Draft Schematic: Power Distribution PCB

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1 Introduction

This document proposes a Power Distribution System PCB for our manipulator end effector that houses a DC motor, gearbox, and an LED ring light. The system is designed to operate on mains power and will include voltage regulation, connectors, and safety switches.

2 System Overview

2.1 Power Source

The system will be powered by a standard AC mains supply (120V AC). A standard AC-to-DC adapter will be used to convert the mains voltage to a lower DC voltage. This adapter will provide a stable intermediate 12V DC voltage that will then be stepped down to 3.7V DC using the converter on the PCB.

2.2 Subsystems to be Powered

The following subsystems will be powered:

1. **DC Motor:**
   - Voltage Range: 3.7V DC.
   - Continuous Current Draw: 2.4A.
   - Peak Current Draw: 4.7A (during high torque or stall conditions).
   - Regulation: Required to maintain a stable 3.7V output.
2. **LED Ring Light:**
   - Voltage Range: 3.7V DC.
   - Current Draw: 0.3A
   - Regulation: Not required since connected in parallel with the motor.

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We used the Texas Instruments [] calculator with the following inputs

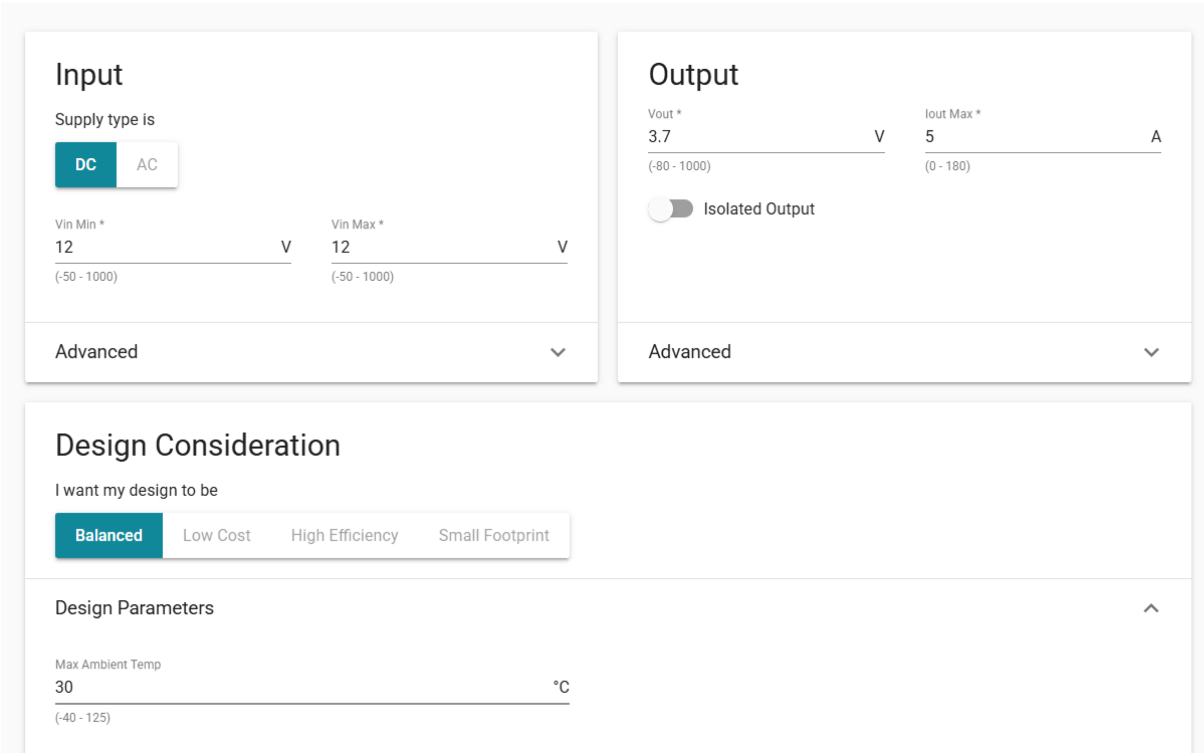

Figure 1: Enter Caption

To get the basic idea and variations of circuit. Since we found it easiest to integrate the LM2678-ADJ voltage regulator, we decided to go with that for our proejct

4 Analysis

1. Voltage Regulator LM2678-ADJ:
    - Input Voltage Range: 8V to 40V.
    - Output Current: Up to 5A.
    - Efficiency: Up to 85-92% under optimal conditions
    - Meets the requirement for handling up to 5A for motor operation.
    - Adjustable output allows flexibility for tuning motor speed by setting V_{out} via R_f1 and R_f2 .
    - High efficiency minimizes power loss, critical for high-current applications.
2. Inductor (L1) 10 μH
    - Chosen to handle peak currents without saturation while maintaining low DC resistance.
    - Value decided as per below calcualtion

3. Schottky Diode (D1) : 5A Rating
   - A low forward voltage drop diode is critical for high efficiency.
   - The current rating exceeds the peak inductor current.
4. Input Capacitors (Cin: 82μF, Cnx: 100 nF):
   - Filters input ripple; must handle RMS current equal to half the load current.
   - Values decided as per TI calculator
5. Output Capacitor (Cout: 330 μF):
   - Smooths output voltage; ESR should be low to minimize ripple.
   - Values decided as per TI calculator
6. Boost Capacitor (Cb: 10 nF):
   - Enhances the performance of the internal switch driver
   - Values decided as per TI calculator and datasheet
7. Schottky Diode (D2) : 5A Rating
   - To prevent reverse polarity from Vin
8. Fuse : 5A Rating
   - To prevent overcurrent from source

