Interim Design Report

Micromouse Power Subsystem

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April 21, 2024

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Chapter 1

Introduction

1.1 Problem Description

This project encompasses the development of a power module and it was assigned as part of the EEE3088F course offered by the EBE faculty at the University of Cape Town. It exists under a larger project aimed at developing a micromouse robot. A micromouse is a battery-powered, wheeled robot whose goal is to traverse and solve a maze. In this micromouse project, the robot will navigate through a walled maze structure and attempt to reach its center. The micromouse project is structured around four distinct yet interconnected subsystems namely: the motherboard, processing, power, and sensing subsystems.

This specific project focuses on the power subsystem. The power subsystem needs to provide power from a battery to the motors and it needs to be able to charge the battery. Additionally, it must interface appropriately with the other three subsystems and provide them access to the battery.

1.2 Scope and Limitations

This project's scope covers the design, manufacturing, and hardware testing of the power subsystem for the micromouse project. The developed module only needs to meet the requirements detailed in section 2.1. Note this project does not cover the development of the other three subsystems; this includes any programmed communication or inputs to the power subsystem from other subsystems. Additionally, the physical assembly of this module is done by a third party and lies outside the scope of this project.

This project was limited to a fixed budget of $8.25 and a design completion deadline of 24 March 2024. Additionally, the design was limited by the following:

- The module with all its components had to be manufactured through JLCPCB.
- The module size and interfacing capabilities were limited by the motherboard subsystem.
- The module could only be tested through simulations or calculations before manufacturing.
- The power supplied was limited to a single 1S1P LiPo battery.

1.3 GitHub Link

All relevant information and documentation can be found in the following GitHub repository:
https://github.com/Luke-VDW/micromouse/tree/main.

Chapter 2

Requirements Analysis

2.1 Requirements

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

Table 2.1: User and functional requirements of the power subsystem.

Requirement ID	Description
R01	Must operate off a single 1S1P LiPo battery
R02	Must be able to charge the battery from a 5V pin
R03	Must provide sufficient power to the DC brush motors and other subsystems
R04	Must enable speed and direction control for the motors
R05	Must be able to switch the micromouse ON / OFF
R06	Must charge the battery when the micromouse is off
R07	Must provide an analogue battery state of charge signal out
R08	Must cost within the budget
R09	Must be manufactured with all its components through JLCPCB
R10	Must fit on a PCB that can connect to the motherboard

2.2 Specifications

The specifications, refined from the requirements in Table 2.1, for the micromouse power module 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	The battery must connect to the board via a JST PH 2mm connector
SP02	The module must operate from 3.0 - 4.2V
SP03	The battery charging input must not exceed 4.2V
SP04	The battery must be charged at a rate less than 800mA (1C)
SP05	The motors must each be able to receive up to 200mA of continuous current
SP06	The module must supply the other subsystems with power at their peak load
SP07	The motors' speed and direction must be controlled using 3.3V PWM signals
SP08	The module must provide 0V or 3.0 - 4.2V to the motors and other subsystems
SP09	When the micromouse is OFF the battery must draw below 500uA
SP10	When the micromouse is OFF the charging circuitry must still connect to the battery
SP11	The SoC output must be less than 3.3V
SP12	The module must cost less than $8.25
SP13	The components chosen for the module must be sufficiently stocked at JLCPCB
SP14	The board must be smaller than 100x100mm
SP15	Must have a 2x8 2.54mm pin pitch header to connect to the motherboard
SP16	The header must be centred in a tab with a minimum height of 18mm and a maximum width of 35mm

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 of the power subsystem derived from the specifications in Table 2.2

Acceptance Test ID	Description
AT01	Check the module turns on
AT02	Measure the input battery voltage
AT03	Measure battery input current
AT04	Measure the current going into the motors
AT05	Measure the current going to the other subsystems
AT06	Measure the frequency and direction of the motor output voltage
AT07	Measure the voltage output to the motors and subsystems when switched off
AT08	Measure the current going to the entire micromouse
AT09	Measure the SoC voltage output
AT10	Use JLCPCB to check prices and stock levels
AT11	Measure the module's physical dimensions
AT12	Check the module can connect to the motherboard using the header

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	R01	SP01,SP02	AT01
2	R02	SP03,SP04	AT02,AT03
3	R03	SP05,SP06	AT04,AT05
4	R04	SP07	AT06
5	R05	SP08,SP09	AT07,AT08
6	R06	SP10	AT02,AT03,AT07
7	R07	SP11	AT09
8	R08	SP12	AT10
9	R09	SP13	AT10
10	R10	SP14,SP15,SP16	AT11,AT12

2.4.1 Traceability Analysis 1

From R01, SP01 and SP02 can be deduced because the battery being used has a JST PH 2mm connector, and the module must operate at the supplied battery voltage which ranges from 3.0V - 4.2V. This can be tested with AT01 to see if the module turns on.

