EE561: Power Electronics Laboratory
Project Report on
PCB Design for Closed-loop Operation of Buck Converter

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1 Objective

Realise a closed loop control of buck converter controlled by analogue PI controller. The specifications for the buck converter are given below.
Input Voltage (V_{in}): 200 V, Output Voltage (V_o): 96 V, Switching frequency: 20 kHz, Output Voltage Ripple (ΔV_o): 10%, Inductor Current Ripple (Δi_L): 20%, Rated Power: 500 W.

2 Calculations

2.1 Output current, Input current:

$$R = \frac{V_o^2}{P_o} \qquad R = \frac{96^2}{500} = 18.432\ \Omega$$

$$I_o = \frac{P_o}{V_o} = \frac{500}{96} = 5.2\ Amps \qquad I_{in} = \frac{P_o}{V_{in}} = \frac{500}{200} = 2.5\ Amps$$

2.2 Duty ratio:

$$D = \frac{Vo}{Vin} = \frac{96}{200} = 0.48$$

2.3 Inductance:

$$L = \frac{(1-D)R}{f_s \Delta i_L} = \frac{(1-0.48)18.43}{20 * 10^3 * 0.2} = 2.4mH$$

2.4 Capacitance:

$$C = \frac{(1-D)}{8f_s^2 * L\Delta V_o} = \frac{(1-0.48)}{8 * 400 * 10^6 * 2.4 * 10^{-3} * 0.1} = 0.68\mu F$$

3 Power Circuit Component Specifications

As per Formulas, values are calculated but there may be the case that these components are not available with the same exact values so one have to take the nearby values which are available in market. So values taken are as following

s.no	Component	Name	Voltage/Current Ratting	Specifications
1	Inductor (2.6mH)	SCF47B-200S1	20A	R_internal=0.0029Ω
2	Capacitor (0.68μF)	C2220C684K2	200V, 4.4A	r=0.026Ω
3	Load (22Ω)	HCHJ355J22RJ	-	Power=500W, Tolerance=5%
4	MOSFET	IRF740	400V, 10A	Vgs=20V, R_ON=0.48Ω
5	Diode	BYT79	400V, 14A	Vf<1.05V, Trr<60ns

$Table.1 \qquad Power\ \ Component\ \ Specification$

4 Controller design

4.1. Transfer function:

$$\frac{\hat{V_o(s)}}{\hat{d(s)}} = \frac{R(1+rCs)V_{in}}{R + s(L + CRr) + s^2(LC(R+r))}$$

$$= \frac{4400(1 + 0.17.68 * 10^{-9}s))}{22 + 2.6 * 10^{-3}s + 38.896 * 10^{-9}s^2}$$

system with the above transfer function is having Phase Margin $(PM) = 11.7degree$ at gain crossover frequency(w_{gc}) of $53.157kHz$
Controller is designed to get $PM = 35\ degree$ at $w_{gc} = 2kHz$
Designed PI Controller Transfer Function(G_c)

$$G_c(s) = 61.9 * 10^{-6} + \frac{100}{s}$$

5 Realization of Control Circuit Part

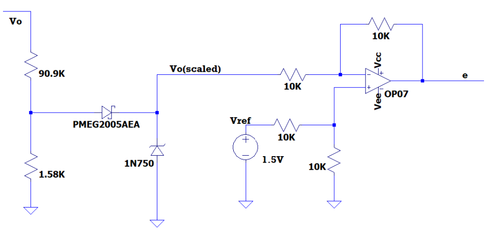

Figure 1: Sensor and summer

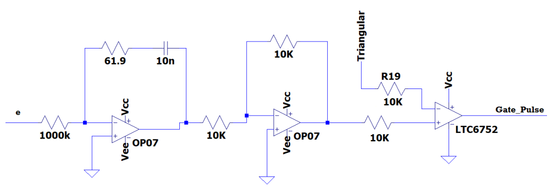

Figure 2: PI and Comparator

The voltage divider Circuit is used to step down and sense output Voltage, and then the diode configuration is to get steady voltage and to avoid any damage to the lower power rating devices like Op-Amp. The error amplifier has $V_{Oscaled}$ and V_{ref} as input and gives the scaled error at output. Circuitry for the same is given in Fig.1 Scaled error is then given to the PI controller, which is made using the OP-AMP, as shown in Fig.2. Transfer function of the PI controller can be found by simply taking the ratio of feedback impedance to the input impedance. For fine-tuning of PI controller, its input resistance is kept variable. The output of that is given to the inverting OP-AMP because the PI controller is acting as an inverting OP-AMP. Comparator IC LTC6752 is used to compare the output of the PI controller with the 20kHz triangular signal and generate pulses. The output of the comparator is given to the Driver IC, which will generate gate pulses for MOSFET. In Fig.3, the complete circuitry to generate a triangular wave with an amplitude of 10V is given. This triangular wave generator is used as a carrier wave generator to compare with the output of the PI controller. The first square wave with the desired frequency is obtained using positive feedback of LT6231 IC, and then it is integrated simply using LT6231 as an integrator function. Then another OP-AMP is used to increase the magnitude of the triangular signal to the +10V.($+V_{cc} = 10V$ and $-V_{cc} = -10V$)

