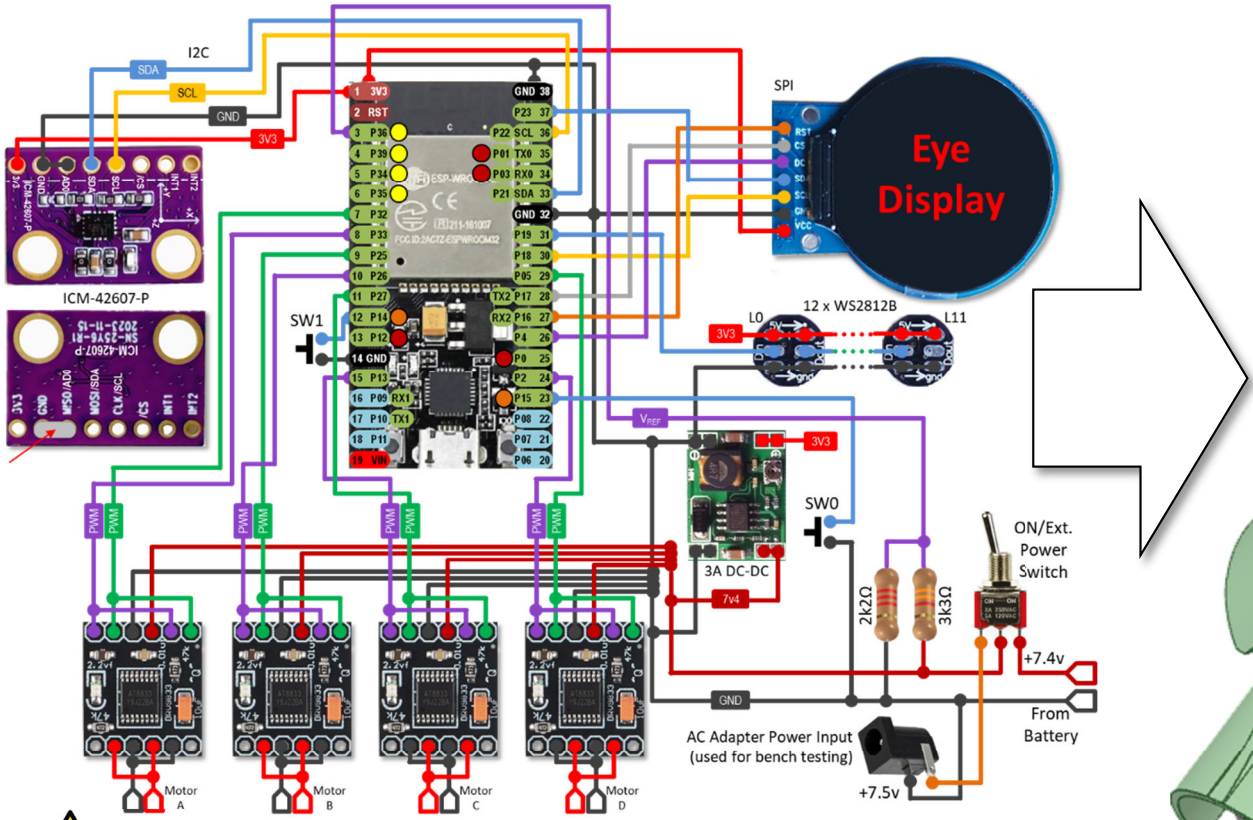
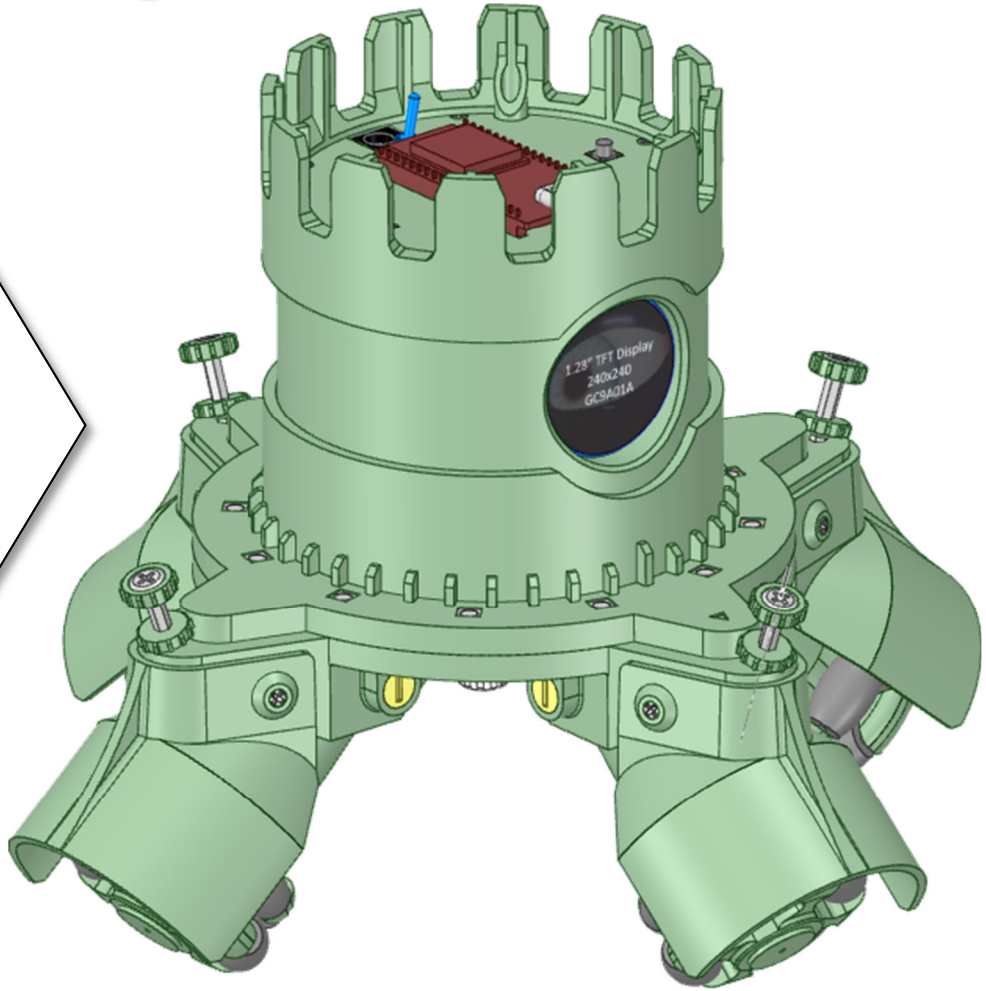
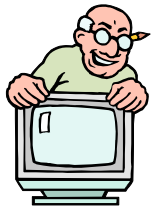
Project BallBot ESP 4x4

Circuits & Wiring







Read through this documentation completely before attempting this project.

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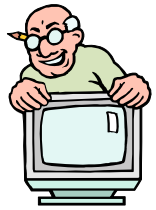
CAUTION



Lithium batteries can be extremely dangerous, if not handled and cared for properly. This design does not include any form of current limiting circuit, like a fuse. So, care must be taken to ensure that the wiring guidelines are followed accurately, that checks are made for short-circuits, and that battery polarities are marked, and they are inserted the correct way round. Failure to do so, could result in an explosive fire.

Charging Practices: Always remove batteries from your project to charge them. Use a charger, designed for the battery used, and from a trusted supplier. Choose a flat, non-flammable surface to charge on, away from flammable materials. Never leave unattended when charging. Don't charge overnight. Monitor charging to ensure charge characteristics are as expected. Only pair batteries with similar characteristics. Do not overcharge, or leave charging for prolonged periods. This increases the risk of damage and fire.

Battery care & maintenance: Stop using a battery if it is swollen, damaged, dented or leaking. Never charge a damaged battery. Never allow a Lithium battery to discharge below 3.2 volts, as cell damage will occur. Avoid extreme temperatures. Do not charge or store batteries in very hot or cold environments. Don't cover batteries whilst charging, as this can trap heat, causing overheating.

In case of fire: Get out and stay out. If a fire starts, leave immediately, and call the fire brigade. For low voltage Lithium batteries, water is a safe extinguisher.

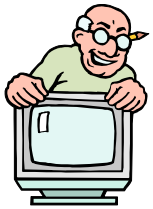
Built-in Monitoring: Most of my project designs include code, and circuitry, to monitor battery voltage, whilst in use. This code then seeks to alert the operator, when the battery has reached a critical low voltage, before shutting down power consuming circuitry; including the micro. Time should therefore be spent on calibrating this feature, as a precaution, for good battery management and maintenance.

Carefully dispose of batteries that have been discharged below their critical voltage.

Hand Tools:

Recommended:

- Fine nosed pliers
- Side cutters
- 1.5 mm Drill
- 2.0 mm Drill
- 4.0 mm Drill
- Needle files
- Screwdrivers
- Craft knife



Note: Not all items needed are shown here.

Some printed components act as aids and gauges. Use them.