2.4.2 Traceability Analysis 2

From R02, SP03 and SP04 can be deduced because the battery has a maximum voltage of 4.2V and a maximum rated charge current of 800mA (1C). These can be tested with AT02 and AT03 by measuring the voltage across and the current flowing into the battery.

2.4.3 Traceability Analysis 3

From R03, SP05 and SP06 can be deduced because the module should allow the motor to operate at the maximum current they can draw at the rated voltage of the battery, which is 200mA. The module should also be capable of transferring power to the other subsystems at their peak loads. This can be tested with AT04 and AT05 to check that the module can transfer enough power.

2.4.4 Traceability Analysis 4

From R04, SP07 can be deduced because the module only has access to 2 PWM signals for motor control and these come from the STM32 processor which outputs 3.3V logic signals. This can be tested with AT06 to ensure that the module will output the correct response from a set of PWM inputs.

2.4.5 Traceability Analysis 5

From R05, SP08 and SP09 can be deduced because when the micromouse is considered switched off the output voltage from the module must be 0V the battery current must be below 500uA; when switched on the output voltage must be between 3.0-4.2V and adhere to SP05. This can be tested with AT07 and AT08 by measuring the output voltage and battery current when it is switched on or off.

2.4.6 Traceability Analysis 6

From R06, SP10 can be deduced because the charging circuit must always be connected to the battery so it can charge when the micromouse is switched off. This can be tested with AT02, AT03 and AT07 to check that at 0V output voltage, the battery is charging at its rated values.

2.4.7 Traceability Analysis 7

From R07, SP11 can be deduced because the output of the analogue battery state of charge signal goes to an ADC input on the STM32L4 processor, which has a maximum rated reading input voltage of 3.3V. This can be tested with AT09 to ensure it is below 3.3V.

2.4.8 Traceability Analysis 8

From R08, SP12 can be deduced because this project has a budget of $8.25. This can be tested with AT10 to check the total board price.

2.4.9 Traceability Analysis 9

From R09, SP13 can be deduced because all manufacturing done and components used in this project are limited to what is offered on JLCPCB. This can be tested with AT10 to check that the components used are available at JLCPCB.

2.4.10 Traceability Analysis 10

From R10, SP14, SP15, and SP16 can be deduced because the module must be able to connect with the motherboard through a 2x18 pin connector and because the size of the module is limited by the motherboard. This can be tested with AT11 and AT12 to check that the board fits onto the motherboard.

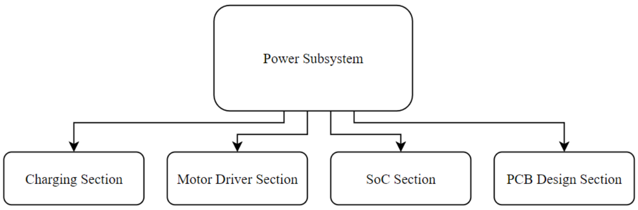
Chapter 3

Subsystem Design

3.1 Design Decisions

The power module was broken up into 4 main sections for the sake of the design decisions. These sections are the charging, driver, SoC and PCB design sections as seen in Figure 3.1.

Figure 3.1: Section diagram for the power module



3.1.1 Charging Section

The charging section for the battery must meet requirements: R02, R06, R08 and R09 listed in Table 2.1. Therefore the circuit must comply with specifications: SP03, SP04, SP09, SP10, SP12, and SP13 listed in Table 2.2.

Considerations to take into account when meeting the requirements include:

- The solution should be very reliable since improperly charging the battery is a fire hazard
- The solution should draw below 500uA when it is not charging because it will remain connected to the micromouse when it is switched off
- The battery charging current should be optional to allow for different charging currents
- The battery should not take excessively long to charge

Possible design solutions can be seen in Table 3.1.

