Power Electronics
Boost Converter Circuit

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I. Problem solving.

1. From the PSIM Circuit of Boost Converter shown in Figure 1(a), the inductor current has $\Delta i_L = 2[\mathrm{A}]$. It is operating in dc steady state under the following conditions: $\mathrm{V_{in}} = 5[\mathrm{V}]$, $\mathrm{V_{out}} = 12[\mathrm{V}]$, $\mathrm{P_{out}} = 11[\mathrm{W}]$, and $f_s = 200[\mathrm{kHz}]$.
(a) Assuming ideal components, calculate L and draw the waveforms of duty, MOSFET voltage, inductor voltage, inductor current, diode current and capacitor current.

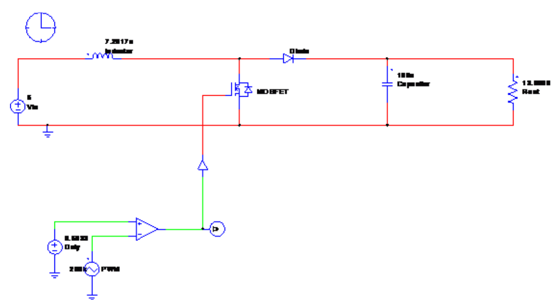
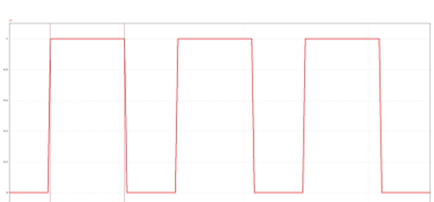


Figure 1. Circuit of Boost Converter (PSIM)

$$R_{out} = \frac{(V_{out})^2}{P_{out}} = 13.09[\Omega]$$

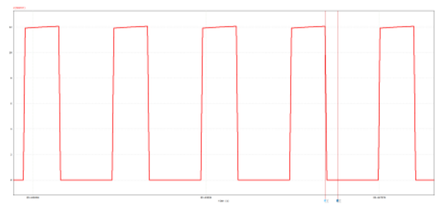
$$V_{in} = \frac{V_{out}}{D'}, \quad D = 0.5833, \quad DT_s = 2.9165 \times 10^{-6}$$

$$L = \frac{V_{in}}{\Delta i_L} DT_s = 7.2917[\mu\mathrm{H}]$$



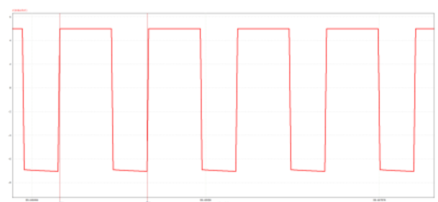
	X1	X2	Δ	Average
Time	6.73850e-02	6.73879e-02	2.90283e-06	
V1	1.00000e+00	9.71721e-01	-2.82794e-02	9.83333e-01

Figure 1-(a). $Duty$ waveform and measured values



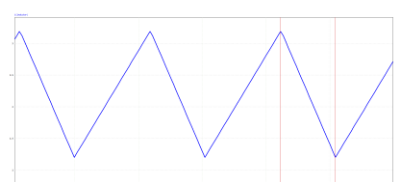
	X1	X2	Δ	Average
Time	8.96649e-02	8.96656e-02	7.00000e-07	
V(MOSFET)	1.20631e+01	1.14866e-04	-1.20630e+01	8.61754e-01

Figure 1-(b). V_{MOSFET} waveform and measured values



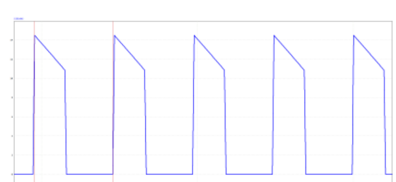
	X1	X2	Δ	Average
Time	8.96500e-02	8.96549e-02	4.90000e-06	
V(Indu...)	4.99989e+00	-7.06312e+00	-1.20630e+01	2.25736e-01

Figure 1-(c). V_L waveform and measured values



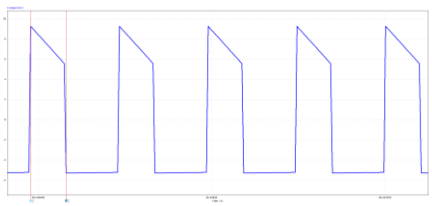
	X1	X2	Δ	Average
Time	8.74029e-02	8.74050e-02	2.10000e-06	
I(Indu...)	3.18965e+00	1.20109e+00	-1.98855e+00	2.20892e+00

