Electrical Documentation

MiniMuck

Herman Darjes (254100@usn.no) 2025-11-23

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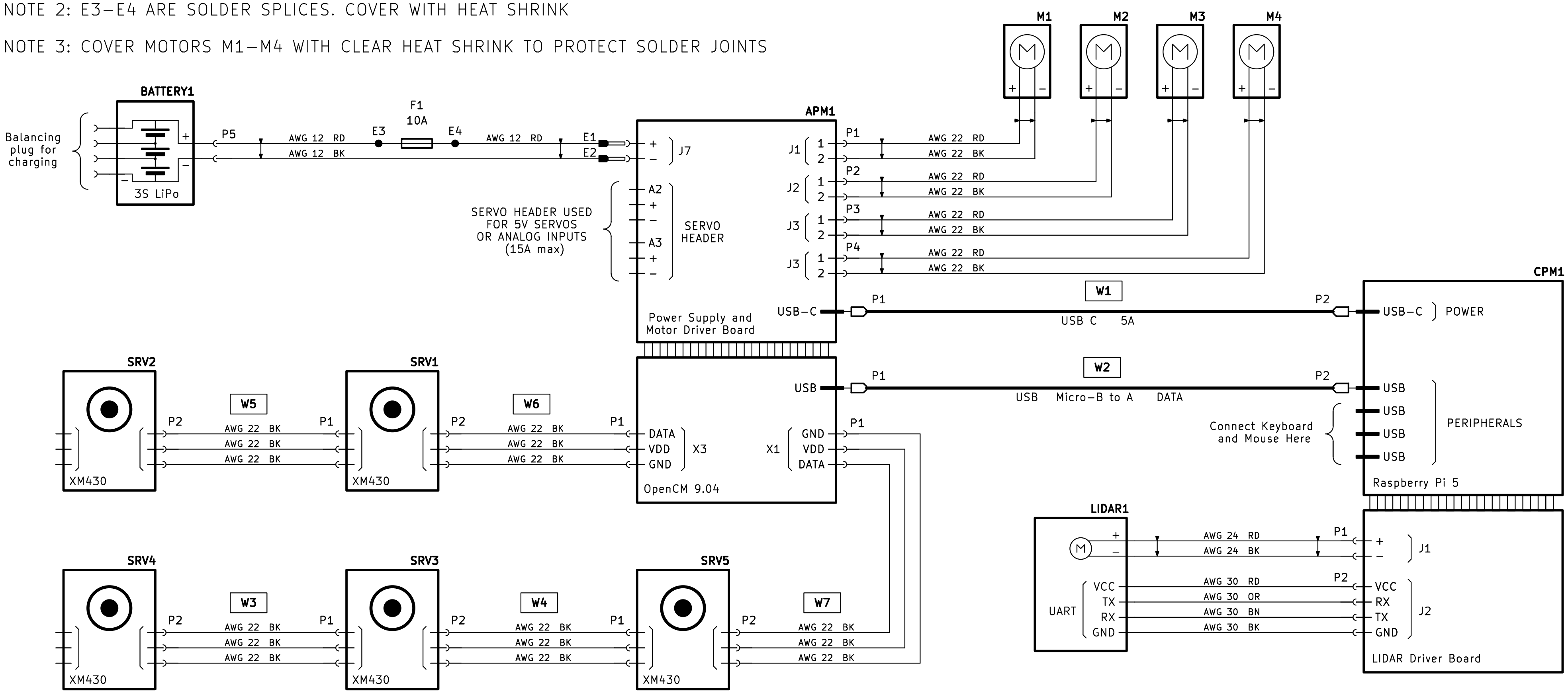
NOTE 1: MOUNTING TORQUE OF SCREW TERMINALS APM1:J7 1.5 Nm

NOTE 2: E3–E4 ARE SOLDER SPLICES. COVER WITH HEAT SHRINK

NOTE 3: COVER MOTORS M1–M4 WITH CLEAR HEAT SHRINK TO PROTECT SOLDER JOINTS



BILL OF MATERIALS

REFERENCE DESIGNATOR	PART
W1	CABLE, USB–C to USB–C, 5A Compliant
W2	CABLE, USB–Micro–B to USB–A, Data Cable
W3–W5	CABLE, Dynamixel TTL Bus Cable
W6–W7	CABLE, Dynamixel TTL Bus to OpenCM Cable
E1–E2	FERRULE, AWG12
P1–P4	CONNECTOR, JST–XHP–2 & SXH–001T–P0.6
P5	CONNECTOR, XT30
M1–M4	MOTOR, TT
SRV1–SRV5	SERVO, DYNAMIXEL XM430–W210–T
BATTERY1	BATTERY PACK, Three Cells LiPo
LIDAR1	LIDAR, NEATO XV11
APM1	Actuation and Power Supply Module
CPM1	Computation and Perception Module

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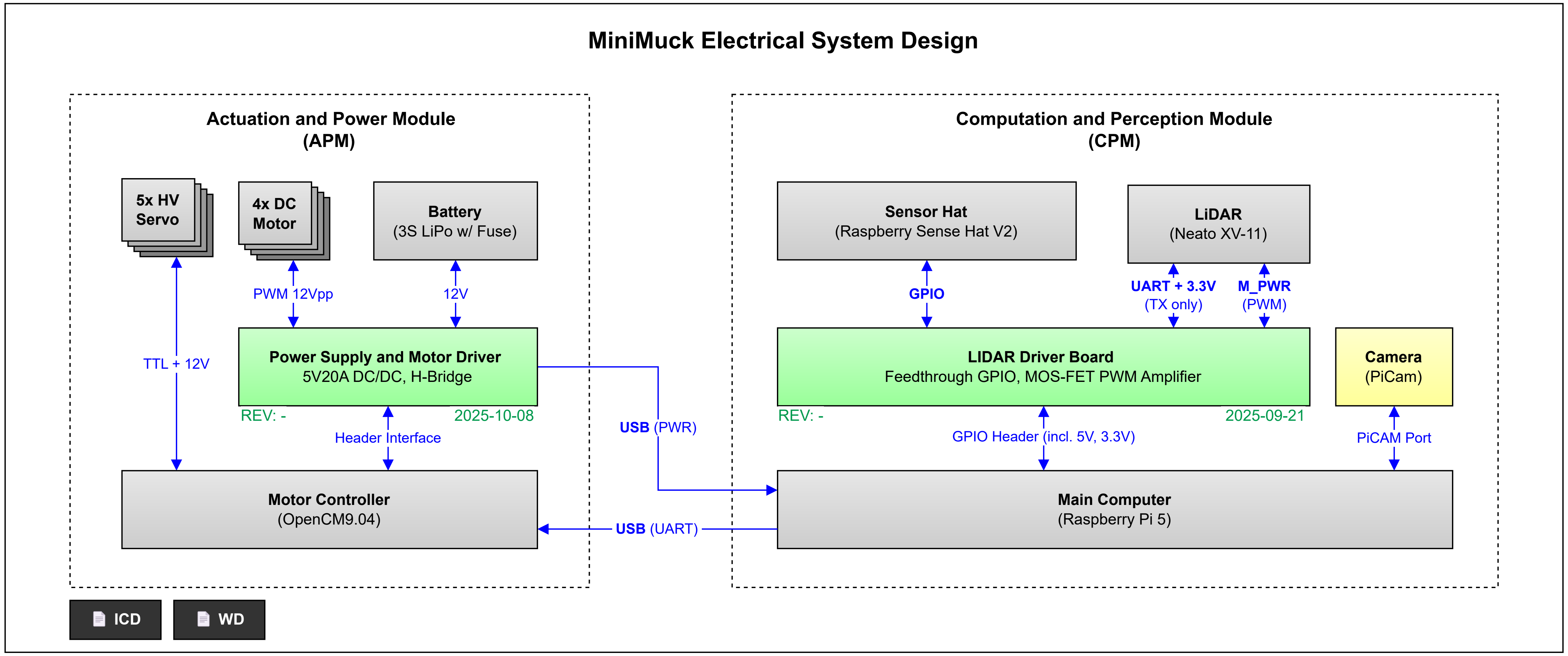
Wiring Diagram
MiniMuck

Sheet: /
File: minimuck.kicad_sch

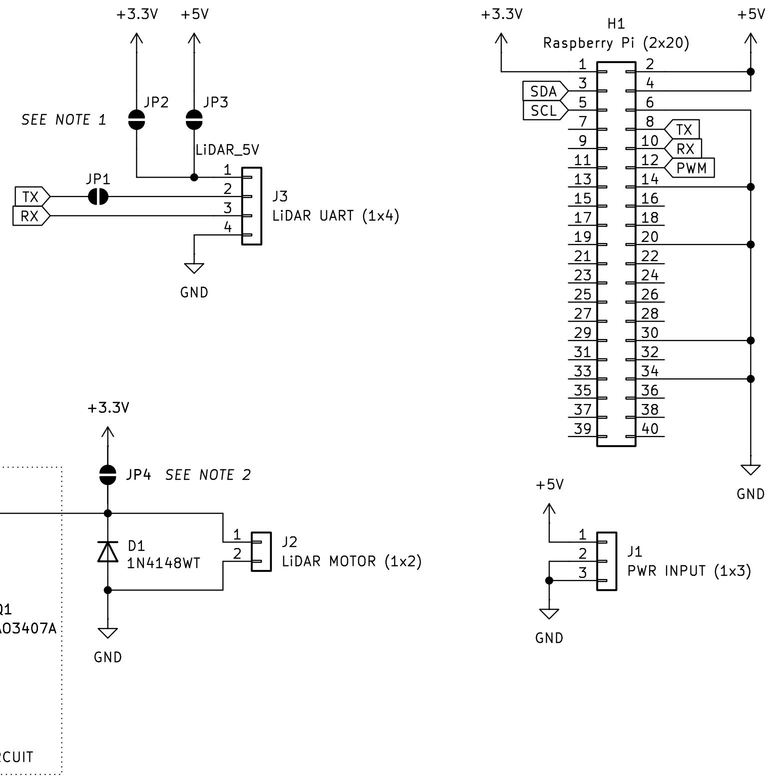
Wiring Diagram

Size: A4	Date: 2025–10–30	**Rev: –**
Designed by Herman Darjes for MiniMuck		Page: 1/1


MiniMuck Electrical System Design
Actuation and Power Module
(APM)
5x HV
Servo
4x DC
Motor
Battery
(3S LiPo w/ Fuse)
PWM 12Vpp
12V
TTL + 12V
Power Supply and Motor Driver
5V20A DC/DC, H-Bridge
REV: -
2025-10-08
Header Interface
Motor Controller
(OpenCM9.04)
USB (PWR)
USB (UART)
Computation and Perception Module
(CPM)
Sensor Hat
(Raspberry Sense Hat V2)
LiDAR
(Neato XV-11)
GPIO
UART + 3.3V
(TX only)
M_PWR
(PWM)
LIDAR Driver Board
Feedthrough GPIO, MOS-FET PWM Amplifier
REV: -
2025-09-21
Camera
(PiCam)
GPIO Header (incl. 5V, 3.3V)
PiCAM Port
Main Computer
(Raspberry Pi 5)
ICD
WD

NOTE 1: SOLDER BRIDGE: JP1 TO USE TX. JP2 FOR 3.3V. JP3 FOR 5V. JP2 AND JP3 CANNOT BE SOLDERED AT THE SAME TIME.

NOTE 2: SOLDER BRIDGE: JP4 FOR UNCONTROLLED 3.3V ONLY IF Q1 IN MOTOR FEEDBACK CONTROL CIRCUIT IS UNPOPULATED



Electrical Schematic
Computation and Perception Module
MiniMuck

Sheet: /
File: MiniMuck.kicad_sch

Title: CPM LiDAR Driver

Size: A4	Date: 2025-08-28	**Rev: –**
KiCad E.D.A. 9.0.4		Id: 1/1

Test Report

MiniMuck

Date:	2025-09-15	**Performed by:**	Herman Darjes Ask Helmersen
Place:	Kongsberg, The Cave	**Documented by:**	Herman Darjes

✔ APPROVED

Herman Darjes 2025-09-15

✔ RELEASED

Herman Darjes 2025-09-15

1 TEST EQUIPMENT

- Raspberry Pi
- Neato XV11 LIDAR
- Analog Discovery
- CPM Control & Interface Board
- 220Ω resistor
- Breadboard
- Jumper Wires

2 ACRONYMS & ABBRIVIATIONS

APM Actuation and Power Module

CPM Computation and Perception Module

CIB Control and Interface Board

LIDAR Light Detection and Ranging

PWM Pulse Width Modulation

PMOS P-channel MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor)

UART Universal Asynchronous Receiver-Transmitter

GPIO General Purpose Input/Output

IAW In Accordance With

3 VERIFY PWM PIN ON PI

Connected Analog Discovery to Raspberry Pi to check if the PWM pin (GPIO 18) functions properly, to rule this out in case of issues.