Tools & Materials:

Temperature controlled iron
Solder flux
Resin cored solder
Hot melt glue gun {optional)
2-part epoxy resin glue
Screw drivers
Wire wrapping tool
Wire wrapping wire 30 AWG
24 AWG stranded wire (red & black)
Multimeter

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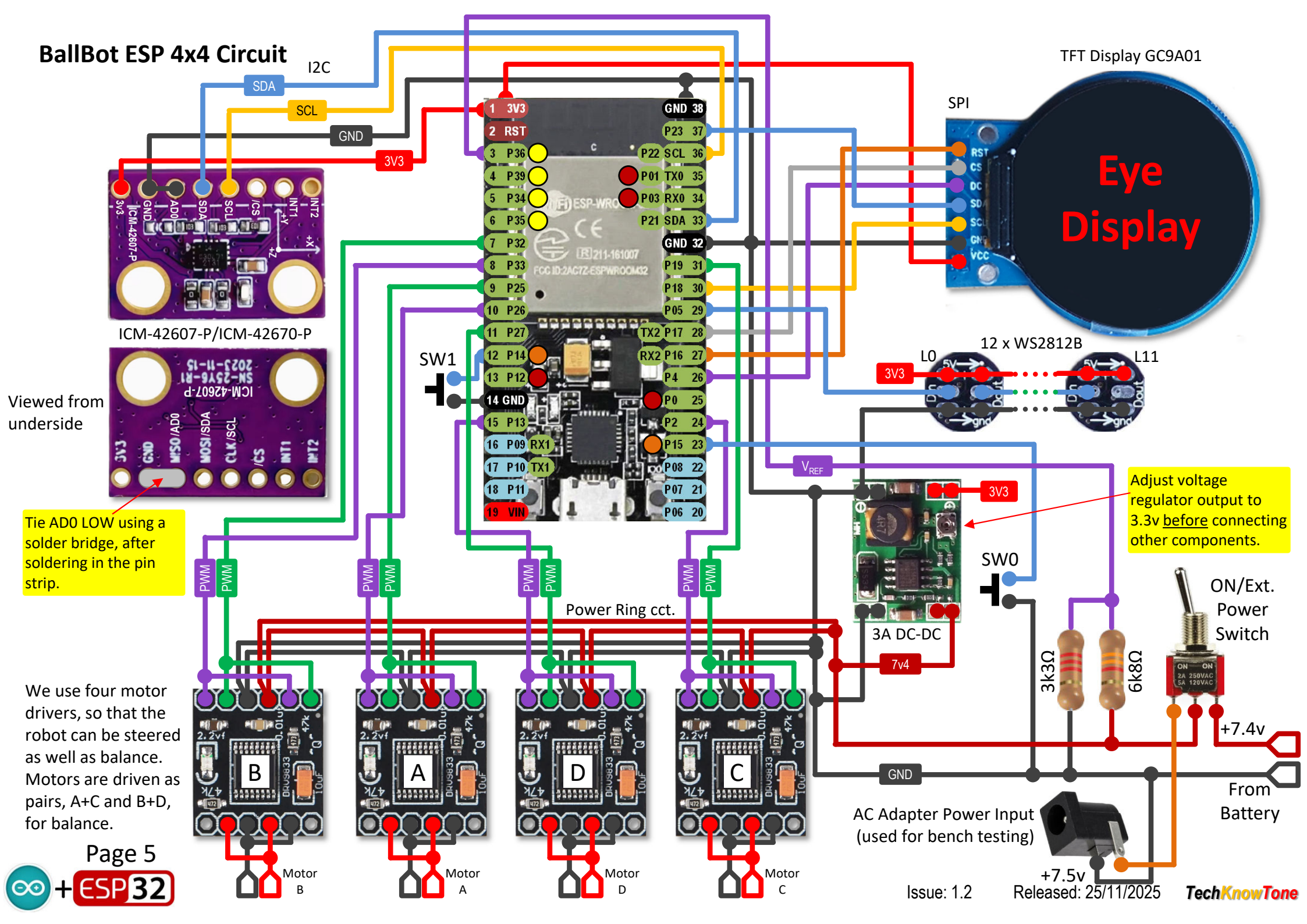
BallBot ESP 4x4 Circuit



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Micro Plate Wiring – step 1

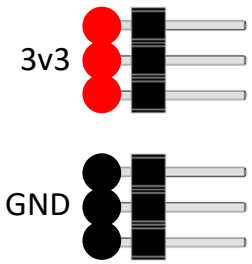
This isometric view should make some of the connections relating to the power switch, clearer.

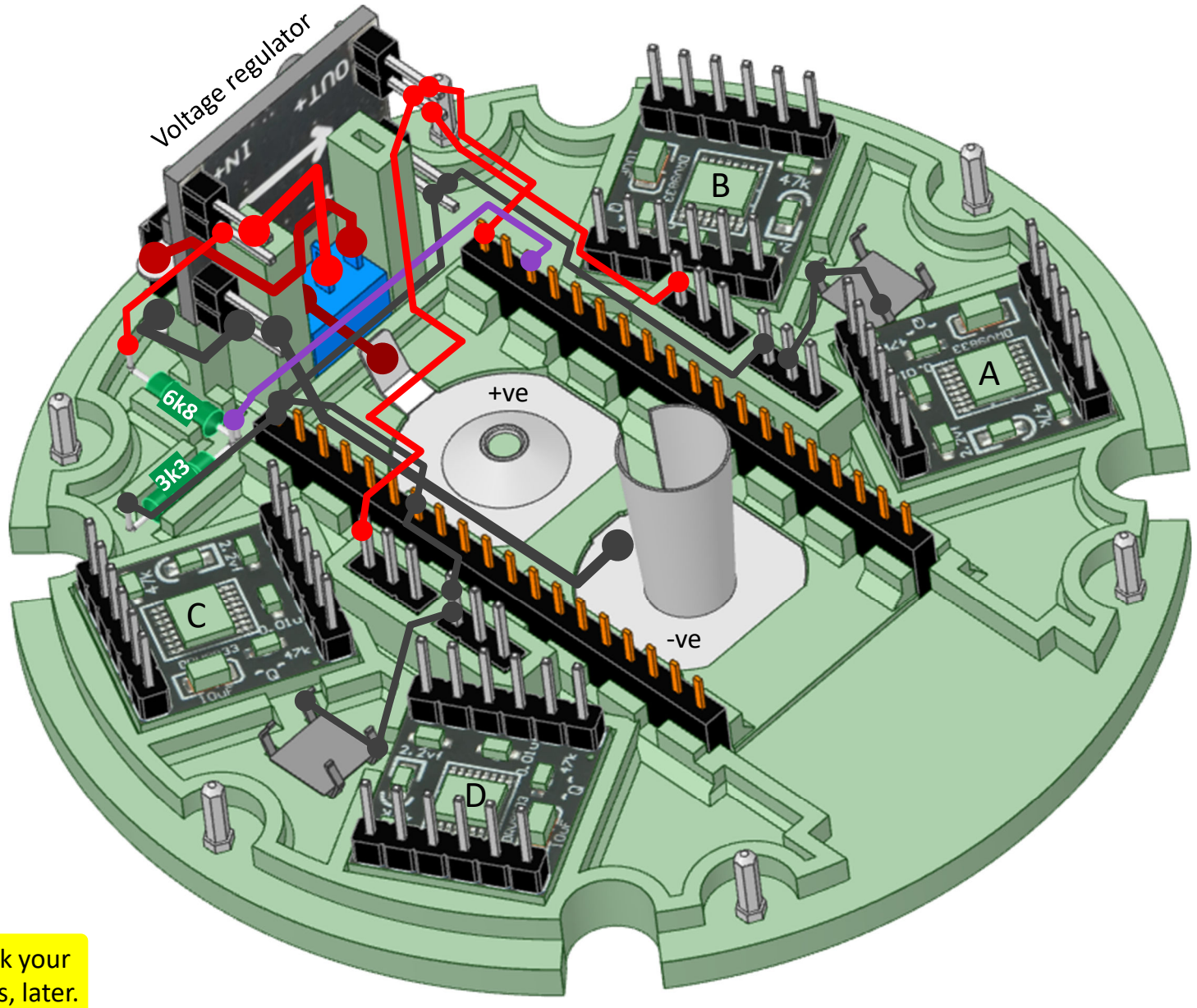
Start by wiring in the power supply connections, including the DC socket, power switch, voltage regulators, battery connectors, resistors.

I recommend that you attach wires to the power switch before it is glued into position, making the process much easier.

The 3-pin common connection points for 3v3 and GND are pre-wired, prior to gluing them into the micro plate.

Crop and bend the battery connectors prior to gluing them into the plate.





CAUTION – Check and double-check your wiring before inserting the batteries, later.

