Interim Design Report

Micromouse X Power subsystem

Prepared by:
Chloe James

Prepared for:
EEE3088F
Department of Electrical Engineering
University of Cape Town

April 20, 2024

Declaration

1. I know that plagiarism is wrong. Plagiarism is to use another's work and pretend that it is one's own.
2. I have used the IEEE convention for citation and referencing. Each contribution to, and quotation in, this report from the work(s) of other people has been attributed, and has been cited and referenced.
3. This report is my own work.
4. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as their own work or part thereof.

April 20, 2024

Chloe James

Date

Contents

Chapter 1

Introduction

1.1 Problem Description

The project for the course EEE3088F: *Electrical Engineering Design Principles* at the *University of Cape Town*(UCT), requires students to apply electrical engineering concepts to develop different subsystems for a micro-mouse maze-solving robot. The project emphasizes both teamwork and individual assessment, reflecting the collaborative and independent aspects of engineering practice.
The greater project involves creating a fully functional micro-mouse robot that can autonomously navigate a maze. It is made up of multiple PCB boards all integrated to create a micro-mouse. This requires two subsystems, power and sensing, as well as the processor, and the processor board. The project aims to provide students with practical experience in applying electrical engineering principles to complex design problems, as well as in working collaboratively.
The specific problem in the context of the greater problem consists of designing and manufacturing the power subsystem PCB to power the micro-mouse. This subsystem must meet multiple specifications, such as operating two motors, providing an analog connection for the processor to sense the battery's state of charge(SoC), charging the battery from a 5V input, and including an ON/OFF switch with specific power draw characteristics. Additionally, the design must fit onto the motherboard and adhere to size constraints to minimize the robot's distance from the center of rotation. Successfully designing and implementing the power subsystem contributes to the overall functionality and performance of the micro-mouse robot, bringing the project closer to its goal of autonomously navigating a maze.

1.2 Scope and Limitations

Designing and manufacturing the power subsystem PCB for a micro-mouse maze-solving robot on Kicad and utilizing JCLPCB. The project does not entail the design and manufacturing of other subsystems, such as the sensing subsystem or the motherboard. It also does not include the programming or integration of the subsystems into the final robot design. The limits of the project design include the need to meet strict performance requirements, which are shown in Table 2.1, within a constrained budget of $8.25 per board. Testing will be limited to the functionality and performance of the power subsystem. Development will be limited by the availability of components and time available for designing and manufacturing the subsystem.

1.3 GitHub Link

Shared GitHub link

Chapter 2

Requirements Analysis

2.1 Requirements

The requirements for a micromouse power subsystem are described in Table 2.1.

Table 2.1: Requirements of the power subsystem.

Requirement ID	Description
R01	Operate two motors.
R02	Provide an analog connection for the processor to sense the battery's voltage for determining the battery state of charge(SoC).
R03	Charge the battery from a 5V input pin.
R04	Include an ON/OFF switch with specific power draw characteristics.
R05	Adhere to size constraints to minimize the motherboard distance from the center of rotation.

2.2 Specifications

The specifications, refined from the requirements are described in Table 2.2.

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

Specification ID	Description
SP01	Each motor must be able to draw 200mA at the highest voltage(12V) of the battery.
SP02	The analog connection for the battery's voltage must be within a specified range.
SP03	The battery charging circuit must be able to charge the battery from a 5V input.
SP04	The ON/OFF switch must have a power draw of less than 500uA in the OFF state and be able to supply the peak current in the ON state.
SP05	The board must be designed to fit onto the motherboard with specific size constraints to minimize the distance from the center of rotation.

2.3 Testing Procedures

A summary of the testing procedures detailed in chapter 4 is given in Table 2.3.

Table 2.3: Testing procedures

Acceptance Test ID	Description
AT01	Check the continuity between power input and motor terminals.
AT02	Measure voltage at analog connection for battery voltage sensing.
AT03	Test charging functionality from 5V input pin.
AT04	Test if the circuit switches ON/OFF.
AT05	Measure the distance of the power circuit board from the center of rotation.

2.4 Traceability Analysis

This shows 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	R01	SP01	AT01
2	R01	SP02	AT02
3	R03	S03	AT03
4	R04	S04	AT04
5	R05	S05	AT05

2.4.1 Traceability Analysis 1

Requirement R01 states that the power subsystem must operate two motors. Specification SP01 specifies that each motor must be able to draw 200mA at the highest voltage of a 1S1P battery. Testing procedure AT01 checks the continuity between the power input and motor output terminals, ensuring that the power subsystem can effectively drive the motors.