Figure 1-(d). I_L waveform and measured values



	X1	X2	Δ	Average
Time	9.67230e-02	9.67279e-02	4.90000e-06	
I(Diode)	3.12083e+00	0.00000e+00	-3.12083e+00	8.69970e-01

Figure 1-(e). I_{Diode} waveform and measured values



	X1	X2	Δ	Average
Time	9.67230e-02	9.67250e-02	2.00000e-06	
I(Capa...)	2.20539e+00	-9.17345e-01	-3.12273e+00	1.21479e+00

Figure 1-(f). I_C **waveform and measured values**

2. In a Boost converter, $L = 25[\mu H]$. It is operating in dc steady state under the following conditions: $V_{in} = 12[V]$, $D = 0.4$, $P_{out} = 25[W]$, and $f_s = 400[kHz]$. Assume ideal components. Calculate the critical value of the output load R_{Load} and P_{out} below which the converter will enter the discontinuous conduction mode of operation.

$$V_{out} = \frac{V_{in}}{1-D} = \frac{12}{1-0.4} = 20[V]$$

$$I = \frac{V_{in}}{D'^2 R_{load}}, \quad \Delta i_L = \frac{V_{in} D T_s}{2L}$$

$$DCM: when\ I = \Delta i_L$$

$$\frac{V_{in}}{(1-D)^2 R_{load}} = \frac{V_{in} D T_s}{2L}$$

$$R_{load} = \frac{V_{in} \times 2L}{(1-D)^2 \times V_{in} D T_s} = 138.888[\Omega]$$

$$P_{out} = \frac{(V_{out})^2}{R_{load}} = 2.88[V]$$

3. In the Boost converter from problem 2, the input voltage is varying in a range from 9[V] to 15[V]. For each input value, the duty-ratio is controlled to keep the output voltage constant at its nominal value (with $V_{in} = 12[V]$ and $D = 0.4$). Calculate the critical value of the inductance L such that this Boost converter remains in the continuous conduction mode at and above $P_{out} = 5[W]$ under all values of the input voltage V_{in}.

$$I_L > \Delta i_L, \qquad \frac{P_{in}}{V_{in}} \geq \frac{V_{in} D T_s}{2L}$$

$$L \geq \frac{V_{in}^2 D T_s}{2 P_{in}}$$

$$Boost\ : \frac{V}{V_g} = \frac{1}{1-D}, \quad D = 1 - \frac{V_g}{V}$$

$$L \geq \frac{V_{in}^2 \times T_s}{2 P_{in}} \times \left(1 - \frac{V_{in}}{V_{out}}\right), \quad P_{in} = P_{out}$$

$$L_{cri} = \frac{V_{in}^2}{2 \times 5[W] \times 400[kHz]} \times \left(1 - \frac{V_{in}}{20[V]}\right)$$

```
clear; clc; close all;

Vin=9:0.001:15;

Lcri=((Vin.*Vin).*(1-Vin/20))/4000*1000;

diffLcri=diff(Lcri);

plot(Vin, Lcri);

max = max(Lcri)
```

```
명령 창
max =

    14.8148

fx >>
```

Figure 2. MATALB Problem 3 Code

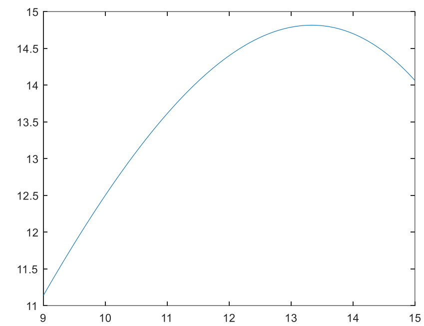


Figure 3. MATLAB Result Problem 3

$$according\ to\ MATLAB,\ \max(L_{cri}) = 14.8148[\mu H]$$

$$at\ \max(L_{cri}),\quad V_{in} = 13.3333[V]$$

4. A Boost converter is to be designed with the following values: $V_{in} = 5[V]$, $V_{out} = 12[V]$, and the maximum output power $P_{out} = 40[W]$. The switching frequency is selected to be $f_s = 200[kHz]$. Assume ideal components, Estimate the value of L if the converter is to remain in CCM at one-third the maximum output power.