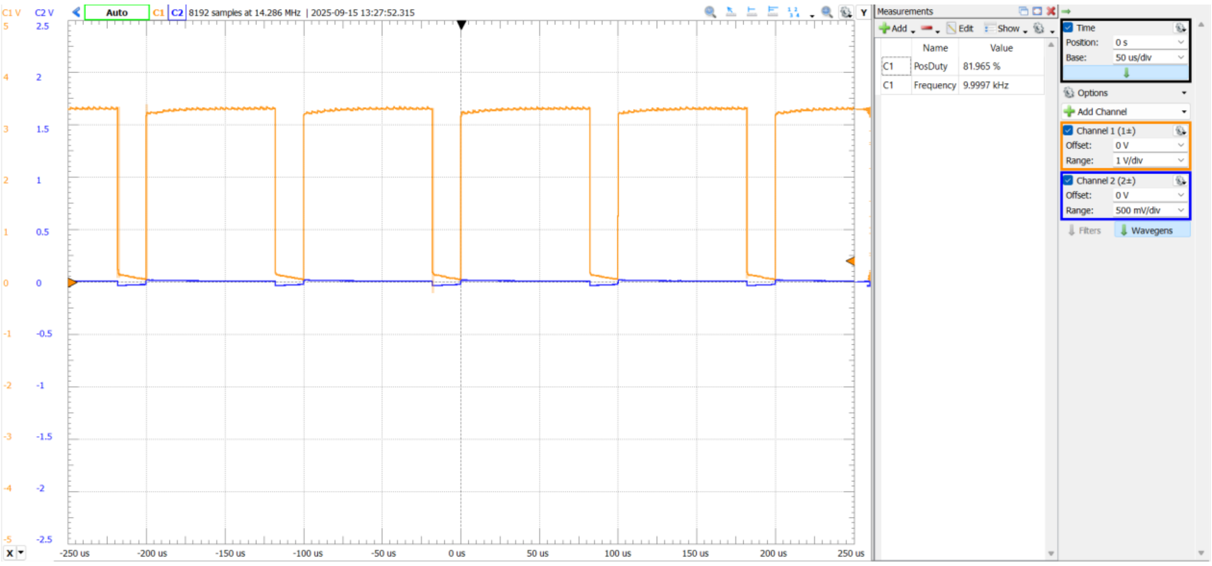


Figure 1: PWM control on Raspberry Pi 5

4 ASSEMBLY

The board is assembled iaw. CPM CIB Electrical Schematic and prototyping board setup.

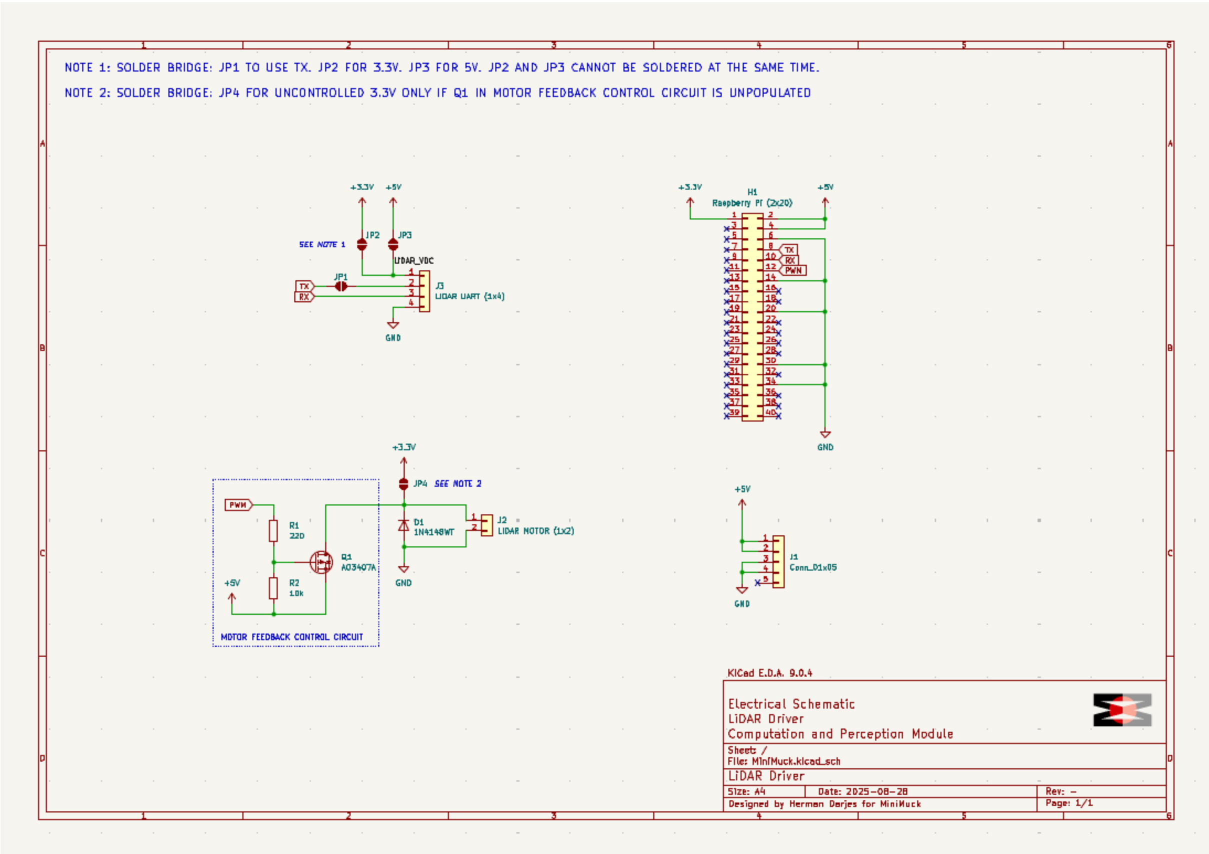


Figure 2: Electrical Schematic CPM:CIB

4.1 Configuration

Parameter	Configuration
JP1	Open
JP2	**Closed**
JP3	Open
JP4	Open

Table 1: Configuration of Schematic Variables

4.2 Inspection

Verification Method: Continuity test of each net iaw. CPM Electrical Schematic

Error	Resolution
1. Missing wire	Connect Wire
2. Missing connection from R2 to Q1:D	Add jumper
3. LiDAR TX connected to Pi TX	Connecter to Pi RX

Table 2: Non Conformances

4.2.1 Continuity Test - Power Net

From	To	Measurement	Expected
+5V	GND	1364Ω	Through Semiconductor (1kΩ range)
+3V3	GND	>200MΩ	No connection
GND_L	GND_R	0.1Ω	~0Ω

Table 3: Continuity of Power Nets

4.2.2 Continuity Test – Connectors

No pins shorted except J1:1-2 and J1:3-4, which is correct

4.2.3 Visual Inspection

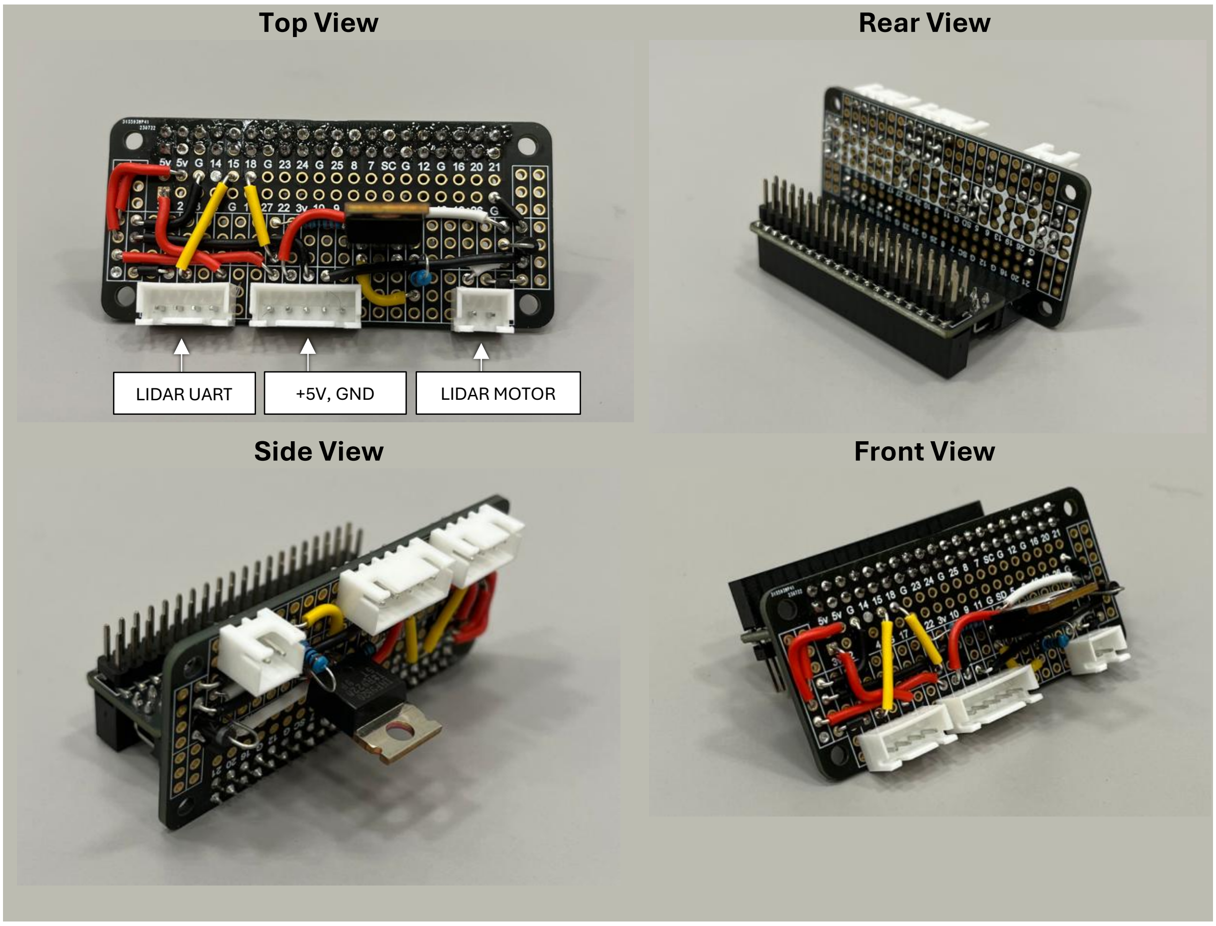


Figure 3: Visual Inspection

✔ **Inspection passed with satisfactory results.**

5 TEST

5.1 Standalone Test

220 Ω load resistor to limit current draw for on test equipment.

