Interim Design Report

Micromouse X Subsystem

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Chapter 1

Introduction

1.1 Problem Description

The context of the project is to design and manufacture a micro-mouse, a simplified version of a maze-solving robot. This part of the project is focusing on the hardware design of micro-robots, with a specific emphasis on the power module. The greater project involves the comprehensive design and assembly of a micro-mouse robot, which includes four main modules: the processor,motherboard, sensing, and power. The processor and motherboard are pre-designed and provided, focusing the project's scope on the sensor and power modules.

The focus of the report within this greater project is to design and manufacture the power module. This module is crucial for powering the robot motors and charging the battery. It must operate the two motors each drawing 200mA when the battery is at full capacity.The battery must be recharged from a 5V input pin, and include an ON/OFF switch with specific current requirements. The design must consider the physical constraints of the PCB board like avoiding collisions with motors and connections, and the desire to minimize the maximum distance of the robot from its center of rotation.

1.2 Scope and Limitations

The project entails designing and manufacturing the power module for the micro-mouse robot, ensuring it meets the specified requirements for powering motors, charging the battery, and providing an analog connection for the processor to sense the battery's state of charge. The design must fit onto the motherboard's pin headers and be appropriately sized for the robot, including specific connectors and physical constraints for the PCB board.

The limitations of the project include a strict budget constraint, with a total of R360 allocated for the board manufacturing, component costs, and the provision of the footprint on the PCB. The design challenge is to meet the budget requirements without the use of additional resources, highlighting the importance of efficient design and cost management in the project's scope and limitations.

1.3 GitHub Link

https://github.com/MRXTHA009/EEE3088F_2024

Chapter 2

Requirements Analysis

2.1 Requirements

The requirements for a micro-mouse power module are described in Table 2.1.

Table 2.1: The requirements for the power subsystem of a micro-mouse.

Requirements	**Description**
Motor Operation	The power subsystem must operate two motors, each drawing up to 200mA at the highest voltage of a 1S1P battery.
Battery Charging	The 5V input pin must recharge the battery when it goes below required value. It must provide an analog connection that gives information on the battery's voltage to the processor.
On/Off Switch	The power subsystem must include an ON/OFF switch with specific current requirement. In the OFF state, the battery draw should be less than 500uA. In the ON state, it should support the micro-mouse's peak current draw.
Physical Constraints	The design of the power subsystem must consider the physical constraints of the PCB, including the need for a tab to avoid collisions with motors and connections. The PCB must be as small as possible to minimize the maximum distance of the robot from its center of rotation, adhering to the size and weight of the micro-mouse.

2.2 Specifications

The specifications, refined from the requirements in Table 2.1, for the micro-mouse power module are described in Table 2.2.

Table 2.2: Specifications of the power subsystem derived from the requirements in Table 2.1.

Specifications	Description
Motor Operation	The subsystem must support two stepper motors, each rated at 5V DC and 200mA. At very low speeds, the motors may draw closer to 250uA of current such that the minimum current drawn is above 500uA.
Battery Capacity	The battery capacitor required for the micro-mouse is a LiPo battery with a capacity of 800 mAh and a voltage of 3.7V, capable of a maximum discharge rate of 0.5C, allowing for a maximum draw of 400 mA and ensuring the micro-mouse can operate for approximately 2 hours at full capacity.
Physical Constraints	Considering the physical constraints of the PCB, the tab used to prevent collision with the motors and connections must not have width greater than 35mm and the height can be 18mm or greater. The PCB must be as small as possible to minimize the distance of the robot from it's center of rotation.
On/Off State	In the OFF state, the battery draw should be less than 500uA. In the ON state, it should support the micro-mouse's peak current draw. Using a PN2222A NPN transistor and a TIP41C NPN power transistor can be an effective solution to keeping the current below 500uA when OFF and current above 500uA when the switch is ON due to the high current gain.

2.3 Testing Procedures

A summary of the testing procedures detailed in Table 2.3.

Table 2.3: Testing Procedures of the power subsystem derived from the circuit and simulations.

