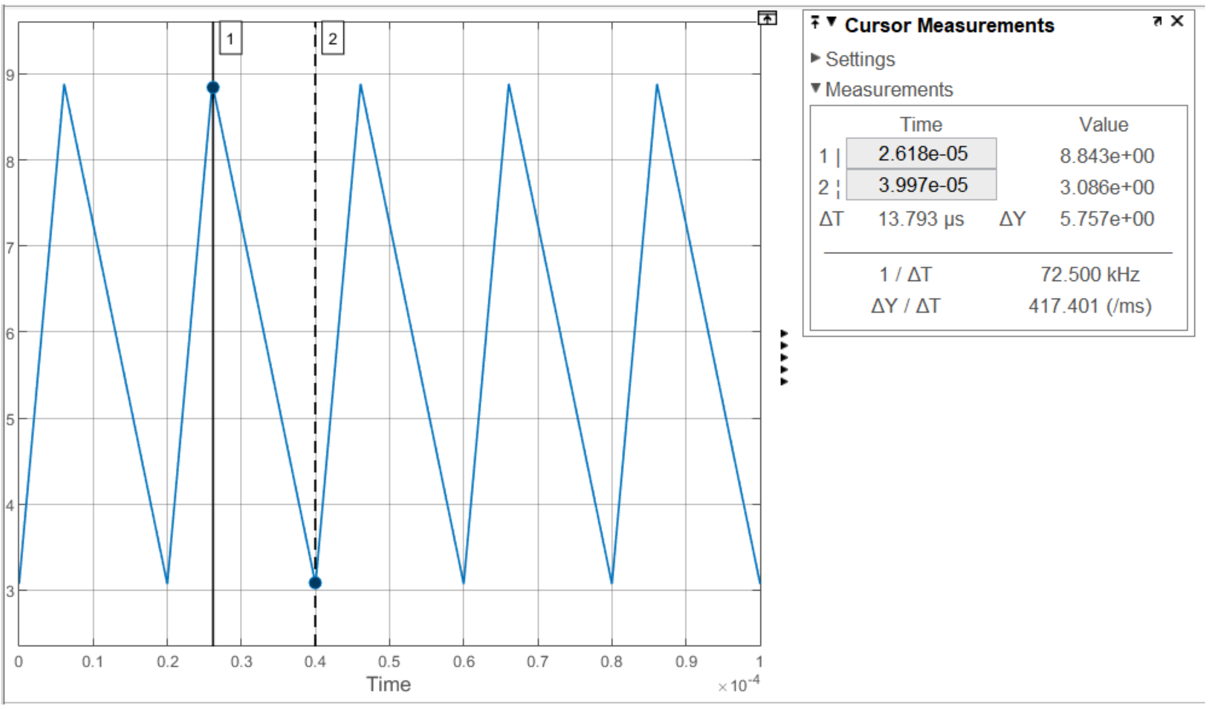
CURRENT RIPPLE

Buck Convertor – ripple CURRENT(4.6A)



BUCK BOOST CONVERTOR

Current Ripple = 5.757A

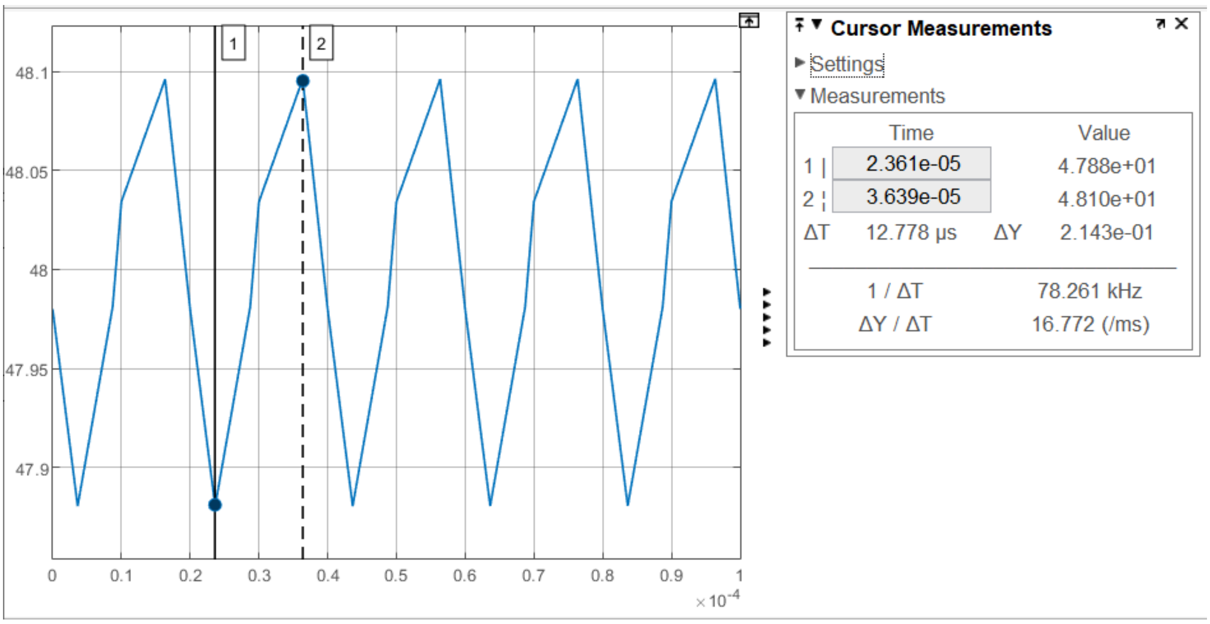


So, a buck-boost converter has higher inductor current ripple than buck converter in given operating condition.