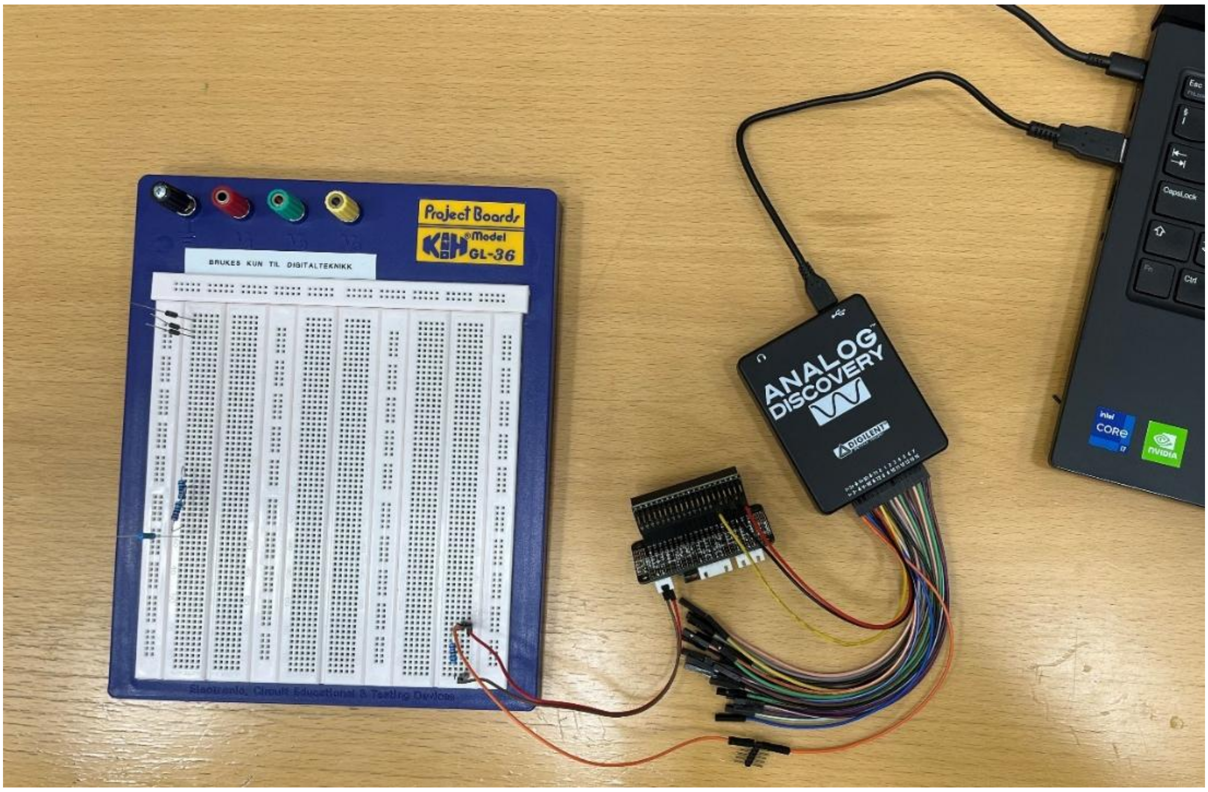


Figure 4: Test Setup for Standalone Test

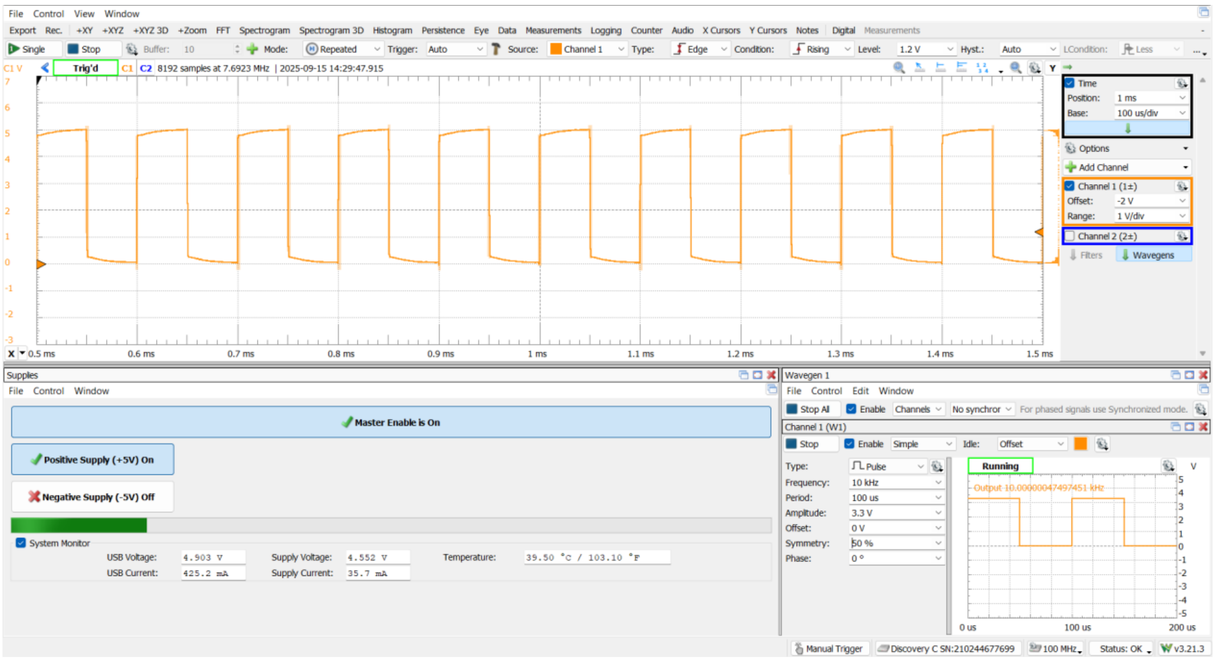


Figure 5: Results from Standalone Test

✔ **Test passed with satisfactory results.**

5.2 In Module Test

Using test software from Ask to control motor

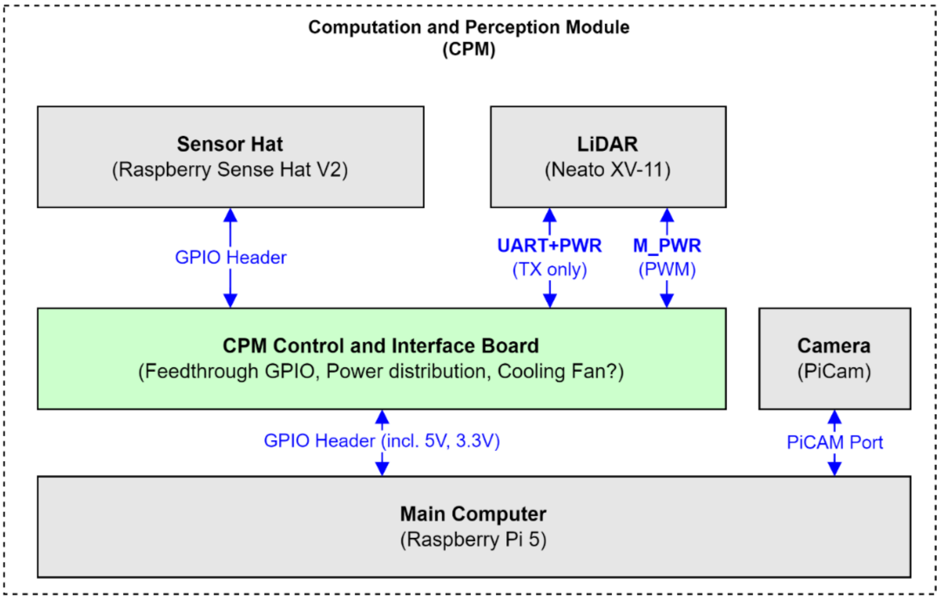


Figure 6: CPM System Design

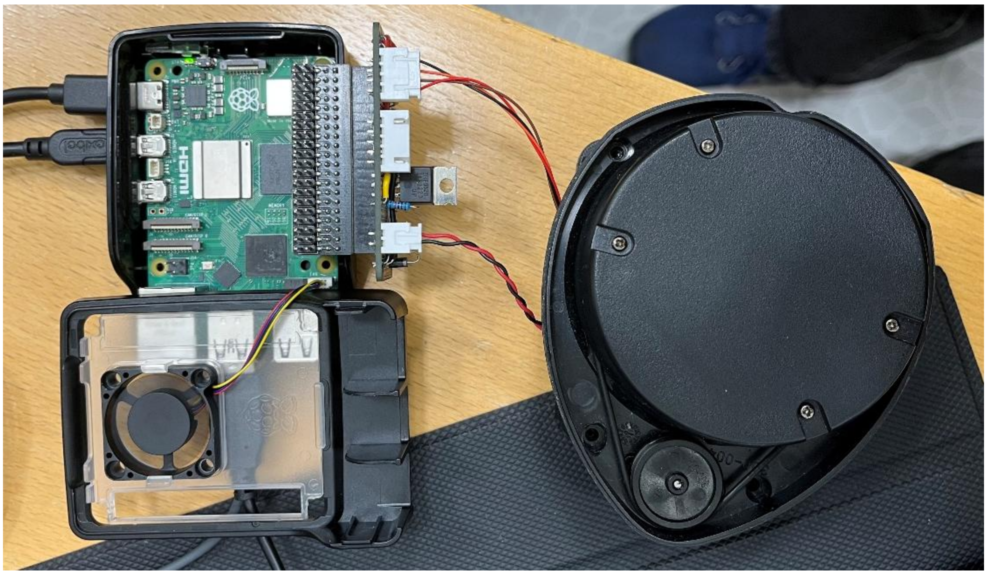


Figure 7: Test Setup for In Module Test

- The UART on the Pi is High Impedance and pulls down when from software, which is to our advantage since a PMOS controller with pullup on the gate was selected to drive the LiDAR.
- Motor can be controlled with PWM from software. Could not test LiDAR readings due to code not available following the change to Ubuntu from Raspbian, however this function can be assumed with high probability based on continuity testing, and prior testing with jumpers.

✔ **Test passed with satisfactory results.**

5.3 In System Test

Not applicable at this stage due to lack of a complete system. Figure shows the intended system for integration.

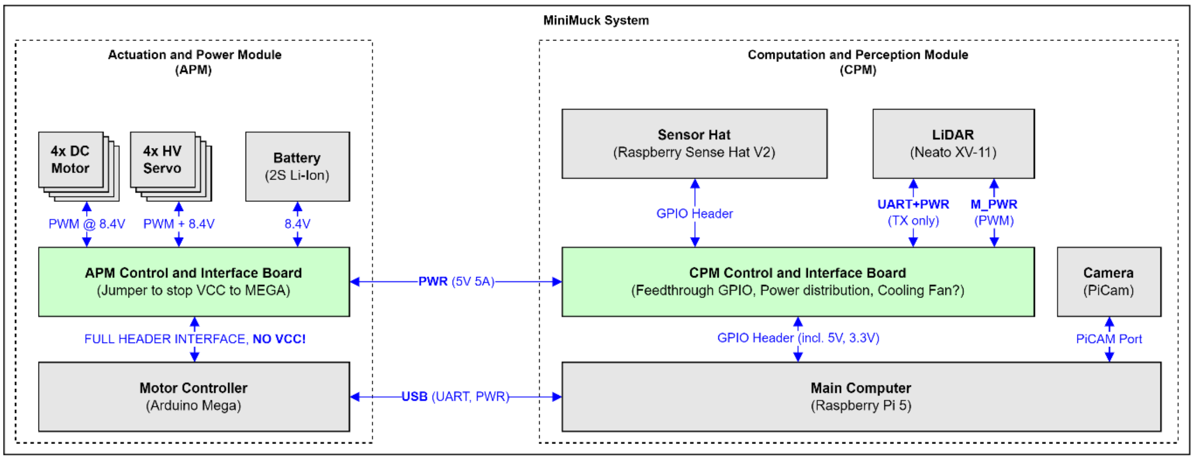


Figure 8: MiniMuck System Design

6 CONCLUSION

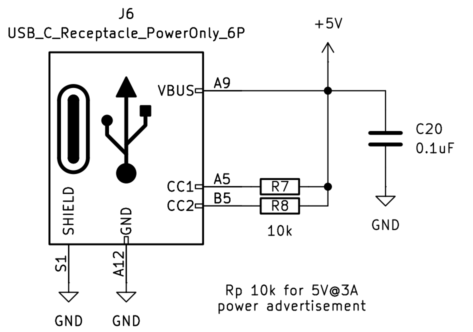
Unit has passed inspection and tests with satisfactory results, and can be used with the system

MiniMuck 2025

NOTE 1: Cable to battery should have fuse.

