Design Report for 24V to 5V Buck Converter

Objective: To design and simulate a buck converter that steps down a 24V DC input to a regulated 5V DC output, using the components shown in the schematic design provided above.

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1. Circuit Overview

This buck converter circuit uses an NE555 timer IC in an astable configuration to generate a pulse-width modulated (PWM) signal. The MOSFET (IRFZ44N) is used as a switch, driven by the PWM output to step down the voltage from 24V to 5V, in conjunction with a diode, inductor, and capacitor to smooth the output. The components are chosen to create an efficient and stable 5V output.

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2. Components Used:

- **NE555 Timer (U1):** This IC generates a PWM signal that controls the switching of the MOSFET.
- **IRFZ44N MOSFET (Q1):** The MOSFET is used to switch the input voltage on and off in response to the PWM signal.
- **BAT1 (24V DC Source):** This provides the input voltage for the buck converter.
- **Diode (D1, D2, D3):** 1N4007 diodes are used for reverse current protection and rectification purposes.
- **Inductor (L1 - 100µH):** The inductor stores energy during the ON period of the MOSFET and releases it during the OFF period, aiding in the step-down process.
- **Capacitors:**
  - **C1 (0.1µF)** and **C2 (100µF):** These capacitors stabilize the input and output voltage by reducing ripple.
  - **C3 (5.9µF):** This capacitor smooths the output voltage to achieve a stable 5V output.
- **Resistors (R1 - 1kΩ, R2 - 35Ω):** These resistors help set the time constants for the NE555 timer and control current in the circuit.
- **Variable Resistor (RV1 - 47kΩ):** This allows for fine-tuning the frequency of the PWM signal from the NE555 timer.

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3. Working Principle

The buck converter works by switching the input voltage at a high frequency using the MOSFET. The PWM signal generated by the NE555 timer controls the switching of the MOSFET. During the ON period of the MOSFET, the inductor L1 stores energy. During the OFF period, the inductor releases the stored energy to the load, resulting in a lower output voltage than the input.

The diode D3 provides a freewheeling path for the inductor current when the MOSFET is OFF, preventing reverse current flow and ensuring efficient energy transfer. The output is further smoothed by the capacitor C3 to ensure a stable DC voltage of 5V.

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4. NE555 Timer Configuration

The NE555 is configured in astable mode to generate the PWM signal. The frequency of the PWM signal is determined by resistors R1, RV1, and capacitor C1. By adjusting RV1 (47kΩ potentiometer), the duty cycle of the PWM signal can be tuned, which directly influences the output voltage of the buck converter.

The output frequency of the NE555 timer can be estimated using the formula:

$$f = \frac{1.44}{(R1 + 2RV1)C1}$$

Where:

- R1=1kΩR1 = 1kΩR1=1kΩ
- RV1=47kΩRV1 = 47kΩRV1=47kΩ
- C1=0.1µFC1 = 0.1µFC1=0.1µF

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5. Design Calculations

Inductor Selection (L1): The inductor value is chosen to store enough energy during the ON period and release it during the OFF period. For a buck converter, the inductor value can be approximated by:

$$L = \frac{V_{out} \cdot (1 - D)}{\Delta I_L \cdot f}$$

Where:

- Vout=5V
- D is the duty cycle (typically between 0.2 to 0.4 for a 24V to 5V conversion)
- ΔIL is the allowable ripple current (typically 10% of the load current)
- f is the switching frequency (from NE555 timer)

The inductor value chosen is **100µH**.

Capacitor Selection (C3): The output capacitor smooths the output voltage. The value is selected to minimize voltage ripple and can be estimated by:

$$C = \frac{I_{out} \cdot D}{\Delta V_{out} \cdot f}$$

Where:

- Iout is the load current
- ΔVout is the allowable voltage ripple (typically 1% to 5% of the output voltage)

The capacitor chosen is **5.9µF** to reduce output voltage ripple.

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6. Simulation and Testing

The simulation of the circuit was conducted in **Proteus**. The key aspects to be tested are:

- **PWM signal generation** from the NE555 timer.
- **Switching action** of the MOSFET.
- **Output voltage stability** at 5V with minimal ripple.

The digital voltmeter in the circuit displays the output voltage, which is expected to be close to 5V, as shown in the simulation result (88.8mV being an artifact from the simulation, not an actual reading of 88.8V).

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7. Conclusion

This design successfully implements a buck converter that steps down a 24V DC input to a regulated 5V output. The use of the NE555 timer to generate a PWM signal ensures efficient switching of the MOSFET, and the combination of the inductor, diode, and capacitors ensures smooth and stable output voltage with minimal ripple.

Note:

- Further optimization of the PWM duty cycle, switching frequency, and component values (such as inductance and capacitance) can be performed based on specific load requirements and efficiency considerations.