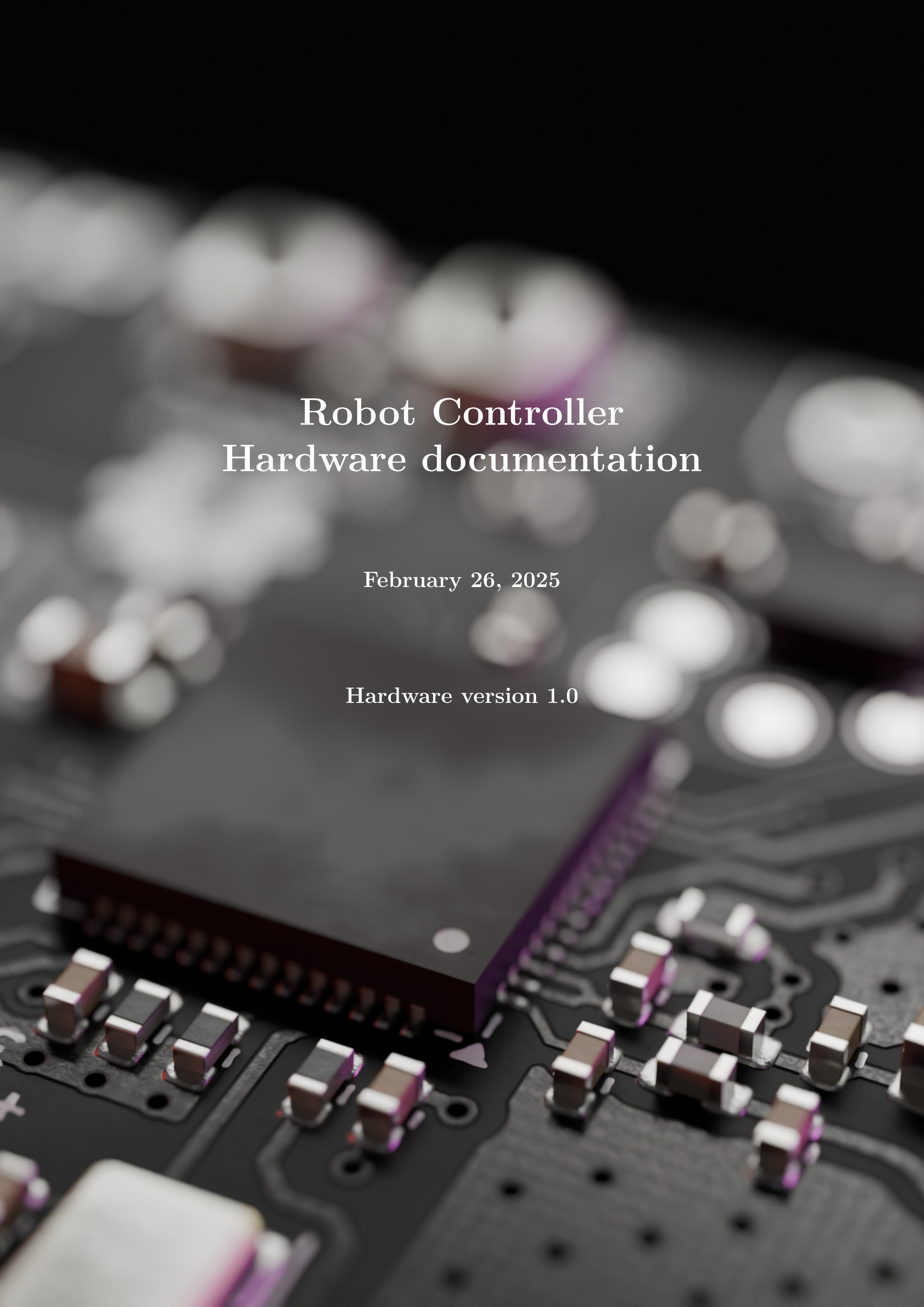


Robot Controller
Hardware documentation

February 26, 2025

Hardware version 1.0

Contents

1 System Overview

ESP32-S3-based robot controller designed for combat robots in the 150g weight class

The controller can control 2 DC motors for vehicle movement and a PWM signal for an ESC for the main weapon. The board also embeds a 3-axis gyroscope and accelerometer which can be used to improve vehicle handling or detect when the robot is flipped. Wireless control is enabled through an integrated 2.4GHz PCB antenna supporting WiFi and Bluetooth.

