POWER ELECTRONICS LAB
Experiment-I
STUDY OF BASIC TRANSISTOR CONVERTERS

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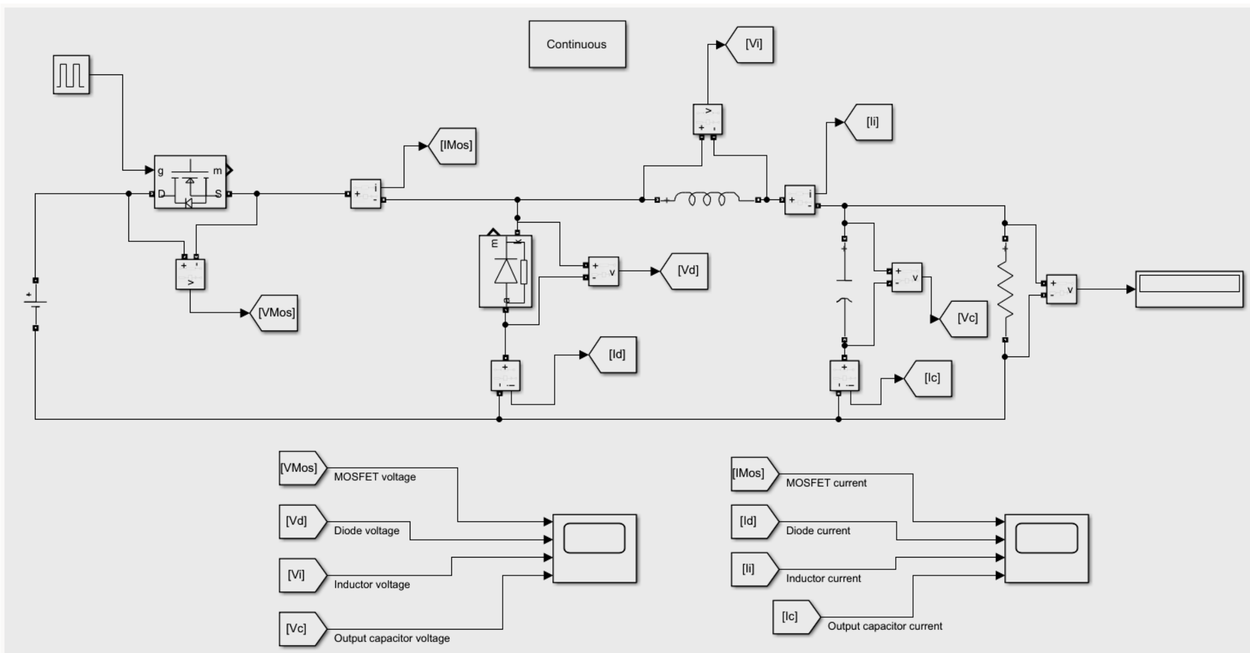
Part-A
Simulate the **buck converter** in MATLAB/simulink using following parameters:
Input Voltage(V_{in}) = 110V, Capacitance C = 4μF, Load resistance R_L=11.52Ω, Switching Frequency = 50kHz. Choose MOSFET and diode resistance as1μΩ, and diode voltage drop as 0 V (to simulate close to an ideal converter).
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(V_{out}/V_{in}) 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).
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.

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.

Buck Converter circuit:



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

I.

For the circuit to operate in CCM, we need

$$L \geq \frac{\left(1-D_{min}\right)\times R_{max}}{2\times f_{sw}}$$

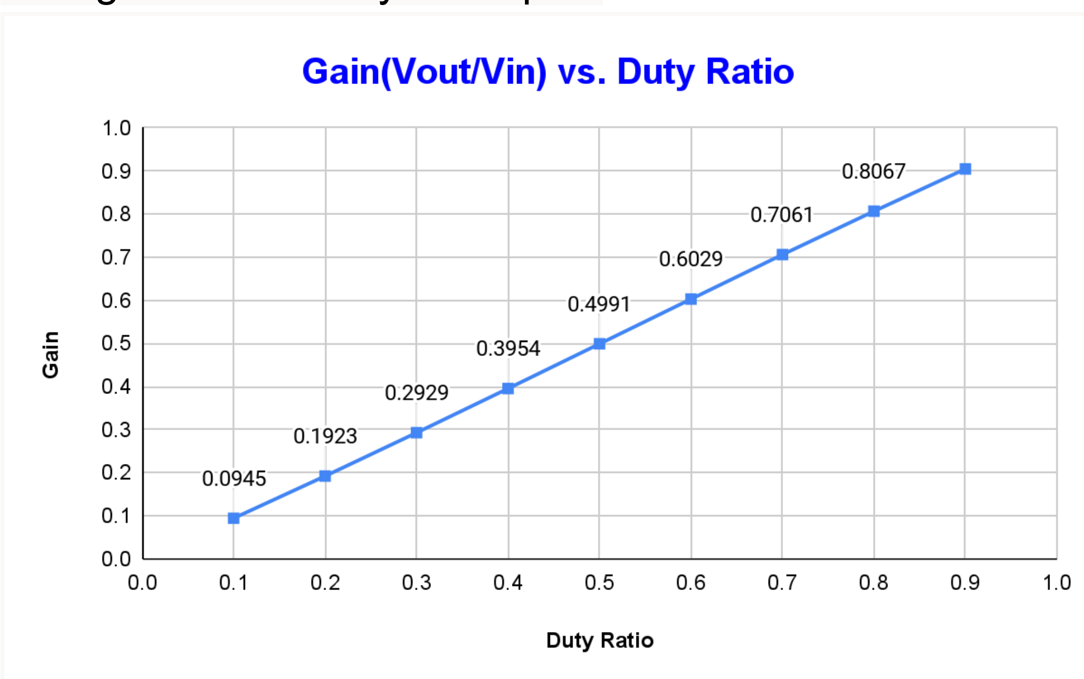
Here D_{min} = 0.1 R_{max} = 11.52Ω, f_{sw} = 50KHz

Hence L ≥ 103.68μH

We have chosen L=110μH for this converter.

Duty Ratio	Calculated V_{out}(V)	Observed V_{out}(V)	Gain (V_{out}/V_{in})
0.1	11	10.39	0.0945
0.2	22	21.15	0.1923
0.3	33	32.22	0.2929
0.4	44	43.49	0.3954
0.5	55	54.90	0.4991
0.6	66	66.32	0.6029
0.7	77	77.67	0.7061
0.8	88	88.74	0.8067
0.9	99	99.54	0.9049

Voltage Gain vs Duty Ratio plot:



II.

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

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

For the circuit to operate in CCM, we need

$$L \le \frac{(1-D_{max})\times R_L}{2\times f_{sw}}$$

Here D_{max} = 0.5 R_{max} = 11.52Ω, f_{sw} = 50KHz

Hence, L≤57.6μH

We have chosen L=50μH for this converter to operate in DCM.

Result:

Output voltage = 57.35V (DCM) (Calculated at L=50μH)

Output voltage = 54.90V (CCM) (Calculated at L=110μH)

(Calculated at L=110μH)

III.

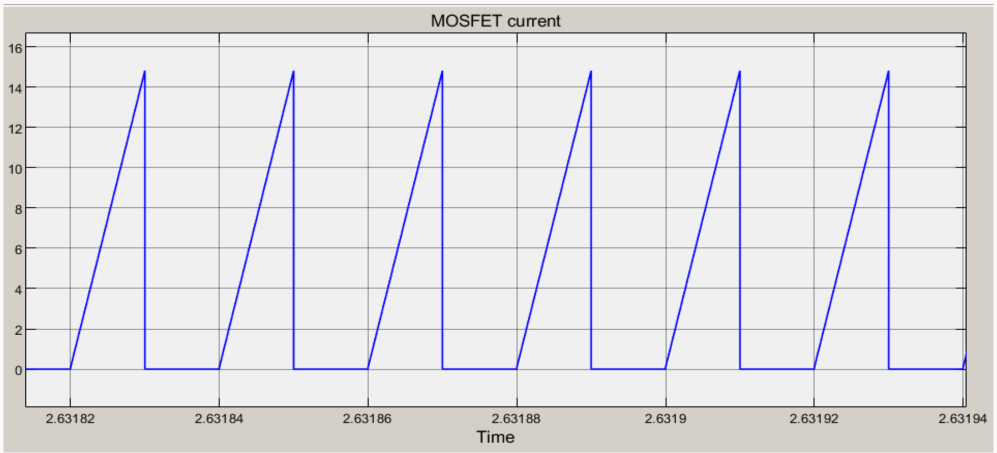
For duty ratio D=0.5 now we will observe the current and voltage waveforms of MOSFET, Diode, Inductor and Output capacitor for both the CCM and DCM case.

Limiting value of L for which the converter operates in DCM at D=0.5 is 57.6μH.