Table 3.1: Possible design solutions for the charging section

Design Solution ID	Possible Design Solution
DS01	Use a custom charging circuit with auto-cutoff and current limiting
DS02	Use a LiPo charging IC available

Chosen solution: DS02

A custom charging circuit would provide and more modifiable circuit than using an IC however it is much more complicated and is less safe than a dedicated LiPo charging IC. Additionally, a charging IC will likely be more efficient than a custom circuit and come with documentation to support all its parameters, hence it is the preferred solution.

Some available battery management ICs that satisfy the charging requirements can be seen in Table 3.2 below:

Table 3.2: Component considerations for the charging section

Component	Price ($)	Stock	Basic part	Adjustable current	Max current (A)
TP4056-42	0.1724	107303	Yes	Yes	1
GX4057	0.0189	14048	Yes	No	0.5
TP4057-42	0.1163	21877	Yes	Yes	0.5

Chosen component: TP4056-42

The GX4057 is much cheaper than the other options, however since it is not a basic part it will have an extended component fee of $2.87 and hence is significantly more expensive than the other options. The TP4057-42 is cheaper than the TP4056-42 however its charging current is limited to 500mA and it is less available, which makes the TP4056-42 the preferred component.

Calculations for the TP4056-42:

The charging current is given as $I_{BAT} = \frac{1}{R_{PROG}} \times 1200$ where R_{PROG} is a resistor connected to the PROG pin (pin 2) and ground.

The maximum charging current for the battery is 800mA and the recommended is 400mA. Any charging current between these values will be fast enough and safe. The associate resistor values are:

$$0.8 = \frac{1}{R_{PROGmax}} \times 1200 \qquad \therefore R_{PROGmax} = 3k\Omega$$

$$0.4 = \frac{1}{R_{PROGrec}} \times 1200 \qquad \therefore R_{PROGrec} = 1.5k\Omega$$

The STDBY and CHRG pins (pins 6 and 7) can be connected to a green and red LED respectively. These are used to indicate when the unit is charging. A $1k\Omega$ resistor can be placed in series with the LED to limit the current through them.

As recommended by the datasheet a $10\mu F$ capacitor can be connected across V_{CC} and ground and across the BAT pin and ground. Additionally, a limiting resistor should be connected in series with V_{CC} that can range between 0.2Ω - 0.5Ω. The max power that could be dissipated across this resistor is $P = I^2 \times R = 0.8^2 \times 0.5 = 0.32W$. Therefore use two or more $250mW$ 1Ω resistors in parallel to achieve this limiting resistance.

3.1.2 Motor Driver Section

The motor driver section must meet requirements: R01, R03, R04, R08 and R09 listed in Table 2.1. Therefore the circuit must comply with specifications: SP02, SP05, SP07, SP08, SP12 and SP13 listed in Table 2.2.

Considerations to take into account when meeting the requirements include:

- The solution should be capable of running at high PWM frequencies to provide a broad range for user selection

- The output impedance for the incoming PWM signals should be kept high since this signal is a logic signal coming from the processor and is not meant to deliver power
- If a motor is connected across the battery directly, its voltage will decrease over time which will affect the motor's speed

Possible design solutions can be seen in Table 3.3:

Table 3.3: Possible design solutions for the charging section

Design Solution ID	Possible Design Solution
DS03A	Use a custom H-bridge circuit powered directly from the battery
DS03B	Use a custom H-bridge circuit powered by a regulated voltage
DS04A	Use a motor driver IC powered directly from the battery
DS04B	Use a motor driver IC powered by a regulated voltage

Chosen solution: DS04A

A custom H-bridge circuit would provide a more modifiable circuit than using an IC however it is much more complicated and could potentially be less reliable than a driver IC. Operating at a constant voltage would provide stability on the output but it would also require a voltage regulator which would decrease the overall efficiency. The loss in efficiency is more important than the improved stability since the output can be controlled with a PWM input, which can be used to compensate for the changing battery voltage, and hence solution DS04A is the preferred solution.

