PCB Design of Closed Loop Operation of DC-DC Buck Converter

EE 561 Power Electronics Laboratory

216102035 - ANANDH N and 214102101 - ABHIJEET ANAND

November 12, 2021

1 Objective

1. To design a closed loop dc-dc buck converter circuit and to simulate the circuit in LT Spice software with appropriate design values and components to verify the operation of the controller.
2. To realize the closed loop control of buck converter controlled by analogue PI controller with the following specifications: Input Voltage (V_{in}): 200 V, Output Voltage (V_o): 96 V, Switching Frequency (f_{sw}): 20 kHz, Output Voltage Ripple (ΔV_o): 10%, Inductor Current Ripple (Δi_L): 20%, Rated Power: 500 W.
3. To design the PCB in Eagle PCB design software with all the complete design procedures and implementation.

2 Circuit Diagram

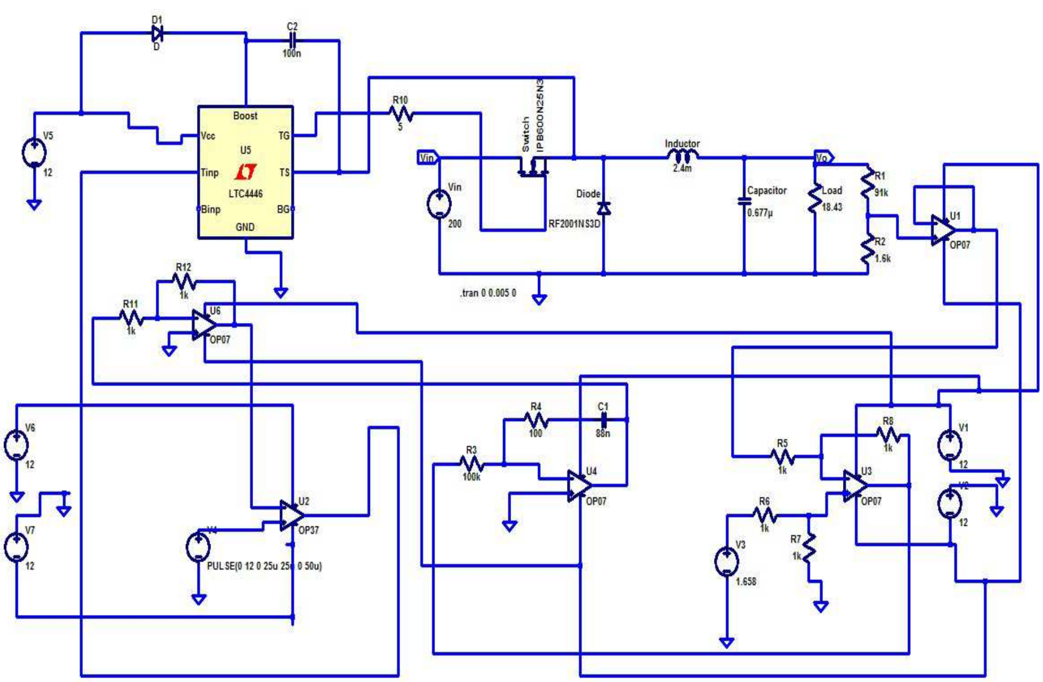

Figure 1: LT SPICE Schematic Diagram of designed Buck Converter with Closed Loop Controller

3 Design Calculations

$R = \frac{V_o^2}{P_o} = \frac{96^2}{500} = 18.43\Omega$, $I_o = \frac{V_o}{R} = \frac{96}{18.43} = 5.20A$ and $D = \frac{V_o}{V_{in}} = \frac{96}{200} = 0.48$

$$L = \frac{(V_{in} - V_o)\,D}{\Delta i_L . f_s} = \frac{(200 - 96)\,0.48}{1.04 \times 20000} = 2.4mH \tag{1}$$

$$C = \frac{(1 - D)\,V_o}{8Lf_s^2 . \Delta V_o} = \frac{(1 - 0.48)\,96}{8 \times 2.4 \times 10^{-}3 \times 20000^2 \times 9.6} = 0.677\mu F \tag{2}$$

4 Controller Design

4.1 Open Loop Transfer Function

$$\frac{V_o\left(s\right)}{D\left(s\right)}=\frac{V_{in}.R\left(1+srC\right)}{R+s\left(L+CRr\right)+s^2LC\left(R+r\right)} \tag{3}$$

$$\frac{V_o}{D}=\frac{3686+s\left(0.4990\times10^{-3}\right)}{18.43+s\left(2.402\times10^{-3}\right)+s^2\left(3.027\times10^{-8}\right)} \tag{4}$$