4.1 L1 Calculation

$$L = \frac{(V_{\text{in}} - V_{\text{out}}) \cdot D}{\Delta I_L \cdot f_s}$$

Where:

$$V_{\text{in}} = 12\,\text{V} \quad \text{(Input Voltage)}$$

$$V_{\text{out}} = 3.7\,\text{V} \quad \text{(Output Voltage)}$$

$$D = \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{3.7}{12} = 0.31 \quad \text{(Duty Cycle)}$$

$$\Delta I_L = 0.2 \cdot I_{\text{load}} = 0.2 \cdot 5 = 1\,\text{A} \quad \text{(Ripple Current)}$$

$$f_s = 260\,\text{kHz} = 260 \times 10^3\,\text{Hz} \quad \text{(Switching Frequency, from LM2678 datasheet)}$$

Substituting:

$$L = \frac{(12 - 3.7) \cdot 0.31}{1 \cdot 260 \times 10^3} \approx 10\,\mu\text{H}$$

4.2 R Calculation

$$V_{\text{out}} = V_{\text{ref}} \cdot \left(1 + \frac{R_{f2}}{R_{f1}}\right)$$

Where:

$$\begin{aligned}
V_{\text{out}} &= 3.7\,\text{V} \quad \text{(Output Voltage)} \\
V_{\text{ref}} &= 1.21\,\text{V} \quad \text{(Reference Voltage of LM2678)} \\
R_{f1} &= 1\,\text{k}\Omega
\end{aligned}$$

Rearranging for R_{f2}:

$$R_{f2} = R_{f1} \cdot \left(\frac{V_{\text{out}}}{V_{\text{ref}}} - 1\right) = 10\,\text{k}\Omega \cdot \left(\frac{3.7}{1.21} - 1\right) = 2.05\,\text{k}\Omega$$

5 Heat Dissipation

The total heat dissipation in the circuit is the sum of the power losses in the LM2678 regulator, the Schottky diode (D_1), and the inductor (L_1):

$$P_{\text{total}} = P_{\text{LM2678}} + P_{D_1} + P_{L_1}$$

5.1 Heat Dissipation in the LM2678 Regulator

The power dissipated in the LM2678 is due to conduction and switching losses:

$$P_{\text{LM2678}} = P_{\text{cond}} + P_{\text{switch}}$$

(a) Conduction Losses:

$$P_{\text{cond}} = I_{\text{load}}^2 \cdot R_{\text{DS(on)}}$$

Where:

$$\begin{aligned}
I_{\text{load}} &= 5\,\text{A} \quad \text{(output current)} \\
R_{\text{DS(on)}} &= 0.15\,\Omega \quad \text{(from LM2678 datasheet)}
\end{aligned}$$

Substituting:

$$P_{\text{cond}} = (5)^2 \cdot 0.15 = 3.75\,\text{W}$$

(b) Switching Losses:

$$P_{\text{switch}} = \frac{1}{2} \cdot V_{\text{in}} \cdot I_{\text{load}} \cdot t_s \cdot f_s$$

Where:

$$\begin{aligned}
V_{\text{in}} &= 12\,\text{V} \quad \text{(input voltage)} \\
t_s &= 50\,\text{ns} \quad \text{(switching time, estimated from datasheet)} \\
f_s &= 260\,\text{kHz} = 260 \times 10^3\,\text{Hz} \quad \text{(switching frequency)}
\end{aligned}$$

Substituting:

$$P_{\text{switch}} = \frac{1}{2} \cdot 12 \cdot 5 \cdot 50 \times 10^{-9} \cdot 260 \times 10^3 = 0.39\,\text{W}$$

Thus, total power dissipated by the LM2678:

$$P_{\text{LM2678}} = P_{\text{cond}} + P_{\text{switch}} = 3.75 + 0.39 = 4.14\,\text{W}$$

5.2 Heat Dissipation in Schottky Diode (D_1)

The power dissipated in D_1 is due to its forward voltage drop:

$$P_{D_1} = I_D \cdot V_f$$

Where:

$$I_D = I_{\text{load}} = 5\,\text{A} \quad \text{(current through diode)}$$
$$V_f = 0.5\,\text{V} \quad \text{(forward voltage drop of typical Schottky diode)}$$

Substituting:

$$P_{D_1} = 5 \cdot 0.5 = 2.5\,\text{W}$$

5.3 Heat Dissipation in Inductor (L_1)

The power dissipated in L_1 is due to its DC resistance (R_L):

$$P_{L_1} = I_{\text{load}}^2 \cdot R_L$$

Where:

$$R_L = 0.05\,\Omega \quad \text{(typical DC resistance for a low-DCR inductor)}$$

$$I_{\text{load}} = 5\,A$$

Substituting:

$$P_L = (5)^2 \cdot 0.05 = 1.25\,W$$

5.4 Thermal Management

Although the heat produced here is minimal, the maximum current conditions could be high. For safety reasons, the overall container housing this PCB will be made to maintain good air flow, and a simple heatsink will be added on top of the LM2678.