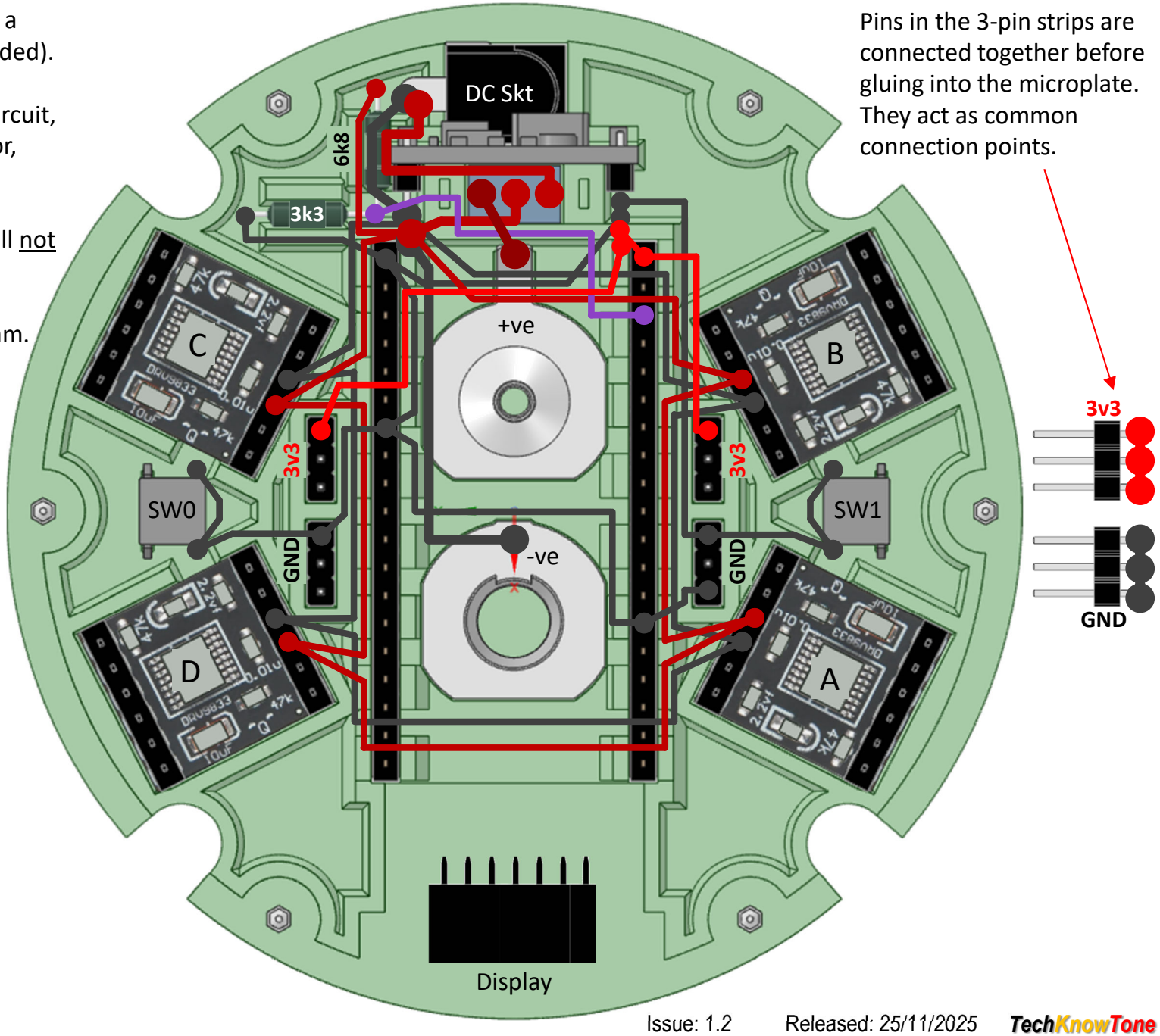
Micro Plate Wiring – step 2

Attach the 4-pin socket strips to the H-bridge drivers if you want to be able to easily replace a driver that has failed in the future (recommended).

The four H-bridge drivers are wired as a ring circuit, fed from the input pins of the voltage regulator, which is at battery voltage.

Note, for clarity, most of these connections will not be shown routed on subsequent diagrams.

Actual wire routing may differ from this diagram. See photos on later pages.



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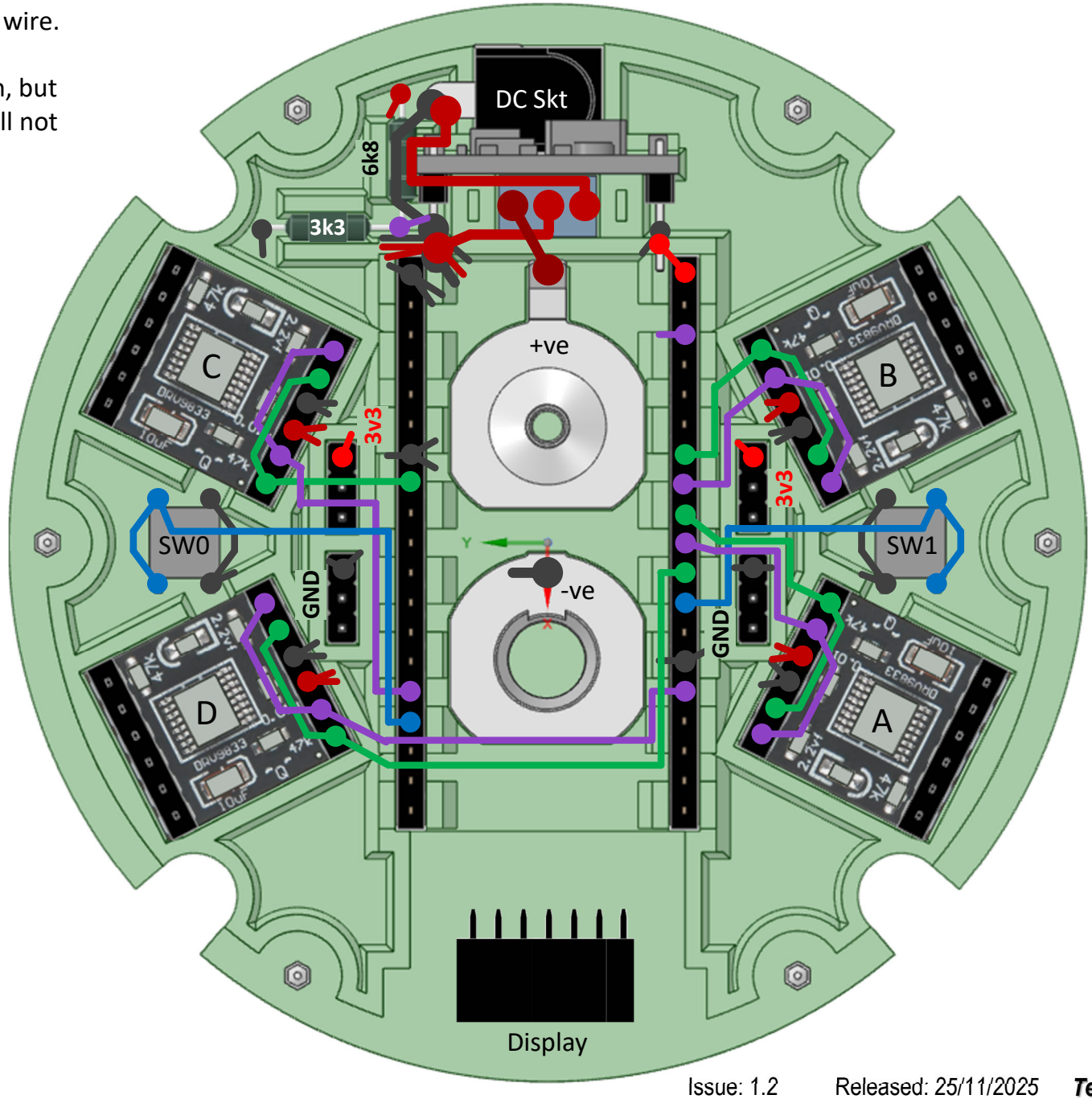
Micro Plate Wiring – step 3

Next we wire in the H-bridge drivers and the two button switches. This is done using wire-wrap wire.

Note that the previous connections are shown, but not routed. And most of these connections will not be shown in the next diagram, to aid clarity.



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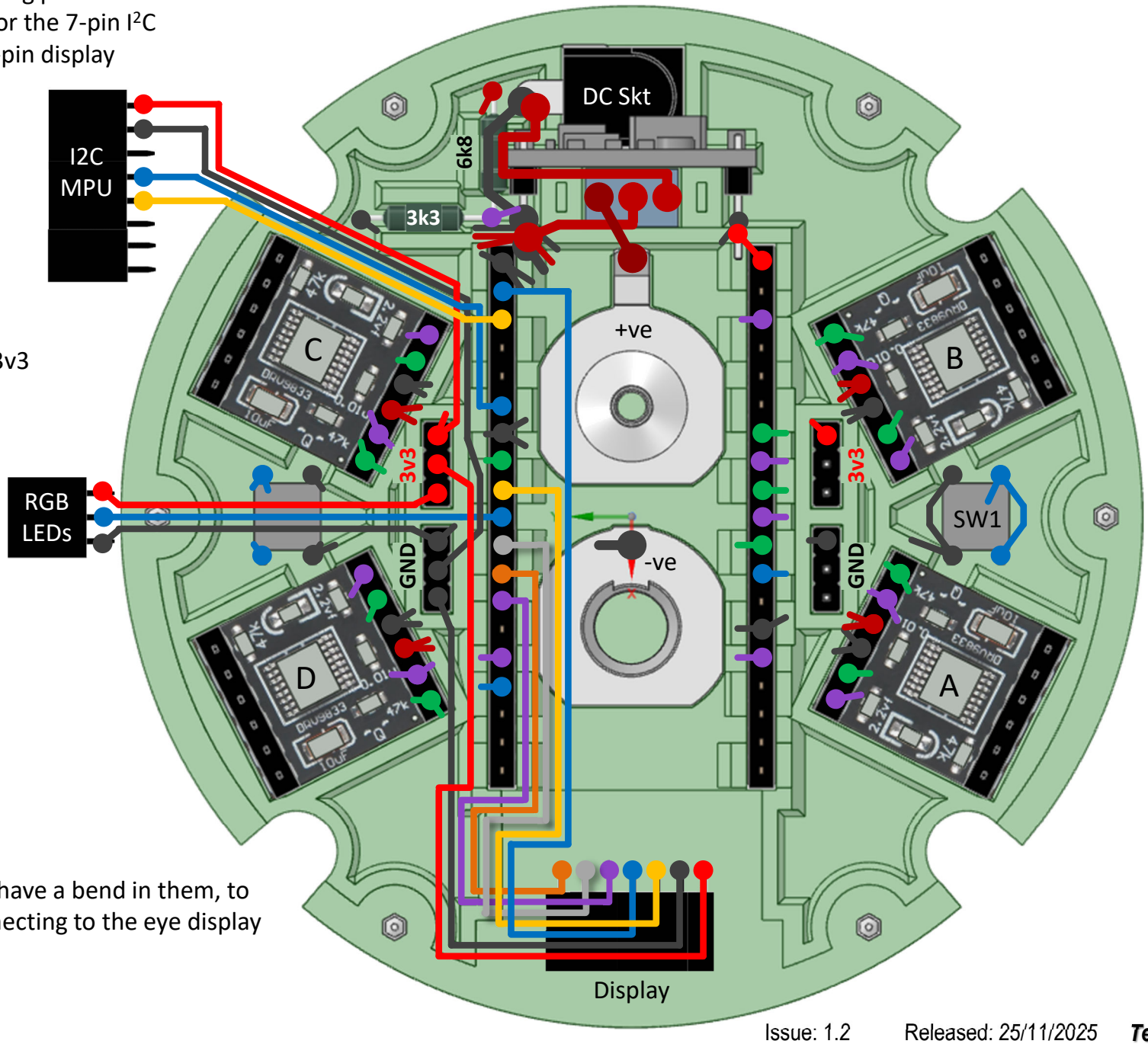
Micro Plate Wiring – step 4

The next step in the micro plate wiring process is to make the external connections for the 7-pin I²C plug, 3-pin RGB LED plug and the 7-pin display plug.