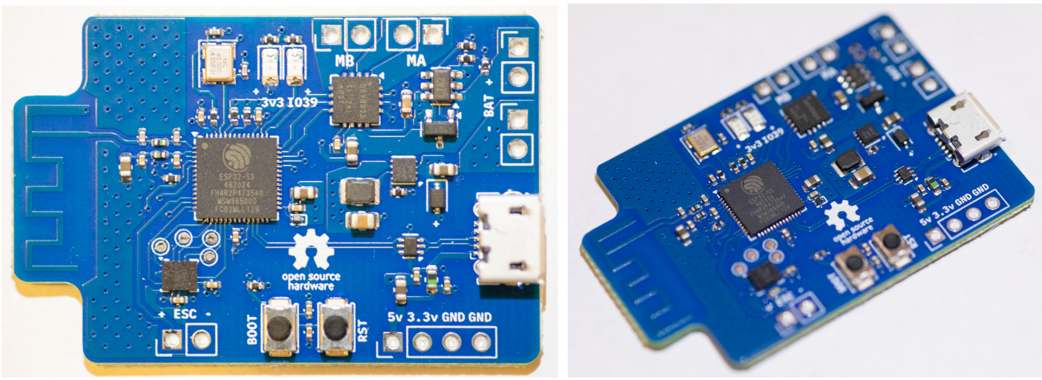


Figure 1: PCB layout

2 Power System

The robot controller has a power management system designed for battery-powered operation with USB power backup. The system accepts a 2-cell LiPo battery (7.4V nominal) as the primary power source and USB-type micro as a secondary power source.

2.1 Power Distribution

The power distribution is managed through an LTC4412 power multiplexer that automatically selects between battery and USB power sources. The USB power is supplied through a USB-B Micro connector, enabling programming and debugging while powering the device.

The system generates two main voltage rails. A 3.3V rail is produced by a TPS62172 step-down regulator, capable of delivering up to 500mA for the ESP32. This regulator utilizes a 2.2µH inductor for power conversion and includes a 10µF input capacitor for energy storage. A status LED indicates the presence of the 3.3V rail. A 7.4V rail for motor power is provided by a LiPo battery.

The 3.3V rail is used for digital circuitry. This rail includes noise filtering through multiple 100nF decoupling capacitors distributed across the board near Vdd pins. Additional bulk capacitance is provided by 22uF and 10uF ceramic capacitors.

The 3.3V power rail has approximately 50mV peak-to-peak ripple (1.5% of nominal voltage), which is within acceptable limits for the ESP32-S3 microcontroller

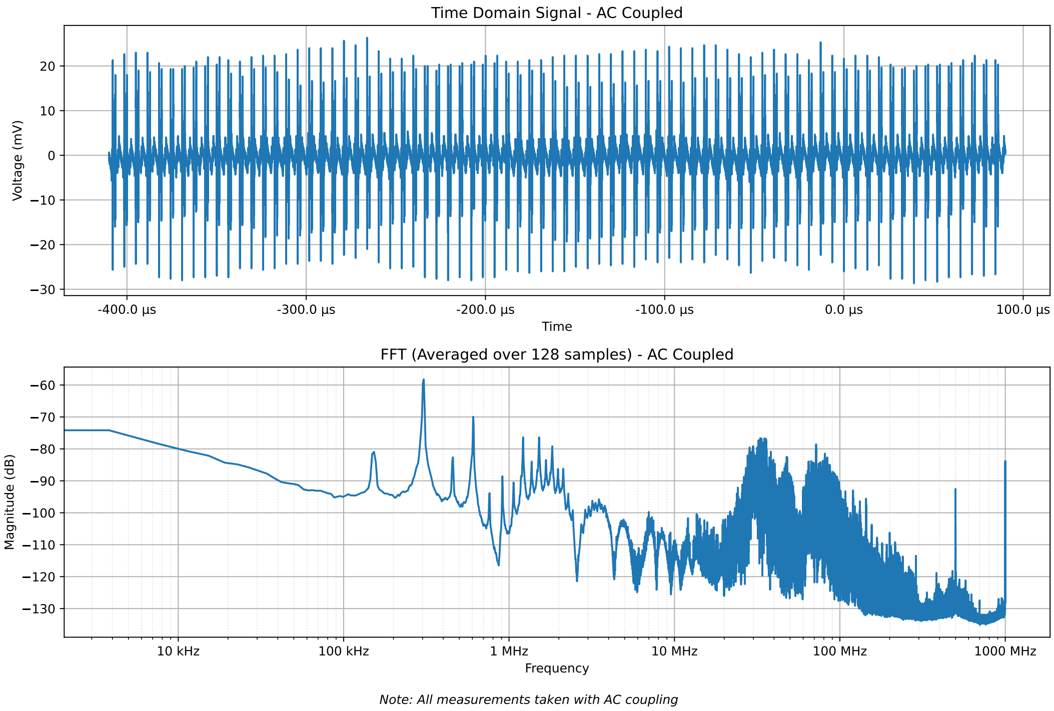


Figure 2: 3.3v power rail noise measurement from debug header

and peripheral circuits. ESP32 documentation specifies that ripple should be <80 mV for MCS7@11n packet transmission and <120 mV for 11 MHz@11b packets [1].

