Buck Converter Design Report

1. Introduction

This report outlines the design of a custom buck converter that steps down 24V input to a 5V output, with a switching frequency of 100 kHz. Efficiency is targeted at 90%, but for simplicity in calculations, we will not include efficiency when calculating the duty cycle. The design avoids using ready-made ICs like the LM2596.

- Input voltage (Vin): 24V ± 2% (i.e., 23.52V to 24.48V)
- Input Power(Pin):24W
- Maximum input current (Iin): 1A
- Efficiency (η): At least 90%
- Output voltage (Vout): 5V
- Target output current (Iout): To be calculated based on power requirements
- Switching Frequency (fs): 100 kHz

Step 1: Understanding Efficiency

We want the output power to be at least 90% of the input power.

$\eta = P_{out}/P_{in} \times 100$

For 90% efficiency:

$P_{out} = \eta \times P_{in} = 0.9 \times 24 = 21.6\ W$

The output power (Pout) is related to the output voltage (Vout) and output current (Iout) by:

$$Pout=Vout\times Iou$$

Thus, the output current can be calculated as:

$$Iout=Pout/Vout=21.6/5=4.32\ A$$

So, the maximum output current is 4.32A.

Step 2: Calculate Duty Cycle

The duty cycle (D) of the buck converter is determined by the ratio of the output voltage to the input voltage.

For the nominal input voltage of 24V:

$$D=Vout/Vin=5/24\approx 0.2083\ (20.83\%\ \text{duty cycle})$$

For the input voltage variation (±2%):

- Maximum input voltage: 24.48V
  $Dmin=5/24.48\approx 0.2043$ (20.43% duty cycle)
- Minimum input voltage: 23.52V
  $Dmax=523.52\approx 0.2126$ (21.26% duty cycle)

Thus, the duty cycle will range from 20.43% to 21.26% depending on the input voltage tolerance.

Step 3: Inductor Selection

The inductor value is determined by the desired inductor ripple current. Typically, the ripple current (ΔIL) is chosen as 20-40% of the output current.

Let's assume the ripple current is 30% of the output current:

$$\Delta IL=0.3\times Iout=0.3\times 4.32=1.296\ A$$

The inductor value L is given by the formula:

$L = (Vin - Vout) \cdot D / fs \cdot \Delta IL$

Let's assume a switching frequency (fs) of 100 kHz.

For the nominal input voltage of 24V: 3.952

$L = (24 - 5) \times 0.2083 / 100 \times 10^3 \times 1.296 \approx 0.0309\,H = 30.9\,\mu H$

Thus, the inductor value should be 30.9 μH to maintain continuous conduction mode with the desired ripple current.

Step 4: Capacitor Selection

The output capacitor is selected to smooth the output voltage ripple. The value of the capacitor is determined by the ripple current and the allowable voltage ripple (ΔVout\Delta V_{out}ΔVout).

Assume a 1% ripple in the output voltage:

$\Delta Vout = 0.01 \times 5 = 0.01$

The capacitor value is given by:

$C = \Delta IL / 8 \cdot fs \cdot \Delta Vout$

Substituting values:

$C = 1.296 / 8 \times 100 \times 10^3 \times 0.48 = 3.24\,\mu F$

Thus, the output capacitor should be at least 3.24 μF. In practice, higher capacitance is used for better filtering, so a 10 μF or higher capacitor is typical.

Step 5: Diode Selection

The diode should be able to handle the maximum output current and voltage.

- Reverse voltage rating: The diode should withstand the input voltage of 24V, so select a diode with a reverse voltage rating of at least 30V.

- Forward current rating: The diode should handle the maximum output current of 4.32A, so select a diode with a forward current rating of at least 5A.

A Schottky diode is preferred due to its low forward voltage drop, which improves efficiency.

Step 6: MOSFET Selection

The MOSFET should handle the input voltage and the peak current through the inductor.

- Drain-source voltage rating (VDS): The MOSFET should withstand the input voltage, so a MOSFET with a rating of at least 30V is required.
- Current rating: The MOSFET should handle the peak inductor current. The peak current is the sum of the output current and half the ripple current: $I_{peak}=I_{out}+\Delta I_L/2=4.32+1.296/2=4.968$ A.

  So, the MOSFET should have a current rating of at least 6A.