Some available motor driver ICs that satisfy the motor driver requirements can be seen in Table 3.4:

Table 3.4: Component considerations for the charging section

Component	Price ($)	Stock	Basic part	No. of drivers	Max current (A)	Operating voltage (V)
DRV8833PWPR	0.6660	9436	No	2	1.5	2.7 - 10.8
DRV8837DSGR	0.1235	71521	No	1	1.8	1.8 - 7.0

Chosen component: DRV8833PWPR

The DRV8837DSGR and the DRV8833PWPR can both meet the requirements for the driver circuit, however, the DRV8833PWPR is a dual driver and can therefore operate both motors at the same time. Having one IC instead of two reduces the complexity of the module which is favoured over the small cost difference between the two and therefore the DRV8833PWPR is the preferred component.

Calculations for the DRV8833PWPR:

As recommended by the datasheet a $10\mu F$ ceramic capacitor can be connected across VM and ground and a $2.2\mu F$ ceramic capacitor can be connected across VINT and ground. Additionally, a $10nF$ ceramic capacitor can be connected across VM and VCP. AISEN and BISEN can be grounded to ignore current limits.

3.1.3 SoC Section

The SoC section must meet requirements: R01, R07, R08 and R09 listed in Table 2.1. Therefore the circuit must comply with specifications: SP02, SP11, SP12, and SP13 listed in Table 2.2.

Considerations to take into account when meeting the requirements include:

- The voltage output should be a linearly scaled version of the input since this output signal will be used to determine the battery state of charge
- The output must be able to be polled by an ADC input without unwanted loading effects

Possible design solutions can be seen in Table 3.5.

Table 3.5: Possible design solutions for the SoC section

Design Solution ID	Possible Design Solution
DS05	Use a voltage diver to scale the input and then output from an op-amp buffer
DS06	Use a voltage diver to scale the input and then output after a capacitor acting as a buffer

Chosen solution: DS06

The op-amp buffer would be reliable and easy to implement however since we are operating at low voltages it would be easier to avoid using active components that can run into headroom issues. Therefore, since it is a passive solution, DS06 is the preferred solution.

Calculations for the SoC section:

The voltage divider input ranges from 3.0 - 4.2V. The output must be below 3.3V for the ADC to be able to properly read it therefore, so for the maximum V_{IN}:

$$V_{OUT} = V_{IN} \times \frac{R2}{R1 + R2}$$

$$\therefore 3.3 = 4.2 \times \frac{R2}{R1 + R2}$$

$$\therefore R1 = R2 \times 0.273$$

$$Let R2 = 10k\Omega \qquad \therefore R1 = 2.73k\Omega$$

Let R1 be a larger E24 value to ensure that the voltage is always lower than 3.3V, i.e. $R1 = 3k\Omega$:

$$\therefore V_{OUTmax} = 4.2 \times \frac{10k}{3k + 10k} = 3.23V$$

The buffer capacitor for the output can be any size that is larger than the internal capacitor on the ADC of the processor.

3.1.4 PCB Design Section

The PCB section must meet requirements: R03, R05, R08, R09 and R10 listed in Table 2.1. Therefore the circuit must comply with specifications: SP01, SP06, SP08, SP12, SP13, SP14, SP15 and SP16 listed in Table 2.2.

Considerations to take into account when meeting the requirements include:

- The switch should hold its position (latching) and should handle the peak current draw
- The PCB power traces should be able to handle the peak current draw of the micromouse
- The PCB should be as short as possible to help maintain a central centre of mass
- Power components should be as close together as possible to reduce the length of power traces

3.1.5 Final Design

The following design was chosen based on the design solutions DS02, DS04A and DS06 and any accompanying design considerations for each section above. The solution makes use of the TP4056-42 and the DRV8833PWPR as ICs for the charging and motor driver sections. For the charging circuit, five 1Ω are placed in parallel with jumpers to provide optional resistance values for the limiter resistor. Also, a parallel resistor loop controlled by a switch is connected alongside R_{PROG} to toggle the charging speed of the battery. The SoC section was designed with a range of buffer capacitor options. A large toggle switch was chosen to switch the micromouse on and off easily.

