Buck Converter Design Report (En-Core 1.0)

1. Introduction

A buck converter is a step-down DC-DC converter that reduces input voltage to a desired lower output voltage with a high efficiency. It is commonly used in various applications where power conversion is necessary, such as power supplies, electric vehicles, and industrial controls.

In this project, we are designing a non-isolated buck converter that steps down a 24V input to a 5V output with at least 90% efficiency. The input voltage has a tolerance of ±2%, and the converter can handle up to 1A of input current. The solution is designed using standard components, and no pre-built buck converter ICs are used.

2. Problem Statement

Specifications:

- **Input Voltage (Vin):** 24V (±2% tolerance)
- **Output Voltage (Vout):** 5V (±0.01V)
- **Input Current:** 1A max
- **Efficiency:** ≥ 90%
- **Form Factor:** PCB size must be within 10 cm x 5 cm.

The objective is to design the schematic, calculate component values, simulate the circuit, and design the PCB.

3. Theoretical Background

A buck converter operates by switching a MOSFET on and off, controlling the energy transfer to an inductor and a capacitor, which smoothens the output. The key components include:

- **Schottky Diode** 1N5817 is used to minimize losses.
- Assuming capacitor of **Astable Multivibrator** to be 0.05µf.
- **Control Voltage** pin of **NE555** is connected to 0.01µf.
- **Silicon diodes** of forward voltage 0.7V are used to achieve **duty cycle of 20.8%**.

The efficiency of the converter is given by:

Buck Converter

→ Calculations :

$Vin_{min} = 23.52\ V$

$Vin_{max} = 24.48\ V$

$V_{out} = 5\ V$

$$\text{Efficiency} = \frac{P_{out}}{P_{in}} \geq 90\%$$

$$\frac{5 \times I_{out}}{24 \times 1} = \frac{90}{100}$$

$$I_{out} = \frac{9 \times 24}{5 \times 10} = 4.32\ A$$

$$\text{Duty Cycle} = \frac{V_{out}}{V_{in}} = \frac{5}{24} = 0.208$$

Inductor ripple current $\Delta I_L = 0.2 \times I_{out} = 0.864$

→ Astable Multivibrator using IC555

Desired Frequency = 500 KHz

$$\text{Duty Cycle} = 0.208 = \frac{T_{ON}}{T_{ON} + T_{OFF}}$$

Diodes are added :

$T_{ON} = 0.693 R_1 . C$

$T_{OFF} = 0.693 R_2 . C$

$$D = \frac{R_1}{R_1 + R_2} \Rightarrow 0.208 = \frac{R_1}{R_1 + 10K}$$

$\therefore R_1 = 2.63 K\Omega \approx 2.7 K\Omega$

$$L = \frac{(V_{in} - V_{out}) \times D}{\Delta I_L \times 500k}$$

$$= \frac{(24-5) \times (0.208)}{0.864 \times 500k}$$

$$= 9.15\,\mu H$$

$$C = \frac{\Delta I_L}{8 f_s \Delta V_o}$$

Assume output ripple current $= \pm 0.01V$

$\therefore \Delta V_o = 0.02V$

$$C = \frac{0.864}{8 \times 500 \times 0.02}$$

$$= 10.8\,\mu F$$

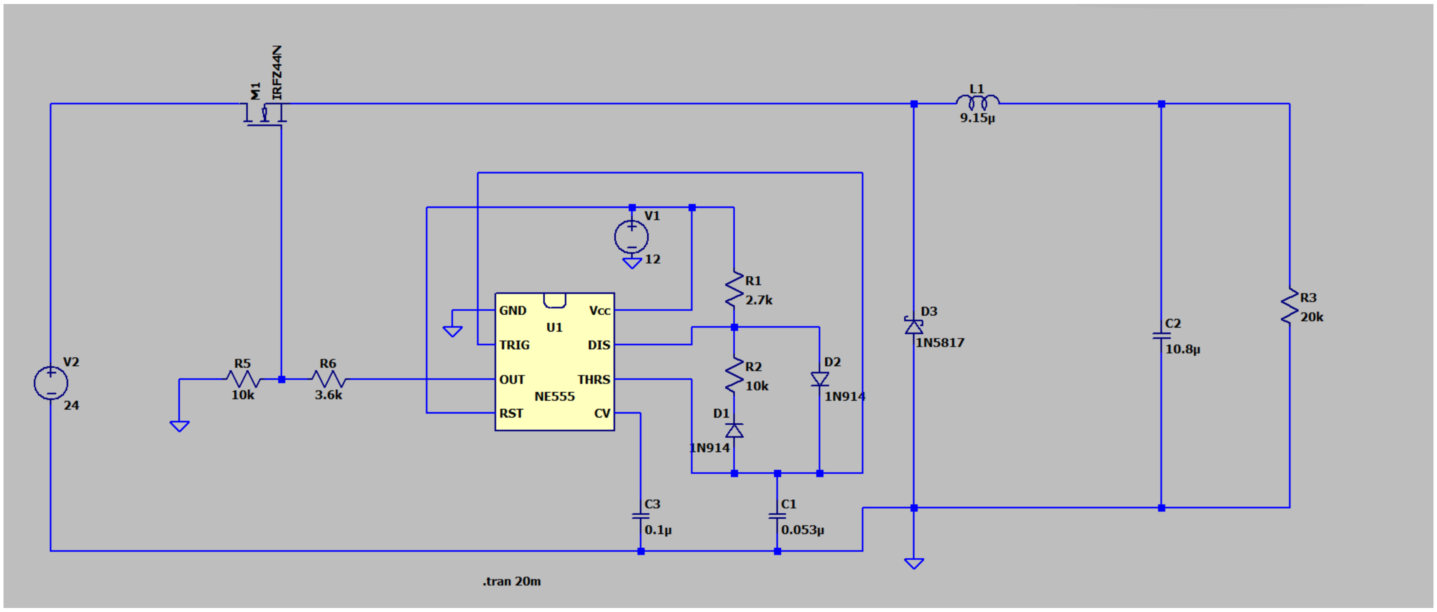
Efficiency Considerations:

Efficiency is influenced by losses in the MOSFET (switching and conduction losses), inductor (core and copper losses), and other passive components.

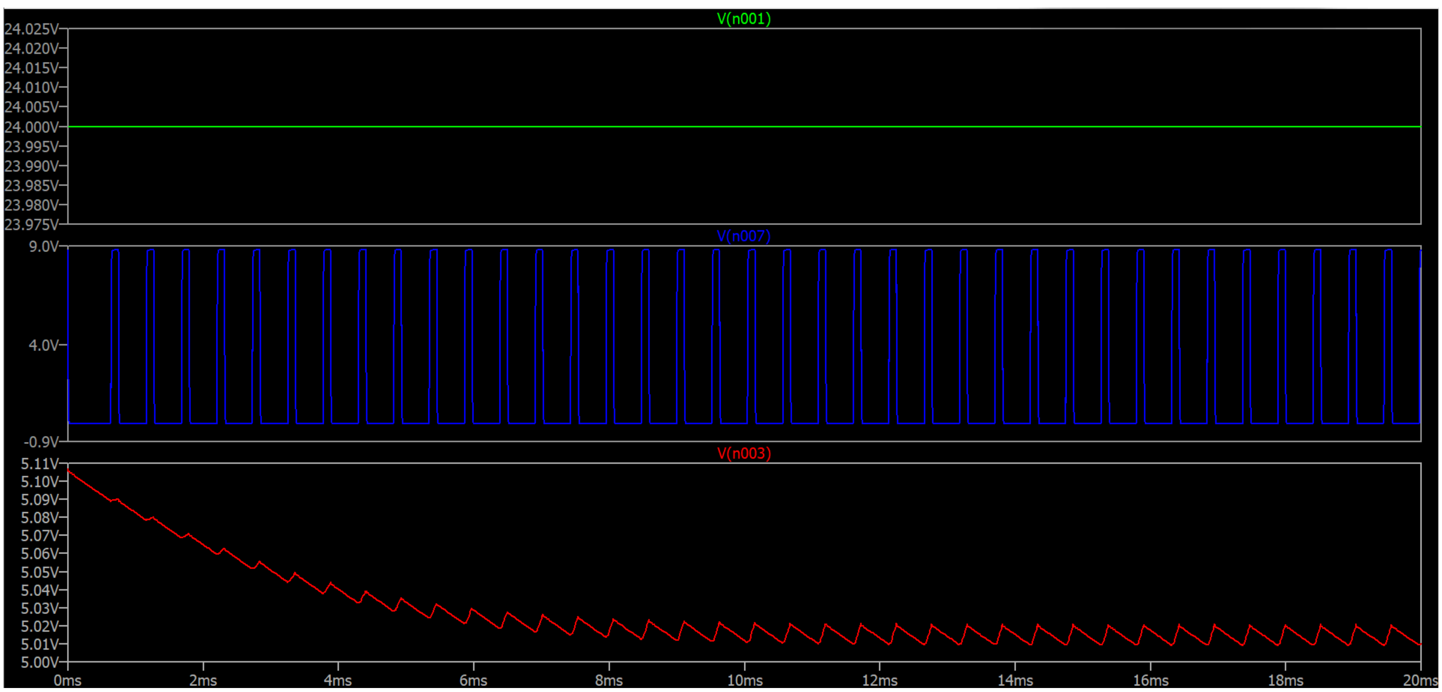
4. Simulation and Testing

Simulation is performed to verify the calculated values, ensuring that the converter outputs 5V with efficiency of 90%. The simulation includes analysis of:

- Input DC Voltage.
- PWM signal generated by NE555 of duty cycle 20.8%.
- Output DC Voltage (Ripple 0.02V).