Allow sufficient wire length for terminating in the sockets later.

This is where the use of the 3-pin, 3v3 and GND connection points are mainly used.

The wires to the round TFT display have a bend in them, to give increased flexibility when connecting to the eye display later.



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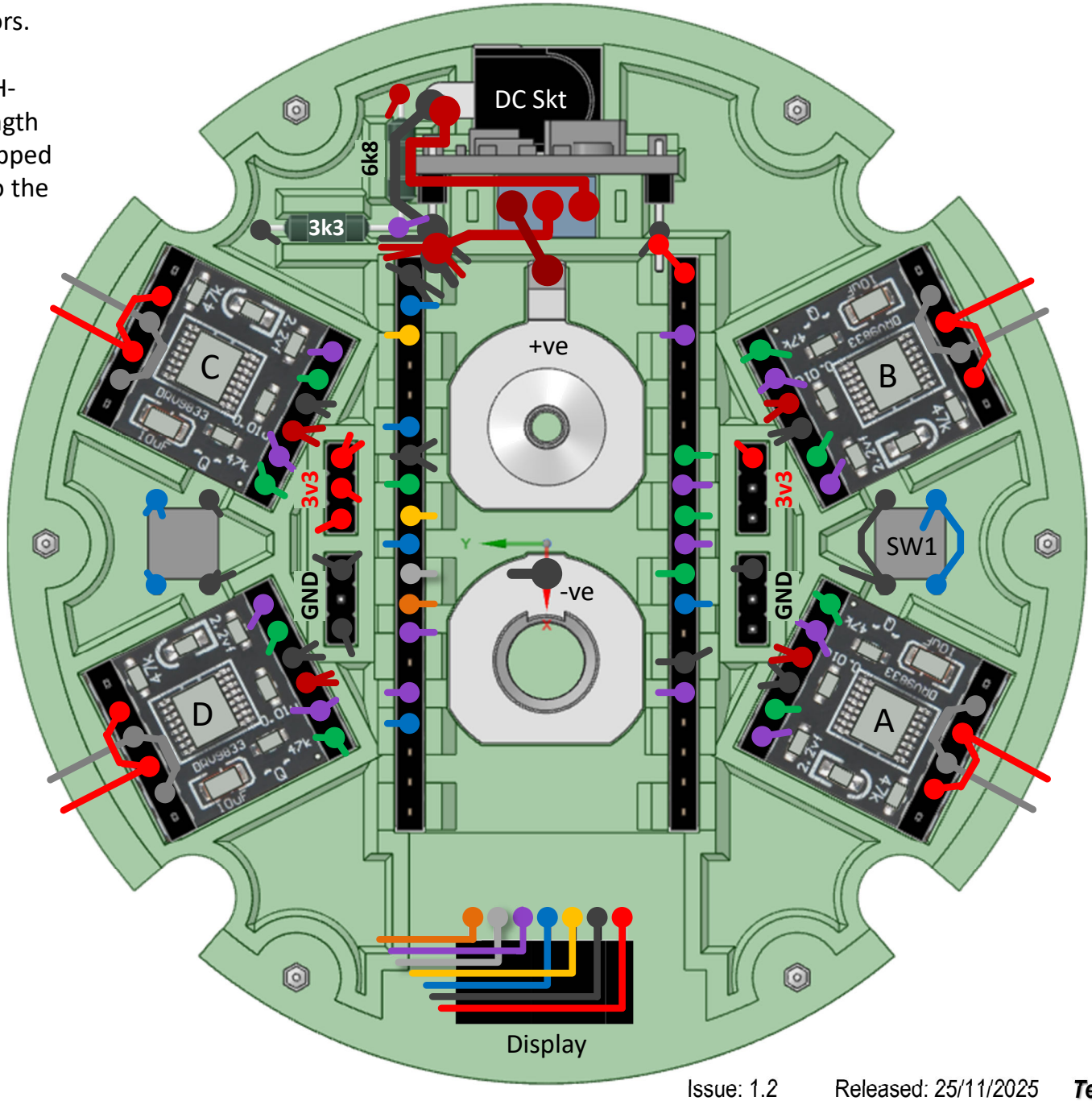
Micro Plate Wiring – step 5

The final step in the micro plate wiring process is to make the external connections for DC motors.

The 6-pin sockets are wired as shown, to the H-bridge drivers A,B,C and D. Allow sufficient length in the wiring to reach the DC motor. To be cropped and soldered, once the hip plate is attached to the robots LED plate and body.



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Dual H-bridge Wiring

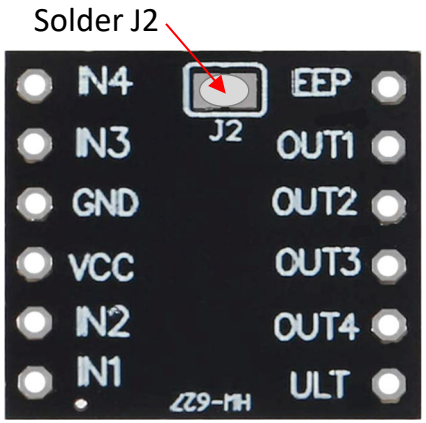
In this design I used one DRV8833 H-bridge dual channel controller for each motor, and combined each channels 2A max current capability, and halved their MOS-FETs on-channel resistance. Giving a more efficient drive signal for each motor.

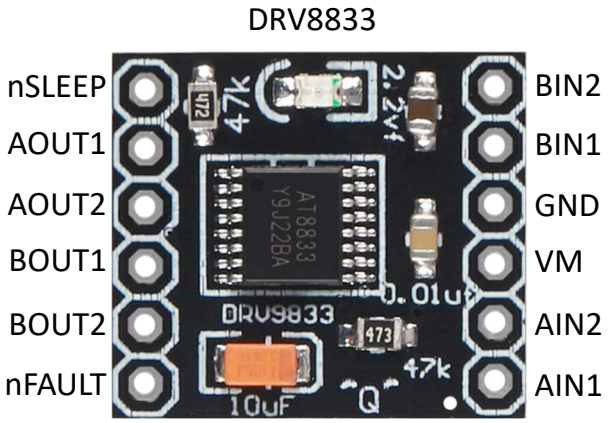
This is achieved by wiring the controllers as shown here. Both the input pins and output pins are connected together as shown. Make sure that you wire the controllers correctly, or you are likely to damage the controller, and draw excessive current from the batteries.

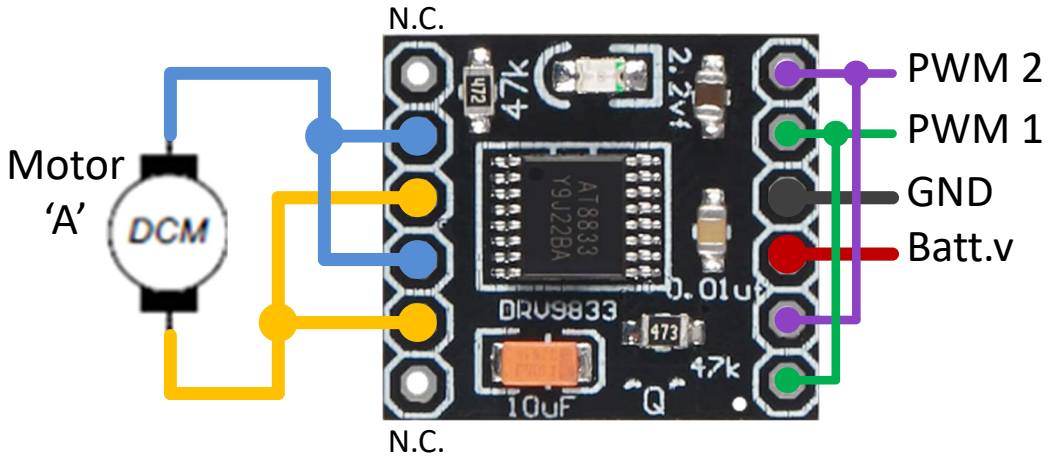
The nSLEEP and nFAULT pins are not connected; however, the nSLEEP pin is pulled HIGH by an on-board 47kΩ resistor when you bridge J2 with a blob of solder, as shown. Do this **first**, before soldering in the pin strips to the boards.

You will find more information on the DRV8833 driver on a later slide. This should enable you to understand how the code producing the PWM signals in the ESP32, controls the motion of the DC motor. For each direction of travel, one PWM input pin is held HIGH, whilst PWM signals are applied to the other.

As the supply voltage affects motor speed and torque, the code monitors the battery voltage and adjusts the applied PWM to give a maximum average voltage of 7.6v.