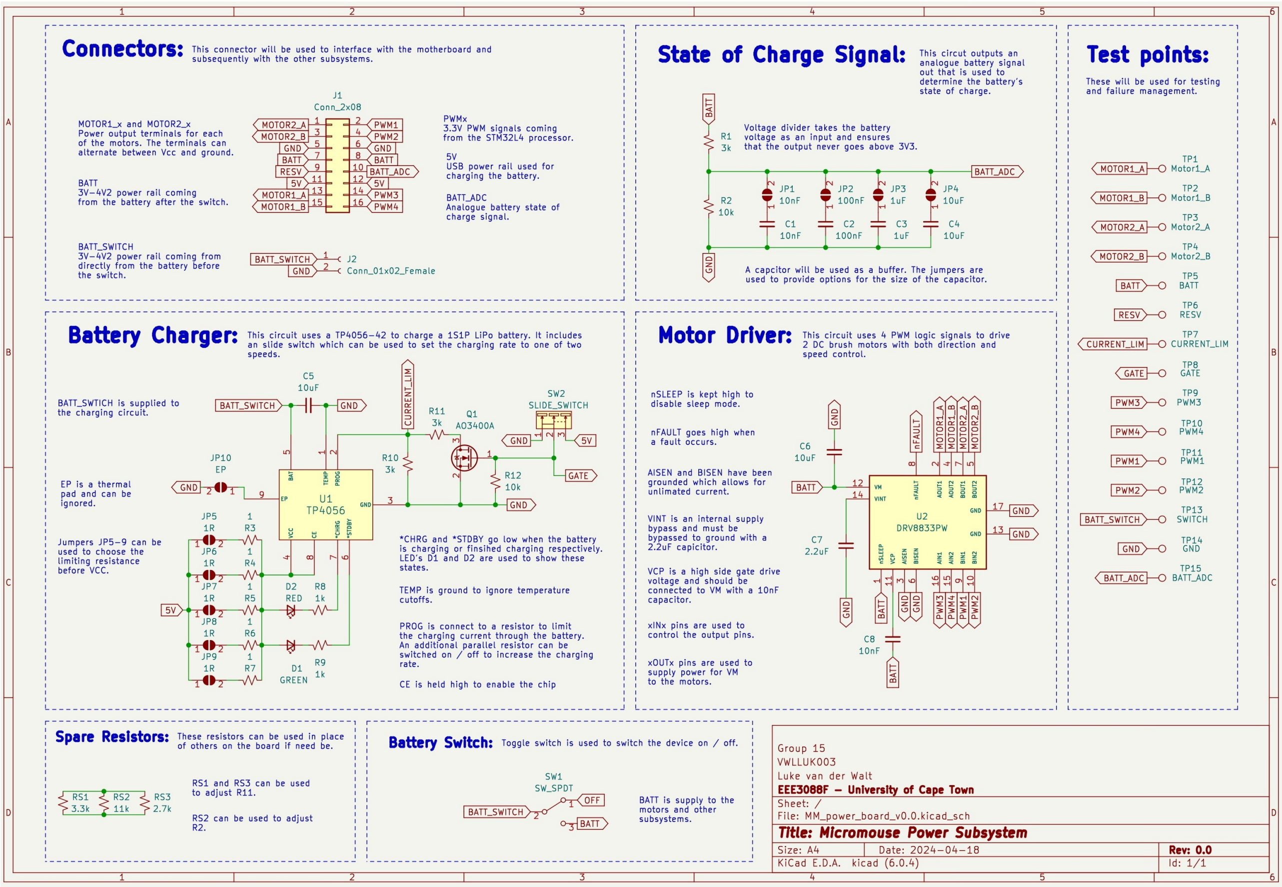
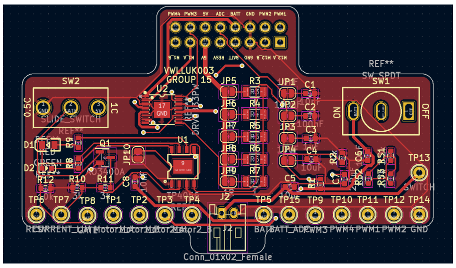
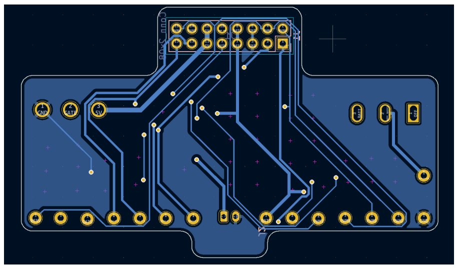


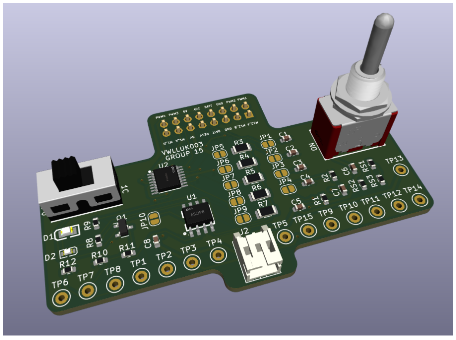
Figure 3.2: Final Schematic



(a) Front PCB



(b) Back PCB



(c) 3D PCB

Figure 3.3: PCB

3.2 Failure Management

The steps taken to manage potential errors are detailed in Table 3.6.