2.4.2 Traceability Analysis 2

Requirement R02 requires the power subsystem to provide an analog connection for the processor to sense the battery's voltage for determining the battery's state of charge. Specification SP02 specifies that the voltage at the analog connection must be within a specified range below 4.2V. Testing procedure AT02 measures the voltage at the analog connection to ensure it falls within the specified range, validating the functionality of the voltage sensing.

2.4.3 Traceability Analysis 3

Requirement R03 mandates that the power subsystem must charge the battery from a 5V input pin. Specification SP03 specifies that the battery charging circuit must be able to efficiently charge the battery from a 5V input. Testing procedure AT03 tests the charging functionality from the 5V input pin to ensure that the battery charges successfully, verifying the charging circuit's efficiency.

2.4.4 Traceability Analysis 4

Requirement R04 states that the power subsystem must include an ON/OFF switch with specific power draw characteristics. Specification SP04 specifies that the ON/OFF switch must have a power draw of less than 500uA in the OFF state and be able to supply the robot's peak current in the ON state. Testing procedure AT04 verifies the functionality of the ON/OFF switch, ensuring that it meets the specified power draw characteristics and can supply the required current to the robot.

2.4.5 Traceability Analysis 5

Requirement R05 mandates that the power subsystem PCB must adhere to size constraints to minimize the distance from the center of rotation. Specification SP05 measures the distance of the PCB from the center of rotation. Testing procedure AT05 verifies that the distance of the PCB from the center of rotation is within the specified limits, ensuring that the power subsystem design effectively minimizes the distance from the center of rotation.

Chapter 3

Subsystem Design

3.1 Design Decisions

3.1.1 Final Design

The final design is shown in Figure 3.2 below. It was chosen as this design was the most suitable and cost-effective solution to the design problem.
The power subsystem requirements shown in Table 2.1 of Chapter 1 were met by the use of an H-bridge for the motor drivers, an ADC voltage divider circuit, a switching circuit, and a battery charging circuit. In selecting components for each part of the subsystem, several factors were considered to ensure suitability for the project:

- Motor driver circuit:
  The DRV8837, a dual H-bridge motor driver IC (Integrated Circuit), was selected for the project. Its choice was based on several key features: the dual H-bridge configuration, which aligns with R01 requirements; it is used in 'low-voltage or battery-powered motion control applications'[1], meeting SP01 specifications; the inclusion of PWM control for motor speed regulation; built-in current limiting for motor protection; and its compact form factor, which is advantageous for meeting the design constraints, particularly R05.

- ADC voltage divider circuit:
  An ADC (Analog-to-Digital Converter) voltage divider circuit, in accordance to SP02, is used to scale down a higher voltage signal to a level that is within the input range of the ADC. This is necessary because the ADC has a limited input voltage range, and exceeding this range can damage the ADC or result in inaccurate readings.
  The voltage divider circuit consists of two chosen resistors of equal value connected in series, with the ADC input connected to the junction between the two resistors.
  Given that the battery is a LiPo 800mAh 3.7V, it means that when fully charged, the battery voltage can be around 4.2V. This voltage exceeds the typical operating range of the ADC, which is limited to 0V to 3.3V. Using 2 10kΩ in series which creates a voltage divider.

- Switching circuit:
  The switching circuit controls the power subsystem, turning it ON or OFF. In the OFF state, the battery charges, while in the ON state, the battery powers the motors. A general-purpose low-voltage tactile switch, SW SPST, is used.

- Battery charging circuit:
  The TP4056 IC was chosen as the battery charging circuit.
  It has built-in features such as overcharge protection, thermal regulation, and over-discharge protection [2] which are essential for safe and efficient charging of lithium-ion batteries.
  Many of the component values are set according to the datasheet [2] to perform specific operations. But certian values need to be calculated as follows.
  The charging current (I_{charge}) is calculated using the formula:

$$I_{\text{charge}} = \frac{1.2\text{V}}{R_{\text{prog}}}$$

  The resistor needs to be set at 2.4Ω for the desired charge current (500mA) to be reached.
  The approximate charging time (t_{charge}) can be estimated as:

$$t_{\text{charge}} \approx \frac{1.5 \times \text{Battery Capacity (mAh)}}{\text{Charging Current (mA)}}$$

$$t_{\text{charge}} \approx \frac{1.5 \times 800\text{(mAh)}}{500\text{ (mA)}}$$

$$t_{\text{charge}} \approx \ 2.4s$$

  The LED resistor values are set to 10kΩ and the capacitors are set to 10uF as given in the datasheet [3].