Summary of Design Specifications

- Input Voltage (Vin): 24V ± 2%
- Output Voltage (Vout): 5V
- Duty Cycle (D): 20.43% to 21.26%
- Inductor: 30.9 µH
- Output Capacitor: 10 µF or higher
- Diode: Schottky diode with reverse voltage ≥ 30V, forward current ≥ 5A
- MOSFET: Vds ≥ 30V, Id ≥ 6A
- Switching Frequency (fs): 100 kHz

4. Schematic Diagram

Connections:

1. **Input Stage (24V):**
   - Connect the input capacitor (22 μF) between the input voltage and ground.
   - The Drain of the high-side MOSFET is connected to the 24V input.
2. **PWM Generation:**
   - Use the 555 Timer to generate the PWM signal and connect it to the Gate of the high-side MOSFET.
3. **Inductor:**
   - The Source of the high-side MOSFET connects to one side of the inductor (200 μH), which in turn is connected to the output**.**
4. **MOSFET:**
   - Connect the MOSFET to ground. The gate is driven by the inverted PWM signal.
5. **Schottky Diode**:
   - The Schottky Diode (SS34) connects from the inductor to ground to provide a path for the freewheeling current.

6. Output Stage (5V):

The other side of the inductor is connected to the Output Capacitor (220 μF), which smooths the output ripple to provide a stable 5V output.

5. Efficiency Estimation

While the design calculations for the duty cycle were made without considering efficiency, the converter's real-world efficiency will depend on the losses in the

MOSFETs, diode, and inductor. Careful selection of low Rds(on) MOSFETs and a high-efficiency Schottky diode helps meet the efficiency target of 90%.

- MOSFET Losses: Minimized by using the IRLZ44N with low Rds(on).
- Switching Losses: The chosen switching frequency of 100 kHz balances efficiency and size of passive components.
- Diode Losses: Minimized by using a Schottky diode with low forward voltage drop.

6. Conclusion

This custom buck converter design successfully steps down a 24V input to a stable 5V output at a switching frequency of 100 kHz. The design avoids ready-made ICs like the LM2596, focusing instead on discrete components such as MOSFETs, inductors, and capacitors. The estimated efficiency is 90%, and all component values were calculated to meet the required specifications.

KI-CAD

1. Set Up a New Project

1. Open KiCad and click on New Project.
2. Choose a location and name for your project.
3. KiCad will create two files: a .pro (project) file and a .sch (schematic) file.

3. Drawing the Schematic

In Eeschema, the schematic editor in KiCad, follow these steps to build the buck converter:

a. Adding Components

1. **555 Timer (or PWM Generator):** If you can't find a 555 timer, you can use a square wave voltage source in place of the 555 timer to generate the PWM signal.
2. **MOSFETs (IRLZ44N):**
   - Click Place > Add Component or press the A key.
   - Search for and place two N-channel MOSFETs (IRLZ44N).
3. **Inductor (200 µH):**
   - Press A and search for an inductor.
4. **Capacitors:**
   - Use 22 µF for the input capacitor and 220 µF for the output capacitor. Search for and place them accordingly.
5. **Schottky Diode (SS34):**
   - Search for a Schottky diode and place it.
6. **Voltage Source (24V):**
   - **P**lace a DC voltage source for the input**.**