Frequency analysis shows a primary switching component at 300 kHz, with corresponding harmonics at higher frequencies. Additional noise components in the 20-100 MHz range originate from the ESP32-S3's digital clock and RF subsystem operations.

The implemented decoupling network of distributed 100nF capacitors near VDD pins, combined with 10µF and 22µF bulk capacitors, provides sufficient filtering for stable operation of the digital circuits, wireless communication system, and inertial measurement unit. No additional filtering components are required at this noise level.

2.2 Power Management Features

Battery voltage monitoring is implemented through a voltage divider network connected to the *V_SENSE* line, enabling software-based battery level tracking. The B_STAT signal provides power source status monitoring so that the ESP32 knows which source is powering it. The motor driver is powered directly from the LiPo battery and can deliver up to 1.5A per channel.

3 RF-design

The RF design uses a Texas Instruments AN043 Inverted-F Antenna for 2.45GHz wireless communication with 50Ω characteristic impedance.

3.1 Impedance Matching

The esp32c3 low noise amplifier input port has an input impedance of approximately $35 \pm j10\,\Omega$, and the AN043 has a characteristic impedance of $50\,\Omega$ at 2.45GHz. This means the ESP impedance has to be matched to the antenna impedance for a good wireless range.

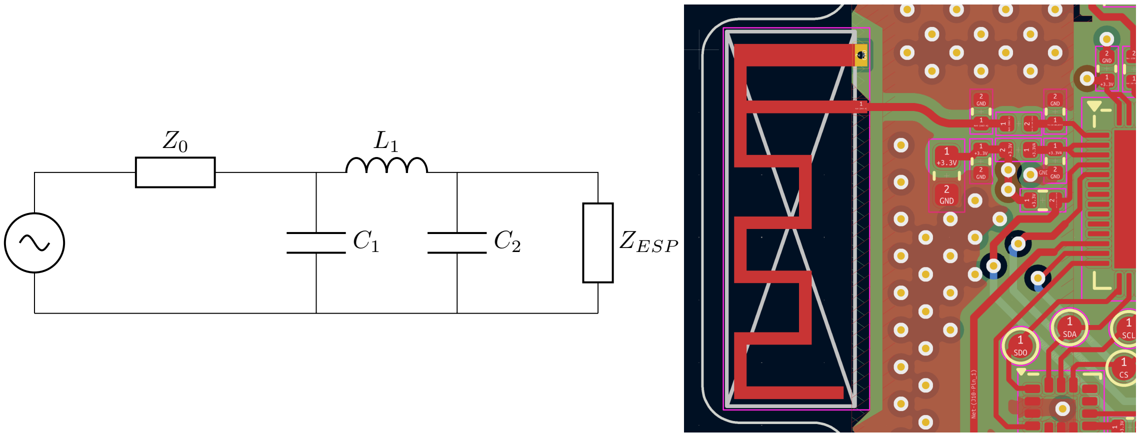


Figure 3: ESP32 RF Front-End Equivalent Circuit and PCB implementation

ESP32's LNA input impedance ($Z_{ESP} = 35 \pm j10\Omega$) is matched to the 50Ω antenna using a π-network as recommended by the ESP32 data sheet [1]. The normalized impedance is:

$$z_0 = \frac{35 + j0\Omega}{50\Omega} = 0.7 \tag{1}$$

Component values calculated using Smith chart:

$$L_1 = \frac{X\,Z_0}{2\pi f} = \frac{0.8 \cdot 50\Omega}{2\pi \cdot 2.45 \cdot 10^9 Hz} = 2.60nH \tag{2}$$

$$C_1 = C_2 = \frac{B}{2\pi f Z_0} = \frac{1.65}{2\pi \cdot 2.45 \cdot 10^9 Hz \cdot 50\Omega} = 2.2pF \tag{3}$$

3.2 PCB Implementation

The PCB has a 4-layer stack up with the RF signals on the top layer and a ground pour on layer 2. Microstrip transmission line dimensions $w = 0.32\,\text{mm}$ and $h = 0.2\,\text{mm}$ for 50Ω impedance calculated using KiCad's impedance calculator. A solid ground plane is used under the RF section for consistent impedance and antenna implementation according to the AN043 application note [2].