Output:



The green coloured graph indicates 24V input DC voltage.

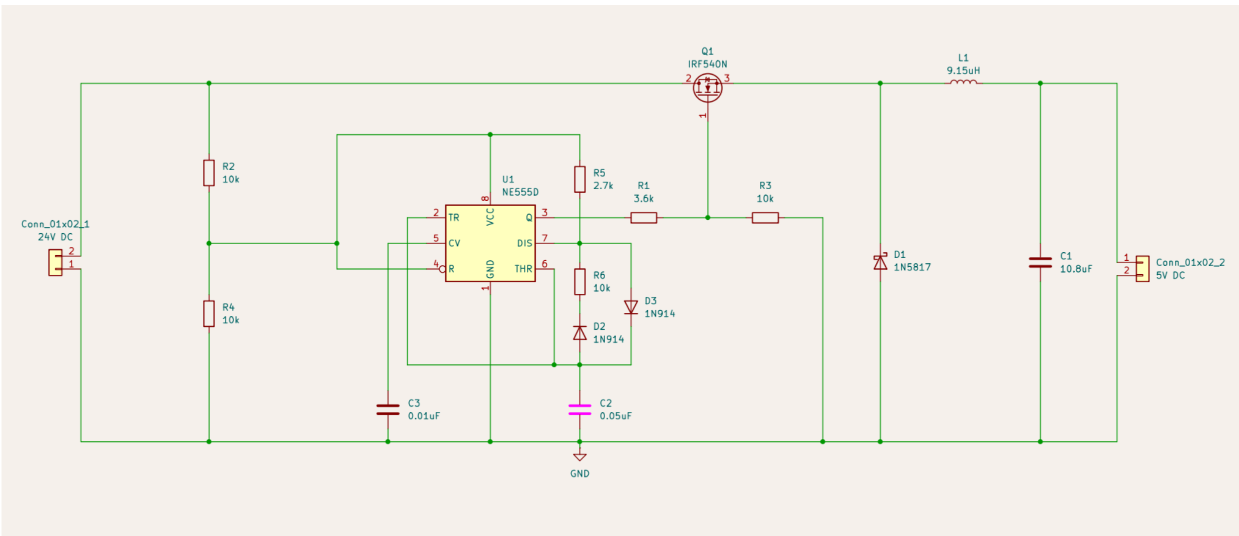
The blue coloured graph indicates pulse width modulation by NE555.

The red coloured graph indicates 5V output DC voltage.

5. Schematic Design in KiCad

The schematic design will include:

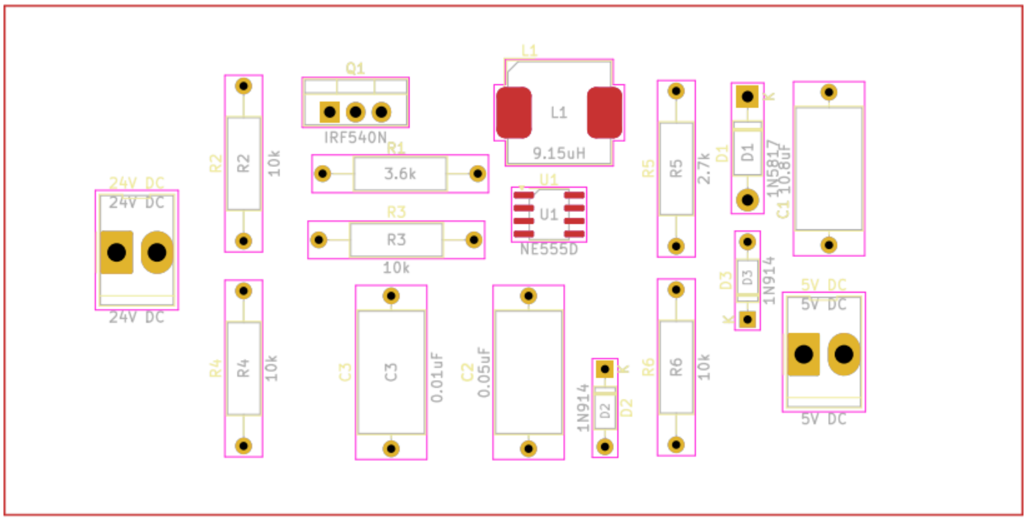
- A PWM signal generator (555 timer) for MOSFET switching.
- MOSFET and diode for switching.
- Inductor and output capacitor for energy storage and voltage smoothing.