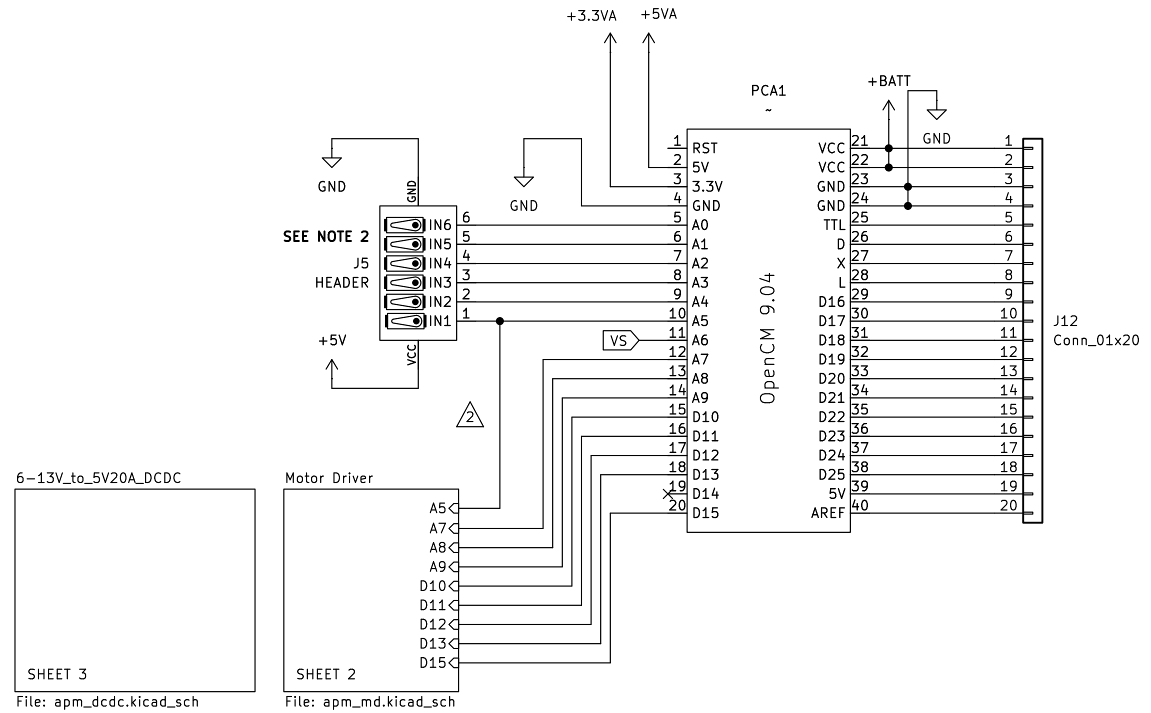
NOTE 2: A0–A1 are inputs only. Max 3.3V. A2–A5 are inputs and outputs 3.3V

USB Power Output 3A

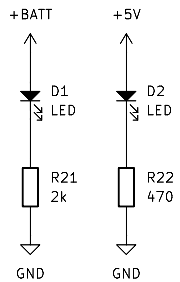


Advertised Current	Rp to 5V
500 mA (Default)	56k
1.5A	22k
3.0A	10k

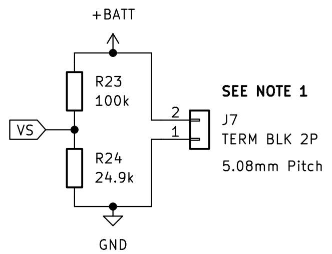
OpenCM 9.04
Microcontroller and Motor Driver



Power Indicators



Power Input



$\boxed{R_{23} = 100k\Omega, \quad V_{IN(max)} = 16V, \quad V_{AREF} = 3.3V}$

$$V_{AREF} = V_{IN(\max)}\frac{R_{23}}{R_{23}+R_{24}} \Rightarrow R_{24} = R_{23}\cdot\frac{V_{AREF}}{V_{IN(\max)} - V_{AREF}}$$

$$\Rightarrow R_{24} = 100k\Omega \cdot \frac{3.3V}{16V - 3.3V} = 26k\Omega \Rightarrow I_{max} = \frac{16V}{126k\Omega} \approx 0.1mA$$

Advisory Sheet

SHEET 4

File: mm_advisory.kicad_sch

Block Diagram

SHEET 5

File: BD.kicad_sch

Notes for Revision A:
– [*] Add TVS Diode
– [1] Remove R13–R20
– [2] U4:IN2 to U5:A5 instead of D15 for PWM capability

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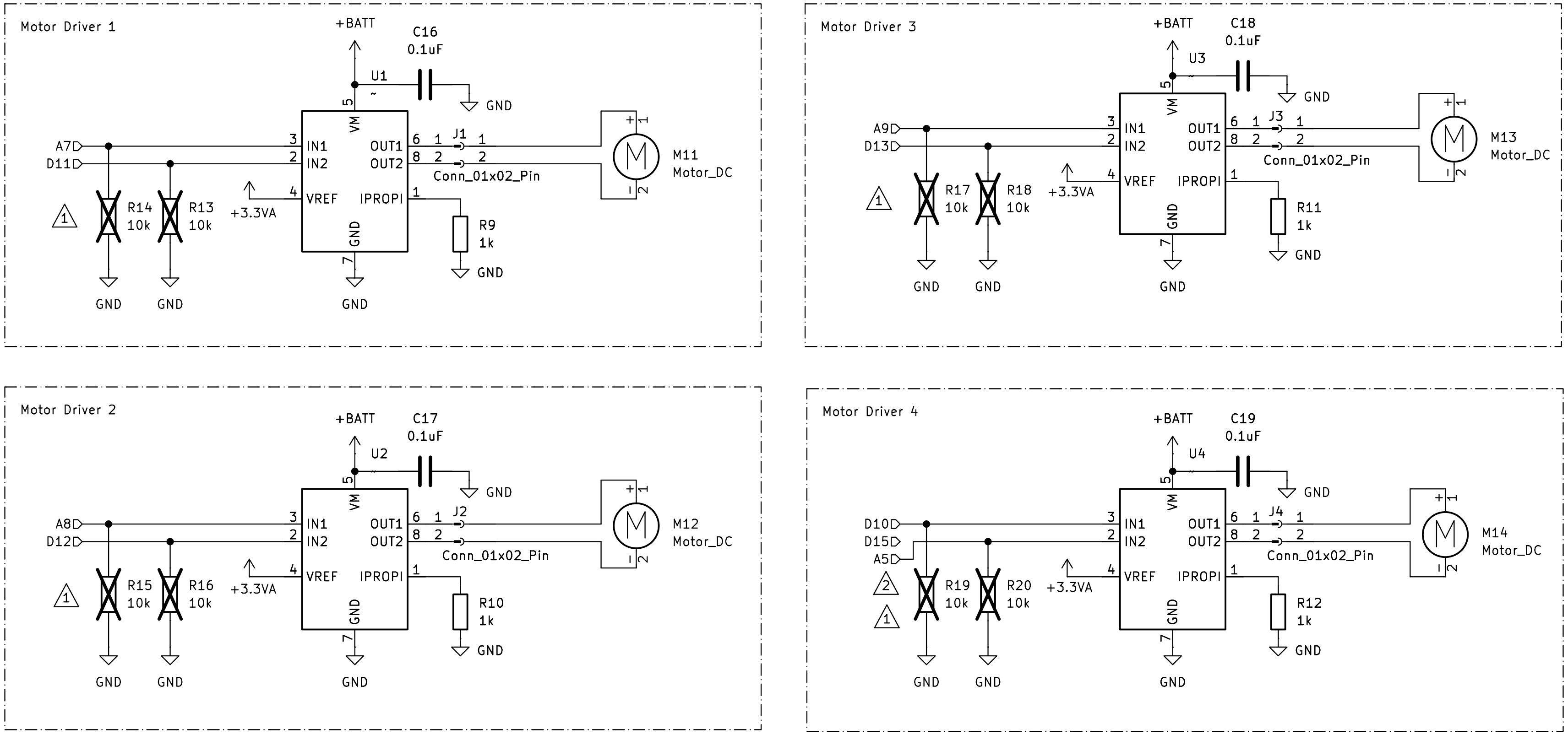
Electrical Schematic
APM
Mini Muck

Sheet: /
File: APM.kicad_sch

Actuation and Power Module

Size: A4 | Date: | **Rev: –**

Designed by Herman Darjes for MiniMuck | Page: 1/5



1	**Change 1**	: IC has integrated pull down resistors. R13–R20 is redundant.
	Resolution H.D 2025-10-16	: Do not populate R13–R20
2	**Change 2**	: High-Z on outputs when IN1=0 and IN2=0 stops motor from spinning
	Resolution H.D 2025-10-26	: Connect PWM pin A5 and remove connection to D15 to get PWM on IN2

MAX CURRENT = 2.2A,
V_REF = 3.3V

I_PROPI = (I_LS1+I_LS2)*A_IPROPI

I_TRIP * A_IPROPI = V_VREF * R_IPROPI =>

R_IPROPI = I*A/V = 2.2A * 1500 uA/A / 3.3V = 1000 Ohm

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Electrical Schematic
APM
Mini Muck

Sheet: /Motor Driver/
File: apm_md.kicad_sch

Actuation and Power Module

Size: A4	Date:	**Rev: –**
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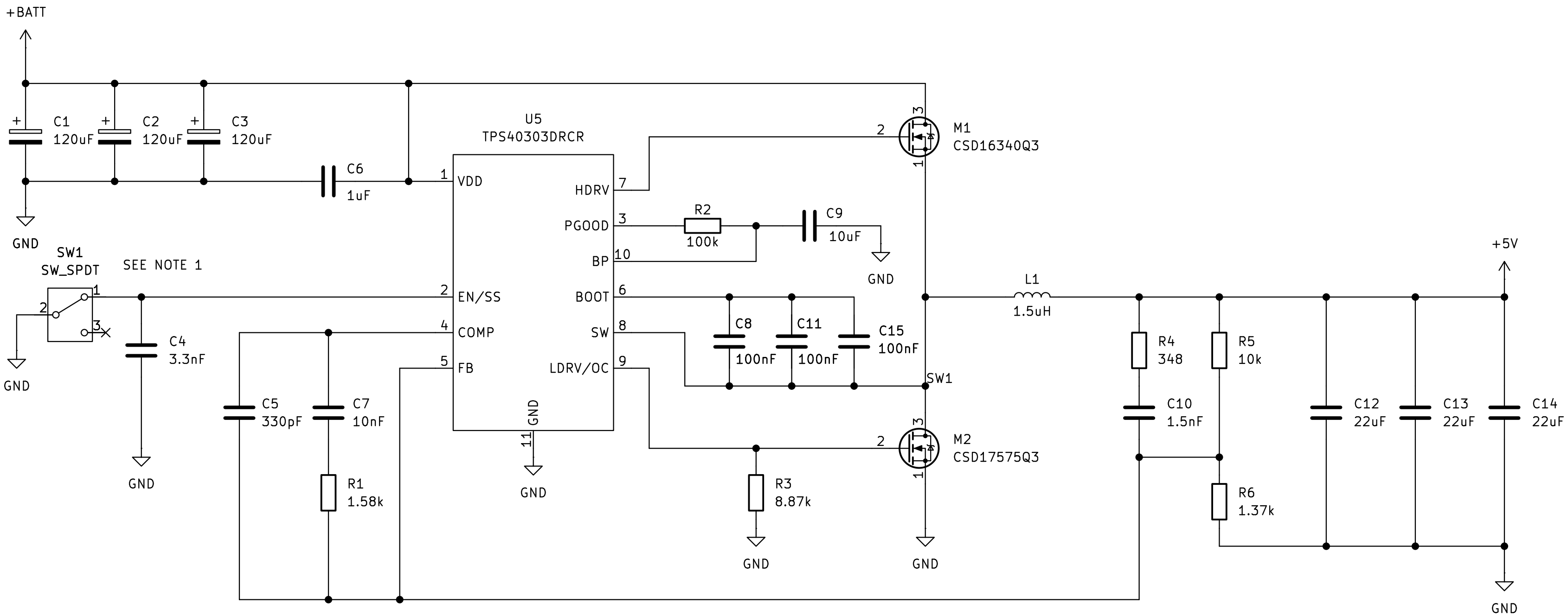
DCDC Power Supply

NOTE 1: Switch is shown in off position



Original Design Copyright © 2025, Texas Instruments Incorporated

WEBENCH® Design Report TPS40303DRCR:
TPS40303DRCR 6V–13V to 5.00V @ 20A August 28, 2025 16:49:24 GMT–05:00

See attachment for more information.