4 Motor Driver

The robot controller implements motor control using the DRV8833RTY dual H-bridge driver from Texas Instruments. This driver provides bidirectional control for two DC motors or single stepper motor operation, making it ideal for combat robot applications.

4.1 Motor Driver Specifications

The DRV8833 implementation includes the following features:

- Dual H-bridge configuration supporting two DC motors
- Operating voltage range: Direct battery voltage (7.4V nominal)
- Current capability: Up to 1.5A per channel
- Protection features:
  - Overcurrent protection through internal current limiting
  - Thermal shutdown protection
  - Undervoltage lockout
  - Fault condition reporting via *M_FAULT* signal

4.2 Control Interface

The motor driver is controlled through four input signals (IN1-IN4) from the ESP32-S3, configured as:

Input Pair	Motor	Function
IN1, IN2	Motor 1	Forward/Reverse control for motor 1
IN3, IN4	Motor 2	Forward/Reverse control for motor 2

Table 1: Motor Control Signal Configuration

Motor outputs are provided through two 2-pin connectors, indicated *MA* and *MB* on the PCB.

5 Inertial Measurement Unit

The robot controller integrates an LSM6DS3 6-axis inertial measurement unit, combining a 3-axis gyroscope and a 3-axis accelerometer. This sensor enables precise motion tracking and robot orientation detection, essential for advanced control algorithms and flip detection.

5.1 IMU Specifications

The LSM6DS3 provides:

- 3-axis gyroscope with programmable full-scale range
- 3-axis accelerometer with a programmable full-scale range
- 16-bit data output
- SPI interface operating in Mode 1

5.2 Interface Configuration

The IMU communicates with the ESP32-S3 through a dedicated SPI bus, configured as shown in Table 2. The SPI bus signals have test points 1 to 4 for debugging purposes.

Signal	ESP32-S3 Pin	Function
MISO	GPIO10	Master In Slave Out data line
MOSI	GPIO11	Master Out Slave In data line
SCLK	GPIO12	Serial Clock
CS	GPIO13	Chip Select

Table 2: LSM6DS3 SPI Bus Hardware Configuration

6 System Pin Configuration

6.1 ESP32-S3 Pin Mapping

Table 3 gives a complete overview of all ESP32-S3 pin assignments and their functions in the robot controller.

6.2 Important Notes

The ESP32-S3 uses several pins for boot mode configuration and strapping. GPIO5 has a weak pull-up, while GPIO45 and GPIO46 have weak pull-down resistors as per the ESP32-S3 datasheet requirements [1]. The IMU interface operates in SPI Mode 1 with the LSM6DS3 sensor. All motor control signals are buffered through the DRV8833RTY dual H-bridge driver.

GPIO	Function	Direction	Description
GPIO0	BOOT	Input	Boot mode selection with SW1
RESET	RESET	Input	System reset with SW2
GPIO5	GPIO5/BOOT	Input	Weak pull-up (strapping)
GPIO45	GPIO45	-	Weak pull-down (strapping)
GPIO46	GPIO46	-	Weak pull-down (strapping)
GPIO39	DEBUG_LED	Output	Programmable indicator LED
GPIO19	USB_D-	Bidirectional	USB Data Negative
GPIO20	USB_D+	Bidirectional	USB Data Positive
GPIO18	B_STAT	Input	System power source indicator
GPIO8	Battery Voltage	Input	Battery voltage monitoring
GPIO10	SPI MISO	Input	IMU data input
GPIO11	SPI MOSI	Output	IMU data output
GPIO12	SPI SCK	Output	IMU clock
GPIO13	SPI CS	Output	IMU chip select
GPIO19	IMU INTR 1	Input	IMU Interrupt 1
GPIO13	IMU INTR 2	Input	IMU Interrupt 2
GPIO34	Motor1 Input 1	Output	Motor 1 control
GPIO33	Motor1 Input 2	Output	Motor 1 control
GPIO37	Motor2 Input 1	Output	Motor 2 control
GPIO36	Motor2 Input 2	Output	Motor 2 control
GPIO35	Motor Sleep	Output	Motor driver sleep control
GPIO14	M_FAULT	Input	Motor driver fault input
GPIO38	M_FAULT	Input	Motor driver fault
GPIO7	ESC_PWM	Output	ESC PWM Speed control
LNA_IN/RF	Antenna	Bidirectional	2.4GHz PCB antenna connection