$$\frac{V}{V_g} = \frac{1}{1-D}, \quad D = 1 - \frac{V_g}{V} = \frac{7}{12} = 0.5833$$

$$I_L \geq \Delta i_L, \qquad I_L \geq \frac{D \times V_{in}}{2 L f_s}$$

$$\frac{P_{in}}{V_{in}} \geq \frac{V_{in} \times D}{2 L f_s}$$

$$L \geq \frac{V_{in}^2 D}{2 \times P_{in} \times f_s} = \frac{V_{in}^2}{2 \times P_{in} \times f_s}\left(1 - \frac{V_{in}}{V_{out}}\right)$$

$$P_{out} = P_{in} = \frac{40[W]}{3}$$

$$L \geq \frac{(5[V])^2 \times \frac{7}{12}}{2 \times \left(\frac{40[W]}{3}\right) \times 400[kHz]} = 1.3672[\mu H]$$

Experiment

1) Following values are given: f = 150[kHz], R_Load = 20[Ω], Vin = 5[V], Pout,max = 10[W], L = 150[μH], C = 1,800[μF], ΔVout ≤ 0.1%·Vout. With these, find following values before further procedures: V_out,max, D_max, L_crit, and ΔVout,max. Are L and C suitable for the design?

We need to find value of L and C are suitable for the design of Boost Converter before start experiment. In Boost Converter, we know that $V_{out} = \frac{1}{1-D} \times V_{in}$. So, we need to find the maximum duty value that does not exceed the P_{max}

$$P_{max} = \frac{V_{out}^2}{R_{Load}} = \frac{V_{out}^2}{20[\Omega]} = 10[W]$$

$$V_{out,max} = \sqrt{200}[V] = 14.14[V] = \frac{V_{in}}{1 - D_{max}}$$

$$D_{max} = \frac{4 - \sqrt{2}}{4} = 0.6464$$

For the boost converter to operate in the CCM interval, I_L must bigger than $\frac{\Delta I_L}{2}$. Then calculate I_L and ΔI_L.

1) calculate I_L

$$P_{in} = V_{in} \cdot I_{in} = V_{out} \cdot I_{out} = \frac{V_{out}^2}{R_{Load}}$$

$$I_L = I_{in} = \frac{P_{in}}{V_{in}} = \frac{V_{out}^2}{V_{in} \cdot R_{Load}} = \frac{\frac{V_{in}^2}{(1-D)^2}}{V_{in} \cdot R_{Load}} = \frac{V_{in}}{R(1-D)^2}$$
$$= 2[A]$$

2) calculateΔI_L

$$\Delta I_L = \frac{V_{in} \cdot D_{max} \cdot T}{L}$$

Using the equation 1) and 2),

$$I_L \geq \frac{V_{in} \cdot D_{max} \cdot T}{2 \cdot L} \Rightarrow I_L \geq \frac{V_{in} \cdot D_{max}}{2 \cdot L \cdot f}$$

$$L \geq \frac{V_{in} \cdot D_{max}}{2 \cdot I_L \cdot f} = \frac{5[V] \cdot 0.65}{2 \cdot 2 \cdot 150[kHz]} = 5.3871[\mu H]$$

Next, use the conditions of the capacitor to obtain the required values. In given conditions, $\Delta V_{out} \leq 0.1\%$.

$$\Delta V_{out} = \frac{V_{out} \cdot D_{max} \cdot T}{R_{Load} \cdot C} = \frac{V_{out} \cdot D_{max}}{R_{Load} \cdot C \cdot f} \leq 0.1\% \cdot V_{out}$$

$$\frac{\Delta V_{out}}{V_{out}} = \frac{D_{max} \cdot T}{R_{Load} \cdot C} = \frac{D_{max}}{R_{Load} \cdot C \cdot f} \leq 0.1\%$$

$$C \geq \frac{D_{max}}{R_{Load}\left(\frac{\Delta V_{out}}{V_{out}}\right) f} = \frac{0.65}{20[\Omega] \cdot 150[kHz] \cdot \frac{1}{1000}}$$
$$= 215.4822[\mu F]$$

Therefore, now we know that the given values are suitable for use in this experiment.

However, if duty over the D_{max}, P_{out} will be over the $P_{out,max}$. It can cause damage to the circuit, so circuit must be operated within a safe range of duty. Therefore, this experiment was conducted under $D = 0.5$.

2) One must create the Boost converter circuit and have a clear picture of the circuit.