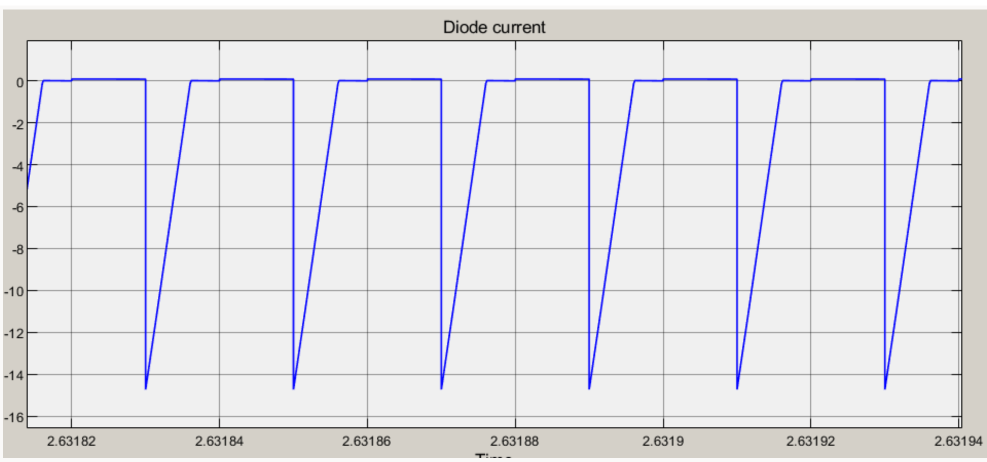
So we have chosen L=30μH for DCM and L=90μH for CCM operation of the converter circuit.

DCM current waveforms:

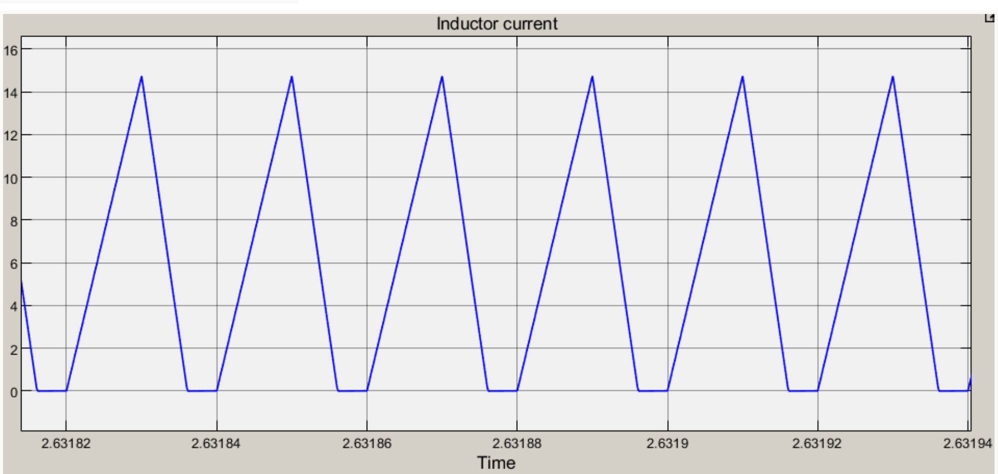
MOSFET current



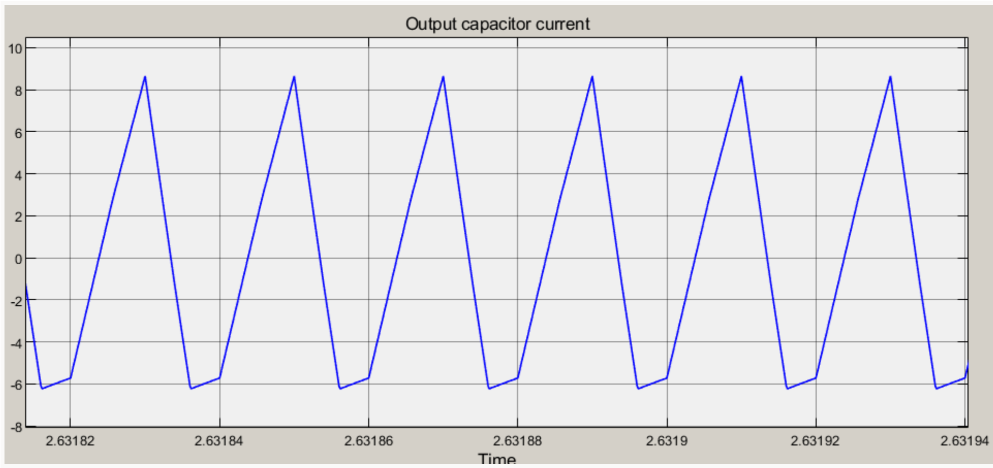
Diode current



Inductor current

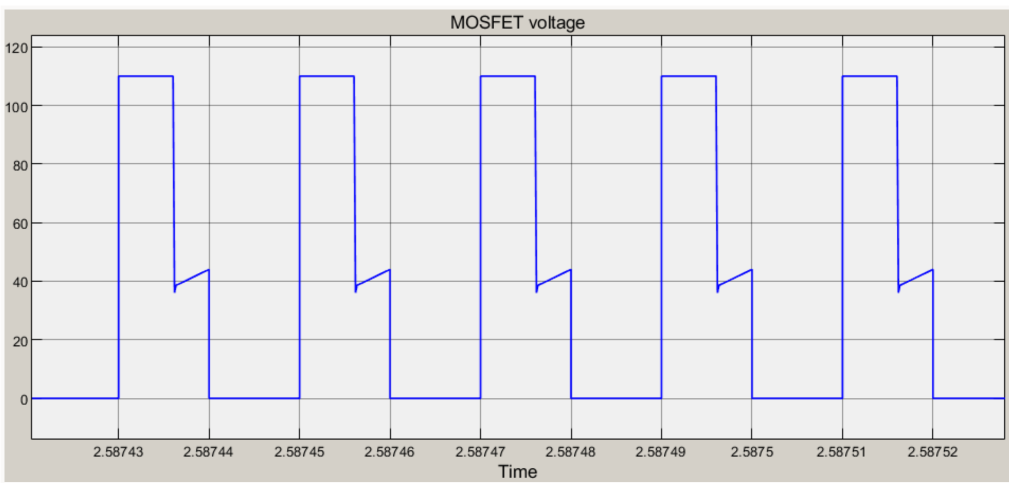


Output Capacitor Current

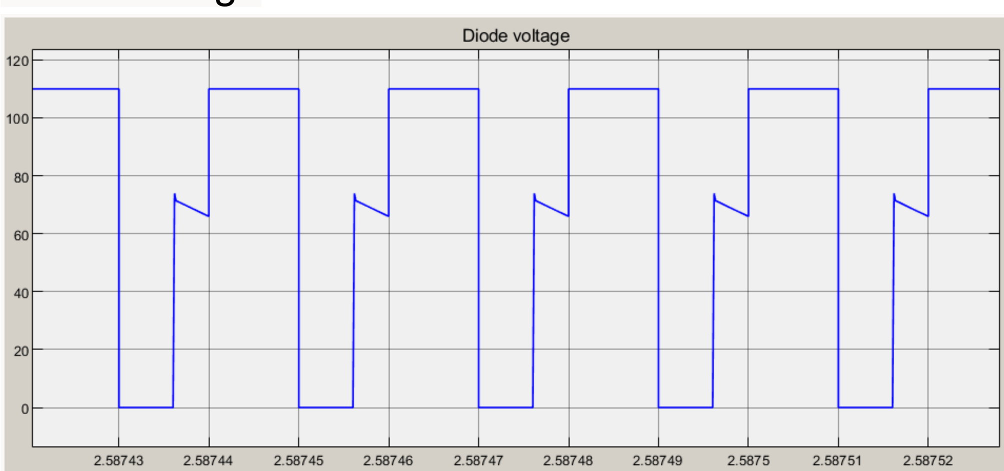


DCM voltage waveforms:

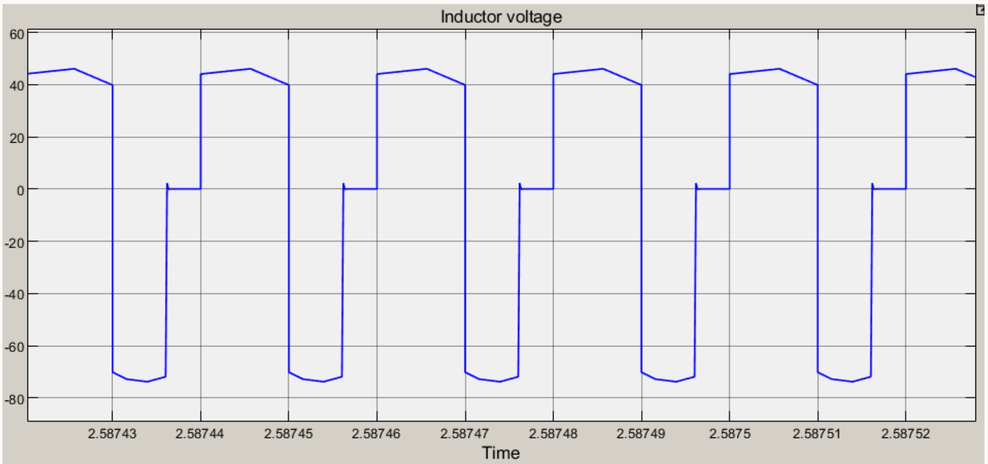
MOSFET voltage



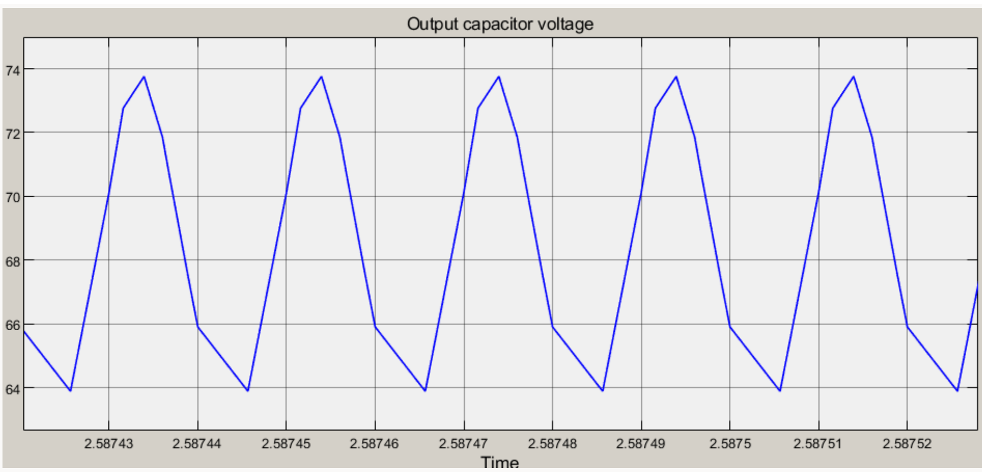
Diode voltage



Inductor Voltage

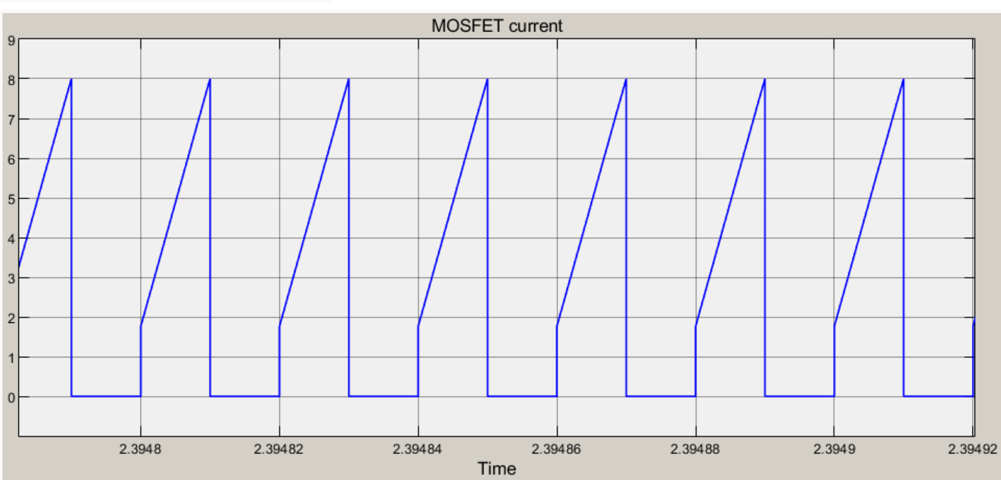


Output capacitor voltage

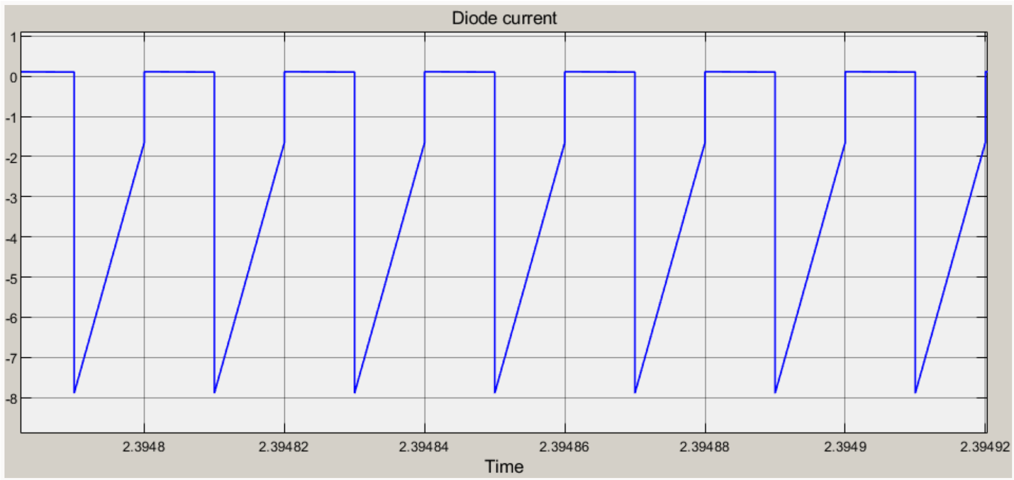


CCM current waveforms:

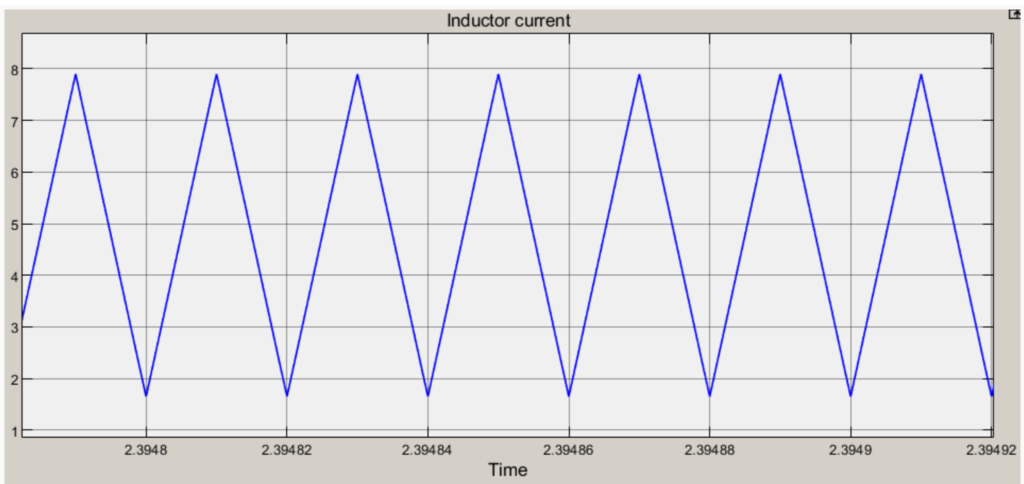
MOSFET Current



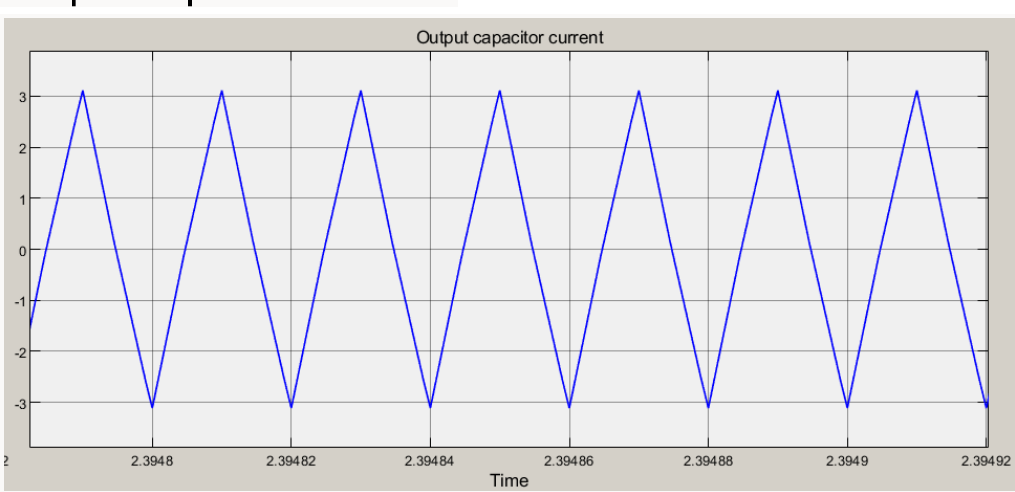
Diode current



Inductor current

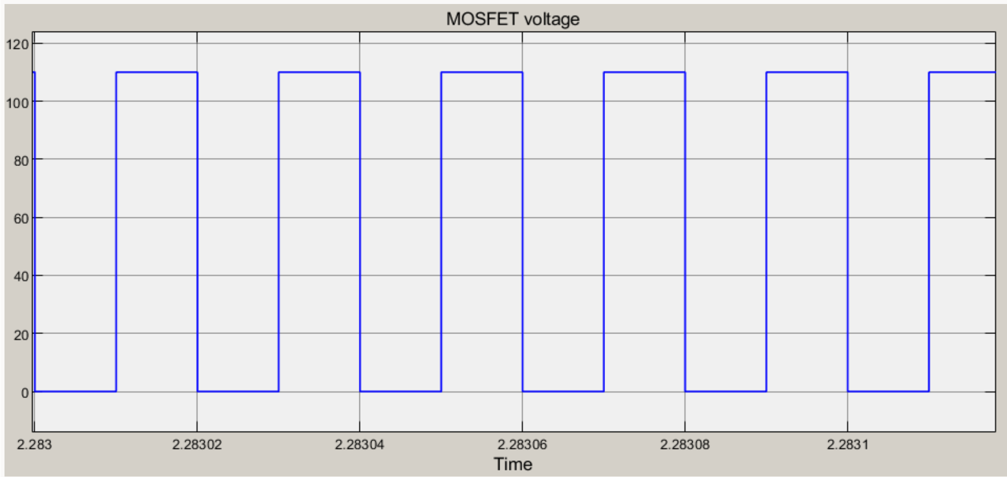


Output capacitor current

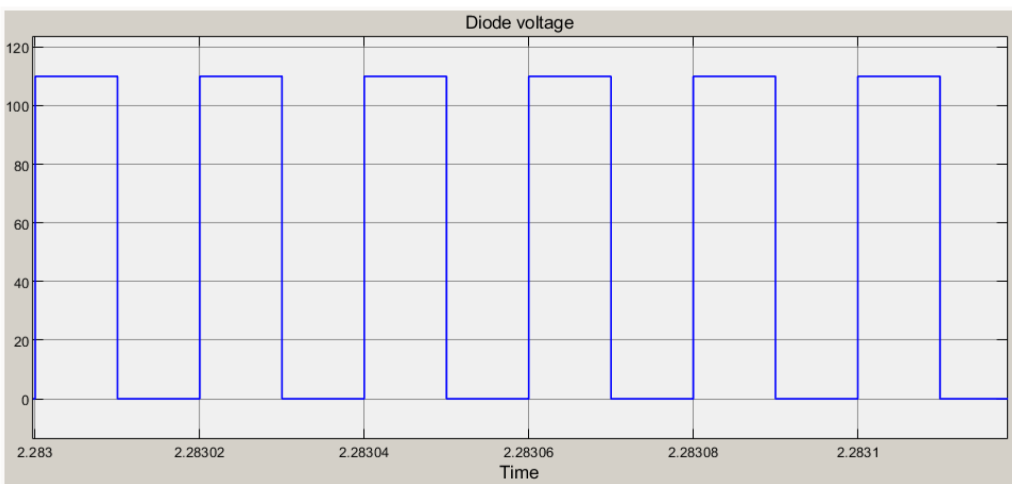


CCM voltage waveforms:

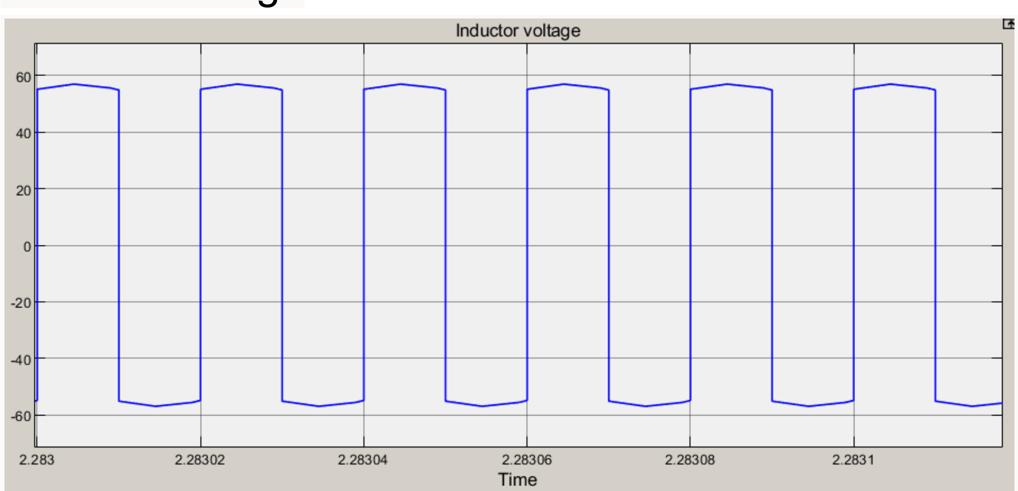
MOSFET voltage



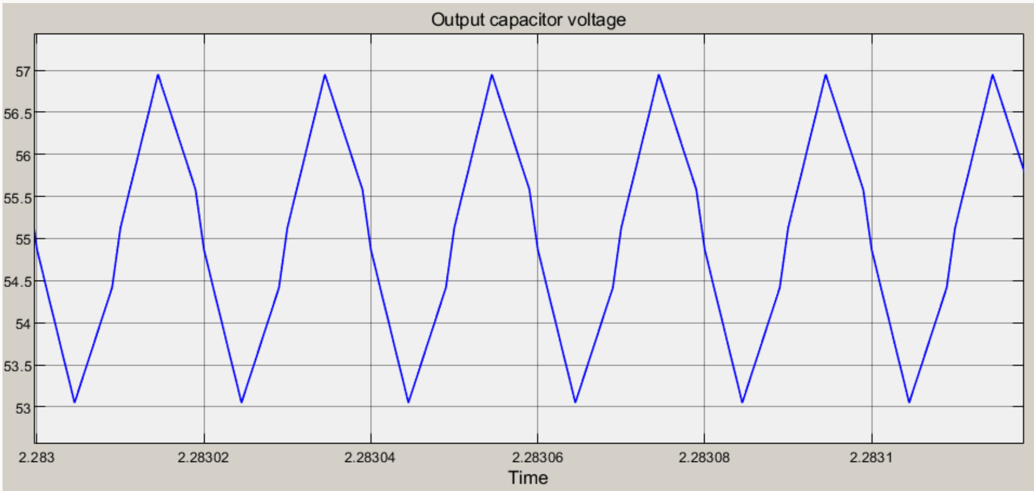
Diode voltage



Inductor voltage



Output capacitor voltage



Part-B

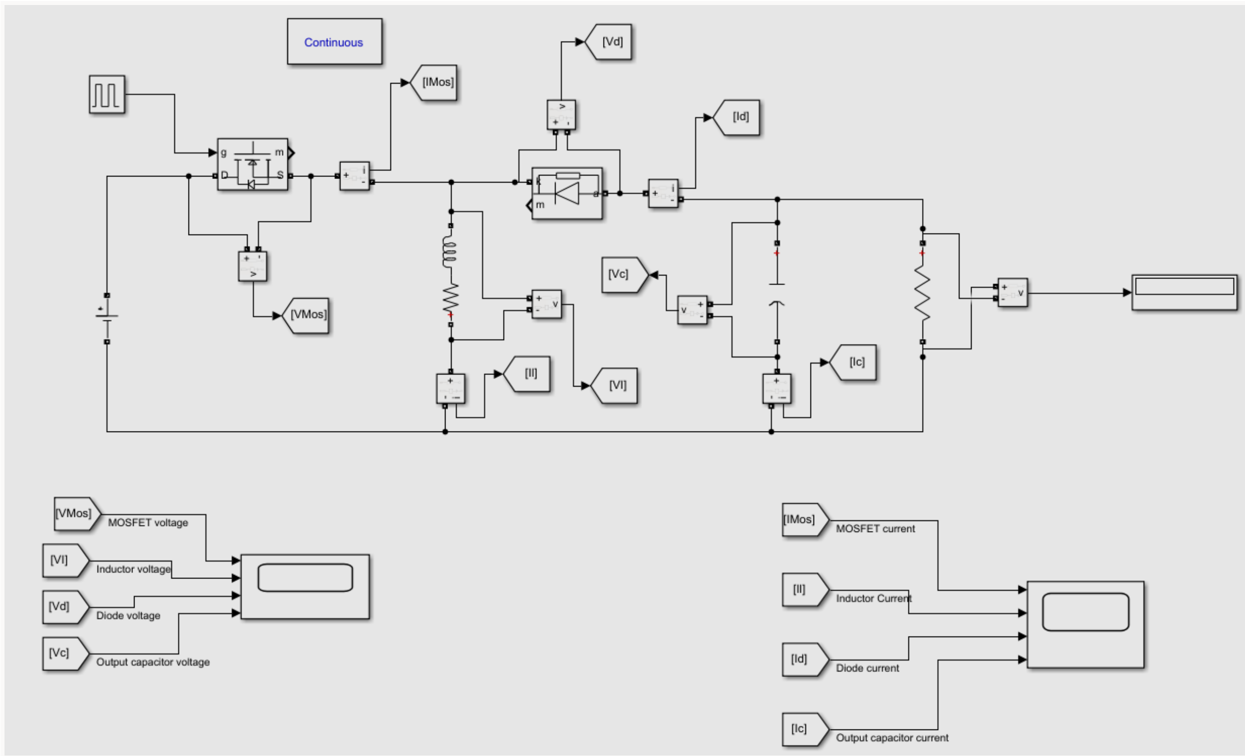
Simulate the **buck-boost converter** in MATLAB/Simulink using following parameters: Input Voltage(V_{in}) = 57V, Inductor L = 226μH, Capacitance C = 54μF, Load resistance R_{Load} = 11.52Ω, Switching Frequency = 50kHz, Duty Cycle = 0.457. Choose MOSFET and diode resistance as 1μΩ, and diode voltage drop as 0.Select parasitic resistance of inductor R_L = 0 Ω in case(i) and R_L = 5% of R_{Load} 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.