Table 3: ESP32-S3 Pin Mapping and Functions

7 Programming Guide

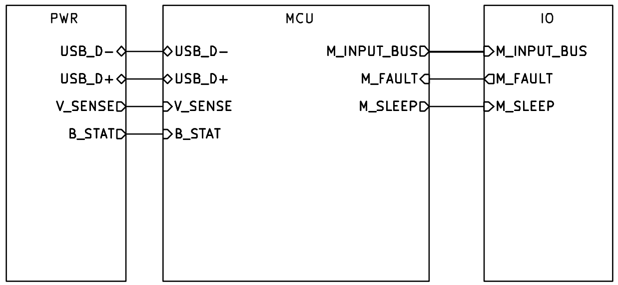
The Robot Controller is programmed via the USB-B Micro connector using the ESP32-S3's integrated USB-JTAG interface. Firmware source code is provided in the repository.

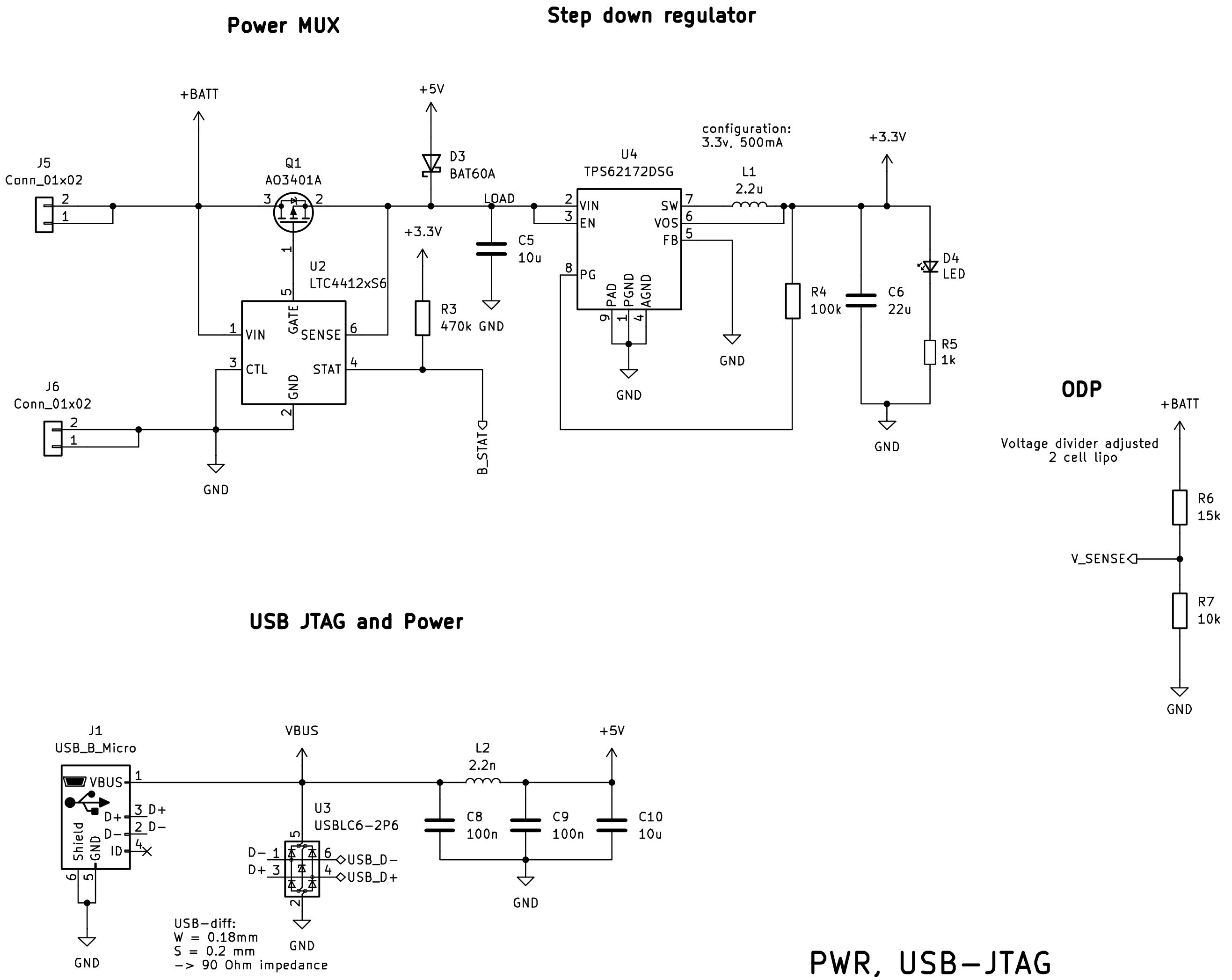
To flash the firmware:

1. Install the ESP-IDF toolchain following Espressif's official documentation
2. Connect the board to your computer with a USB Micro cable
3. Navigate to the firmware directory
4. Execute `idf.py build && idf.py flash`

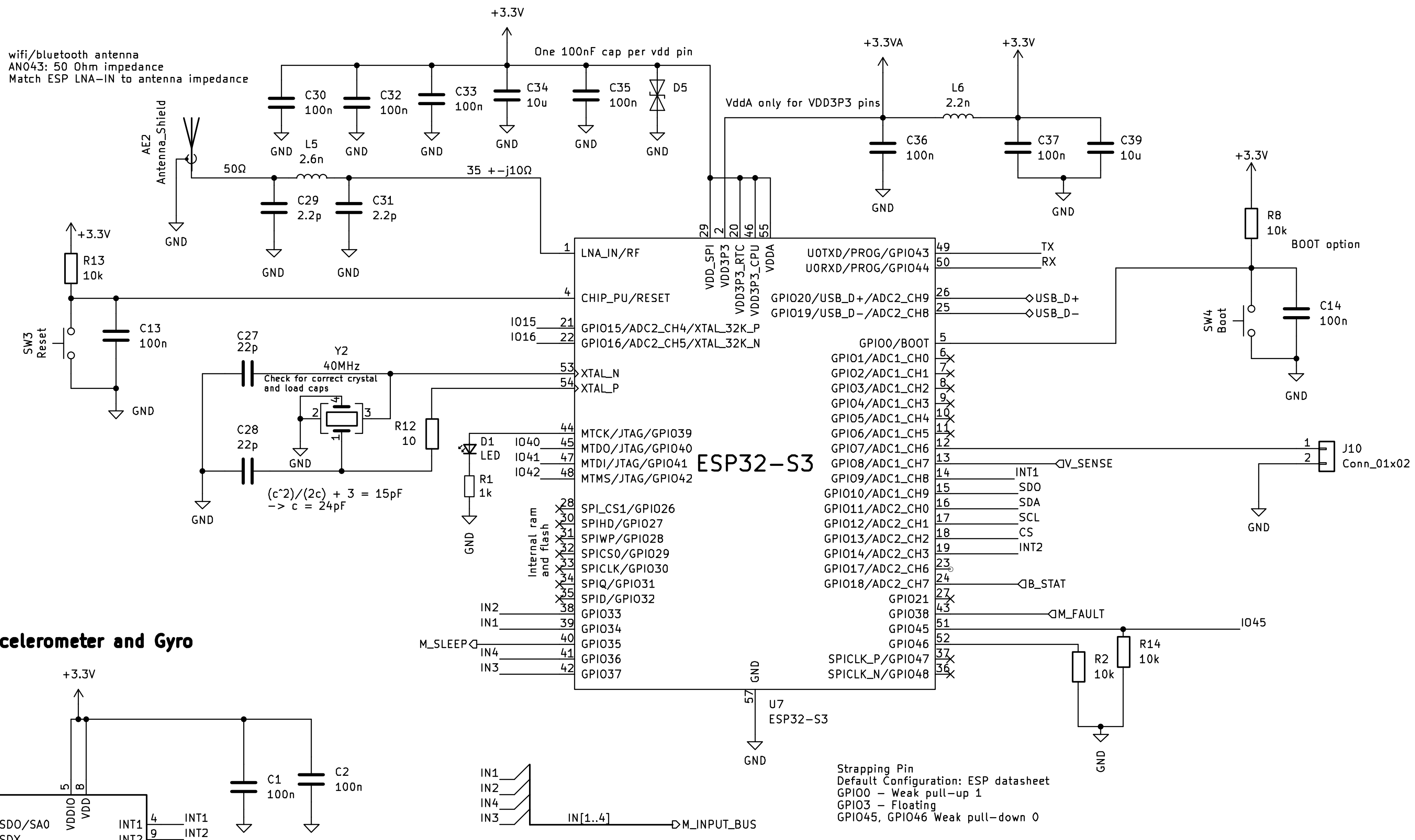
The serial monitor can be accessed at 115200 baud for debugging purposes.