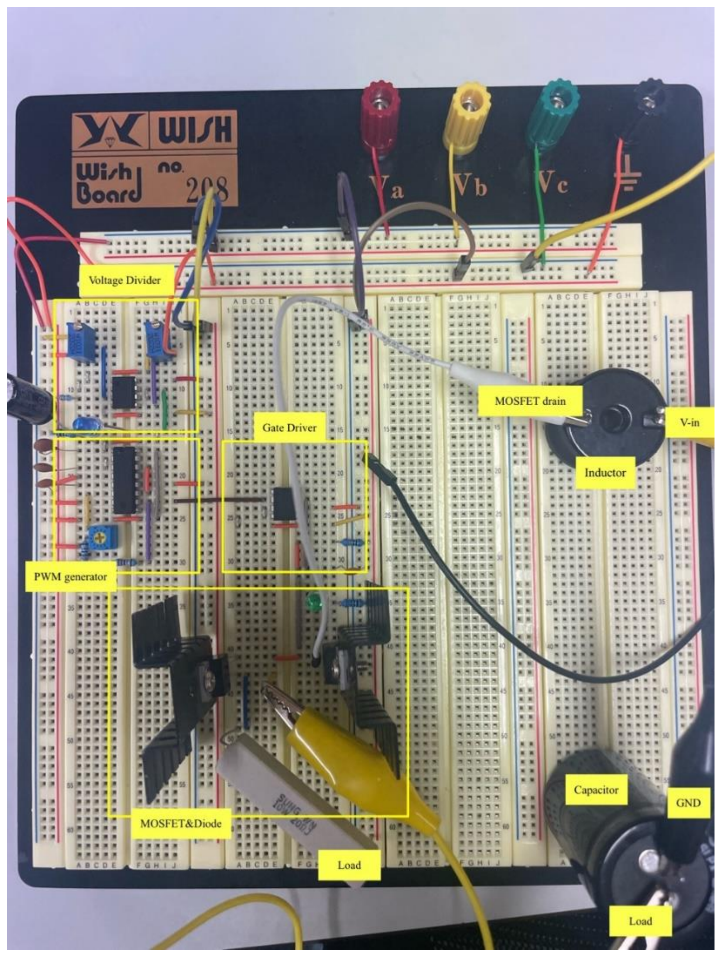


Figure 4. Boost Converter Circuit

3) One must show duty – output voltage curve when input voltage is set to 5[V] and Switching frequency is set to 150[*k*Hz] (Don't go over the Pout,max).

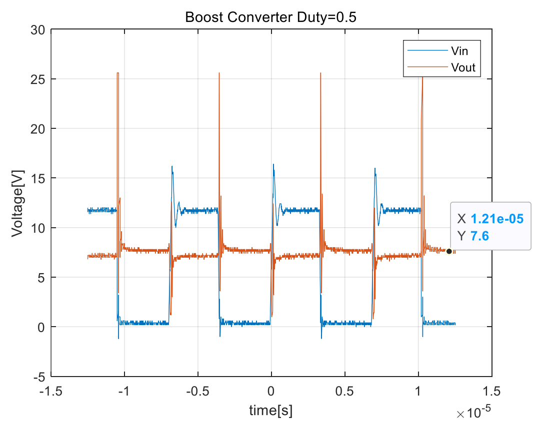


Figure 5. Duty-Output Voltage (Duty = 0.5)

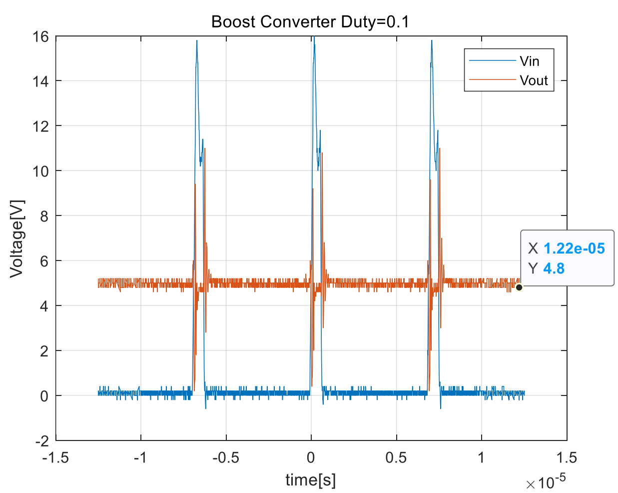


Figure 6. Duty-Output Voltage (Duty = 0.1)

	Duty(0.1)	Duty(0.5)
Theorical	5.55[V]	10[V]
Experimental	4.8[V]	7.8[V]

Table 1. Comparison of Experimental and Actual Values

In fact, when the duty is 0.5, the power voltage should be 10[V], but the experimental value is lower than that, which can be seen as a low value due to energy loss generated by the inductor and the capacitor.