b. Wiring the Circuit

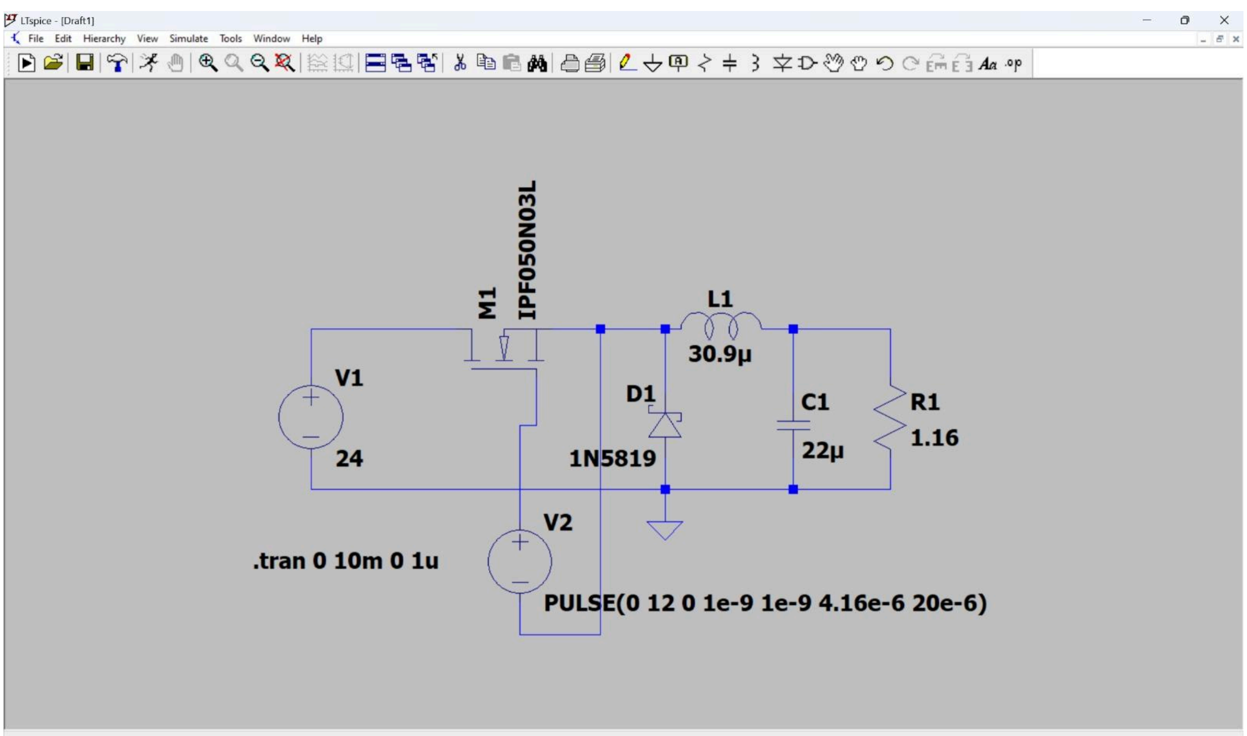
1. Connect the 24V power source to the input capacitor (22 µF) and the drain of the high-side MOSFET.
2. PWM signal from the 555 timer (or square wave generator) goes to the gate of the high-side MOSFET.
3. Source of the MOSFET connects to one end of the inductor (200 µH).
4. Other end of the inductor connects to the output capacitor (220 µF) and the Schottky diode.
5. Schottky diode connects to ground, allowing freewheeling current.
6. Low-side MOSFET:
   - Connect the drain of the low-side MOSFET to the source of the high-side MOSFET.
   - The source of the low-side MOSFET goes to ground.