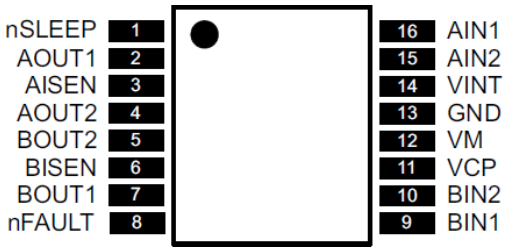


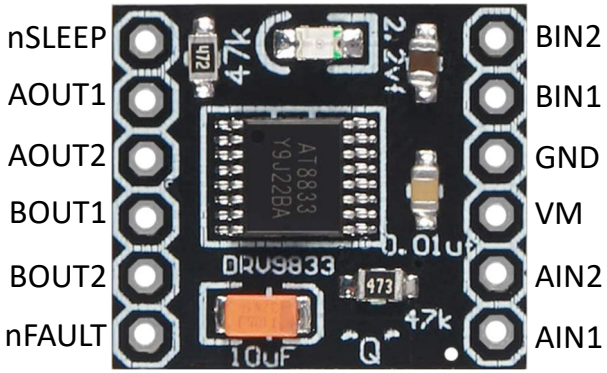




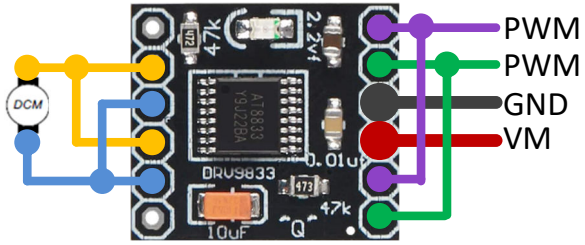
CAUTION – This design does not include any form of current limiting protection (like a fuse). Incorrect wiring can result in large currents, which can cause damage and even the risk of a **fire**. Check and double check your wiring before inserting the batteries.

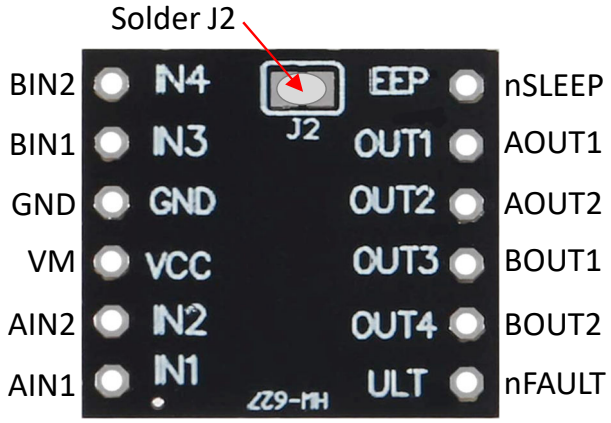
DRV8833 H-bridge Driver





Combined H-bridge.





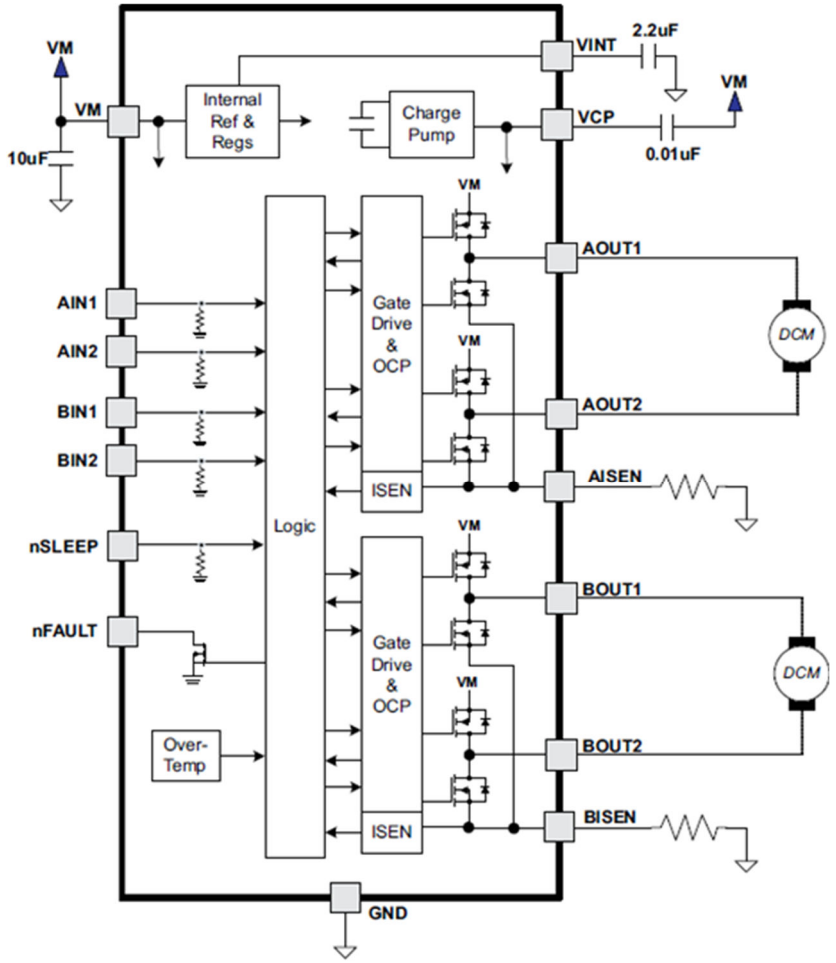
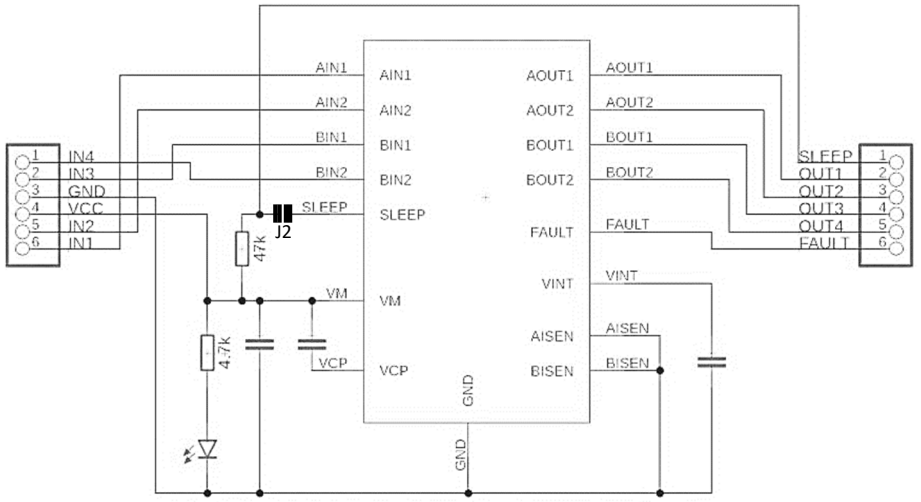


Table 1. H-Bridge Logic

xIN1	xIN2	xOUT1	xOUT2	FUNCTION
0	0	Z	Z	Coast/fast decay
0	1	L	H	Reverse
1	0	H	L	Forward
1	1	L	L	Brake/slow decay

Table 2. PWM Control of Motor Speed

xIN1	xIN2	FUNCTION
PWM	0	Forward PWM, fast decay
1	PWM	Forward PWM, slow decay
0	PWM	Reverse PWM, fast decay
PWM	1	Reverse PWM, slow decay