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Electrical Schematic
APM
Mini Muck

Sheet: /6–13V_to_5V20A_DCDC/
File: apm_dcdc.kicad_sch

Actuation and Power Module

Size: A4	Date:	**Rev: –**
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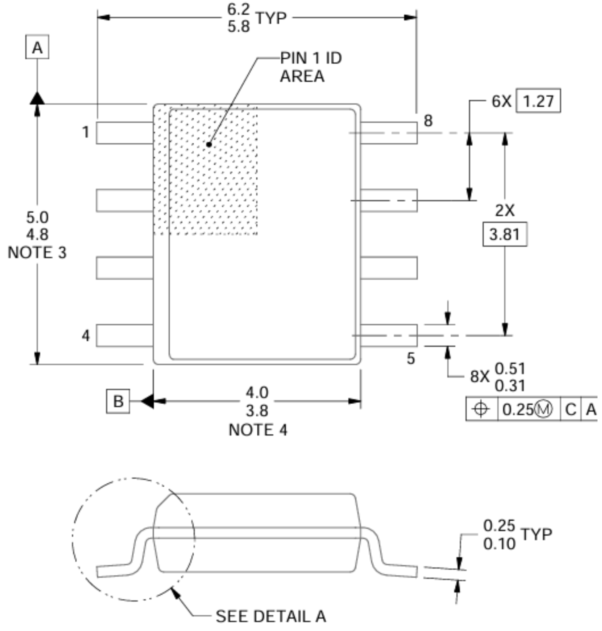
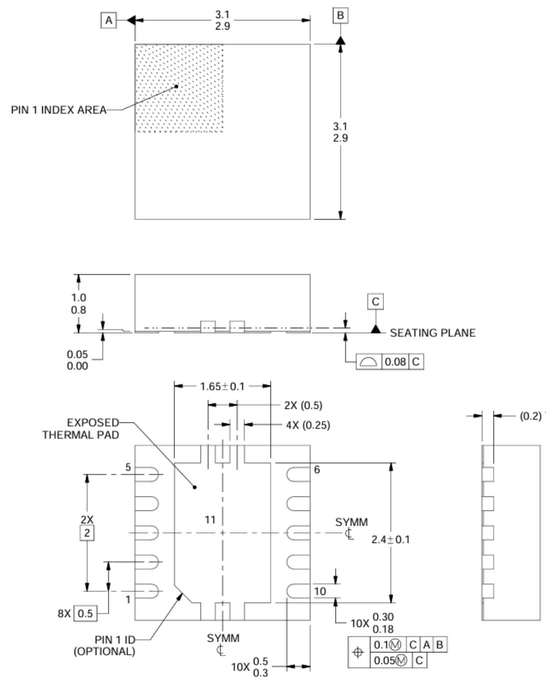
ADVISORY SHEET FOR ASSEMBLY

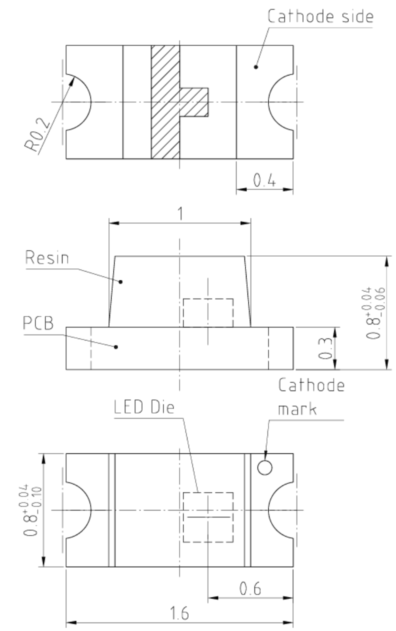
U1–U4



U5



D1–D2



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Electrical Schematic
APM
Mini Muck

Sheet: /Advisory Sheet/
File: mm_advisory.kicad_sch

Actuation and Power Module

Size: A4	Date:	**Rev: –**
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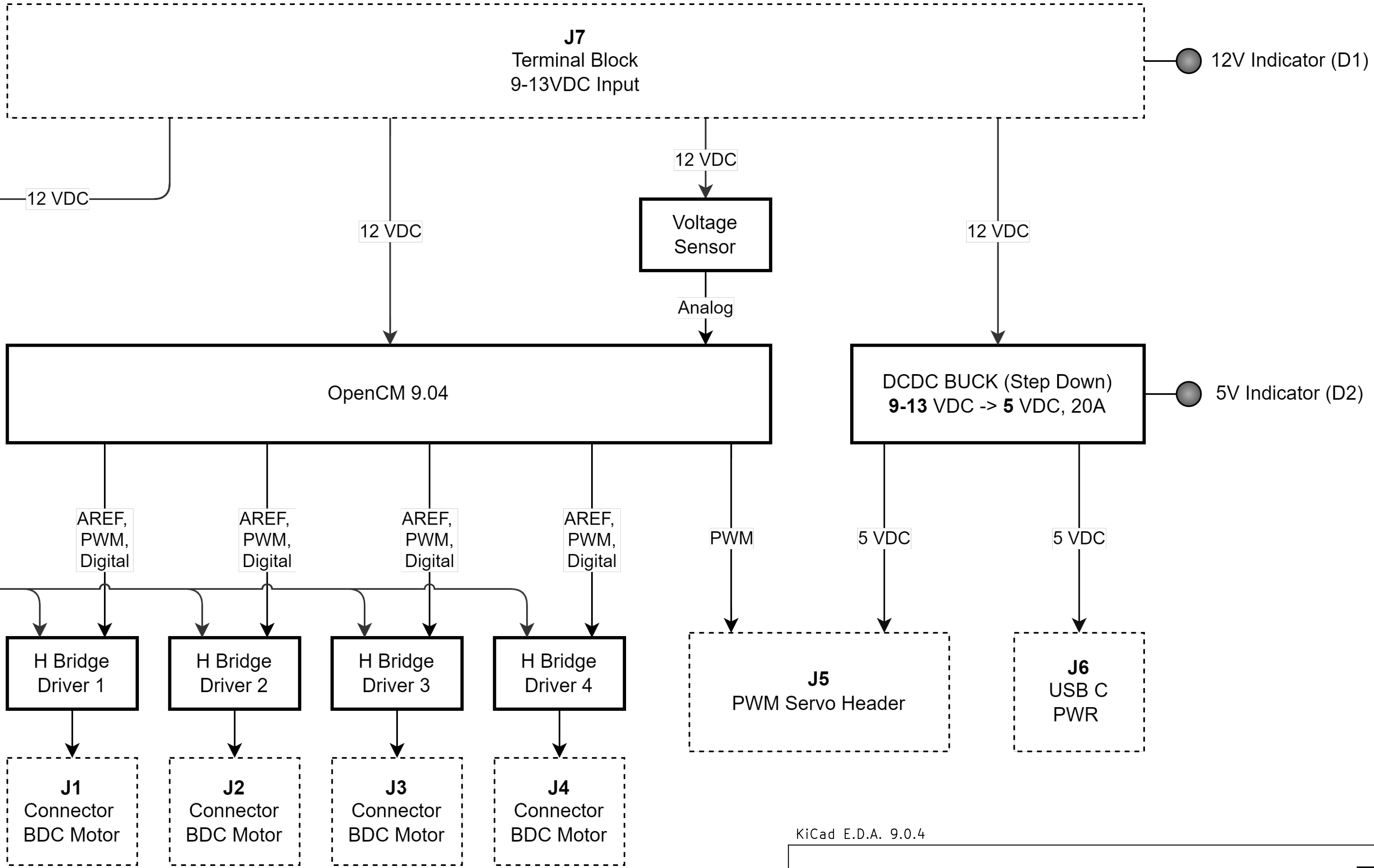
BLOCK DIAGRAM



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Electrical Schematic
APM
Mini Muck

Sheet: /Block Diagram/
File: BD.kicad_sch

Actuation and Power Module

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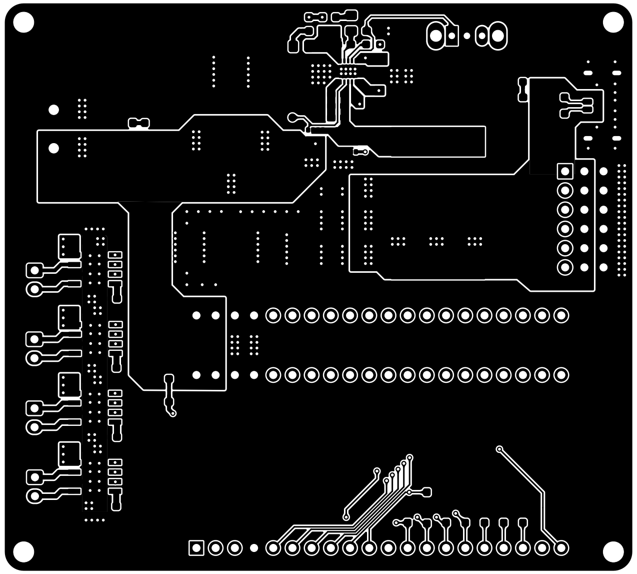

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Board Layout
Actuation and Power Supply Module
MiniMuck

Sheet:
File: APM.kicad_pcb

Board Layout

Size: A4	Date: 2025-11-23	**Rev: –**
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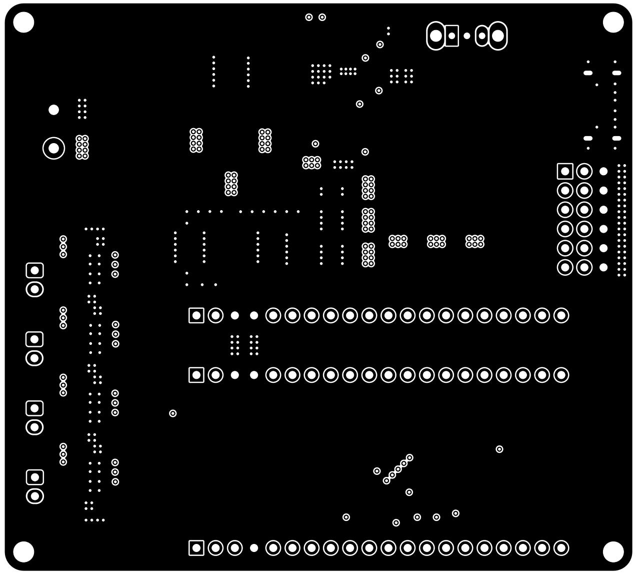

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Board Layout
Actuation and Power Supply Module
MiniMuck

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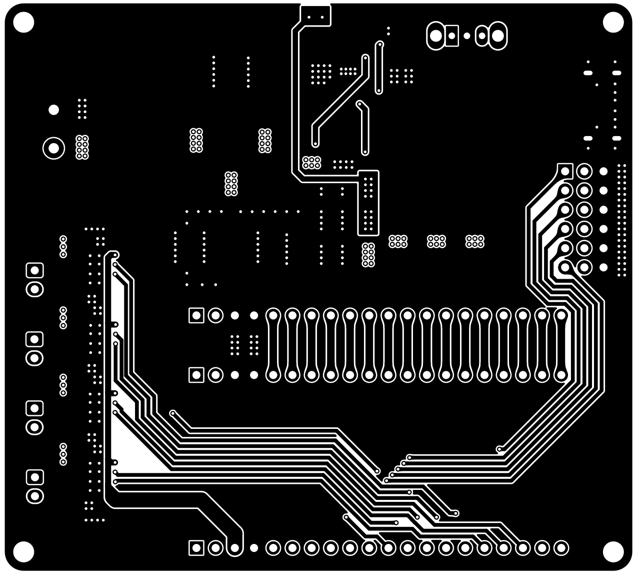

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Board Layout
Actuation and Power Supply Module
MiniMuck

Sheet:
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Board Layout

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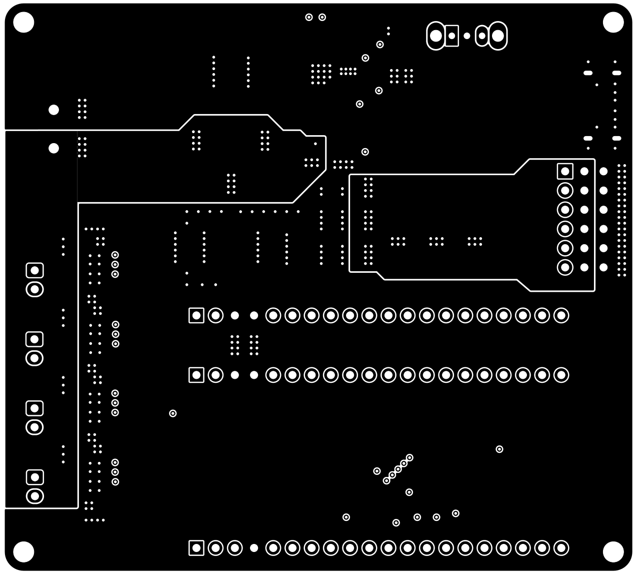

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Board Layout Actuation and Power Supply Module MiniMuck		
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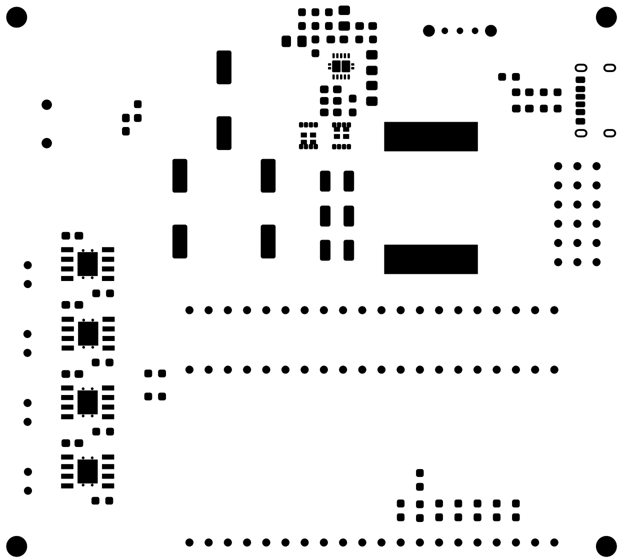