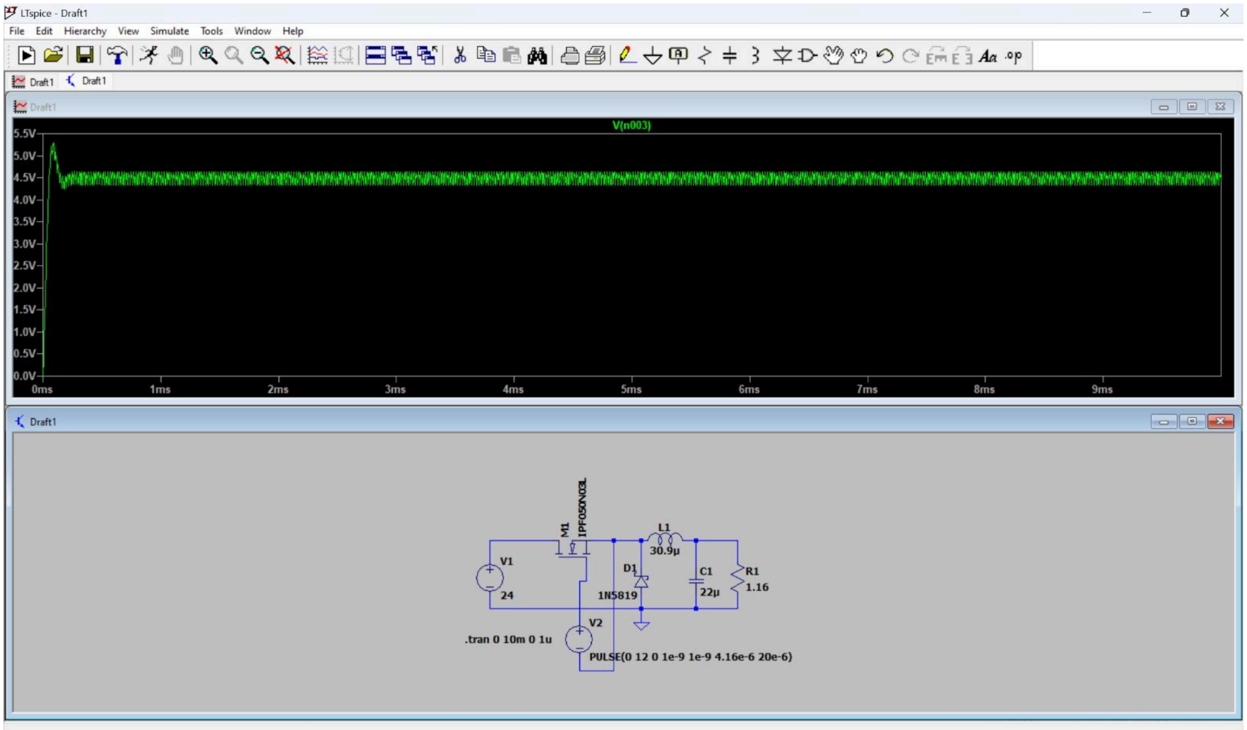
c. Place Probes

1. Add voltage probes at the input, output, and across the inductor to monitor the voltage and current during the simulation.

3. Running the Simulation

1. Go to Simulator settings (from the Tools menu).
2. Set up a Transient Analysis for a suitable duration (e.g., 1ms to 5ms).
3. Define the PWM signal frequency (100 kHz) and duty cycle (20.8%) for the 555 Timer or square wave generator.
4. Run the simulation and observe the output voltage and current waveforms.





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L1
30.9µ
V1
24
D1
1N5819
C1
22µ
R1
1.16
V2
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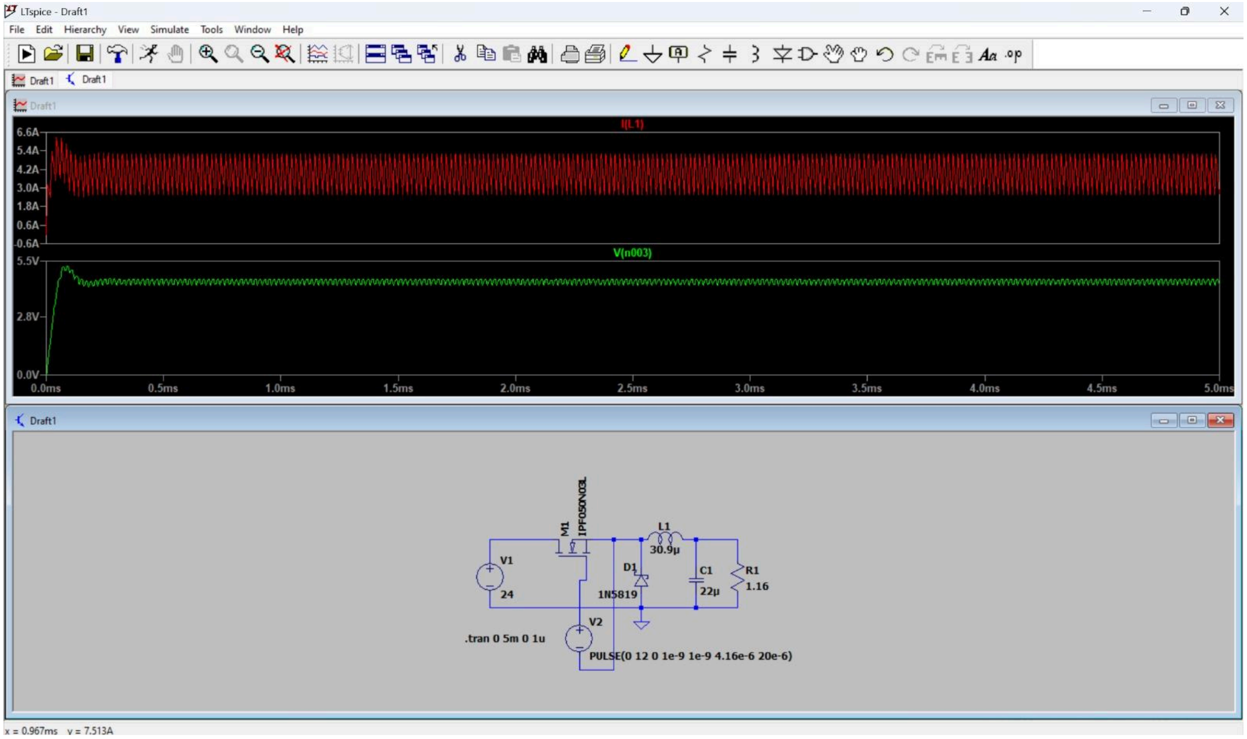
PULSE(0 12 0 1e-9 1e-9 4.16e-6 20e-6)


