A report on

PCB Designing of closed loop buck converter

[Self-project]

AKESH KOTNNA
224102102

Aim: To design a printed circuit board (PCB) for controlling the output voltage of a given buck converter. An analogue type PI controller is considered.

Converter Requirements:

Input Voltage	= 300V	Current ripple	= 10%
Output Voltage	= 120V	Voltage ripple	= 5%
Switching frequency	= 25KHz	Power rating	= 300W

Calculations:

Duty Ration D $= \frac{V_O}{V_{in}} = \frac{120}{300} = 0.4$

Output Current $= \frac{300}{120} = 2.5A$, Load Resistance R$=\frac{120}{2.5} = 48\Omega$

Inductor $L = \frac{(1-D)V_0}{f_S \Delta I_L} = \frac{(1-0.4)x\,120}{25K*(0.1*2.5)} = 0.115mH$

Capacitor $C = \frac{(1-D)}{f_S^2 8LC\Delta V_0} = \frac{1-0.4}{(25k)^2*8*4.8e^{-3}*(0.05*120)} = 0.2\mu F$

Transfer function of non-ideal Buck Converter:

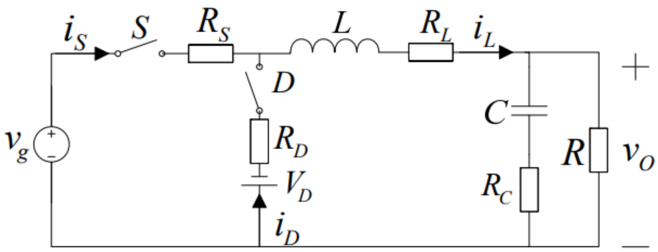


Figure 2:Non-ideal Buck converter considered parasitic parameters

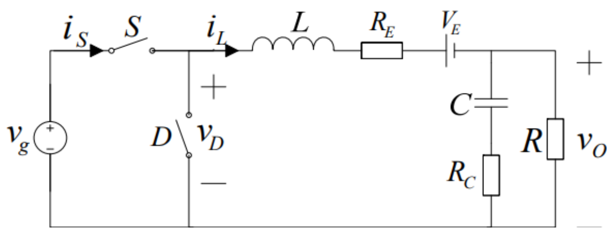


Figure 1:Non-ideal Buck converter after equivalent conversion

Where $R_E = [R_L + DR_S + (1-D)R_D]\left[1 + \frac{\Delta i_L^2}{3I_L^2}\right]$ and $V_E = (1-D)V_D$

Transfer function for the above converter can be written as:

$$G_{vd}(s) = \frac{\hat{v}_0(s)}{\hat{d}(s)}\bigg|_{\hat{d}(s)=0} = \frac{V_g R}{R+R_E} \cdot \frac{1+\frac{s}{\omega_{z1}}}{1+\frac{s}{Q\omega_0}+\left(\frac{s}{\omega_0}\right)^2}$$

Where

Quality factor $Q = \frac{\sqrt{(R+R_E)(R+R_C)LC}}{RR_E C + RR_C C + R_E R_C C + L}$

Zero point $\omega_{z1} = \frac{1}{R_C C}$

Resonance frequency $\omega_0 = \sqrt{\frac{R+R_E}{(R+R_C)LC}}$

Controller Design:

Design Requirements: Phase Margin = 120° and Gain Crossover frequency ω_{gc} =2000 rad/sec

Let, Controller transfer function $G_c(s) = K_p + \frac{K_i}{s}$

And plant (buck) transfer function $G_p(s) = G_{vd}(s)$

now, overall transfer function $G(s) = G_C(s)G_P(s)$

Now we have two unknowns to find, those are K_p and K_i .We need two equations to solve these two unknowns. Phase margin and Gain relations give these two equations.