Attachments

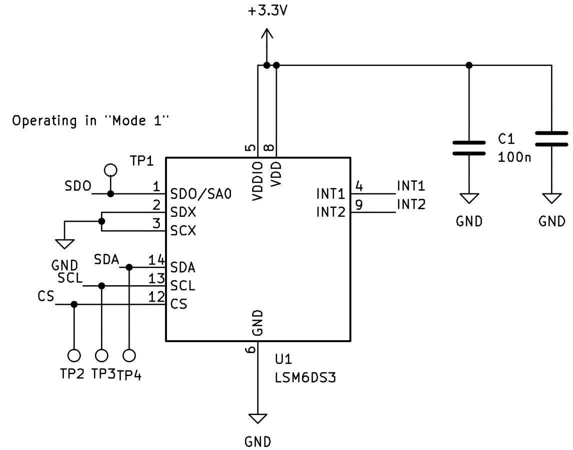

PWR
USB_D-
USB_D+
V_SENSE
B_STAT
MCU
USB_D-
USB_D+
V_SENSE
B_STAT
M_INPUT_BUS
M_FAULT
M_SLEEP
IO
M_INPUT_BUS
M_FAULT
M_SLEEP


Power MUX
Step down regulator
+BATT
+5V
J5
Conn_01x02
Q1
AO3401A
D3
BAT60A
LOAD
U4
TPS62172DSG
configuration:
3.3v, 500mA
L1
2.2u
+3.3V
VIN
EN
SW
VOS
FB
PG
PAD
PGND
AGND
C5
10u
+3.3V
R3
470k
GND
U2
LTC4412xS6
GATE
SENSE
VIN
CTL
STAT
GND
R4
100k
C6
22u
D4
LED
R5
1k
GND
J6
Conn_01x02
B_STAT
GND
ODP
+BATT
Voltage divider adjusted
2 cell lipo
R6
15k
V_SENSE
R7
10k
GND
USB JTAG and Power
J1
USB_B_Micro
VBUS
D+
D-
ID
Shield
GND
VBUS
U3
USBLC6-2P6
USB_D-
USB_D+
L2
2.2n
+5V
C8
100n
C9
100n
C10
10u
GND
USB-diff:
W = 0.18mm
S = 0.2 mm
-> 90 Ohm impedance