LTspice - Draft1
File Edit Hierarchy View Simulate Tools Window Help
Draft1
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5.4A
4.2A
3.0A
1.8A
0.6A
-0.6A
V(n003)
5.5V
2.8V
0.0V
0.0ms
0.5ms
1.0ms
1.5ms
2.0ms
2.5ms
3.0ms
3.5ms
4.0ms
4.5ms
5.0ms
M1
1PF050N03L
L1
30.9µ
V1
24
D1
1N5819
C1
22µ
R1
1.16
V2
.tran 0 5m 0 1u
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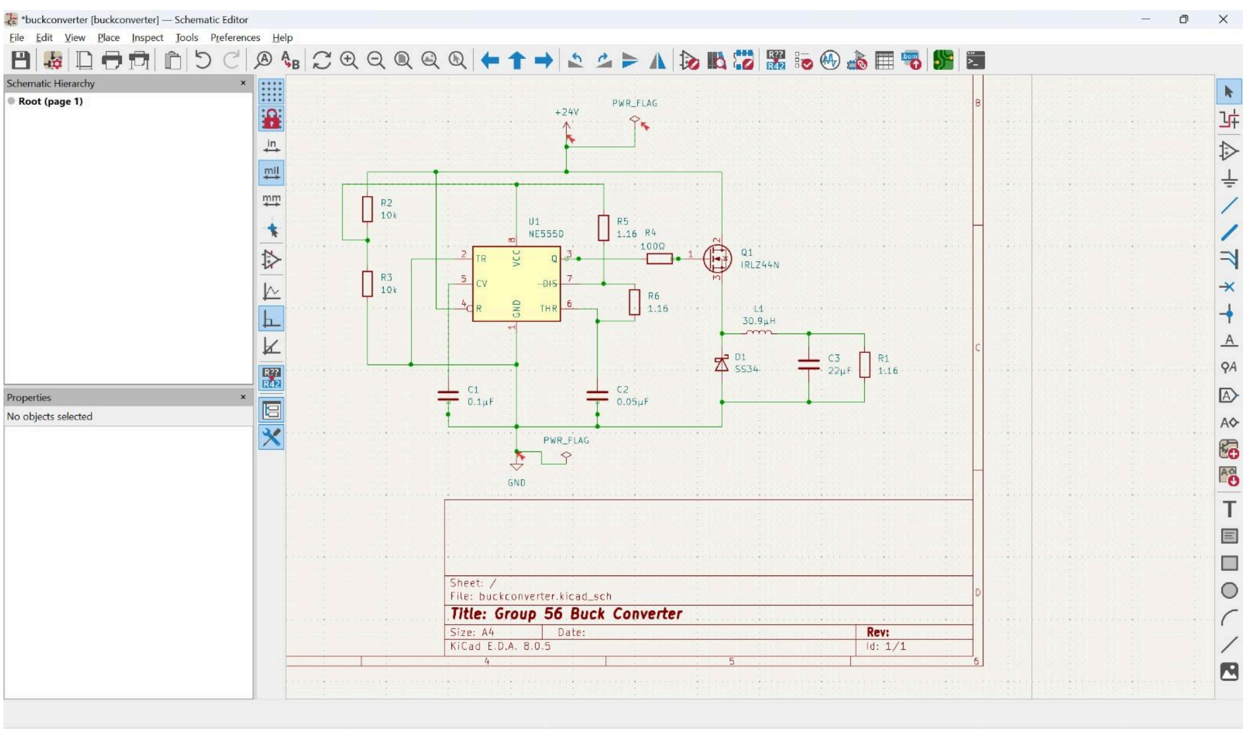
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File Edit View Place Inspect Tools Preferences Help
Schematic Hierarchy
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Properties
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+24V
PWR_FLAG
R2
10k
R3
10k
U1
NE555D
R5
1.16
R4
100Ω
Q1
IRLZ44N
R6
1.16
L1
30.9µH
D1
SS34
C3
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R1
1.16
C1