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Board Layout
Actuation and Power Supply Module
MiniMuck

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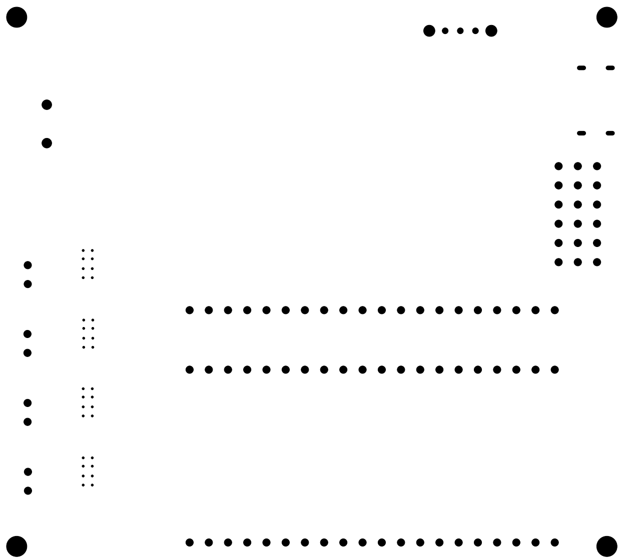

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Actuation and Power Supply Module
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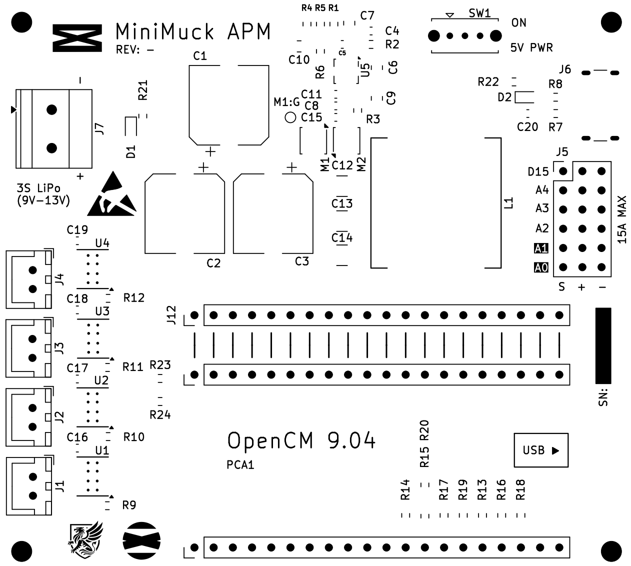

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Board Layout
Actuation and Power Supply Module
MiniMuck

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Board Layout

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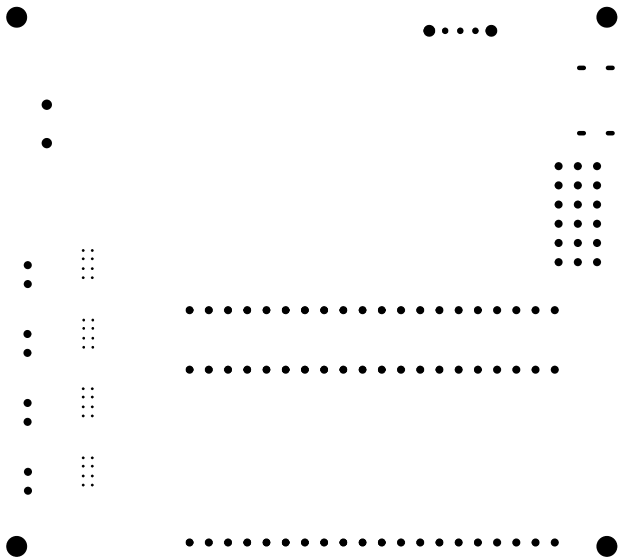

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Board Layout
Actuation and Power Supply Module
MiniMuck

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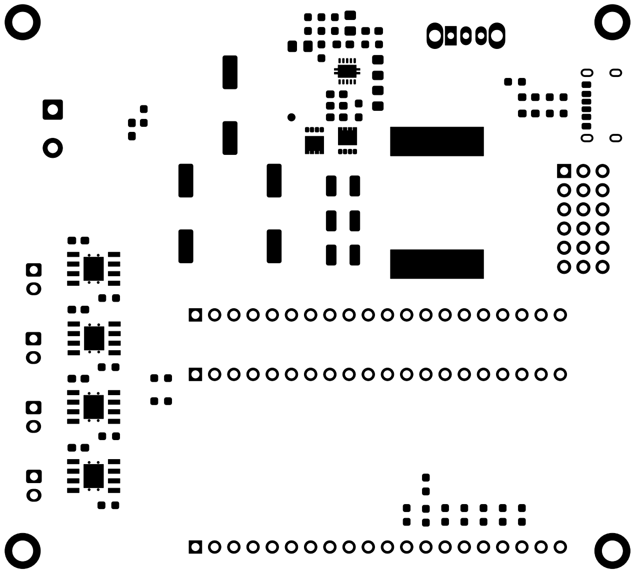

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Board Layout
Actuation and Power Supply Module
MiniMuck

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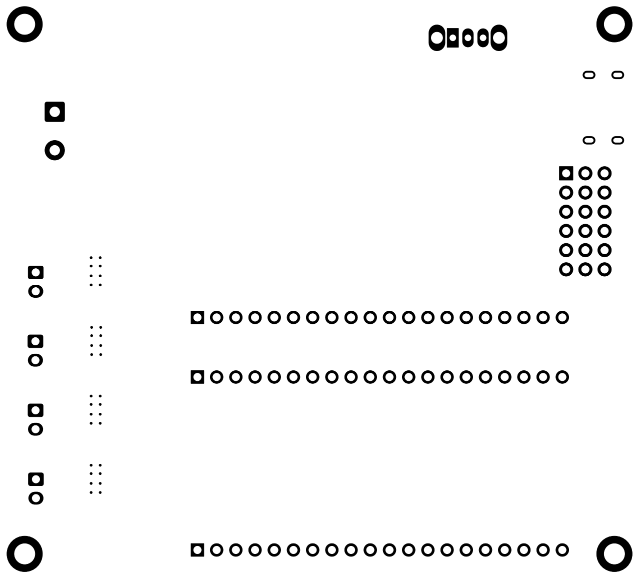

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Board Layout Actuation and Power Supply Module MiniMuck	
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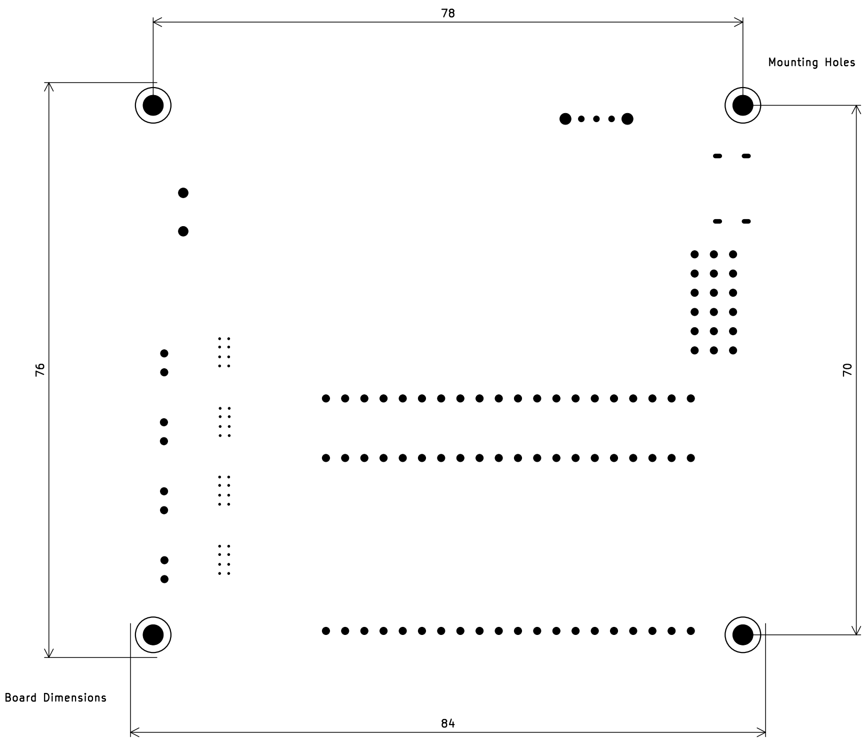
Board Layout	
Size: A4 Date: 2025-11-23	**Rev: -**
Designed by Herman Darjes for MiniMuck	Page: 10/12



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Board Layout
Actuation and Power Supply Module
MiniMuck

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Board Layout

Size: A4	Date: 2025-11-23	**Rev: –**
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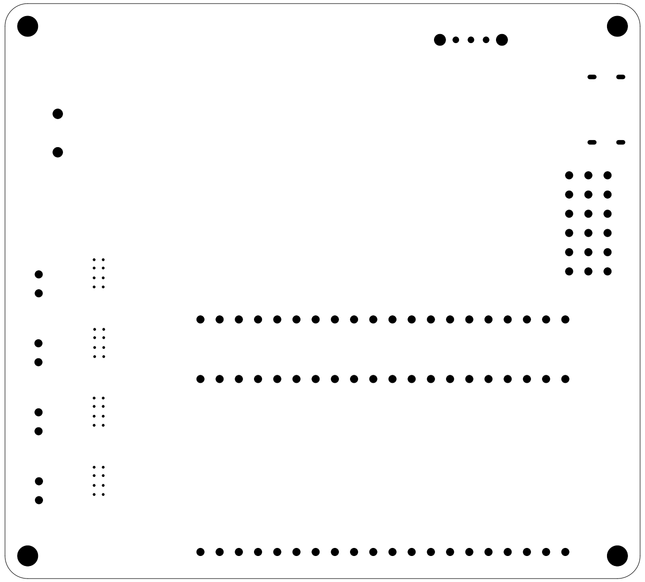

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Board Layout
Actuation and Power Supply Module
MiniMuck