we know that

$$\text{Phase margin PM} = 180° + \angle G(s)|_{\omega_{gc}}$$

$$120° = 180 + \left[\angle\left(K_p + \frac{K_i}{s}\right) + \angle\, G_p(s)\right]$$

$$120 = 180 + \left[\tan^{-1}\left(\frac{\omega K_p}{K_i}\right) - 90° - 31.9077°\right]$$

$$\frac{K_p}{K_i} = \frac{1.873}{\omega_{gc}} \quad \text{-------- (1)}$$

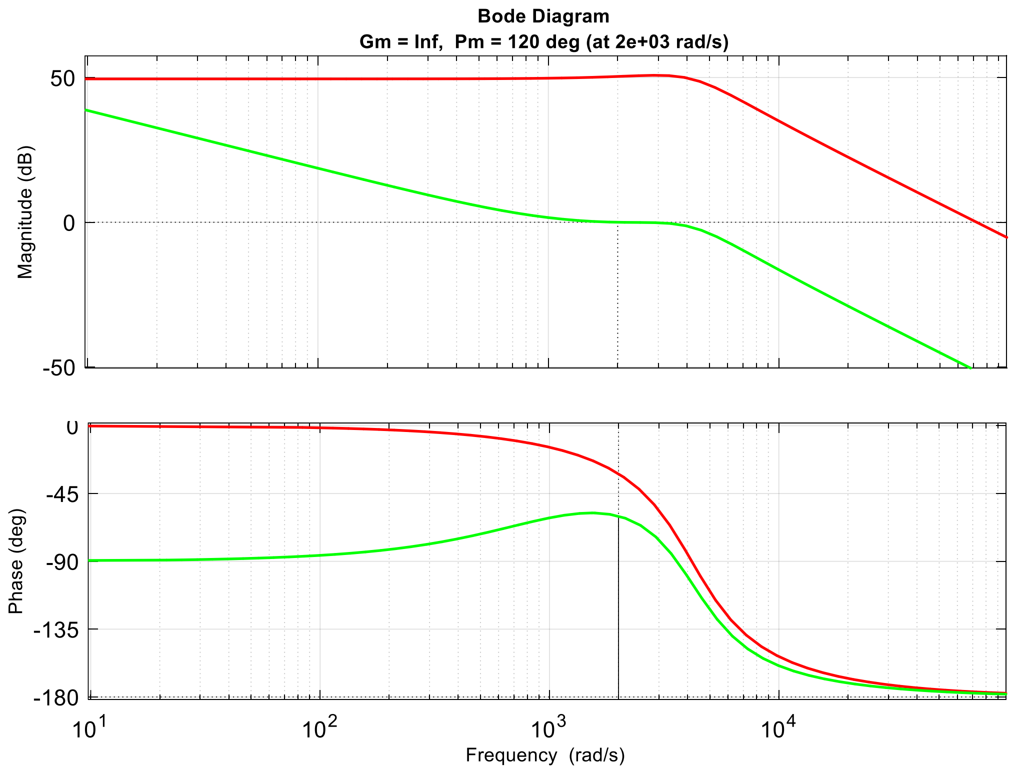
Another equation can be obtained from gain relation

$$1 = \left|K_p + \frac{K_i}{s}\right| . \left|\, G_p(s)\right|$$

$$\left(\frac{\omega_{gc}}{330.3362}\right)^2 = \left(\frac{1.873}{\omega_{gc}}K_i\right)^2 \omega_{gc}{}^2 \quad \text{------------- (2)}$$

By solving above two equations we can get K_p and $K_i$values [$K_p = 2.851$ and $K_i = 0.0027$].

Bode plot:



Power Circuit components:

Component	Specifications
MOSFET	IRF440-500V,8A,0.85 Ω Power MOSFET
Diode	400V/600V ,8A, Trr<135ns fast switching soft recovery diode
Inductor	SC-03-05GS 250V/(0.1mH-8mH)/6A/27 mΩ
Capacitor	B58043, SMD 2220 series 400V/0.25 μF/ESR-0.004 Ω

Block diagram:

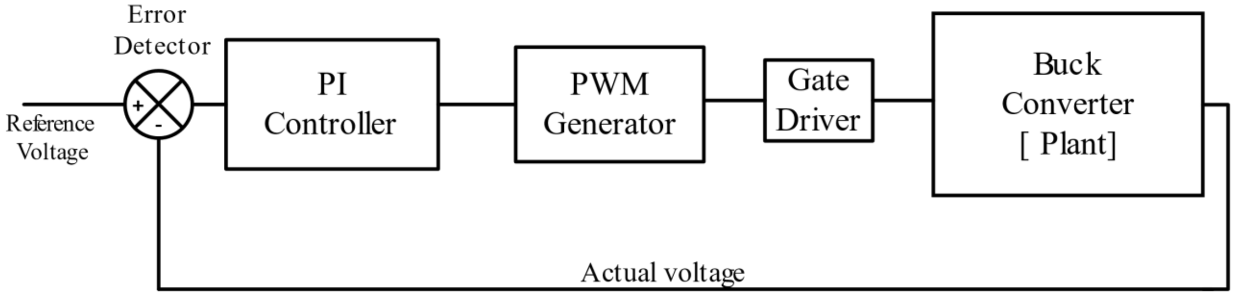


Figure 3:Block diagram of closed loop buck converter

Output voltage from the buck converter is given to the error detector. This actual output voltage is fed to the error detector to get the error with respect to reference voltage. Error detector is realised by subtractor using OP-AMP. This is error signal will go to the PI controller. PI controller can be implemented by a series RC circuit in the OP-AMP feedback. Output from the PI controller is given to the comparator, another input for the comparator is sawtooth signal having frequency same as switching frequency. These two signals are compared to get the duty signal for the MOSFET. As we cannot give duty signal to the power MOSFET directly, a driver IC is used to give this duty signal to the MOSFET. Gate driver IR2117 is used for this operation.

Gate Driver: The IR2117 is a high voltage, high speed power MOSFET and IGBT driver. The logic input is compatible with standard CMOS outputs. This driver is tolerant to negative transient voltage and dv/dt immune. The output driver features a high pulse current buffer stage designed for minimum cross-conduction.

MATlab & LTspice Simulations:

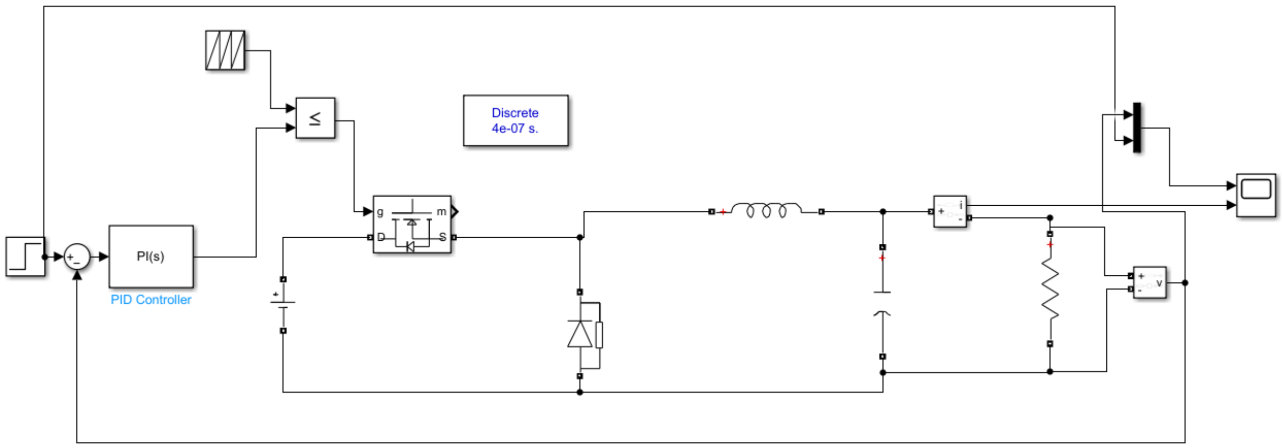


Figure 4:MATlab simulation of PI controlled buck converter

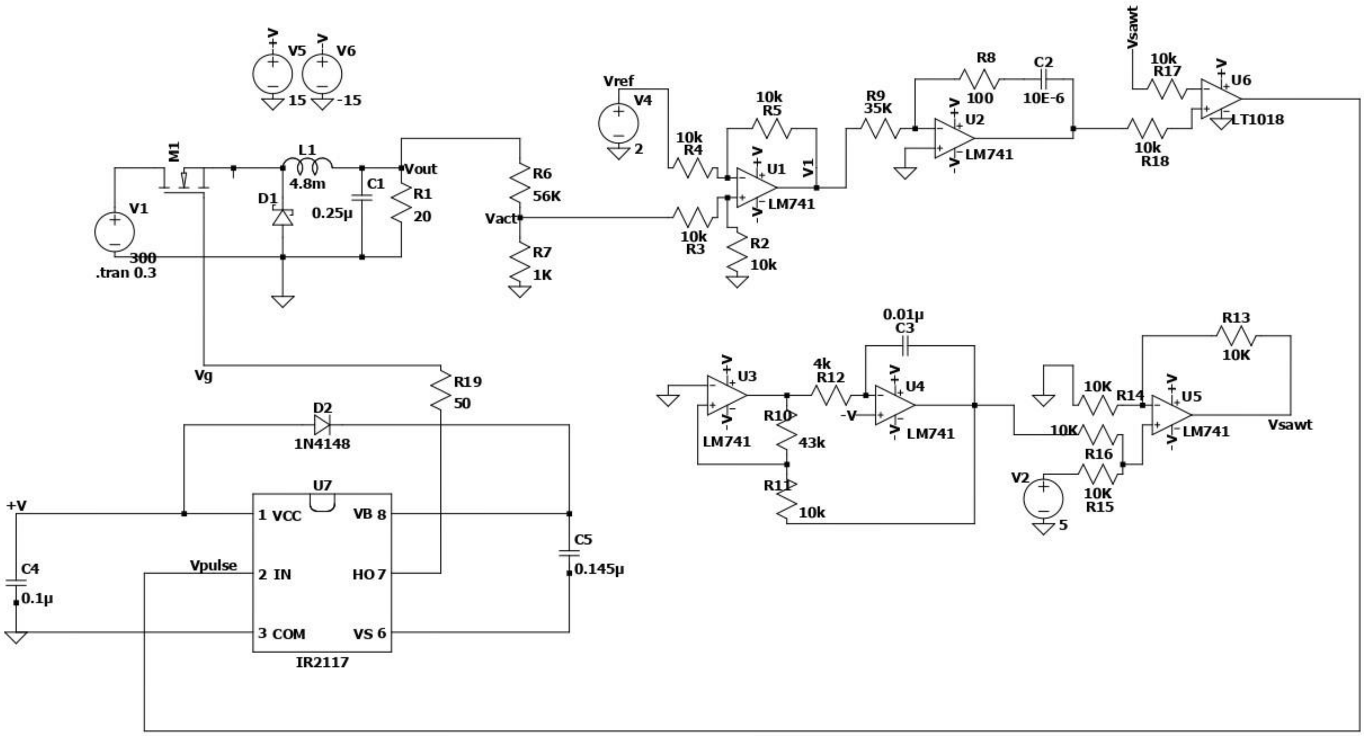
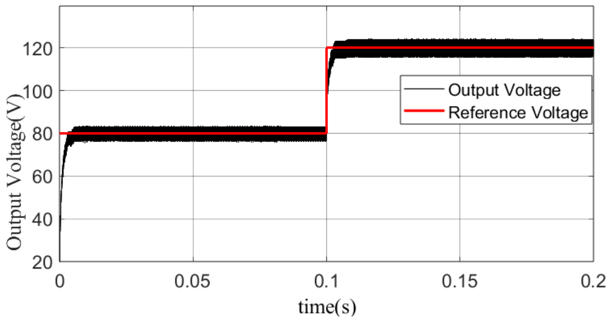
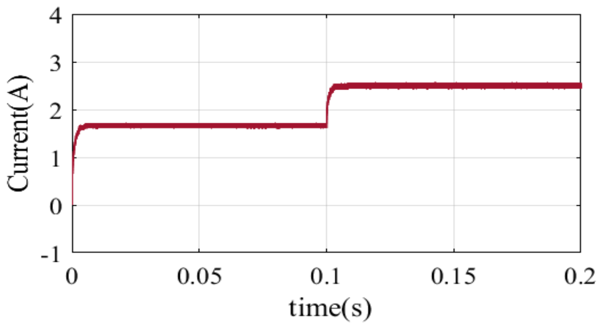


Figure 5:LTspice model of closed loop buck converter

Results:





Signal Circuit Components used:

Component	Specifications
LM741	8-DIP general purpose operational amplifier
IR2117	600V/(10V-20V), 125 ns delay, designed for bootstrap operation
LT1018	Micropower, High frequency Comparator
1N4118	0.2A, Ultra-high speed, fast reverse recovery time
Resistors	1k,4k,10k,35k,43k,
Capacitors	0.145uF,0.1uF,10uF

Designed PCB:

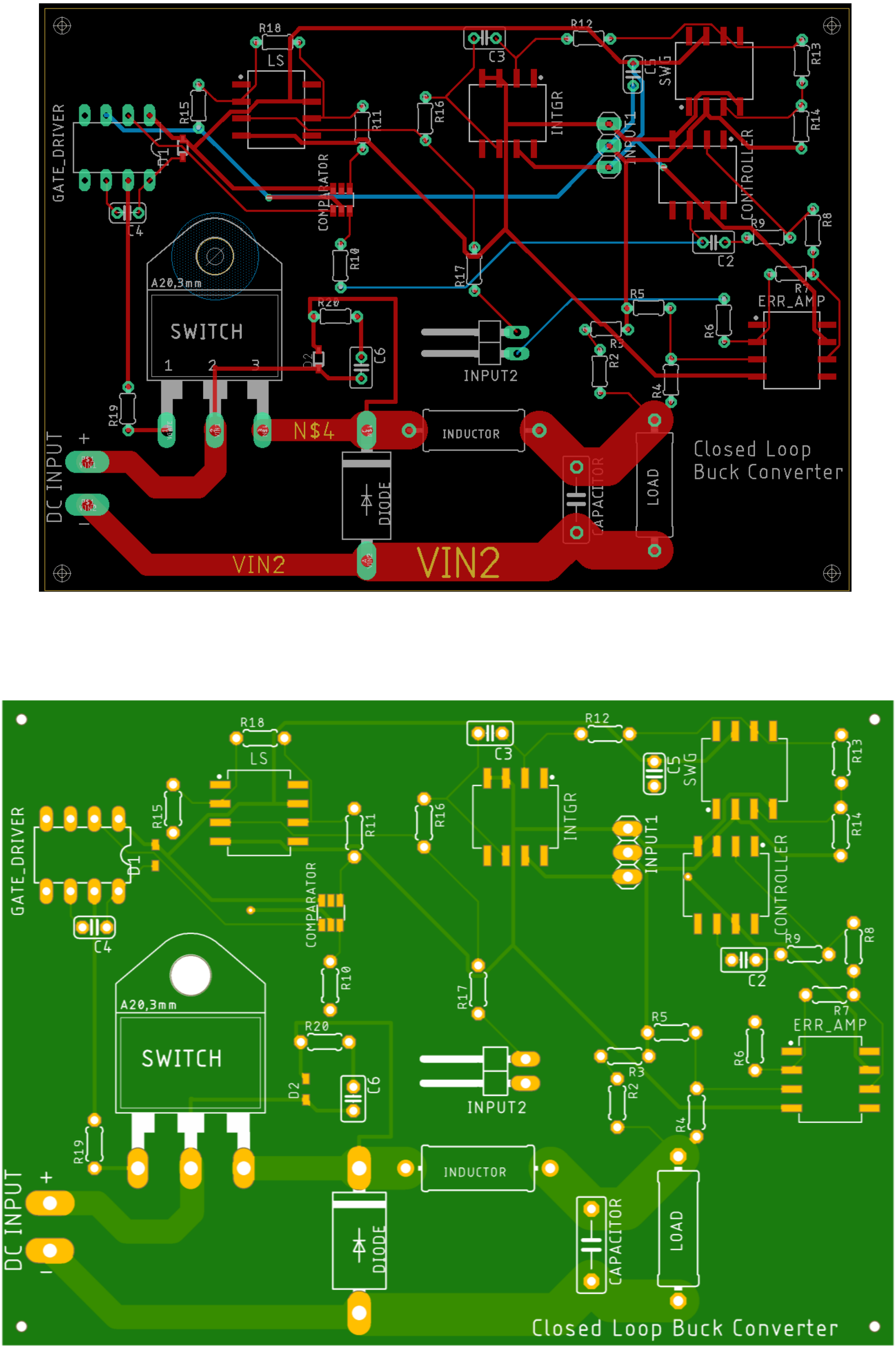


Figure 6: PCB top view

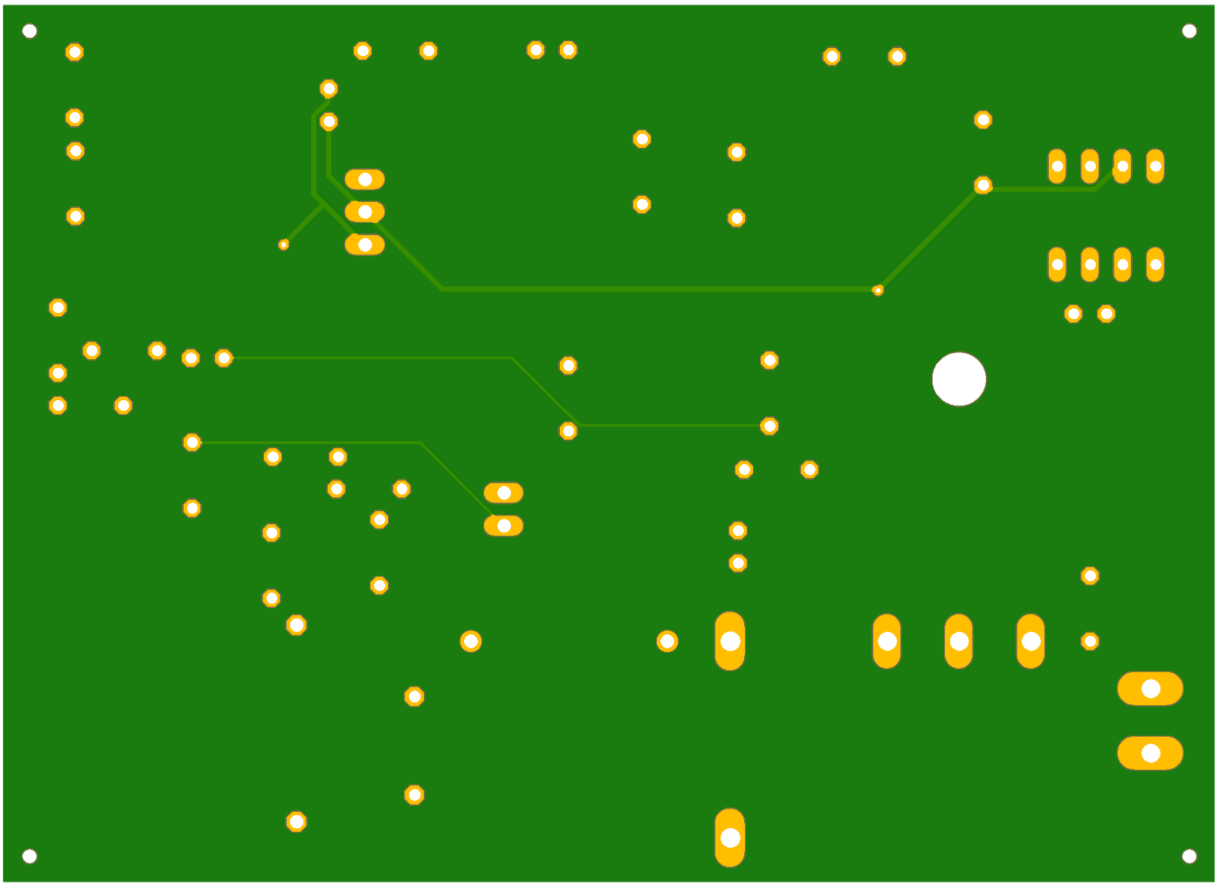


Figure 7:PCB bottom view

Gerber files:

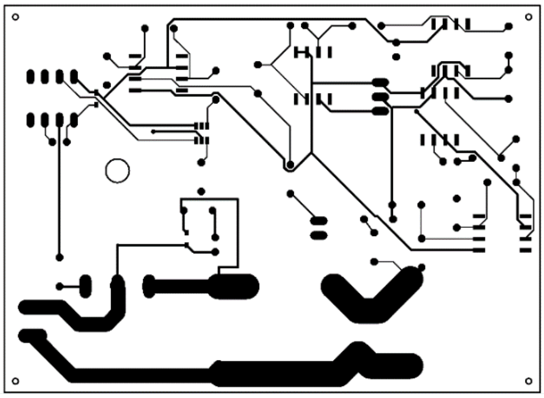


Figure 8: Top copper layer

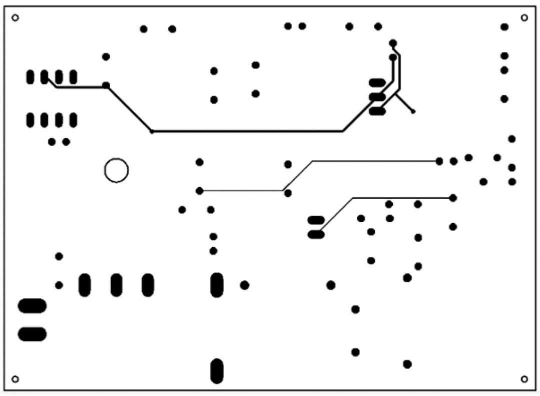


Figure 9: Bottom copper layer