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C2
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Rev:
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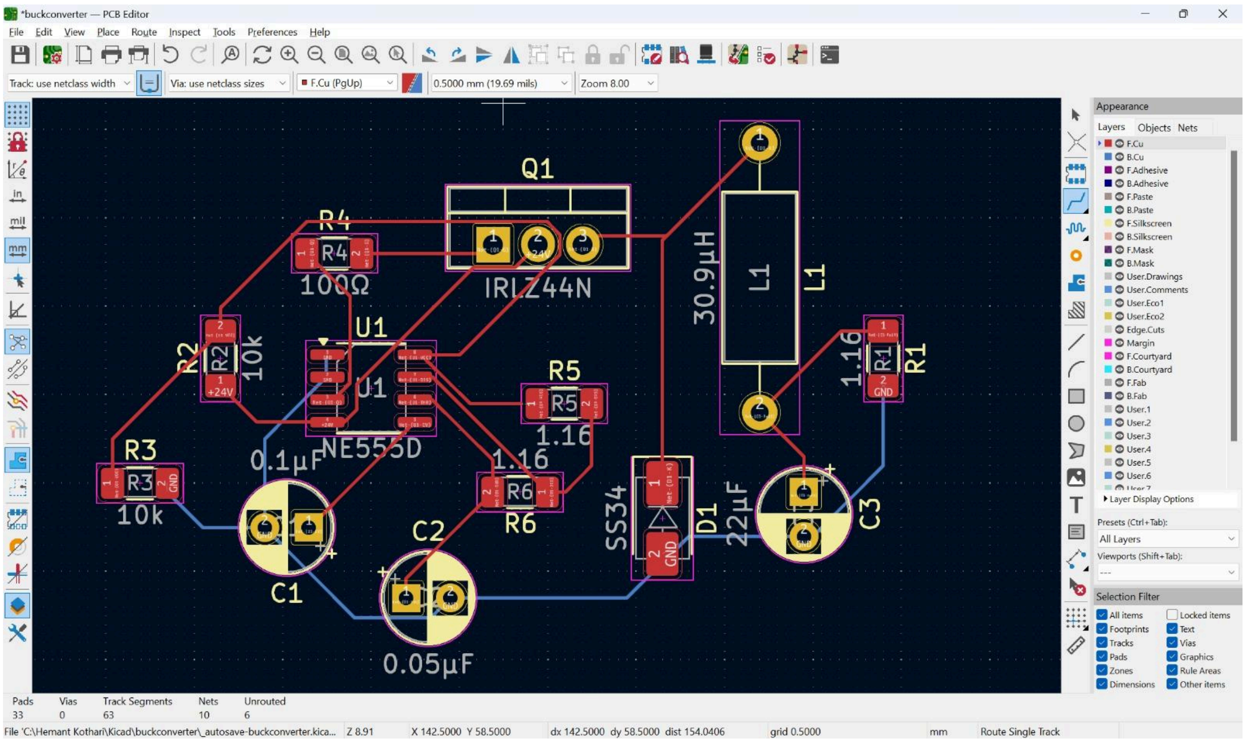
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File Edit View Place Route Inspect Tools Preferences Help
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Via: use netclass sizes
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Zoom 8.00
Q1
IRLZ44N
R4
100Ω
R2
10k
U1
NE555D
R5
1.16
R3
10k
0.1µF
C1
1.16
R6
C2
0.05µF
SS34
D1
22µF
C3
30.9µH
L1
R1
GND
+24V
Appearance
Layers Objects Nets
F.Cu
B.Cu
F.Adhesive
B.Adhesive
F.Paste
B.Paste
F.Silkscreen
B.Silkscreen
F.Mask
B.Mask
User.Drawings
User.Comments
User.Eco1
User.Eco2
Edge.Cuts
Margin
F.Courtyard
B.Courtyard
F.Fab
B.Fab
User.1
User.2
User.3
User.4
User.5
User.6
Layer Display Options