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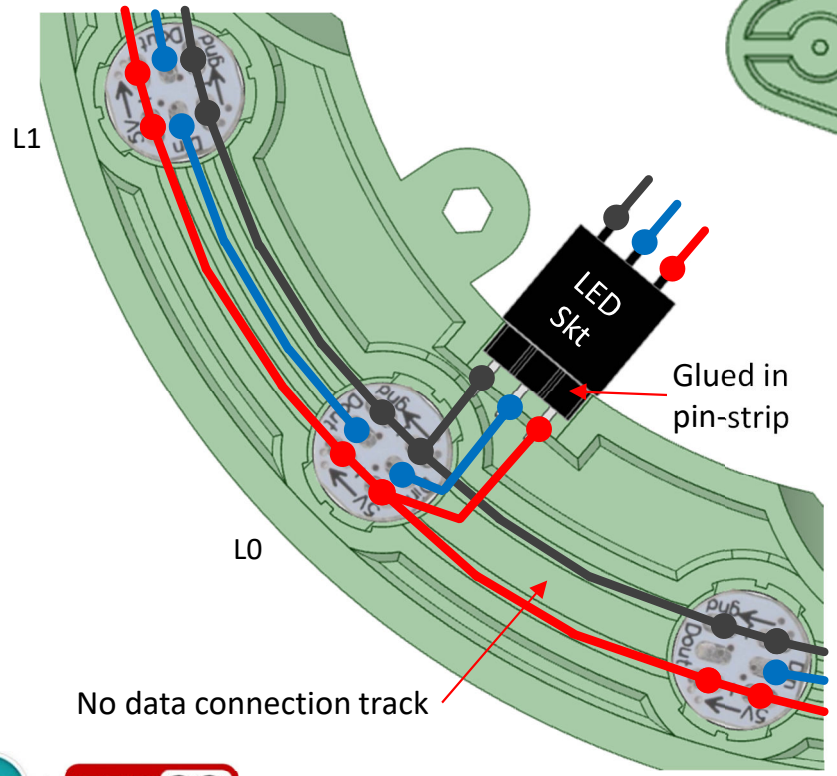
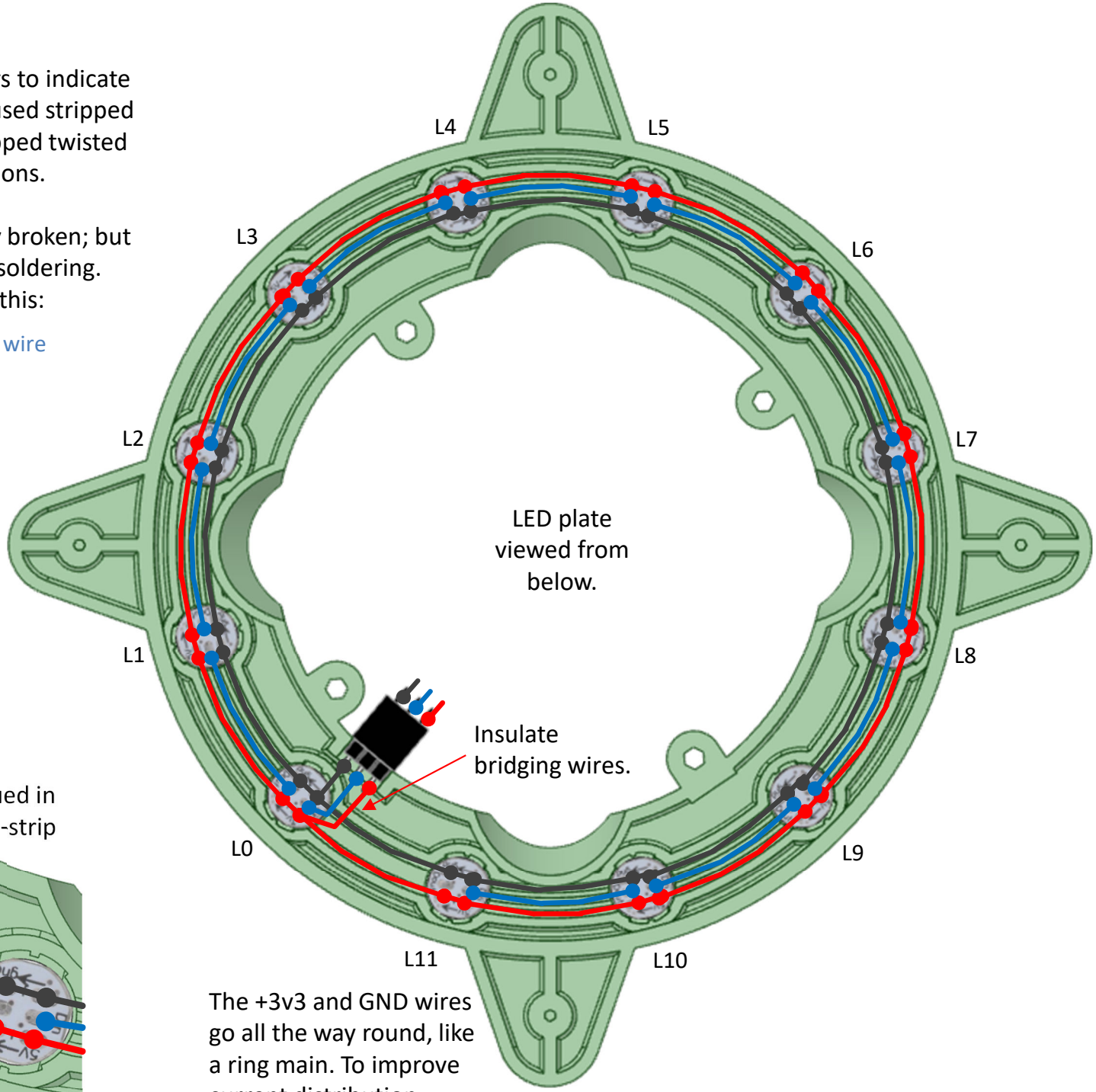
LED Plate Wiring – step 5

The LED plate was wired as shown. I've used colours to indicate the wire types, +3v3, signal and GND. In practise I used stripped wire-wrap wire for the central signal path, and stripped twisted multi-stranded wire for the +3v3 and GND connections.

At each WS2812B chip, the signal wire is effectively broken; but formed initially by putting a step in the wire whilst soldering. Then cropping out the step to make the break, like this:

Run the signal wire in first, all the way round.





The +3v3 and GND wires go all the way round, like a ring main. To improve current distribution.

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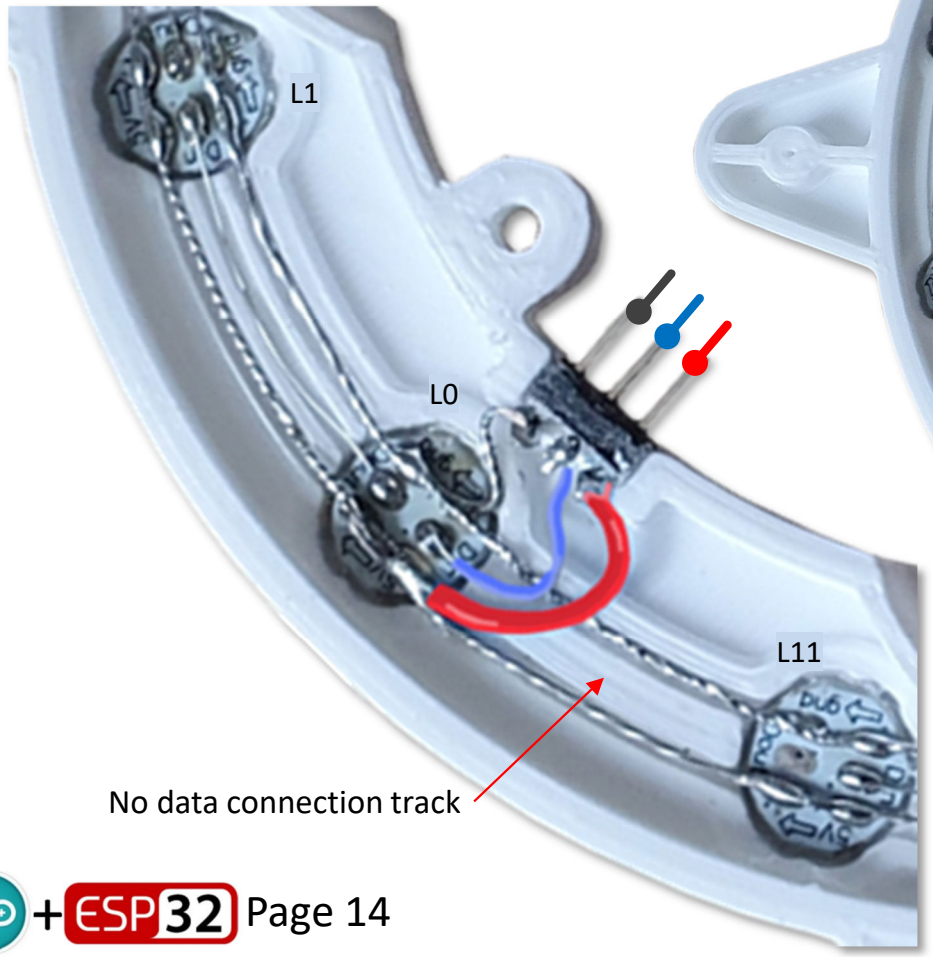
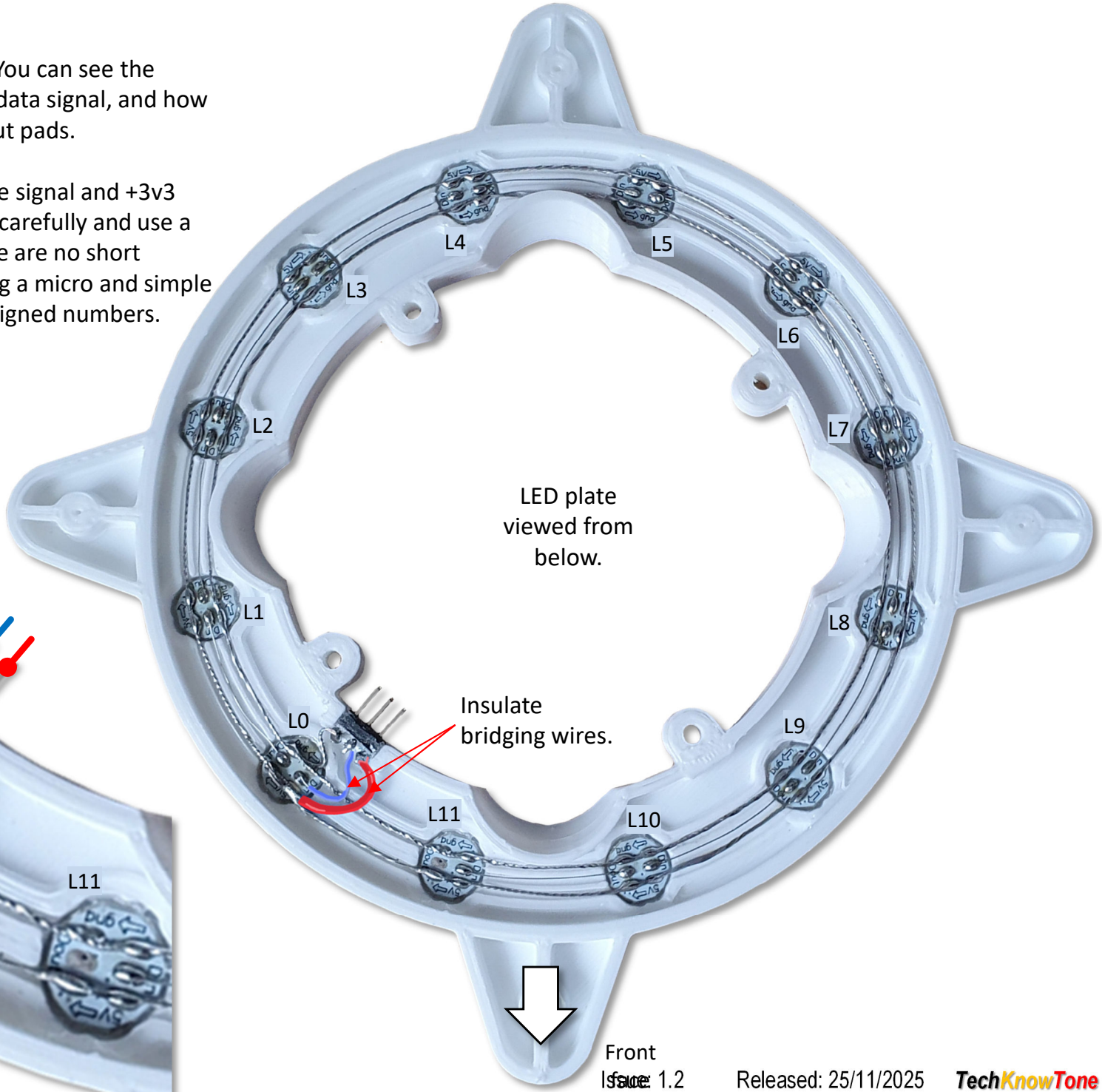
LED Plate Wiring – step 5

The wired plate should look something like this. You can see the thinner wire-wrap wire used for the chip to chip data signal, and how it has been cut between the chip input and output pads.