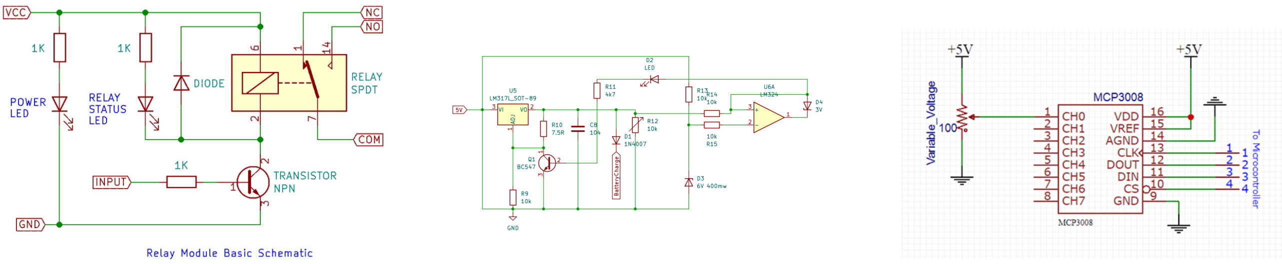
3.1.2 Design options

- Motor driver circuit:
  Alternative options such as the L293D [4] were considered but were not chosen due to higher power consumption, limited control, high supply voltage of 4.5 - 36 V [4], and protection features compared to the DRV8837.

- Switching circuit:
  An option of relays shown in Figure 3.1a was explored but the size and weight of the relays, high power consumption, high-voltage supply circuit [5] and the cost were not appropriate for this project as it is considered an extended part.

- Battery charging circuit:
  The option below, using a voltage regulator, BJT and an op-amp with some additional passive circuitry in Figure 3.1b was not chosen as there was limited current handling, no built-in battery management features, greater costs and the possibility of it not working was greater as it was many different components to create a battery charging circuit.

- ADC voltage divider:
  Other ADC ICs such as the MCP3008, shown in Figure 3.1c were considered but due to strict budget constraints, it could not be chosen as it is an extended part and an additional $3.10 would not fit the budget [6].