Presets (Ctrl+Tab):
All Layers
Viewports (Shift+Tab):
Selection Filter
All items
Locked items
Footprints
Text
Tracks
Vias
Pads
Graphics
Zones
Rule Areas
Dimensions
Other items
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Vias 0
Track Segments 63
Nets 10
Unrouted 6
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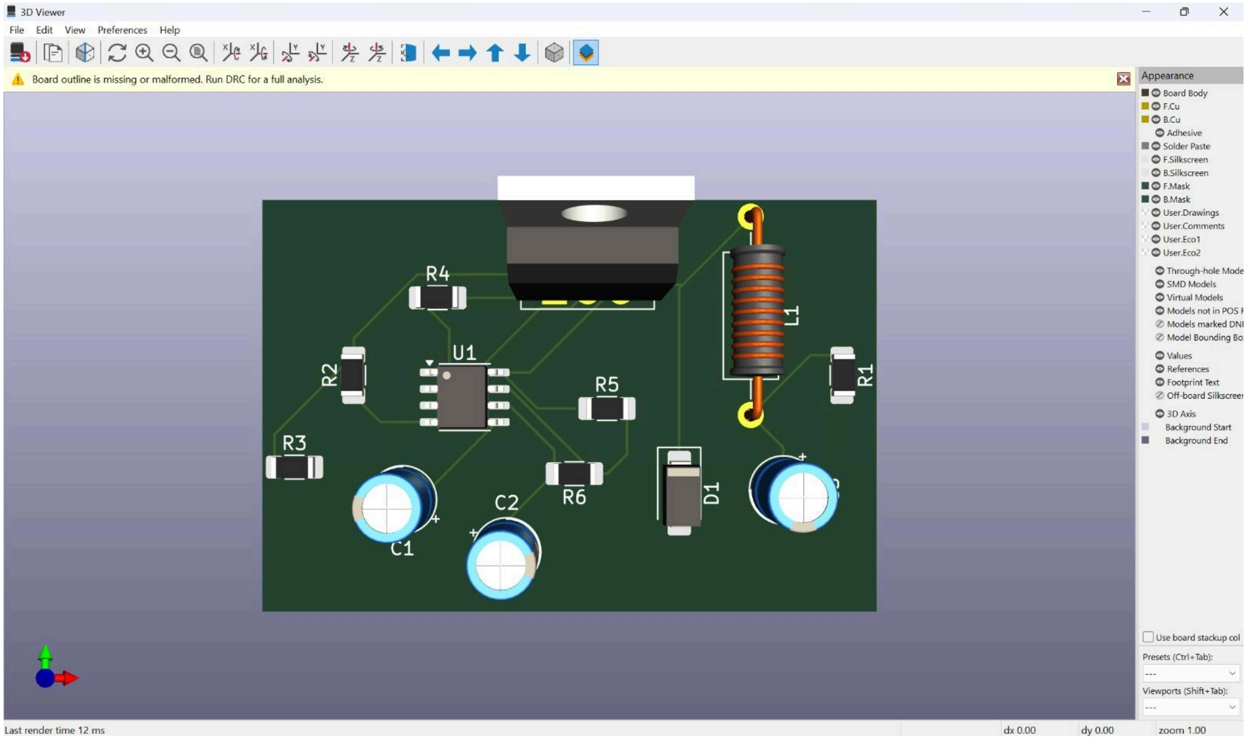
3D Viewer
File
Edit
View
Preferences
Help
Board outline is missing or malformed. Run DRC for a full analysis.
Appearance
Board Body
F.Cu
B.Cu
Adhesive
Solder Paste
F.Silkscreen
B.Silkscreen
F.Mask
B.Mask
User.Drawings
User.Comments
User.Eco1
User.Eco2
SMD Models
Virtual Models
Values
References
Footprint Text
3D Axis
Background Start
Background End
R4
U1
R2
R5
R1
L1
R3
R6
C2
C1
D1
Presets (Ctrl+Tab):
Viewports (Shift+Tab):
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