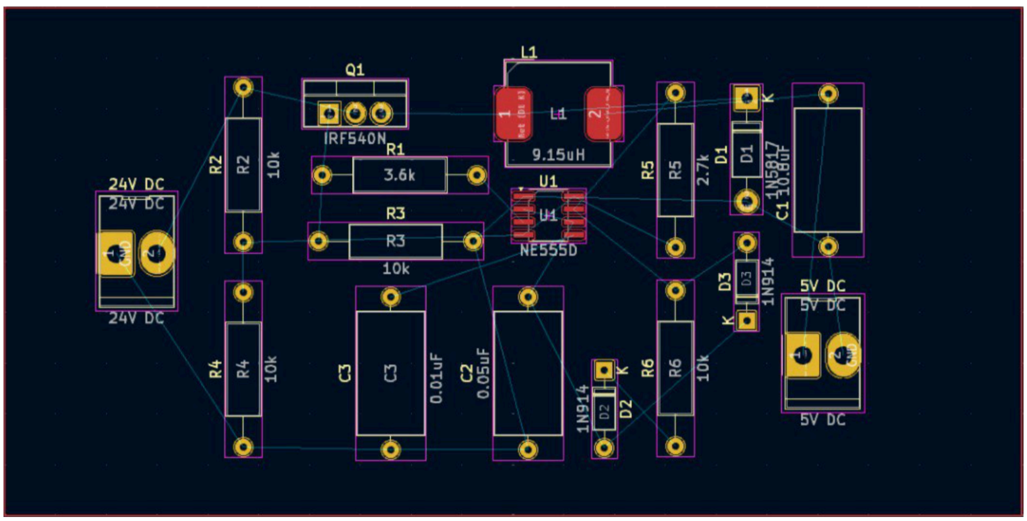


6. PCB Design

The dual-layer PCB design will ensure:

- Proper thermal management for power components.
- Minimized switching noise and EMI.
- Correct trace widths for current handling.


Q1
IRF540N
L1
9.15uH
R1
3.6k
R2
10k
R3
10k
U1
NE555D
R4
10k
C3
0.01uF
C2
0.05uF
1N914
D2
K
R5
2.7k
R6
10k
D1
1N5817
C1 10.0uF
D3
1N914
24V DC
5V DC


Q1
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D2
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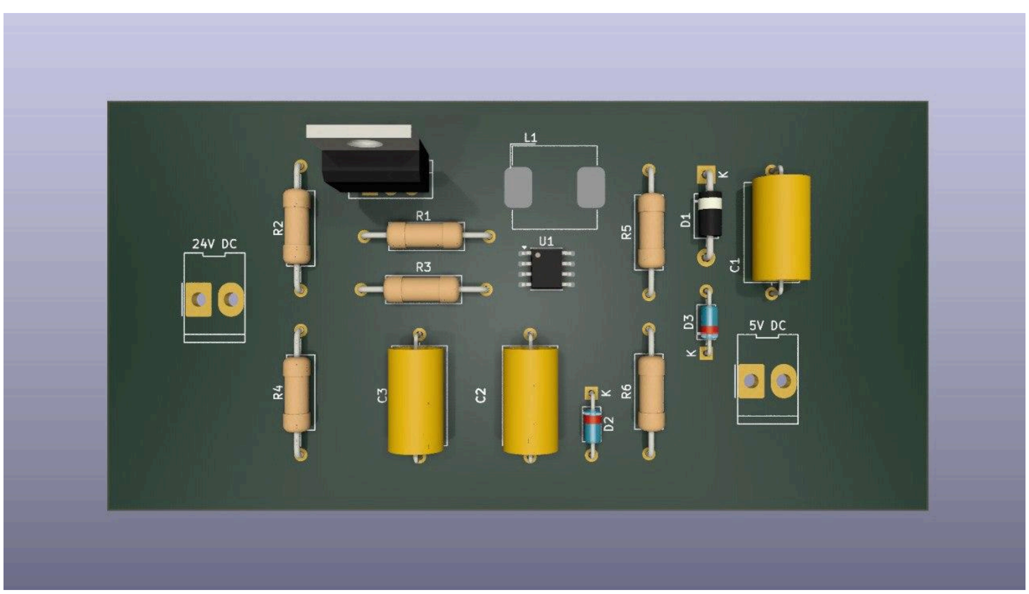
R6
10k
D1
1N5817
C1 10.0uF
D3
1N914
24V DC
5V DC


L1
R1
R2
R3
U1
24V DC
R4
C3
C2
D2
K
R5
R6
D1
C1
D3
5V DC

7. Conclusion

The buck converter was designed to step down 24V to 5V with at least 90% efficiency. The calculated and simulated results verify the functionality of the converter. The design meets the dimensional requirements, and all components are appropriately rated to ensure reliability and efficiency.

GitHub Link: GargeyaOHKO/En-Core-1.0

YouTube Video Link: https://youtu.be/STvGI6kvZm8