Table 3.6: Failure management processes

Name	Description
Spare components	Spare resistors were added to the board. These resistors can be removed and placed elsewhere on the board if any other resistor values are off.
Jumpers	Jumpers have been placed in areas where the value of a component is uncertain to provide multiple options for that component.
TH test points	All test points are keystone / through hole which provides space to connect additional components in the event of a component failure.
Power test points	All power test points in the circuit have been connected using the same thick traces that the dedicated power lines use. This allows for power to be provided from these test points to other components through external connections if their traces have been incorrectly run.
Variable charging speed	A switch has been added to the charging circuit that allows for two different charging rates. If the set charging rate is too slow, this can be used to increase the charging rate, or it can be ignored if the rate is satisfactory.

3.3 System Integration and Interfacing

Table 3.7: Interfacing specifications

Interface	Description	Pins/Output
IJ1	PWM signals from STM to power module through header J1	• PWM1: STM PC6 to header PIN 2 • PWM2: STM PC7 to header PIN 4 • PWM3: STM PC8 to header PIN 14 • PWM4: STM PC9 to header PIN 16
	Power from power module to motors through header J1	• MOTOR1_A: Header PIN 13 to Motor1 PIN A • MOTOR1_B: Header PIN 15 to Motor1 PIN B • MOTOR2_A: Header PIN 1 to Motor2 PIN A • MOTOR2_B: Header PIN 3 to Motor2 PIN B
	3V - 4.2V power from the power module to other subsystems through header J1	• BATT: Header PIN 7 and PIN 8 to STM VBAT • GND: Header PIN 5 and PIN 6 to STM GND
	5V power from USB to power module through header J1	• 5V: USB to header PIN 11 and PIN 12
	Analogue SoC signal from power module to STM through header J1	• BATT_ADC: Header PIN 10 to STM 3V3 ADC
IJ2	3V - 4.2V power from battery to power module through JST connect J2	• BATT_SWITCH: + terminal to JST PIN 1 • GND: - terminal to JST PIN 2