PWR, USB-JTAG



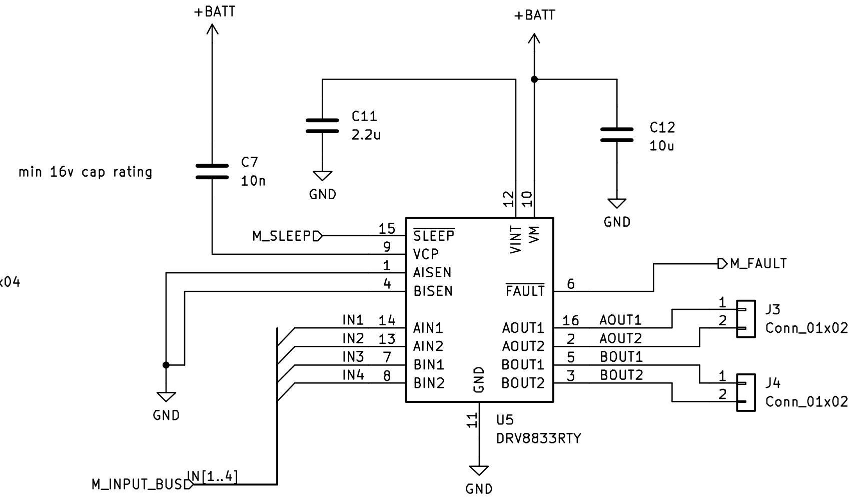
Accelerometer and Gyro



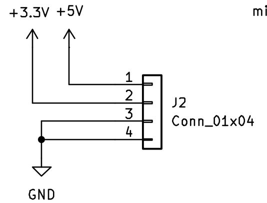
MCU and peripherals

DC-Motor Driver

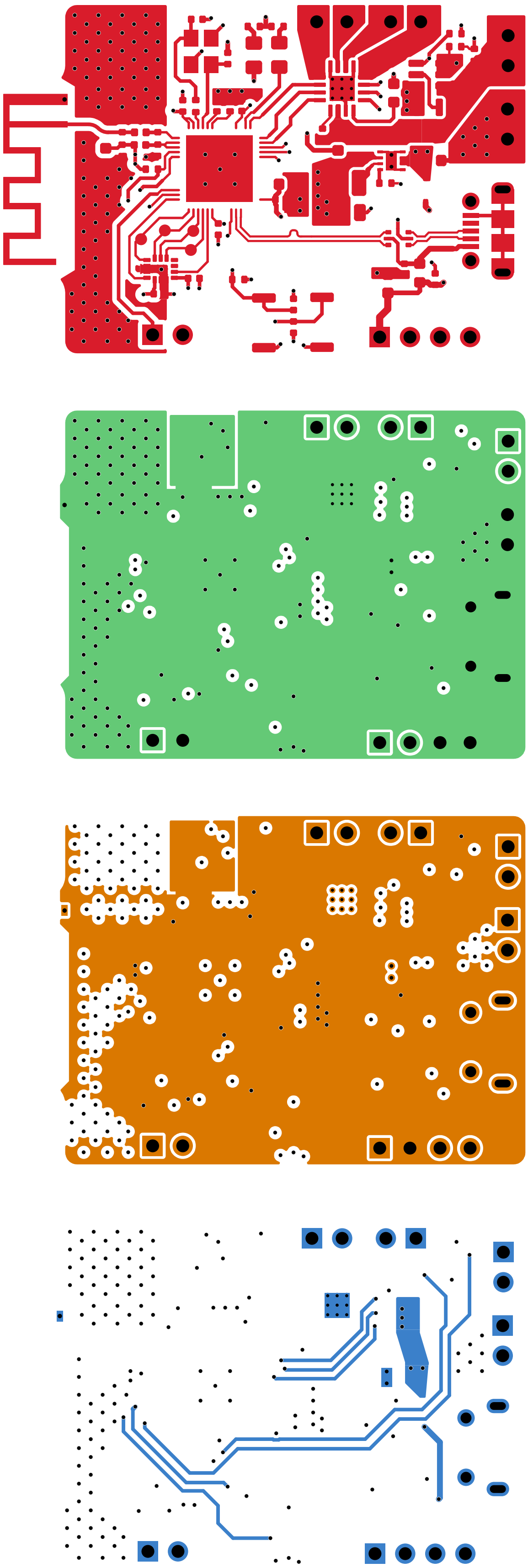
AISEN and BISEN shunt resistor power rating (if used)
1W minimum. Calculated from max IC current (1.5A RMS) through 0.2Ω:
$P = I^2R = (1.5A)^2 \times 0.2\Omega = 0.45W$ continuous
With peak current (2A): $P = (2A)^2 \times 0.2\Omega = 0.8W$ peak
1W rating is safe margin over both continuous and peak dissipation



Debug connector



Designator	Footprint		Quantity	Value	LCSC Part #
C1, C13, C14, C2, C30, C32, C33, C35, C36, C37, C8, C9		402	12	100n	C1525
C10, C12, C34, C39, C5		603	5	10u	C70225
C11		603	1	2.2u	C57895
C27, C28		402	2	22p	C1555
C29, C31		402	2	3.3p	C57895
C6		805	1	22u	C45783
C7		402	1	10n	C15195
D1, D4		805	2	LED	C2295
D3	D_SOD-323		1	BAT60A	C3018529
D5	D_SOD-923		1	SZESD9B5.0ST5G	C328101
J1	CUI_UJ2-MIBH2-4-SMT-TR		1	UJ2-MIBH2-4-SMT-TR	C91146
L1		1008	1	2.2u	C23894
L2		603	1	2.2n	C113061
L5, L6		402	2	2.2n	C86061
Q1	SOT-23		1	AO3401A	C181091
R1, R5		402	2	1k	C11702
R12		402	1	10	C159870
R13, R14, R2, R7, R8		402	5	10k	C25531
R3		402	1	470k	C25562
R4		402	1	100k	C25741
R6		402	1	15k	C25543
SW3	SW_Push_SPST_NO_Alps_SKRK		1	Reset	C115357
SW4	SW_Push_SPST_NO_Alps_SKRK		1	Boot	C115357
U1	LGA-14_3x2.5mm_P0.5mm_LayoutBorder3x4y		1	LSM6DS3	C95230
U2	TSOT-23-6		1	LTC4412xS6	C514442
U3	SOT-666		1	USBLC6-2P6	C15999
U4	WSON-8-1EP_2x2mm_P0.5mm_EP0.9x1.6mm_ThermalVias		1	TPS62172DSG	C59873
U5	Texas_RTY_WQFN-16-1EP_4x4mm_P0.65mm_EP2.1x2.1mm_ThermalVias		1	DRV8833RTY	C154936
U7	QFN-56-1EP_7x7mm_P0.4mm_EP5.6x5.6mm		1	ESP32-S3	C3013940
Y2	Crystal_SMD_3225-4Pin_3.2x2.5mm		1	40MHz	C9010



References

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