Sheet:
File: APM.kicad_pcb

Board Layout

Size: A4 | Date: 2025-11-23 | **Rev: -**

Designed by Herman Darjes for MiniMuck | Page: 12/12

Bill of Materials

Actuation and Power Module

Reference	Description	Qty	Value	MFR	MFR_PN
C1,C2,C3	Cin	3	120uF	Panasonic	35SVT120M
C4	Css	1	3.3nF	MuRata	GRM188R71E332KA01D
C5	Ccomp2	1	330pF	MuRata	GRM1885C2A331JA01D
C6	Cvcc	1	1uF	Taiyo Yuden	TMK212BJ105KG-T
C7	Ccomp	1	10nF	TDK	C2012C0G1H103K060AA
C8,C11,C15	Cbst	3	100nF	Kemet	C0603C104M3VACTU
C9	Cbyp	1	10uF	Kemet	C0805C106K8PACTU
C10	Ccomp3	1	1.5nF	MuRata	GRM2195C1H152JA01D
C12,C13,C14	Cout	3	22uF	Taiyo Yuden	TMK325B7226KMHP
C16,C17,C18,C19,C20	Unpolarized capacitor	5	0.1uF	YAGEO	CC0603KRX7R7BB104
D1,D2	LED, Red	2	LED	ams-OSRAM USA INC.	LS Q976-NR-1-0-20-R18
J1,J2,J3,J4	Generic connector, single row, 01x02, script generated	4	Conn_01x02_Pin	JST Sales America Inc.	B2B-XH-A
J6	USB Power-Only 6P Type-C Receptacle connector	1	USB_C_Receptacle_PowerOnly_6P	Same Sky (Formerly CUI Devices)	UJC-H-G-SMT-2-P6-TR
J7	TERM BLK 2P SIDE ENT 5.08MM PCB	1	TERM BLK 2P	Phoenix Contact	1888687
J12	Generic connector, single row, 01x20, script generated (kicad-library-utils/schlib/autogen/connector/)	1	Conn_01x20	Amphenol ICC (FCI)	10129378-920001BLF
L1	Inductor	1	1.5uH	Vishay-Dale	IHLP6767GZER1R5M01
M1	25-V N-Channel NexFET™ Power MOSFET	1	CSD16340Q3	Texas Instruments	CSD16340Q3
M2	30-V N-Channel NexFET™ Power MOSFETs	1	CSD17575Q3	Texas Instruments	CSD17575Q3
PCA1	Microcontroller Unit (MCU)	1	OpenCM 9.04 B-Type	Robotis	OpenCM9.04_B
R1	Rcomp	1	1.58k	Vishay-Dale	CRCW06031K58FKEA
R2,R23	Resistor,Rpgood	2	100k	Vishay-Dale	CRCW0603100KFKEA
R3	Rs	1	8.87k	Vishay-Dale	CRCW06038K87FKEA
R4	Rcomp2	1	348	Vishay-Dale	CRCW0603348RFKEA
R5,R7,R8	Resistor,Rfbt	3	10k	Vishay-Dale	CRCW060310K0FKEA
R6	Rfbb	1	1.37k	Vishay-Dale	CRCW06031K37FKEA
R9,R10,R11,R12	Resistor	4	1k	Stackpole Electronics Inc	RMCF0603FT1K00
R13,R14,R15,R16,R17,R18,R19,R20	Resistor	8	10k	Vishay-Dale	CRCW060310K0FKEA
R21	Resistor	1	2k	KOA Speer Electronics, Inc.	RK73B1JTTD202J
R22	Resistor	1	470	Stackpole Electronics Inc	RMCF0603JT470R
R24	Resistor	1	24.9k	YAGEO	RC0603FR-0724K9L
SW1	Switch, single pole double throw	1	SW_SPDT	C&K	OS102011MS2QS1
U1,U2,U3,U4	35-V, 3.7-A H-bridge motor driver with integrated current regulation & current-sense feedback	4	DRV8231ADDAR	Texas Instruments	DRV8231ADDAR
U5	3-V to 20-V, 25-A, 300-kHz synchronous buck controller with FSS	1	TPS40303DRCR	Texas Instruments	TPS40303DRCR

Test Report

MiniMuck

Date:	2025-11-17	**Performed by:**	Herman Darjes
Place:	Kongsberg, The Cave	**Documented by:**	Herman Darjes

Preliminary

Herman Darjes 2025-11-17

1 TEST EQUIPMENT

- OpenCM 9.04
- APM Board
- Analog Discovery
- Lab Power Supply
- Breadboard
- Jumper Wires

2 ACRONYMS & ABBRIVIATIONS

APM Actuation and Power Module

CPM Computation and Perception Module

PWM Pulse Width Modulation

UART Universal Asynchronous Receiver-Transmitter

GPIO General Purpose Input/Output

IAW In Accordance With

3 MEASUREMENTS

3.1 Ohm measurements

Without OpenCM 9.04 in socket:

Table 1 Ohm Measurements

Measurement	Result	Pass/Fail
BAT+ GND	>10kOhm	Pass
5V GND	>10kOhm	Pass
5VA GND	>200MOhm	Pass
3.3VA GND	>200MOhm	Pass

3.2 Voltage on VS pin

Table 2 Voltage Measurements

Measurement	Result	Pass/Fail
VS when VBAT = 9V	1.8V	Pass
VS when VBAT = 10V	2.0V	Pass
VS when VBAT = 11V	2.2V	Pass
VS when VBAT = 12V	2.4V	Pass
VS when VBAT = 13V	2.6V	Pass

3.3 Voltage Rail

Table 3 No Load Measurement

Measurement	Result	Pass/Fail
5V Buck No Load	4.95V	Pass

4 MOTOR DRIVER TEST

Using Analog Discovery to test PWM input and output. Using 10k ohm resistor for testing. This does not give realistic response but tests the functionality.

Scope channels looking at separate outputs of the motor driver.

Figure 1 Motor Driver Test IN1

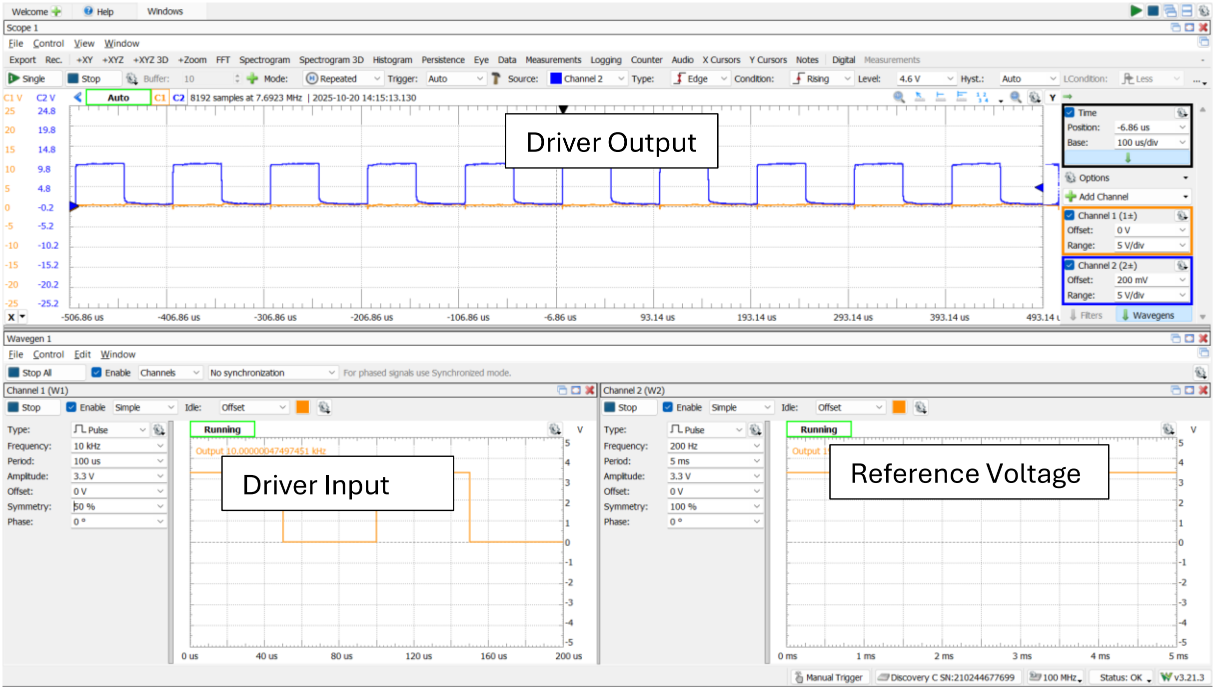
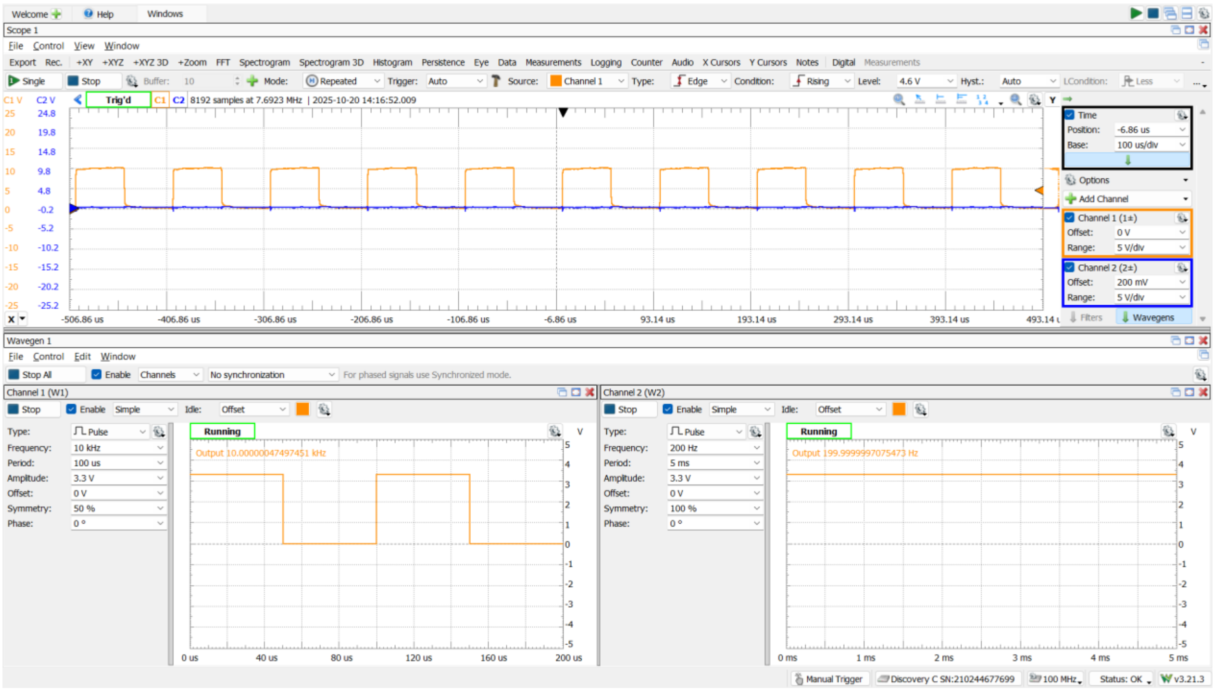


Figure 2 Motor Driver Test IN2



5 TEST WITH OPENCM 9.04

Run test script to see the ADC input for battery voltage. Test servos on 12V and motors.

Table 4 ADC Readings

Battery Voltage	ADC Reading	Pass/Fail
9V	554	Pass
9.5V	583	Pass
10V	613	Pass
10.5V	643	Pass
11V	675	Pass
11.5V	704	Pass
12V	737	Pass
12.5V	766	Pass
13V	798	Pass