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?

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

Buck-Boost converter circuit:



V_{in} = 57V, C = 54µF, R_{Load} = 11.52Ω, f_{sw} = 50KHz, L=226µH

Polarity of Output voltage is always negative, the data shows the magnitude of output voltage.

I.

Case(i):

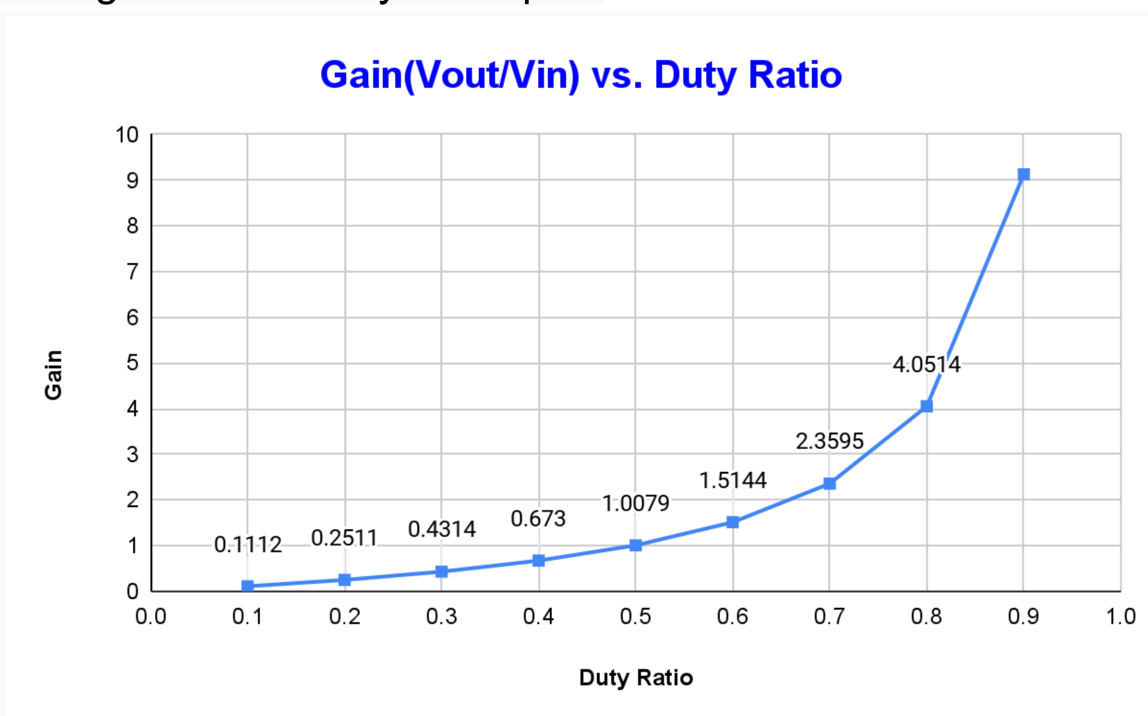
Parasitic resistance R_L= 0Ω

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

V_{in} = 57V, C = 54µF, R_{Load} = 11.52Ω, f_{sw} = 50KHz, L=226µH

Duty Ratio	Calculated V_{out}(V)	Observed V_{out}(V)	Gain (V_{out}/V_{in})
0.1	6.33	6.34	0.1112
0.2	14.25	14.31	0.2511
0.3	24.43	24.59	0.4314
0.4	38.00	38.36	0.6730
0.5	57.00	57.45	1.0079
0.6	85.50	86.32	1.5144
0.7	133.00	134.49	2.3595
0.8	228.00	230.93	4.0514
0.9	513.00	520.43	9.1304

Voltage Gain vs Duty Ratio plot:



The plot strongly 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):

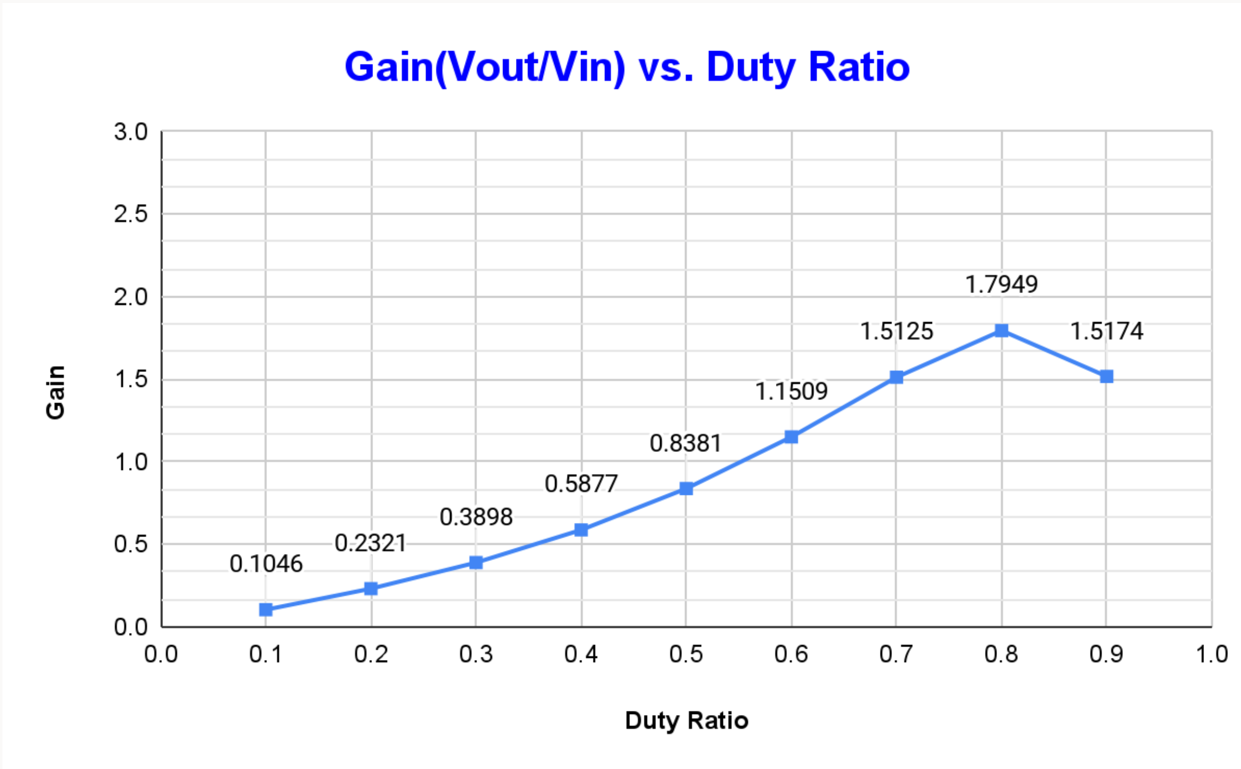
Parasitic resistance R_L= 5% of R_{Load} = 0.576Ω

So, in CCM condition, gain(V_{out}/V_{in}) = $\frac{D}{1-D+\frac{R_L}{R_{Load}(1-D)}}$

V_{in} = 57V, C = 54μF, R_{Load} = 11.52Ω, f_{sw} = 50KHz, L=226μH

Duty Ratio	**Calculated V_{out}(V)**	**Observed V_{out}(V)**	**Gain (V_{out}/V_{in})**
0.1	5.97	5.96	0.1046
0.2	13.22	13.23	0.2321
0.3	22.17	22.22	0.3898
0.4	33.37	33.50	0.5877
0.5	47.50	47.77	0.8381
0.6	65.14	65.60	1.1509
0.7	88.67	86.21	1.5125
0.8	101.33	102.31	1.7949
0.9	85.50	86.49	1.5174

Voltage Gain vs Duty Ratio plot:



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.