(a) Relay switching circuit (b) Charging circuit (c) MCP3008 ADC circuit

Figure 3.1: Options

3.1.3 Final design diagrams

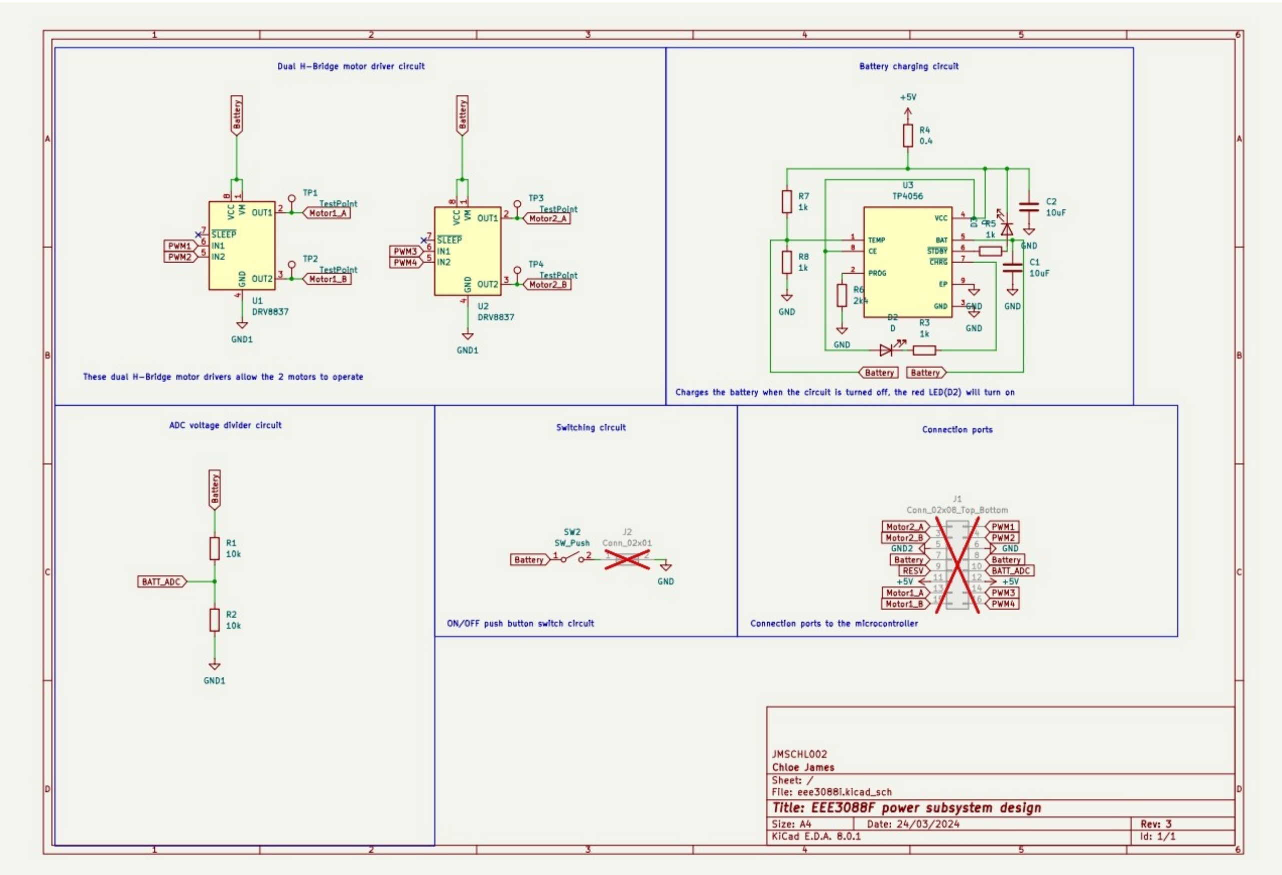
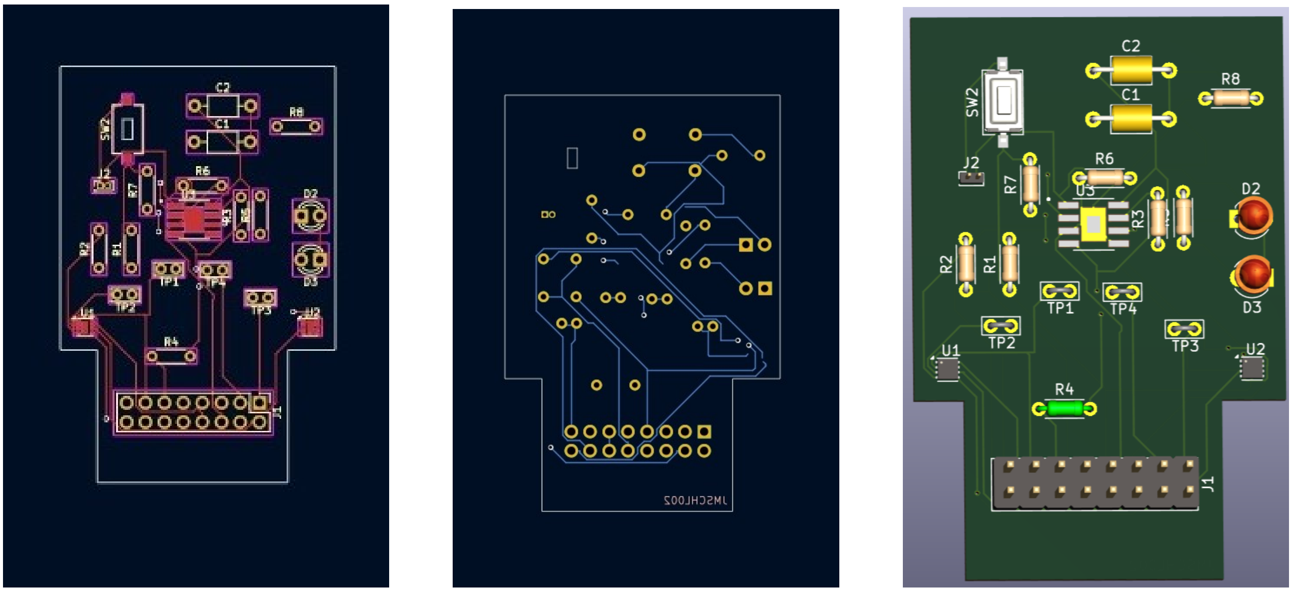


Figure 3.2: Schematic

The connectors in the schematic have been crossed out as they will not be populated on the PCB.

The use of ports was necessary in the design of the PCBs, as shown below in Figure 3.3b by the yellow circles, as multiple connections would overlap if ports were not used. The components are evenly distributed to ensure stability.



(a) Front PCB (b) Back PCB (c) 3D PCB

Figure 3.3: PCB

3.2 Failure Management

Table 3.1: Table showing the failure management of the power subsystem.

Name	Description
Component Redundancy	Incorporating duplicate components,within the budget, or backup circuits to provide redundancy in case of component failure.
The addition of circuitry	Addition of test points to the circuit allows for physical testing upon the arrival of the boards.
Component Selection	Selecting components with appropriate specifications them to ensure they operate within safe limits, reducing the risk of failure.