4.2 System Transfer Function with Controller

$$G\left(s\right).G_c\left(s\right)=\frac{3686+s\left(0.4990\times10^{-3}\right)}{18.43+s\left(2.402\times10^{-3}\right)+s^2\left(3.027\times10^{-8}\right)}\times\left[K_p+\frac{K_i}{s}\right] \tag{5}$$

$$G\left(j\omega\right).G_c\left(j\omega\right)=\frac{3686+j\omega\left(0.4990\times10^{-3}\right)\left(K_p-j\frac{K_i}{\omega}\right)}{18.43+j\omega\left(2.402\times10^{-3}\right)-\omega^2\left(3.027\times10^{-8}\right)} \tag{6}$$

$PM=30^0, \omega_{gc}=2kHz=2\pi\times2k=12566.37rad/s$
$K_p=8.7977\times10^{-4}$ and $K_i=112.744$

5 PI Controller in Analog domain

$$\frac{V_c\left(s\right)}{V_o\left(s\right)}=-\left(\frac{R_2}{R_1}+\frac{1}{R_1Cs}\right) \tag{7}$$

$R_2=100\Omega$, $R_1=\frac{R_2}{K_p}=\frac{100}{0.00087977}=113666.07\Omega$ and $C=\frac{1}{R_1.K_i}=\frac{1}{100k\times112.744}=78nF$

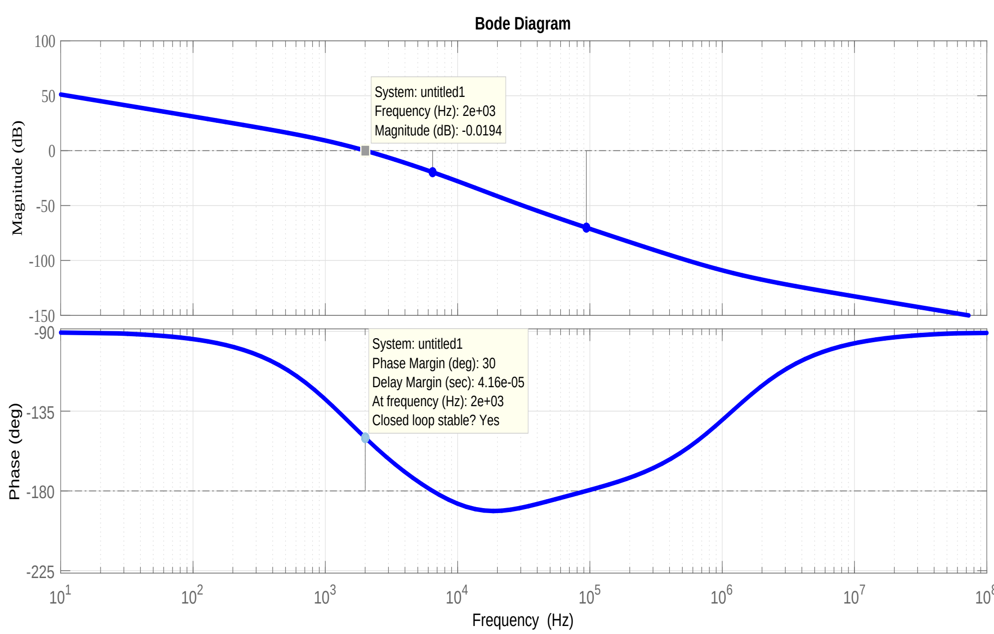

Figure 2: Bode Plot of System with designed PI Controller

6 Results

The simulation results of the designed buck converter with PI controller in LT-SPICE are shown below.