Case(i): V_{in} = 57V, C = 54μF, R_{Load} = 11.52Ω, L=226μH, R_L= 0Ω, Duty ratio(D) = 0.457

We know that,

When **buck-boost converter** operates in CCM,

$Gain = \frac{D}{1-D}$(without considering the sign of output voltage)

And, when it operates in DCM,

$$Gain = \frac{V_{in} D^2 T_{sw}}{2 L I_{out}}$$

So in the limiting region both the gains will be the same.

Putting $I_{out} = \frac{V_{out}}{R_{Load}}$ and solving we get,

$$f_{sw} = \frac{1}{T_{sw}} = \frac{R_{Load}(1-D)^2}{2L}$$

So theoretically DCM to CCM transition happens at f_{sw}=7.515KHz when parasitic resistance of the inductor is 0.

We have already seen that at f_{sw}=50KHz the converter operates in CCM as the gain formula of $\frac{D}{1-D}$ was the same as the observed gain.

Now we will vary the switching frequency from 5KHz to 10KHz to find the transition of DCM to CCM by observing the minimum current through the inductor in steady state. If it reaches 0, then the converter will operate in DCM.

f_{sw}(KHz)	$I_{L,min}$(A)	Mode	f_{sw}(KHz)	$I_{L,min}$(A)	Mode
5	-0.058(<0)	DCM	7.4	-0.008(<0)	DCM
6	-0.054(<0)	DCM	7.5	0.047	CCM
7	-0.049(<0)	DCM	7.6	0.1528	CCM
8	0.5528	CCM	7.8	0.2679	CCM
9	1.302	CCM			
10	2.059	CCM			
7.2	-0.042(<0)	DCM			

Hence, we observe that around 7.5KHz f_{sw} , the converter will transition from DCM to CCM.

Case(i): V_{in} = 57V, C = 54μF, R_{Load} = 11.52Ω, L=226μH, R_L= 0.576Ω, Duty ratio(D) = 0.457
As observed before, this converter operates in CCM at 50KHz switching frequency.
We will vary the switching frequency from 5KHz to 10KHz to find the transition of DCM to CCM by observing the minimum current through the inductor in steady state. If it reaches 0, then the converter will operate in DCM.

f_{sw}(KHz)	$I_{L,min}$(A)	Mode	f_{sw}(KHz)	$I_{L,min}$(A)	Mode
5	-0.037(<0)	DCM	8.2	0.0771	CCM
6	-0.032(<0)	DCM	8.1	0.0100	CCM
7	-0.031(<0)	DCM			
8	-0.0087(<0)	DCM			
9	0.6599	CCM			
10	1.255	CCM			

So, from the table, we can conclude that around 8-8.1KHz switching frequency the converter transitions from DCM to CCM.

III.

Case(i): V_{in} = 57V, C = 54μF, R_{Load} = 11.52Ω, f_{sw} = 50KHz, L=226μH

Parasitic resistance R_L= 0Ω

(Average input and output current measurement)

Duty ratio(D)	Input current(A)	Output current(A)
0.1	0.2454	0.5498
0.2	0.5567	1.238
0.3	1.278	2.124
0.4	2.272	3.310
0.5	5.027	4.946
0.6	11.34	7.416
0.7	23.05	11.55
0.8	66.06	19.78
0.9	295.9	44.58

Part-C

For following operating condition(i.e. Input Voltage(V_{in}) = 110V, Load voltage =48V, Inductance = 115μH Capacitance C =50μF, Load resistance R_L=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:

V_{in} = 110V, R_{Load} = 11.52Ω, L = 115μH, C=50μF, f_{sw} = 50KHz

V_{out} = 48V, Hence,

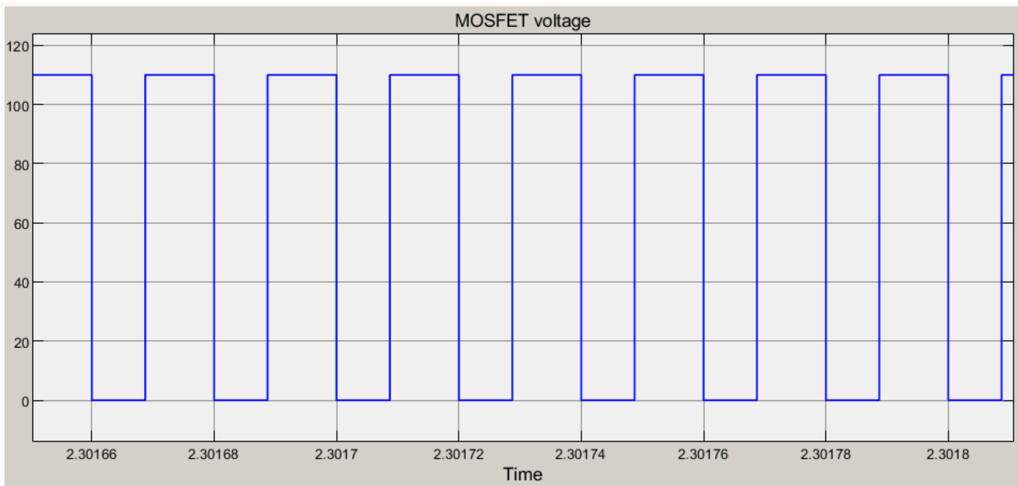
$D_{buck} = \frac{48}{110}$

$D_{buck\text{-}boost} = \frac{48}{158}$

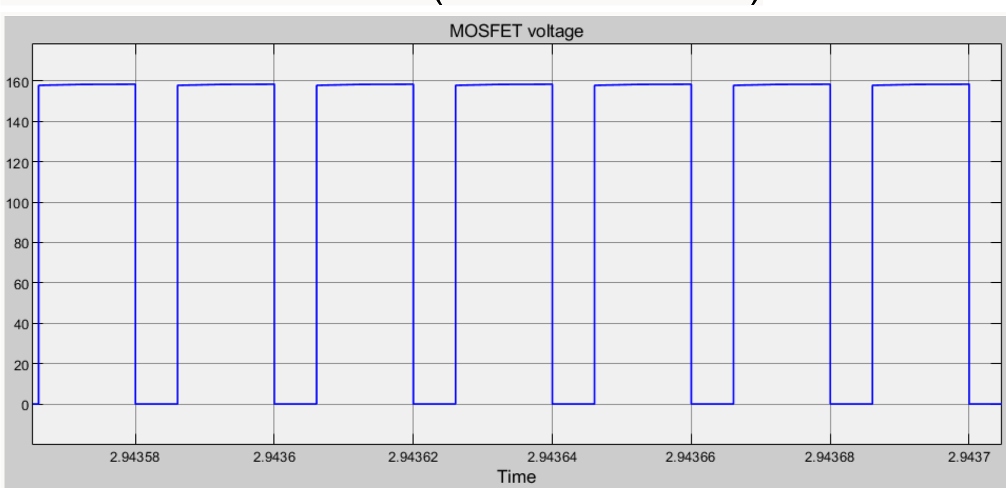
Both converters are operating in CCM condition.