Acceptance Test	Description
Simulation Testing	Simulate the circuit designs on any electronics simulation tool(i.e. LTSpice) to ensure that they produce the required current values with the component values that are calculated.
Initial Component Testing	Before integrating the components into the micro-mouse's power subsystem, test each component individually to ensure they are functioning correctly.
Circuit Integration Testing	After confirming the individual components are working, integrate them into the circuit. This includes verifying that the circuit switches on and off based on the transistors and resistors connected.
Battery Charging Testing	Verify that the battery charging mechanism functions correctly by applying a 5V input and observing the battery voltage increase over time.

2.4 Traceability Analysis

The show how the requirements, specifications and testing procedures all link, Table 2.4 is provided.

Table 2.4: Requirements Traceability Matrix

#	Requirements	Specifications	Acceptance Test
1	Motor Operation	Motor Operation	Initial Component Testing, Simulation Testing, Circuit Integration Testing
2	Battery Charging	Battery Capacity	Battery Charging Testing, Circuit Integration Testing
3	On/Off Switch	On/Off State	Circuit Integration Testing, Simulation Testing
4	Physical Constraints	Physical Constraints	Simulation Testing

2.4.1 Traceability Analysis 1

The requirement for motor operation is derived from the need to operate two motors, each drawing up to 200mA. This requirement is addressed by the specification to support two stepper motors, each rated at 5V DC and 200mA. First step is to simulate the circuit design on a simulation tool to see if it works as expected. After confirming that the practical components behave as expected using initial component testing, use circuit integration testing to verify the circuit behaves as it does on the simulation.

2.4.2 Traceability Analysis 2

The requirement for battery charging is derived from the need to recharge the battery when it goes below the required value. This requirement is addressed by the specification battery capacity that must allow the battery to produce 400mA for 2 hours. Using the integrated circuit(circuit integration testing), connect the LiPo battery to it's specified location on the circuit to observe if the circuit works as required, let the circuit operate until the battery power is depleted, by applying a 5V input, the battery voltage must increase over time (battery charging testing).

2.4.3 Traceability Analysis 3

The requirement for an ON/OFF switch is derived from the need to include an ON/OFF switch. This requirement is addressed by the specification for an ON/OFF state where the battery draw is less than 500uA in the OFF state and supports the micro-mouse's peak current draw in the ON state. Using simulation testing, confirm that the current draw at the base of the 2N2222 below 500uA when the circuit is off. Do the same procedure using circuit integration testing by placing an ammeter in series with the base resistor and observing the current during on and off state.

2.4.4 Traceability Analysis 4

The requirement for physical constraints is derived from the need to consider the physical constraints of the PCB, including the need for a tab to avoid collisions with motors and connections. This requirement is addressed by the specification for the physical constraints of the PCB to keep the width less that 35mm and the height above 18mm. This can be tested using simulation tool testing, using KiCad, ensure the PCB is assembled around a rectangular or square with all the sides of the width less than 35mm.

Chapter 3

Subsystem Design

3.1 Design Decisions

3.1.1 Final Design

The following design...