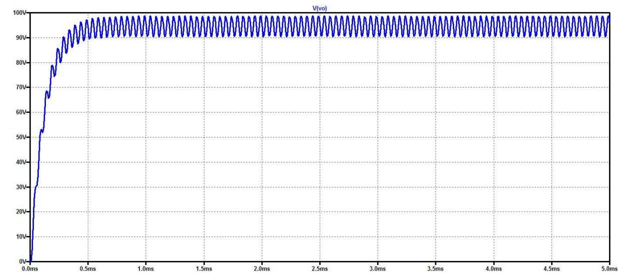

Figure 3: Output Voltage

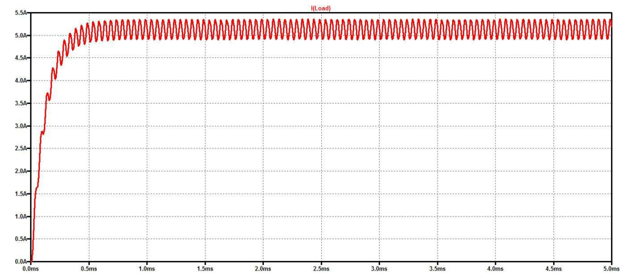

Figure 4: Output current

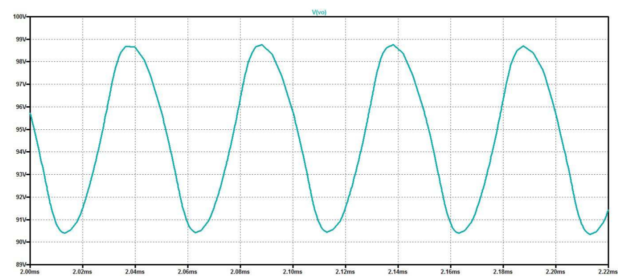

Figure 5: Output Voltage ripple

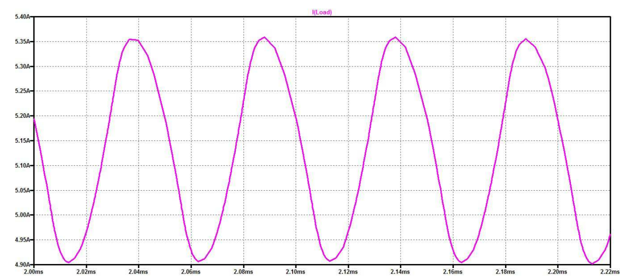

Figure 6: Output current ripple

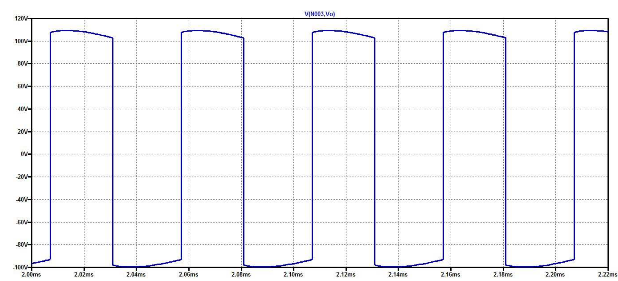

Figure 7: Inductor Voltage

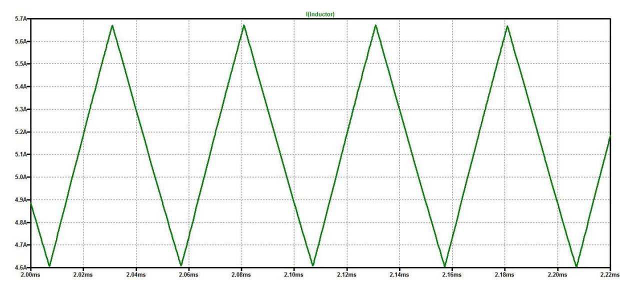

Figure 8: Inductor current

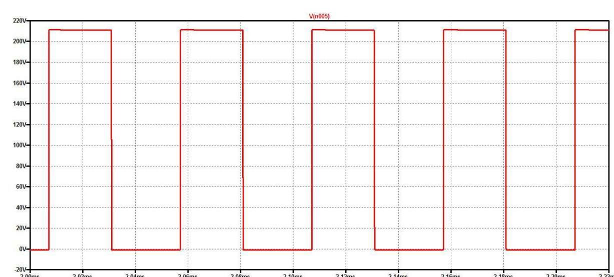

Figure 9: PWM Signal from driver circuit

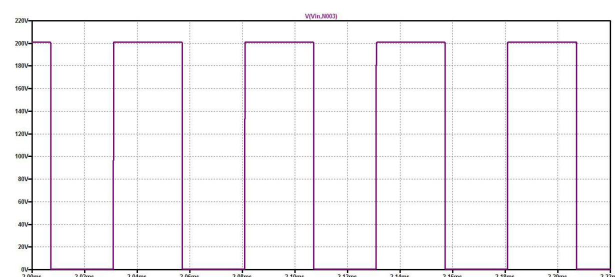

Figure 10: Voltage across MOSFET

7 Hardware Component Selection for Buck Converter

1. Selected MOSFET available in market: IPP600N25N3 G; Package: PG-TO220-3 Through hole; $V_{DS} = 250V$; $R_{DSon} = 60m\Omega$; $I_D = 25A$.