MOSFET Switch voltage stress:

Buck converter- (Stress = 110V)



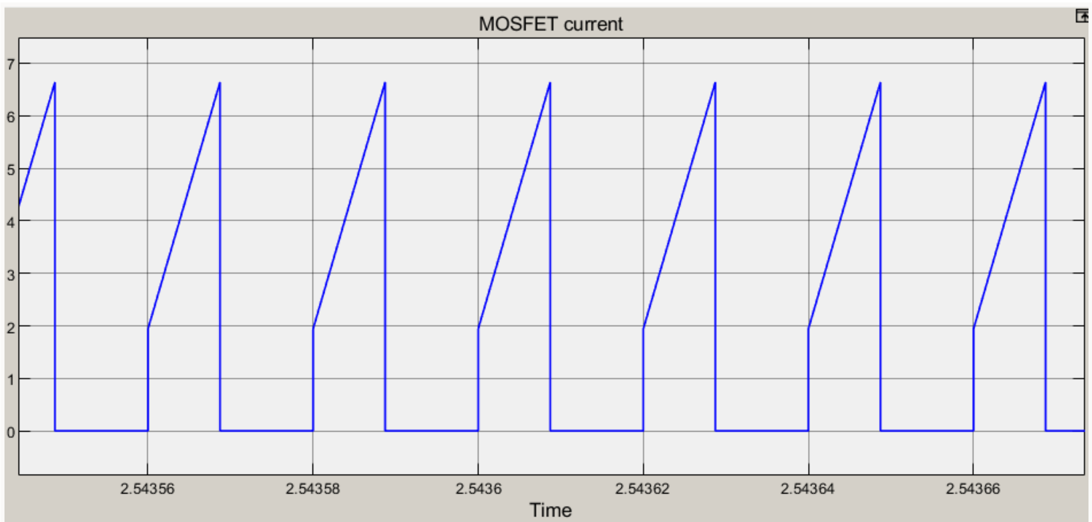
Buck-boost converter- (Stress = 158.4V)



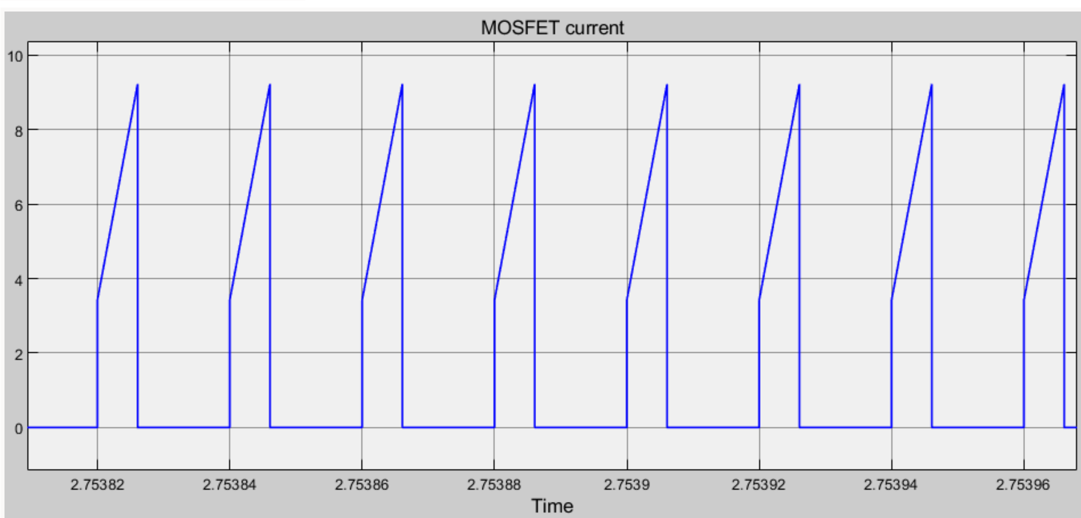
So a buck-boost converter switch has higher voltage stress than a buck converter in given operating condition.

MOSFET Switch current stress:

Buck converter-
Stress = 6.641A



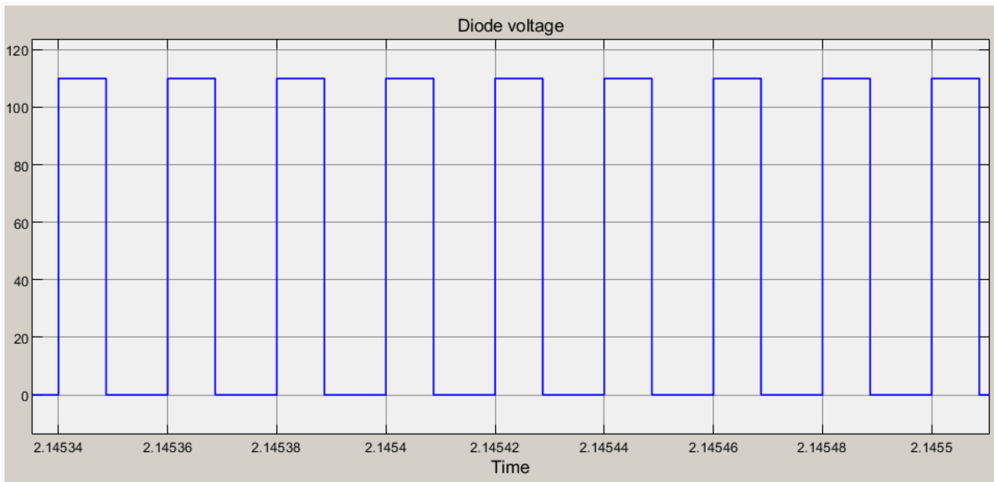
Buck-boost converter-
Stress = 9.225A



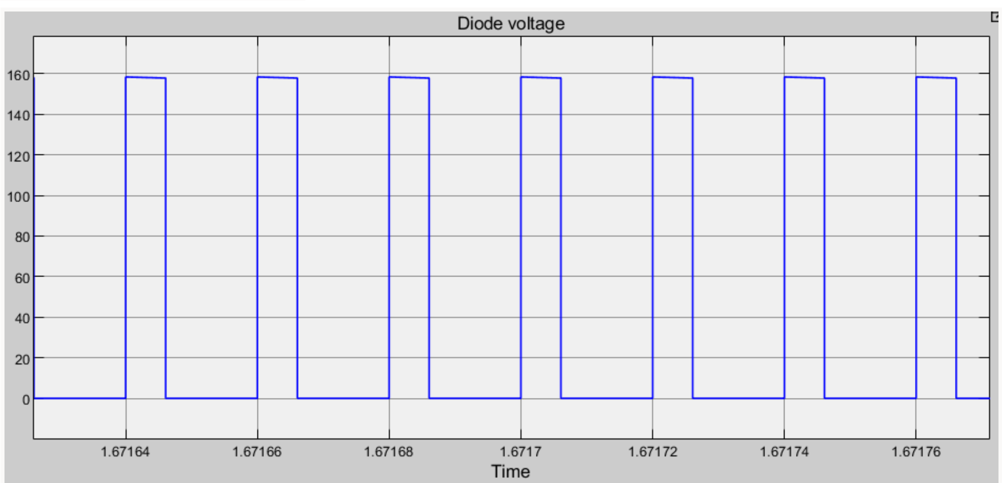
So a buck-boost converter switch has higher current stress than a buck converter in given operating condition.

Diode voltage stress:

Buck converter-
Stress = 110V



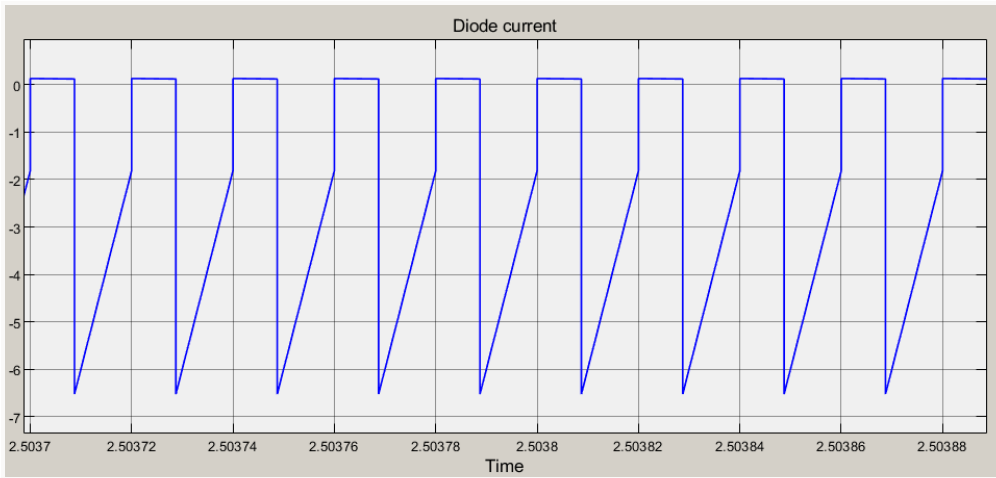
Buck-boost converter-
Stress = 158.4V



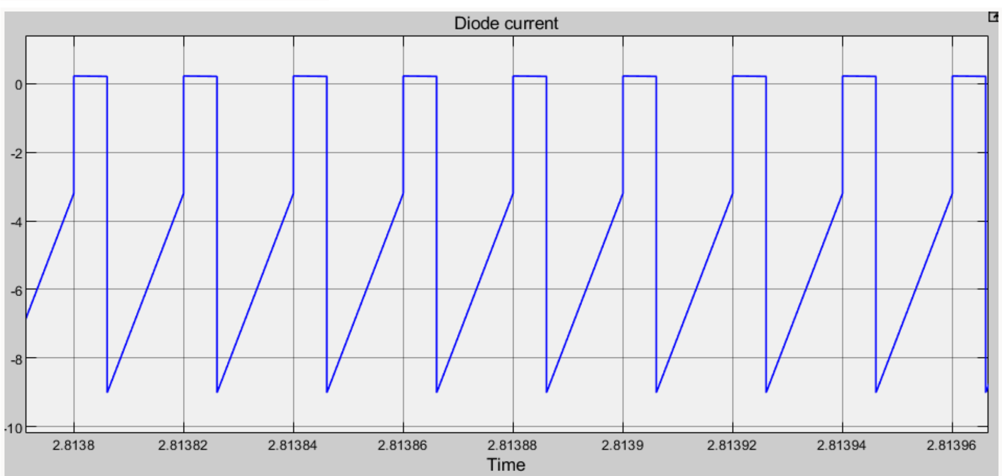
So a buck-boost converter diode has higher voltage stress than a buck converter in given operating condition.