5.1 ICs used

s.no	Component	IC Name	Specifications
1	OP-AMP	OP-07	Input Voltage range=$\pm18V$ slew rate=0.3V/μs
2	Comparator	LTC6752	280MHz, Low Delay(2.9ns), Excellent CMRR
3	OP-AMP	LT6231	Low Noise, Wide supply range($\pm13V$), CMRR=115dB
4	Resistors	-	10kΩ, 5kΩ, 61.9Ω, 90kΩ, 1kΩ, 20kΩ, 90.9kΩ, 1.58kΩ
5	Capacitors	-	10nF, 0.25μF

$Table.2 \quad Control\ Component\ Specification$

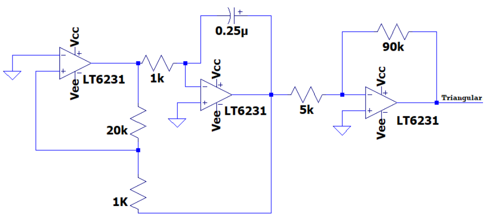

Figure 3: Triangular Wave Generator

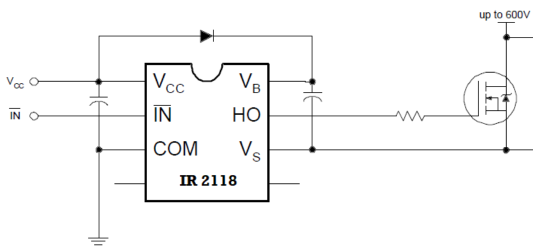

Figure 4: Driver IC Connections

6 Driver IC

The driver is used for isolation between the control circuit and power circuit; sometimes source terminal of MOSFET is floating, i.e., at the variable potential. In such cases, we need to change the reference of gate voltage to make it ON. for that, driver ICs can come in handy. IR2118 is a single-channel driver IC which is a floating channel designed for bootstrap operation. It has a voltage range of up to 600V. Also, it can provide gate drive voltage up to 10 to 20V, its dV/dt immune with a turn ON delay of 125ns and turn OFF delay of 105ns. The connection Diagram for IR2118 is shown in Fig.4

7 PCB Design

After successfully testing the simulation for the whole circuitry, PCB is designed using the EAGLE software. The figure below shows the PCB design.

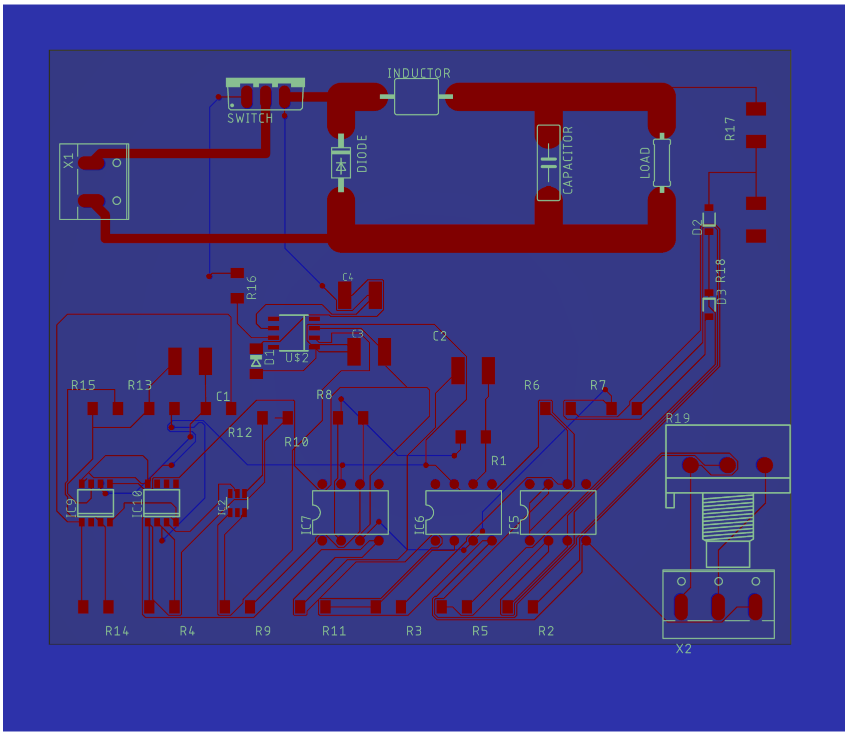

Figure 5: Designed PCB

8 LTSpice Circuit Model

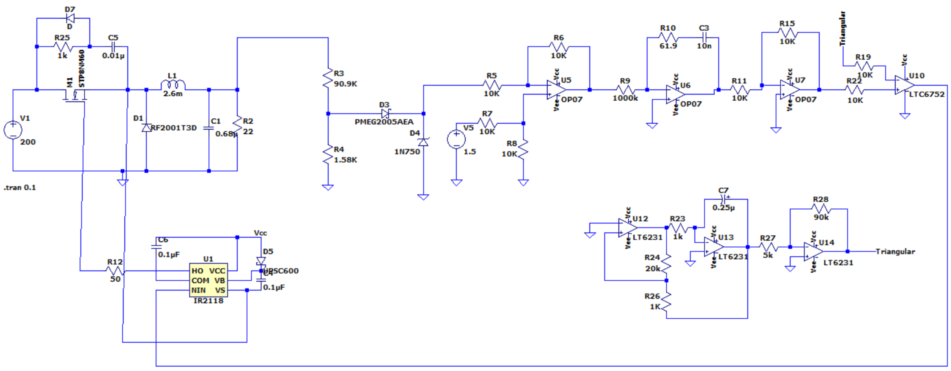

Figure 6: LTSpice Circuit Model