3.3 System Integration and Interfacing

3.3.1 Interfacing table

Table 3.2: Interfacing specifications

Interface	Description	Pins/Output
I001	Motor Driver circuit(motor1)	• Motor1A: Output to control direction of Motor 1. • Motor1B: Output to control direction of Motor 1. • PWM3: Pulse Width Modulation for Motor 1 speed.
I002	Motor Driver circuit(motor2)	• Motor2A: Output to control direction of Motor 2. • Motor2B: Output to control direction of Motor 2. • PWM4: Pulse Width Modulation for Motor 2 speed.
I003	Battery connection	• BATT: Battery positive connection. • GND: Battery ground connection.
I004	Power input for charging	• 5V: Input for charging the battery. • GND: Ground connection for charging.
I005	The processor	• Pin 2 of The Processor to Pin 7 of the power subsystem. • Pin 48 to Pin 10 of the power subsystem board.

3.3.2 High-level Block Diagram

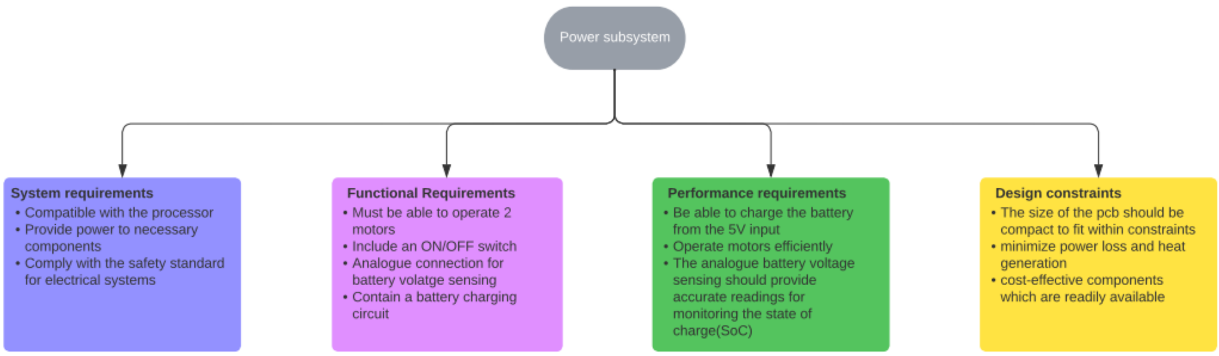


Figure 3.4: High-level Block Diagram

Chapter 4

Acceptance Testing

4.1 Tests

Table 4.1: Subsystem acceptance tests

Test ID	Description	Testing Procedure	Pass/Fail Criteria
AT01	Powers on	• Do the motors spin when a voltage is applied	Motors operate smoothly without excessive noise or vibration
AT02	Battery voltage test	• Measure the analogue voltage connection.	Voltage measurement should be witin 3.75V to 4.2V.
AT03	Battery charging test	• Test the ability of the charging circuit by switching the circuit off and measuring the voltage change across the battery.	Battery charges successfully within a reasonable time frame.
AT04	ON/OFF switch test	• Measure the power draw in the OFF state and ensure it is less than 500uA • Measure the power in the ON state and ensure it can supply approximately 4.2V	Power draw is less than 500uA in the OFF state and supplies peak current.
AT05	Center of rotation distance test	• Measure the distance of the motherboard from the center of rotation with the power subsystem pcb.	Distance of the motherboard from the center of rotation is within limits

Bibliography

[1] Texas Instruments, "DRV883x Low-Voltage H-Bridge Driver," https://www.ti.com/lit/ds/symlink/drv8837.pdf?ts=1713427173464&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FDRV8837, 2021.

[2] NanJing Top Power ASIC Corp. , "TP4056 1A Standalone Linear Li-lon Battery Charger with Thermal Regulation in SOP-8," https://dlnmh9ip6v2uc.cloudfront.net/datasheets/Prototyping/TP4056.pdf.

[3] MicroChip, "TP4056 1A Standalone Linear Li-lon Battery Charger with Thermal Regulation in SOP-8," https://cdn-shop.adafruit.com/datasheets/MCP3008.pdf, 2008.

[4] Micro Robotics, "L293D Driver IC - DIP," https://www.robotics.org.za/L293D-DIP, 2024.

[5] OurPCB, "PCB Relay: Types, Design and Applications," https://www.ourpcb.com/pcb-relay.html, 2024.

[6] Mouser, "MCP3008-I/P Microchip Technology," https://www.mouser.co.za/ProductDetail/Microchip-Technology/MCP3008-I-P?qs=AF%252BffTaPb30XZ0OdV6HdVg%3D%3D, 2024.