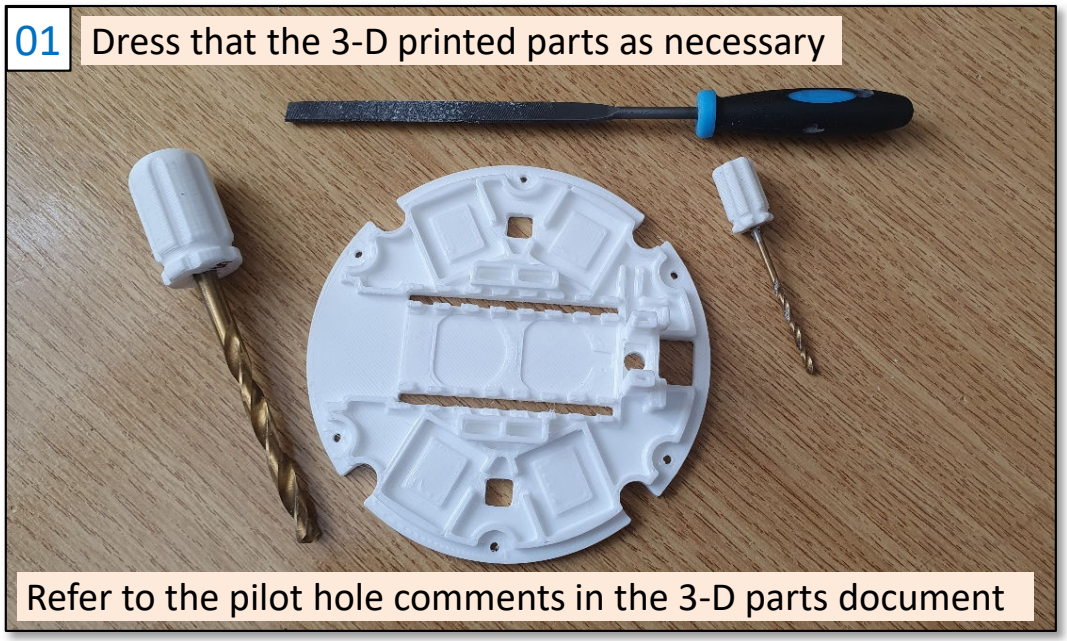
You can also see the use of insulated wires for the signal and +3v3 wire, from the 3-pin plug. Inspect your soldering carefully and use a multimeter to buzz out the wiring to ensure there are no short circuits. The wired plate can be easily tested using a micro and simple code, which exercises the LEDs. Note the LED assigned numbers.





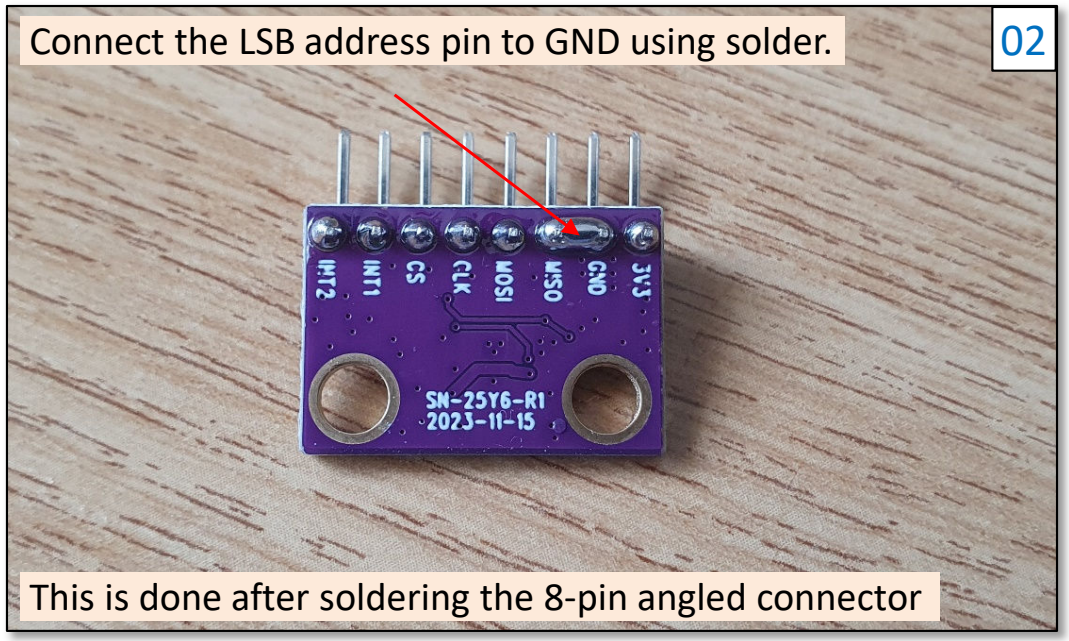
Build Images

01 Dress that the 3-D printed parts as necessary



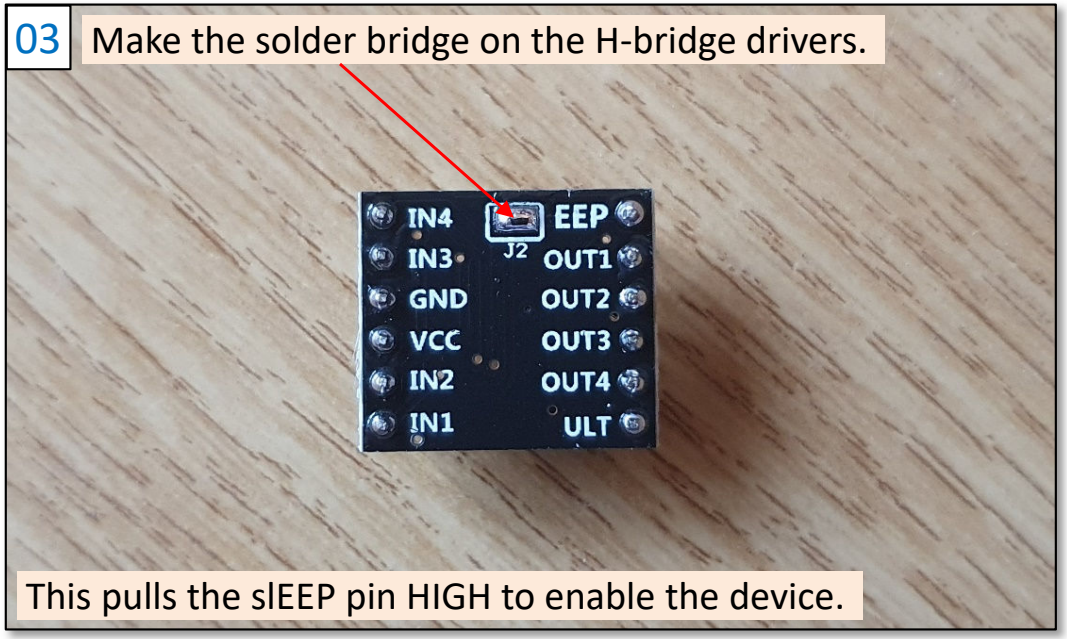
Refer to the pilot hole comments in the 3-D parts document

Connect the LSB address pin to GND using solder. 02



This is done after soldering the 8-pin angled connector

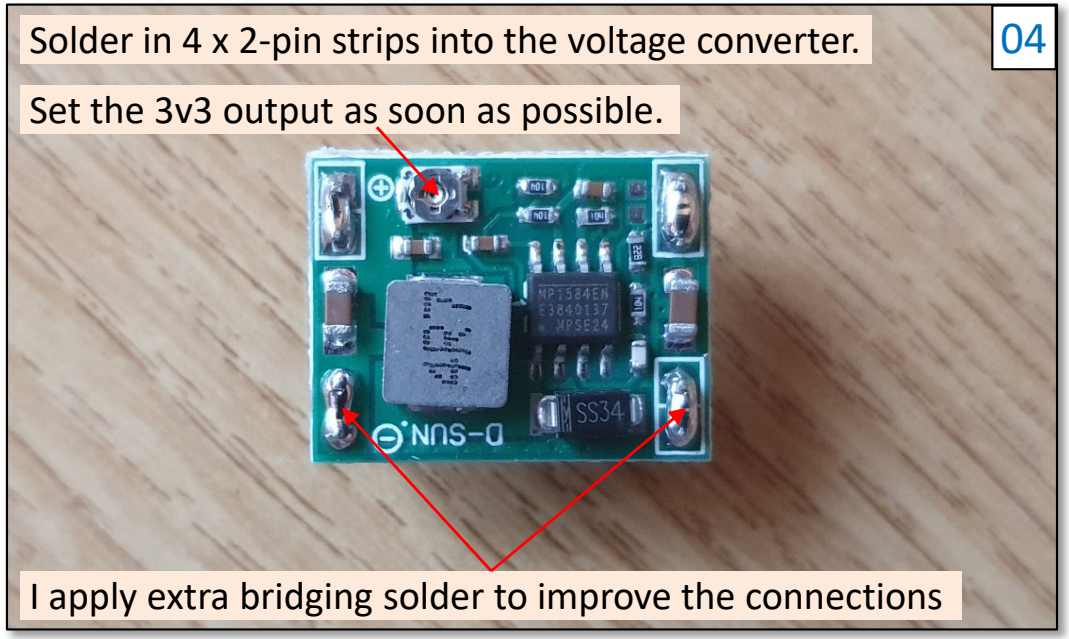
03 Make the solder bridge on the H-bridge drivers.