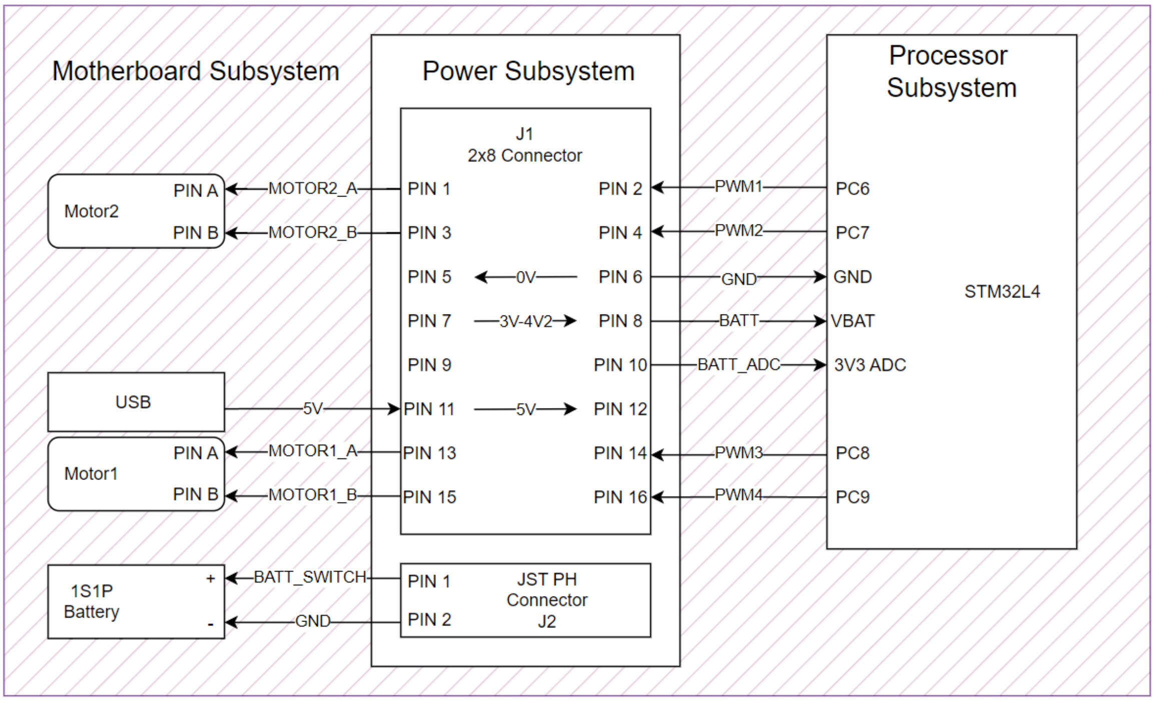


Figure 3.4: Interfacing Diagram

Chapter 4

Acceptance Testing

4.1 Tests

Table 4.1: Subsystem acceptance tests

Test ID	Description	Testing Procedure	Pass Criteria
AT01	Check the module turns on	• Connect the battery to the JST connector • Measure the voltage on the PIN12 (VM) of U2	3V - 4V2
AT02	Measure the input battery voltage	• Power the 5V pins on J1 • Measure the voltage across the terminals of J2 which is V_{BATin}	$V_{BATin} \approx 4V2$
AT03	Measure battery input current	• Connect the positive terminal of an ammeter to TP13 (BATT_SWITCH) • Connect a semi-charged battery across the negative ammeter terminal and TP14 (GND) • Power the 5V pins on J1 • Record I_{BATT}	$I_{BATT} \geq 0.4A$ $I_{BATT} \leq 0.8A$
AT04	Measure the current going into the motors	• Connect the positive terminal of an ammeter to TP1 (MOTOR1_A) • Connect the negative terminal of the ammeter to pin A of Motor1 and PIN15 of J1 to pin B • Connect a battery charged at 4V2 • apply a 3.3V DC signal to TP9 (PWM3) and connect TP10 (PWM4) to ground • Repeat this for motors and record I_M	$I_M > 0A$ $I_M \leq 0A2$
AT05	Measure the current going to the other subsystems	Connect the positive terminal of an ammeter to TP5 (BATT) • Connect the negative ammeter terminal to the BATT pin on the motherboard header • Connect TP14 (GND) to the GND pin on the motherboard header • Connect a charged battery to J2 • • Record I_{SUB}	$I_{SUB} \leq 0A8$
AT06	Measure the frequency and direction of the motor output voltage	• Connect an oscilloscope to TP1 (MOTOR1_A) • Record the f_{OUT} and $\|V_{OUT}\|$ • Repeat for TP3 (MOTOR2_A)	$f_{OUT} = f_{IN}$ $V_{out} = V_{batt}$

AT07	Measure the voltage output to the motors and subsystems when switched off	• Measure the voltage on TP5 (BATT) • Record V_{BATT}	$V_{BATT} = 0V$
AT08	• Measure the current going to the entire micromouse	Connect the positive terminal of an ammeter to TP13 (BATT_SWITCH) • Connect a charged battery across the negative ammeter terminal and TP14 (GND) • Connect header J1 to the motherboard • Record I_{mm}	$I_{mm} \leq 0A8$
AT09	Measure the SoC voltage output	• Measure the voltage on TP15 (BATT_ADC) • Record V_{ADC}	$V_{ADC} \leq 3V3$
AT10	Use JLCPCB to check prices and stock levels taking	• Take note of basic vs extended parts • Make a quote using the bill of materials and determine the total cost of the board • Record $Cost$	$Cost \leq$ 8.25$
AT11	Measure the module's physical dimensions	• Use a measuring tool to measure the board's total area A • Use a measuring tool to measure the tab height H_{tab} • Use a measuring tool to measure the tab width H_{wid}	$A \leq 10 \times 10cm$ $H_{tab} \geq 18mm$ $H_{wid} \leq 35mm$
AT12	Check the module can connect to the motherboard using the header	• Try to place the module header into the motherboard connector • Once placed check that the module has access to the battery connector	Fits wihtout obstruction