Diode Current Stress:

Buck converter-
Stress = 6.6483A



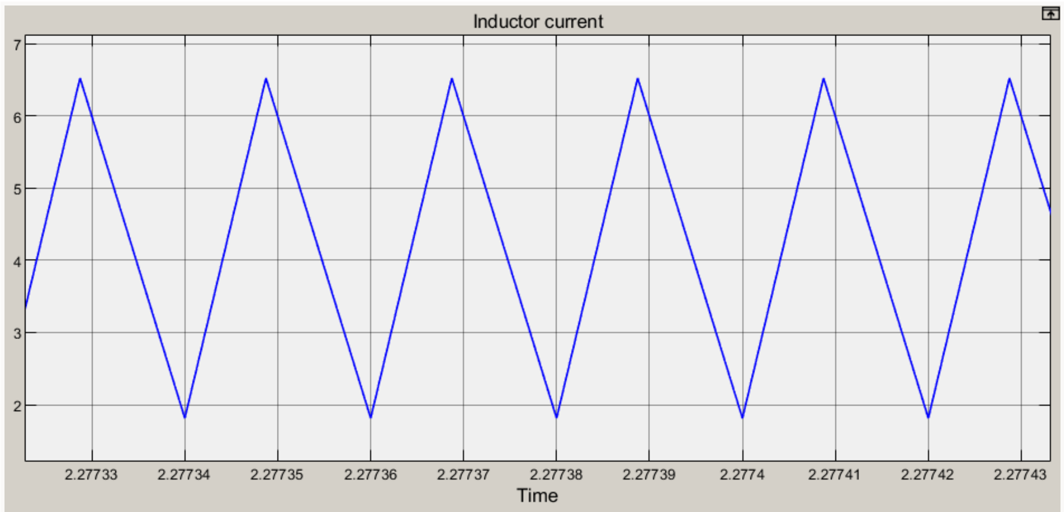
Buck-boost converter-
Stress = 9.2347A



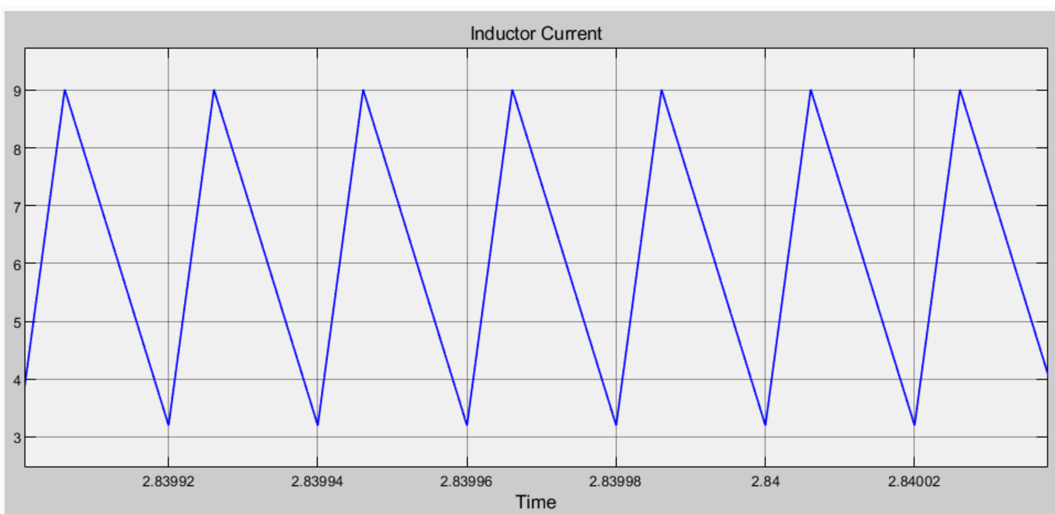
So a buck-boost converter diode has higher current stress than a buck converter in given operating condition.

Inductor current ripple:

Buck converter-
Ripple = 4.706A

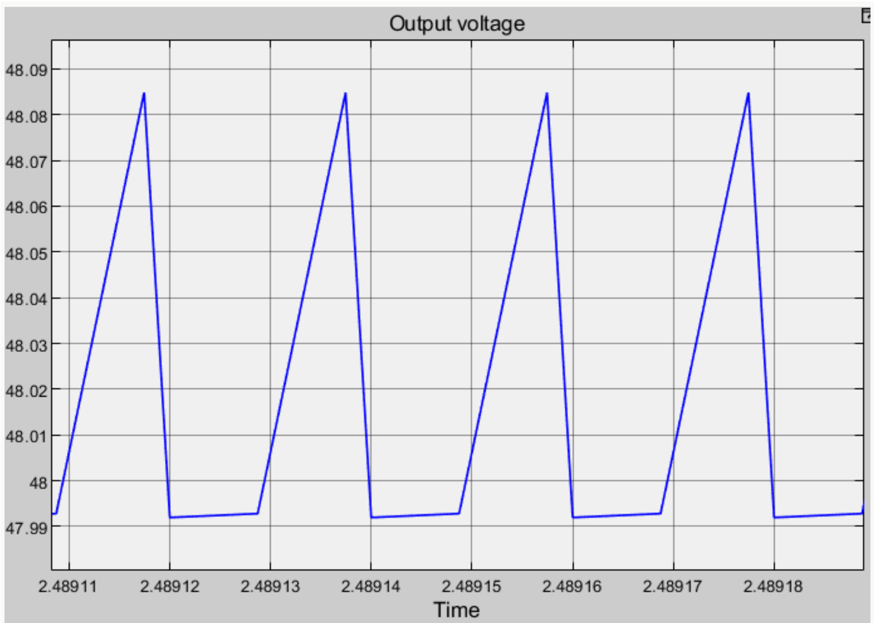


Buck-boost converter-
Ripple = 5.812A

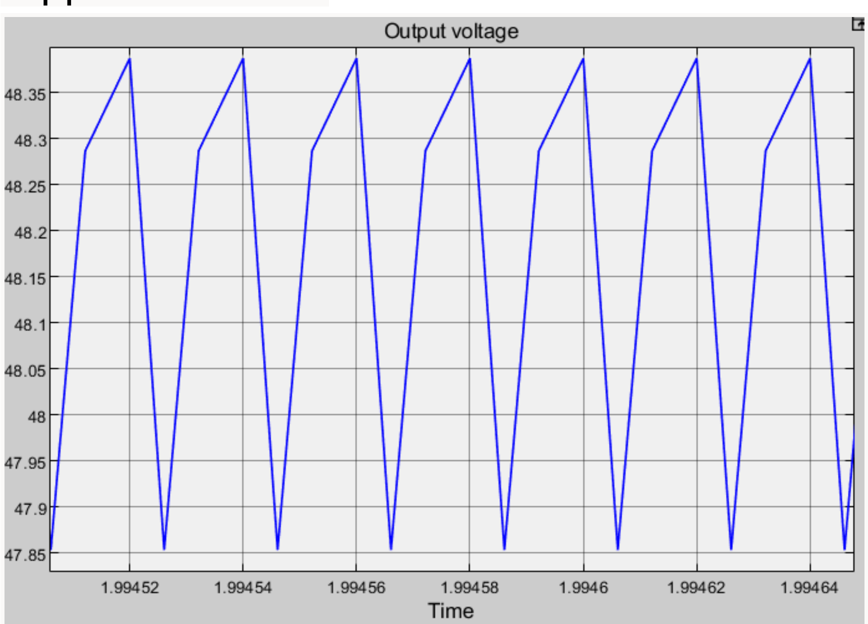


So, a buck-boost converter has higher inductor current ripple than buck converter in given operating condition.

Output voltage ripple:
Buck converter-
Ripple = 0.09286V



Buck-boost converter-
Polarity is opposite but only magnitude is considered here.
Ripple = 0.5343V



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

Discussion:-

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

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?

Keeping all other parameters the same, if we decrease the switching frequency, the inductor current ripple in the converter will increase, which also increases the output voltage ripple. Eventually the converter will move from CCM to DCM. After that, decreasing the switching frequency will increase gain of the converter but the output voltage ripple will also become much higher.

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?