6 5V LOAD TEST

Figure 3 Load Test Setup

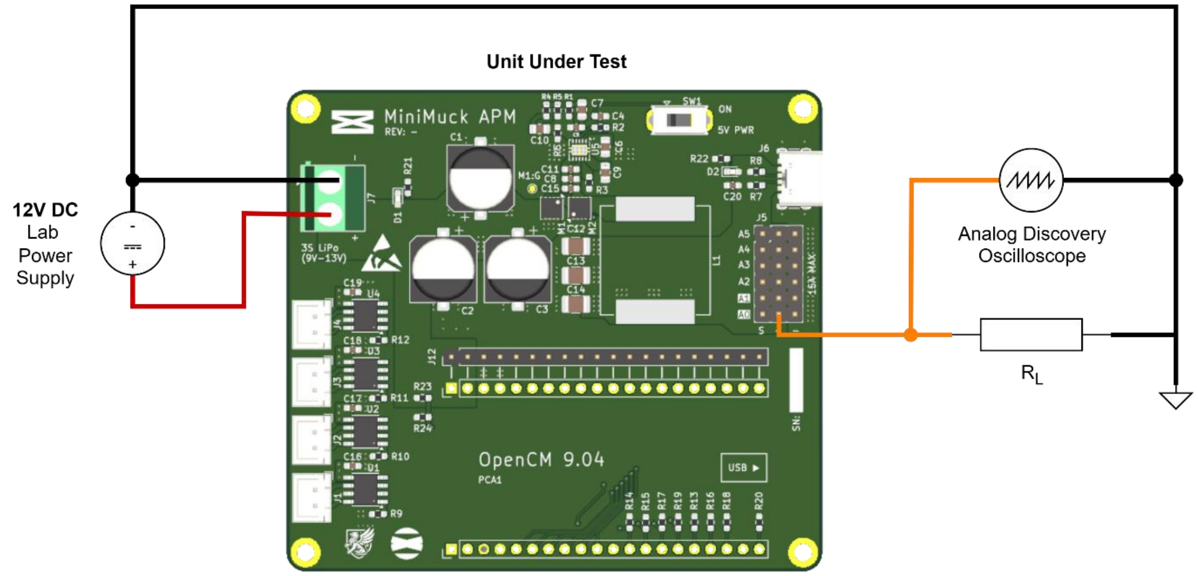


Figure 4 Load Test 1.25A

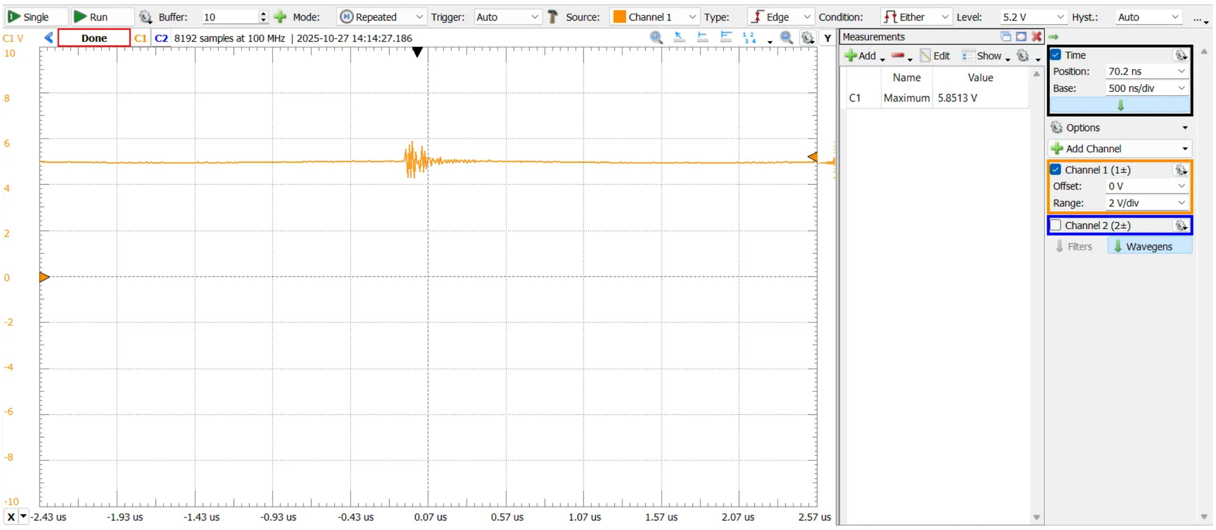


Figure 5 Load Test 2.1A

Figure 6 Steady State Ripple

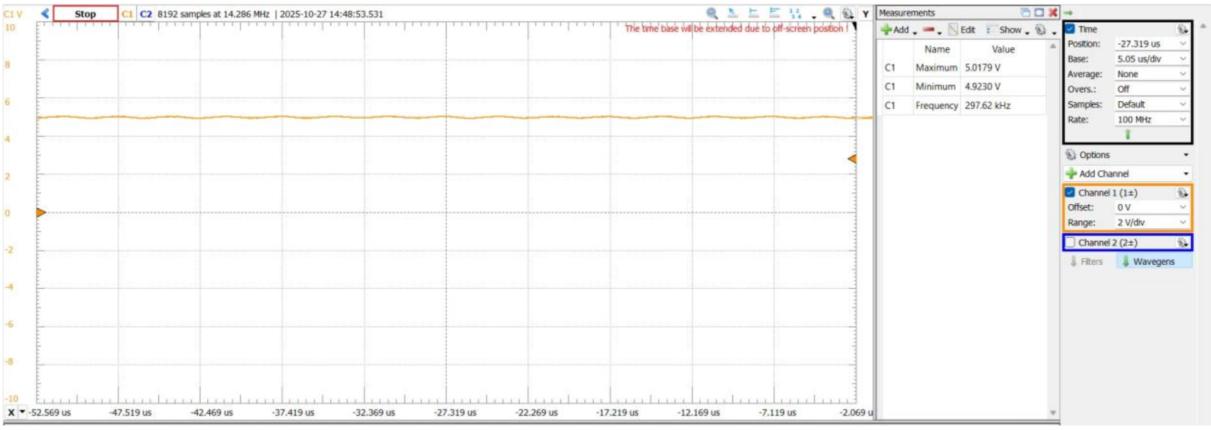
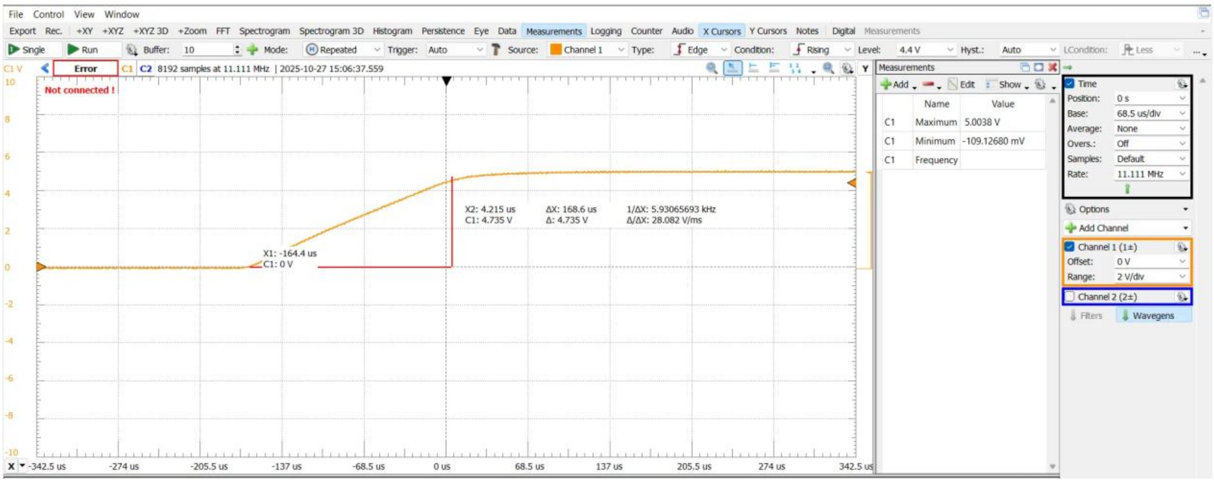


Figure 7 Startup Transient 2.5A (2Ω)



MiniMuck 2025

INTERFACE CONTROL DOCUMENT

MiniMuck

Herman Darjes (251400) 2025-11-03

This document specifies the interface between the APM and the CPM of the Mini Muck. Please refer to this document when referring to the Interface to ensure interfaces are only specified at one place and can therefore only be changed at one place.

APM (ACTUATION AND POWER SUPPLY MODULE)

UART CONTROL

The APM can be controlled by the CPM using UART. An instruction consists of three bytes. The first byte is the opcode, the second byte is the first operand, and the third byte is the second operand.

See the table below for instruction specifics. Byte as hex in normal text, and ASCII in parentheses

<Opcode Byte> <Operand Byte 1> <Operand Byte 2>

Instruction	Opcode	Operand	
Front Left drive with speed and direction	0x41 (A)	Speed (0x00 to 0xFF)	Direction: 0x46 (F) = Forwards Others* = Backwards
Front Right drive with speed and direction	0x42 (B)	Speed (0x00 to 0xFF)	Direction: 0x46 = Forwards Others* = Backwards
Rear Left drive with speed and direction	0x43 (C)	Speed (0x00 to 0xFF)	Direction: 0x46 (F) = Forwards Others* = Backwards
Rear Right drive with speed and direction	0x44 (D)	Speed (0x00 to 0xFF)	Direction: 0x46 = Forwards Others* = Backwards
All Motors Stop	0x4A (J)	Don't Care**	Don't Care**
Turn Direction (degrees)	0x45 (E)	Don't Care**	Servo angle 0x00 to 0xB4
FL Direction (degrees)	0x47 (G)	Don't Care**	Servo angle 0x00 to 0xB4
FR Direction (degrees)	0x48 (H)	Don't Care**	Servo angle 0x00 to 0xB4
RL Direction (degrees)	0x49 (I)	Don't Care**	Servo angle 0x00 to 0xB4
RR Direction (degrees)	0x50 (P)	Don't Care**	Servo angle 0x00 to 0xB4
Request Battery Voltage	0x51 (Q)	Don't Care**	Don't Care**

***** For convention, 0x52 should be used for reverse.

****** Don't care represents a byte which can be anything but must be something.

CPM (COMPUTATION AND PERCEPTION MODULE)

TBD

Power Budget

MiniMuck

Herman Darjes (254100) 2025-11-06

1 TABLE OF CONTENTS

2 TABLE OF TABLES

3 SCOPE

This document provides the power budget of the MiniMuck with information about the consumption of each component, the configuration and power loss and battery operating time calculations.

4 EQUIPMENT

TABLE 1 EQUIPMENT TABLE

Name	Current		Nominal Voltage	Power	
	Nominal	Max		Nominal	Max
Raspberry Pi	2000mA	5000mA	5V	10.0W	25.0W
OpenCM 9.04	50mA	200mA	12V	0.6W	2.4W
TT DC Motor	155mA	1200mA	4.5V	0.8W	5.4W
Dynamixel XM430-W210-T	200mA	2300mA	12V	2.4W	27.6W
LiDAR	170mA	500mA	3.3V	0.6W	1.7W

5 LOSS CASCADE

TABLE 2 POWER LOSS CASCADE

<table>
<tr><th colspan="4">Power Source (Battery)</th></tr>
<tr><th colspan="2">5V DC/DC (95%)</th><th>Motor Driver (95%)</th><td rowspan="3">• 4 x Servo XM430
• OpenCM 9.04</td></tr>
<tr><td rowspan="2">• Raspberry Pi</td><th>LiDAR Driver (95%)</th><td rowspan="2">• 4 x TT DC Motor</td></tr>
<tr><td>• LiDAR</td></tr>
</table>

6 CONFIGURATION BUDGET

TABLE 3 MAXIMUM POWER

Name	Quantity	Max Power	Loss %	Total
Raspberry Pi	1	25.0W	5%	26.3W
OpenCM 9.04	1	2.4W	-	2.4W
TT DC Motor	4	5.4W	5%	22.7W
Dyamixel XM430-W210-T	5	27.6W	-	138.0W
LiDAR	1	1.7W	10%	1.9W
TOTAL				**191.3W**

TABLE 4 NOMINAL POWER

Name	Quantity	Nominal Power	Loss %	Total
Raspberry Pi	1	10.0W	5%	10.5W
OpenCM 9.04	1	0.6W	-	0.6W
TT DC Motor	4	0.8W	5%	3.4W
Dyamixel XM430-W210-T	5	2.4W	-	12.0W
LiDAR	1	0.6W	10%	0.7W
TOTAL				**27.2W**

7 BATTERY BUDGET

7.1 Option 1 (1400mAh)

Battery	3S LiPo
Nominal Voltage	11.1V
Maximum Energy	1400mAh = 15 500mWh
Adjusted Energy	1400mAh * 80% = 1120mAh = 12 432mWh
Current Rating	50 C
Max Power	191.3W
Nominal Power	27.2W
Measured Power	22W w/o LIDAR and Sense Hat

$$T_{min} = \frac{E}{P} = \frac{12\,432mWh \cdot 60\ min/h}{191.2W \cdot 1000mW/w} = 3.9\ min$$

$$T_{nominal} = \frac{E}{P} = \frac{12\,432mWh \cdot 60\ min/h}{27.2W \cdot 1000mW/w} = 27.4\ min$$

$$T_{nominal(measured)} = \frac{E}{P} = \frac{12\,432mWh \cdot 60\ min/h}{22W \cdot 1000mW/w} = 33.9\ min$$

7.2 Option 2 (2300mAh)

Battery	3S LiPo
Nominal Voltage	11.1V
Maximum Energy	2300mAh = 25 530 mWh
Adjusted Energy	2300mAh * 80% = 1120mAh = 20 424 mWh
Current Rating	50 C
Max Power	191.3W
Nominal Power	27.2W
Measured Power	22W w/o LIDAR and Sense Hat

$$T_{min} = \frac{E}{P} = \frac{20\,424mWh \cdot 60\ min/h}{191.3W \cdot 1000mW/w} = 6.4\ min$$

$$T_{nominal} = \frac{E}{P} = \frac{20\,424mWh \cdot 60\ min/h}{27.2W \cdot 1000mW/w} = 45.1\ min$$

$$T_{nominal(measured)} = \frac{E}{P} = \frac{20\,424mWh \cdot 60\ min/h}{22W \cdot 1000mW/w} = 55.7\ min$$

8 CIRCUIT PROTECTION

The MiniMuck shall use a fuse with lug connections, dimensioned above the maximum possible current draw. The Voltage limit of 3S LiPo is set to 10.5V.

$$I_{max} = \frac{P_{max}}{V_{BATT(low)}} = \frac{191{,}3\ W}{10.5\ V} = 18{,}21\ A \Rightarrow I_{\text{rating}} = 20A$$

APPENDIX A LIPO VOLTAGE RANGES

TABLE 5 LIPO BATTERY PACK VOLTAGE RANGES

Cell(s)	Safe Discharge Voltage	Nominal Voltage	Charged Voltage
1	3,2	3,7	4,2
2	6,4	7,4	8,4
3	9,6	11,1	12,6
4	12,8	14,8	16,8
5	16,0	18,5	21,0
6	19,2	22,2	25,2