VOLTAGE RIPPLE

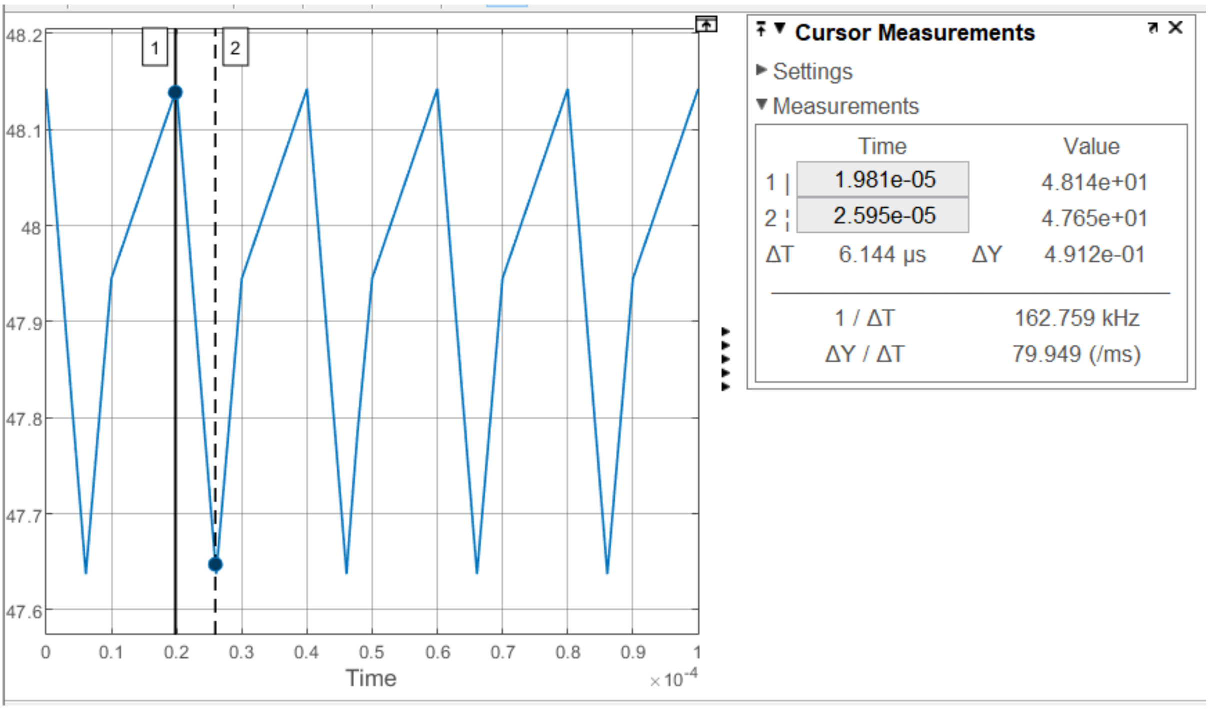
BUCK CONVERTOR

Voltage ripple = 0.2143V



BUCK BOOST CONVERTOR

Voltage ripple = 0.4912V



So, a buck-boost converter has higher output voltage ripple than buck converter in given operating condition.

	Buck	Buck Boost
Voltage Stress	110V	158.27V
Current Stress	6.5226A	8.8946A
Voltage Ripple	0.2143V	0.4912V
Current Ripple	4.6A	5.757A

Discussion:-

1. *For a given duty ratio and load, voltage gain is higher in DCM or CCM? Why?*

   From the experimentation in Part A we can see that for d=0.5, we achieve a higher voltage gain in the case of DCM mode.
   In CCM mode the inductor current is always positive. In DCM mode the inductor current goes to negative in one switching cycle. Gain in CCM mode is independent of load resistance.
   In CCM it does not reach zero so at the end of every switching cycle, there is some energy left.
   In DCM, all the energy each cycle is used up and capacitor stores the extra energy giving higher output voltage.

Also is $Lccm = \epsilon Ldcm \quad 0 < \epsilon \leq 1$
Voltage gain $\frac{D}{\sqrt{\varepsilon}}$

2. *If all other parameters of a buck converter are kept the same, and only the switching frequency is varied, what will be its impact on converter performance?*

   - If frequency is decreased the voltage ripple AND current ripple both will increase.
   - The convertor will move from CCM to DCM conduction mode. As critical value for Inductor to operate in CCM will increase.

3. *If all other parameters of a buck converter are kept the same, and only the load resistance is varied, what will be its impact on converter performance?*

   - Critical Inductance value for Inductor is directly proportional to Load resistance . As we keep on increasing the Rload the convertor will once switch to CCM to DCM mode.
   - Output current is dependent on Load current and as we increase the load resistance The ouput current will decrease.