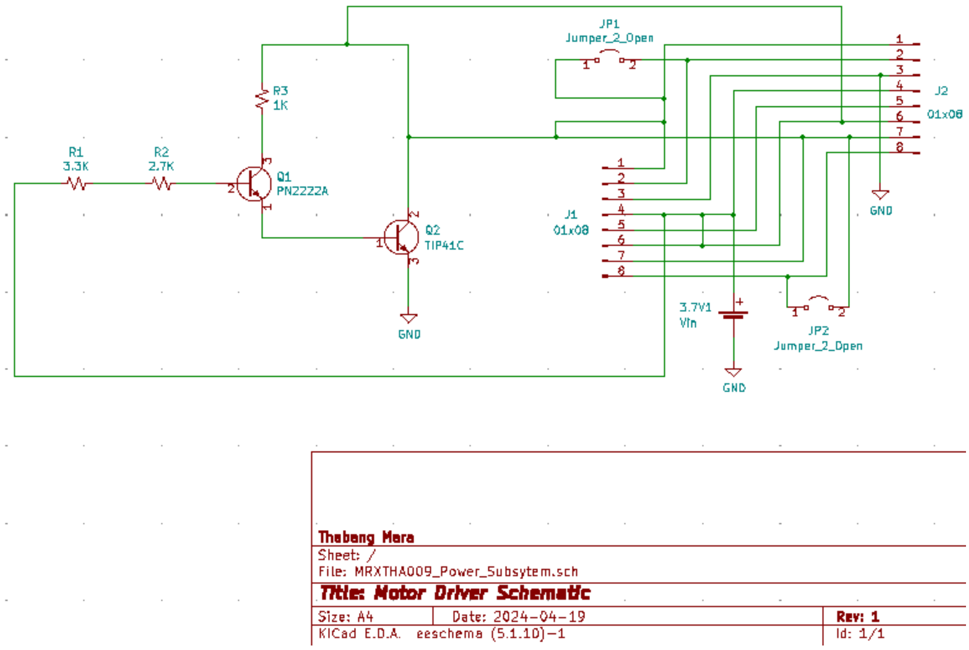
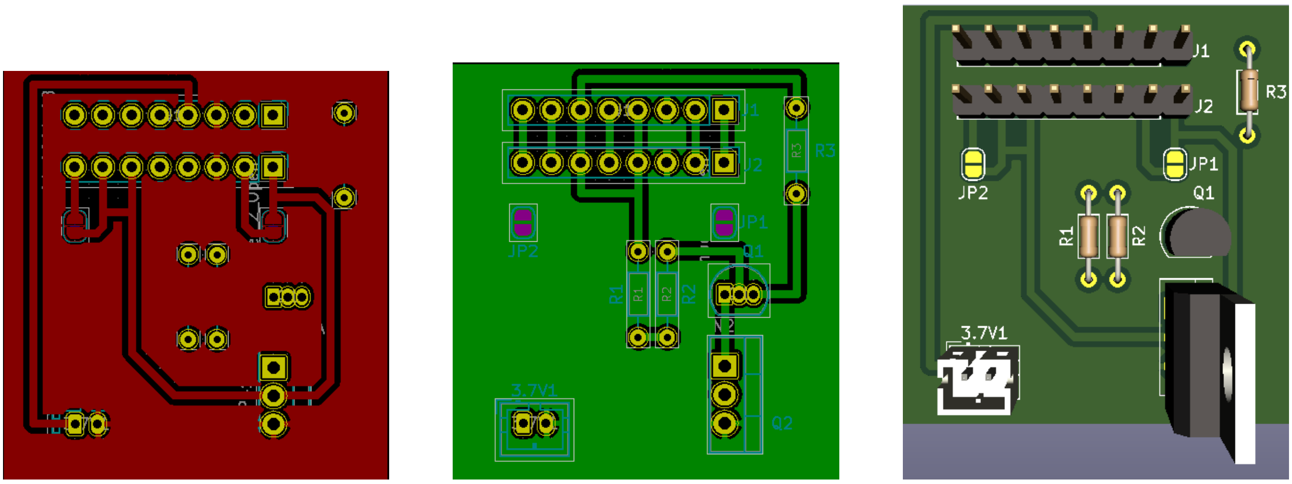


Figure 3.1: Final Schematic

Given:

- $V_{in} = 3.7$ V: Input voltage
- $V_{be} = 0.7$ V: Base-emitter voltage
- $I_b = 500$uA: Base current

To find the value of R_b such that the circuit is off when the current is below 500uA.



(a) Red Layer PCB (b) Green Layer PCB (c) 3D PCB

Figure 3.2: PCB

Using Ohm's Law:

$$
\begin{aligned}
R_b &= \frac{V_{in} - V_{be}}{I_b} \\
&= \frac{3.7 - 0.7}{500 \times 10^{-6}} \\
&= \frac{3}{500 \times 10^{-6}} \\
&= 6k\,\Omega
\end{aligned}
$$

So, $R_b = 6k\,\Omega$. Using E24 values, the sum of $3.3k\,\Omega$ and $2.7k\,\Omega$

To determine the required gain, the base current needs to be amplified such that 500uA on the input of the motor driver is 400mA or more on the output. Given:

- $I_b = 500$uA: Base current
- $I_{out} = 400$mA: Desired output current

To calculate the required gain (B) to achieve the desired output current, use.

$$
\begin{aligned}
B &= \frac{I_{out}}{I_b} \\
&= \frac{400 \times 10^{-3}}{500 \times 10^{-6}} \\
&= 800
\end{aligned}
$$

So, the required gain B is 800 or more depending on the choice of transistor. The choice of transistors for this subsystem is TIP41C and PN2222A:

- The minimum gain of a TIP41C transistor can vary depending on operating conditions and manufacturing tolerances. However, as a general guideline, the minimum guaranteed DC current gain typically falls within the range of 10 to 30.
- The PN2222A transistor is a widely used NPN bipolar junction transistor (BJT). Its minimum DC current gain typically falls within the range of 100 to 300.