2. Selected Diode available in market: LQA30T300; Package: TO220AC Through hole; $V_{RRM} = 300V$; $I_{F(avg)} = 30A$.

3. Required inductor value is 2.4 mH, so a toroidal inductor will be selected based on the saturation current limits.

4. Selected Capacitor available in market: LD series-Aluminium electrolytic capacitor-Through hole; Rated voltage is $150V$; Rated Capacitance is $1\mu F$.

5. Output power of the converter is 500 W, so a rheostat with the rated power can be selected as the load resistance. Required load resistance is 18.43Ω.

6. Selected Opamp IC available in market:LM324N Low Power/Quad Operational Amplifier IC; Package: DIP (14) Through hole.

7. Selected Driver available in market: IR2110PBF; Package: DIL (14) Through hole.

8 Eagle PCB Schematic and Board Design

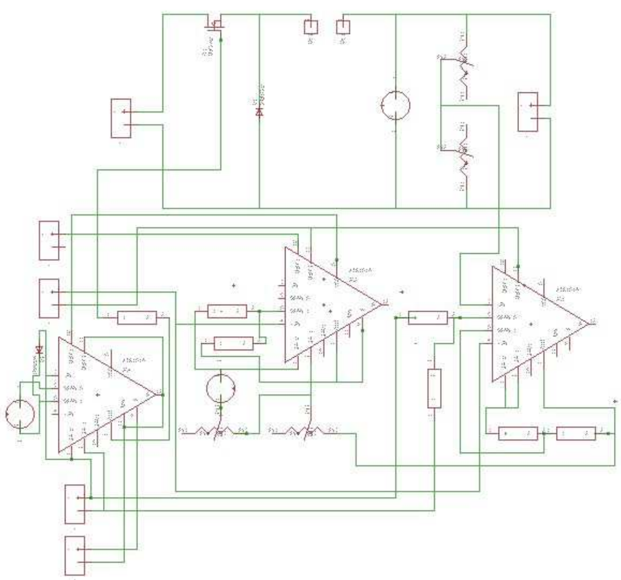

Figure 11: Eagle-Schematic Design of Buck converter

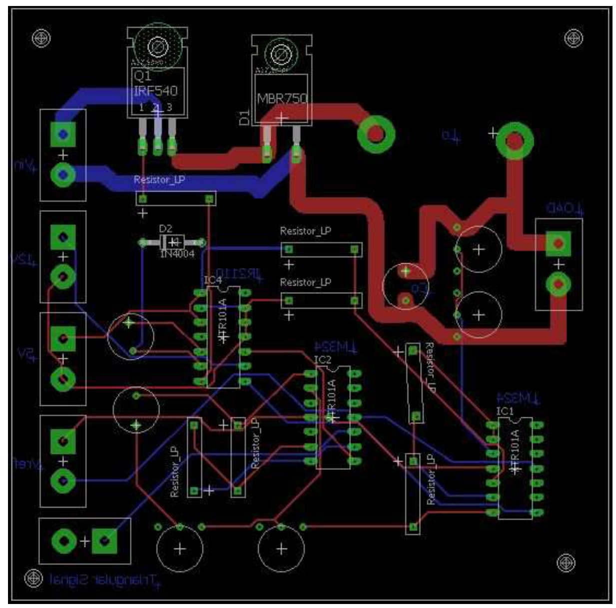

Figure 12: Eagle-PCB Design of Buck converter

9 Conclusion

Thus the design of a closed loop dc-dc buck converter circuit was done and the simulation was carried out in LT Spice software with appropriate design values and components. The closed loop control of buck converter controlled by analogue PI controller with the desired specifications was realized and the output voltage, output current, inductor current, capacitor current, switch and diode voltage waveforms were observed. Finally, PCB was designed and implemented using the Eagle PCB design software with all the complete design procedures.

References

[1] N. Mohan, "First course on power electronics and drives," *MNPERE*, 2003.

[2] "http://www.linear.com/designtools/software/."

[3] "https://www.instructables.com/pcb-creation-with-eagle-for-beginners/."