Reason for transistor choice: Given the required gain of 800, neither the TIP41C nor the PN2222A transistor on its own can achieve this level of gain with a single stage of amplification. Multiple stages of amplification or a different transistor with a higher minimum gain is required for this. By cascading PN2222A and TIP41C the minimum gain that can be obtained is 1000, which is enough to obtain over 400mA on the output of the motor driver.
Reason for jumpers: Open jumpers allow users to easily change the configuration of a circuit without soldering or desoldering components. Since there is uncertainty in whether motor1A and Motor1B connect the jumpers are installed, if they are connected then the jumpers are connected to produce one connection.
Reason for resistors: One of the primary functions of resistors is to limit the current flowing through a circuit. This is essential because excessive current can damage other components or cause the circuit to burn out. By adding resistors R1 and R2, the current flowing into the base of PN2222A is limited such that PN2222A switches off when the current falls below 500uA. The resistor R3 connected to the collector of PN2222A limits the power flowing into the PN2222A.

3.2 Failure Management

Table 3.1: failure Management Table

Name	**Description**
Component Failure	Components such as transistors, resistors, capacitors, and batteries may fail due to manufacturing defects, overheating, or aging. To reduce component failures is to use high quality components from reputable companies.Monitor component temperatures and ensure adequate cooling to prevent overheating.
Battery Failure	Battery failure can occur due to overcharging, over-discharging,or cell degradation. To reduce battery failures use high-quality lithium-ion batteries with built-in protection circuits. Provide an analog connection that provides information on the battery's voltage for the processor to sense battery SoC.
Switching Circuit Failure	Failure of the ON/OFF switch or switching circuitry can lead to unintended operation. To reduce switching circuit failures, use reliable transistors rated for the expected current and voltage levels.
Physical Damage	Physical damage to the PCB, connectors, or other components can occur due to mishandling or impact. To mitigate physical damage, secure mounting to prevent components from becoming loose or detached so that it can maintain mechanical stress.

3.3 System Integration and Interfacing

To integrate the subsystem with the rest of the system ....

Table 3.2: Interfacing specifications

Interface	Description	Pins/Output
I001	MM Power PCB to STM for Analog-to-Digital (ADC)	• MM Power PCB Batt_ADC Pin 10 to STM 3V3 Pin 48
I002	STM 5V to MM Power PCB 5V	• STM 5V Pin 10 to MM Power PCB 5V pin 11 • STM 5V Pin 10 to MM Power PCB 5V pin 12
I003	MM Power PCB (PWM) to STM (PC)	• MM Power PCB PWM1 Pin 2 to STM PC6 Pin 7 • MM Power PCB PWM2 Pin 4 to STM PC7 Pin 5 • MM Power PCB PWM3 Pin 14 to STM PC8 Pin 4 • MM Power PCB PWM4 Pin 16 to STM PC9 Pin 3

Chapter 4

Acceptance Testing

4.1 Tests

Table 4.1: Subsystem acceptance tests

Test ID	Description	Testing Procedure	Pass/Fail Criteria
Simulation Testing	Circuit Designs	• Use a simulation tool to simulate the circuit designs. Ensure the simulation matches the calculated component values and produces the required current values for motor operation and battery charging.	Pass if the simulation results match the expected values. Fail if uncertainties are found.
Initial Component Testing	Individual Components	• Test each component (e.g., resistors, battery, transistors) individually using a multimeter or oscilloscope to ensure they are functioning correctly.	Pass if each component operates within its specified range. Fail if any component does not function as expected.
Circuit Integration Testing	Circuit Switching	• Integrate the components into the circuit and use a multimeter to verify that the circuit switches on and off based on the transistors and resistors connected.	Pass if the circuit switches on and off when base current goes below 500uA. Fail if the circuit does not switch or behaves unexpectedly.
Battery Charging Testing	Battery Voltage Increase	• Apply a 5V input to the battery charging circuit and observe the battery voltage increase over time using a multimeter or oscilloscope.	Pass if the battery voltage increases as expected. Fail if the voltage does not increase or increases at an unexpected rate.