This pulls the slEEP pin HIGH to enable the device.

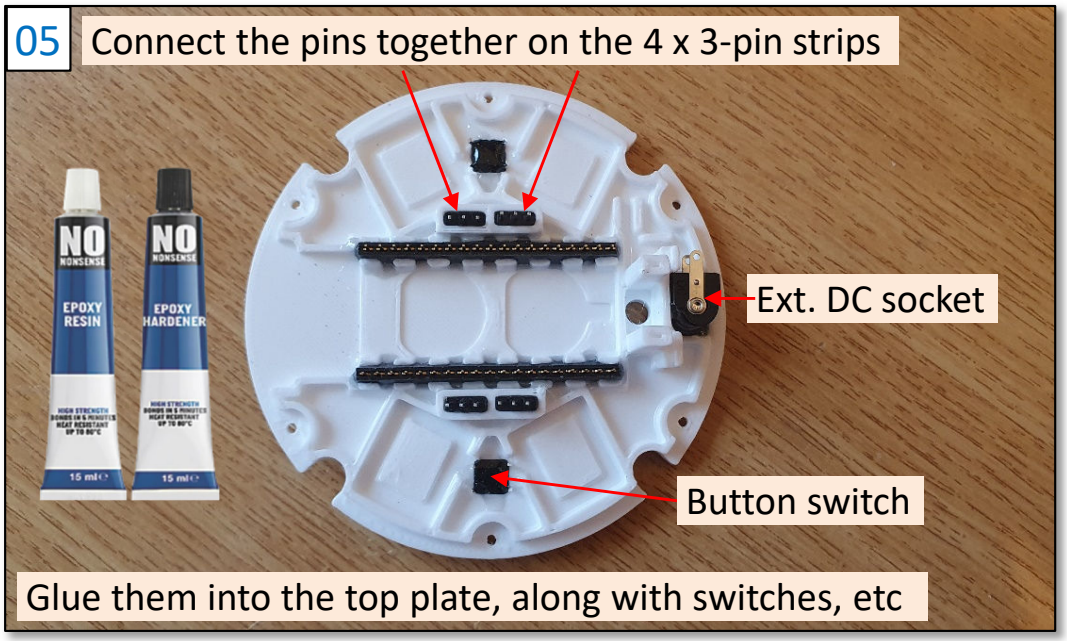
Solder in 4 x 2-pin strips into the voltage converter. 04

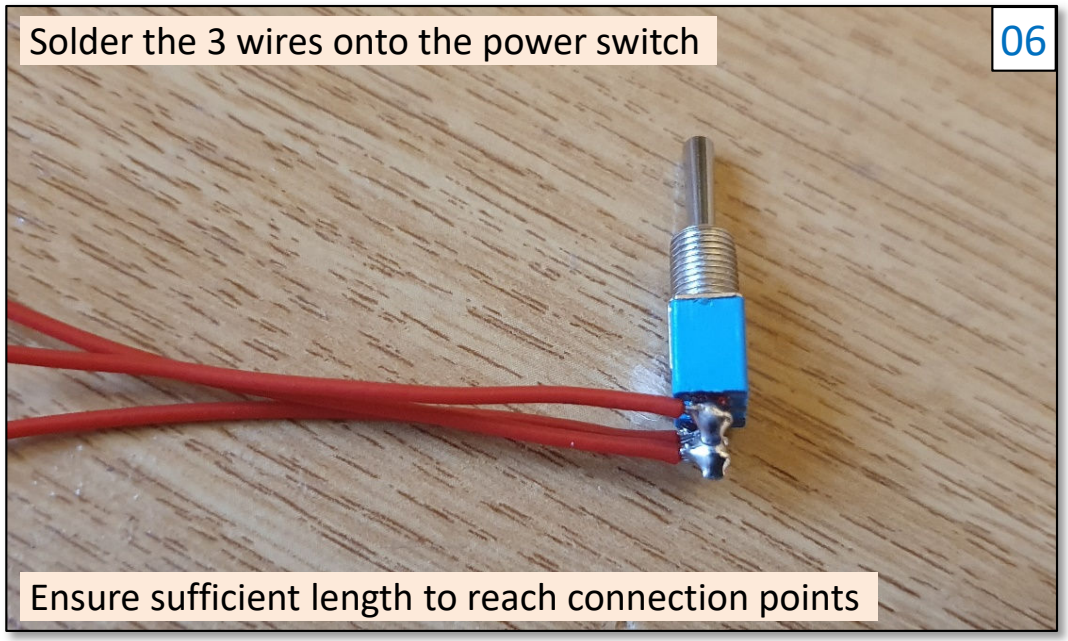
Set the 3v3 output as soon as possible.

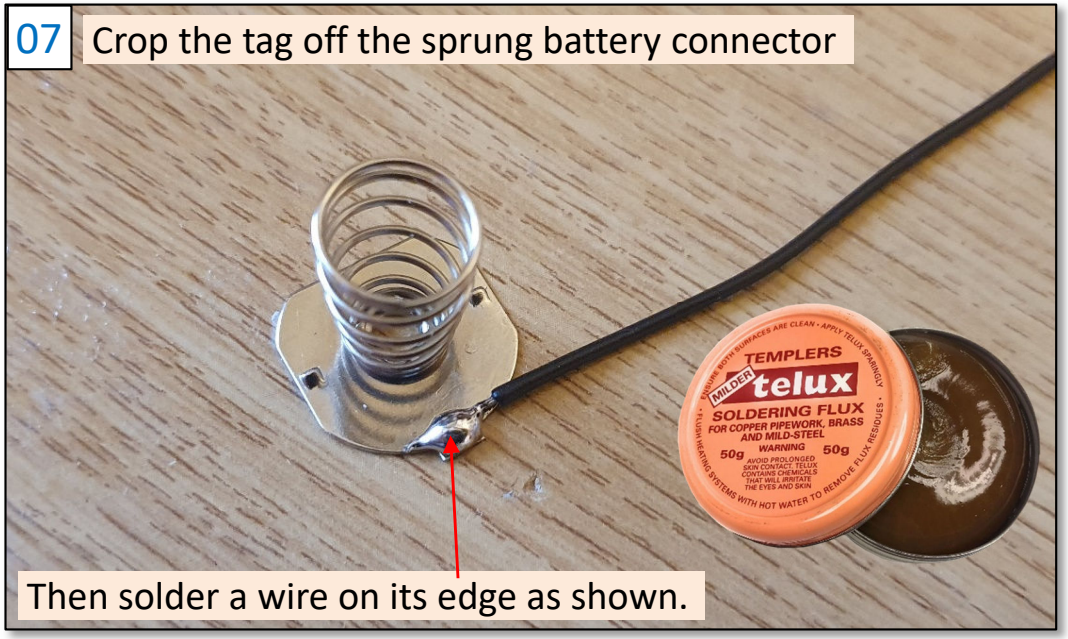


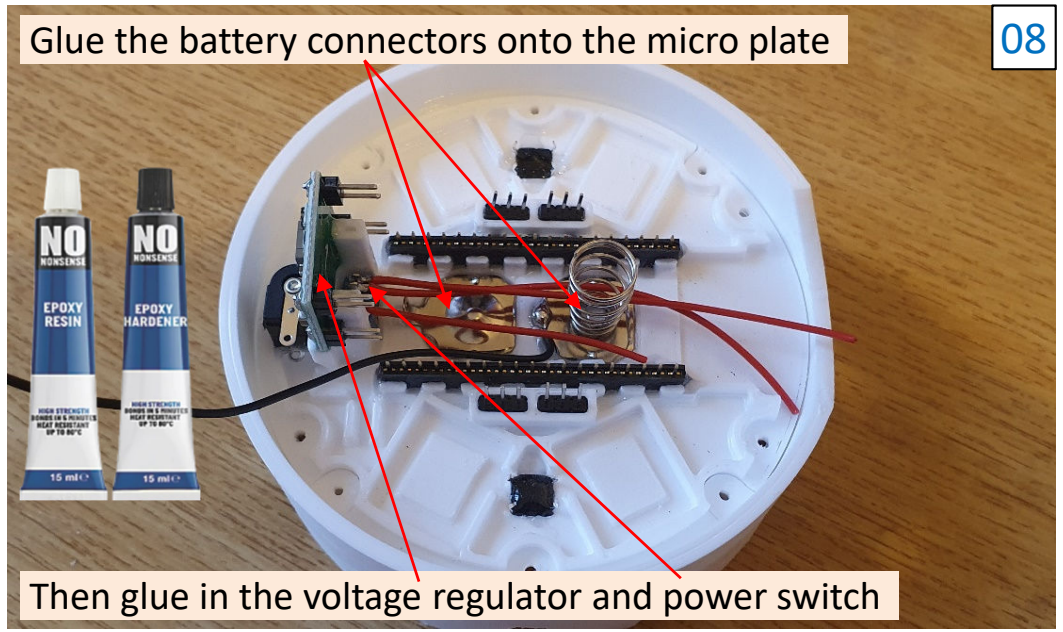
I apply extra bridging solder to improve the connections

Build Images

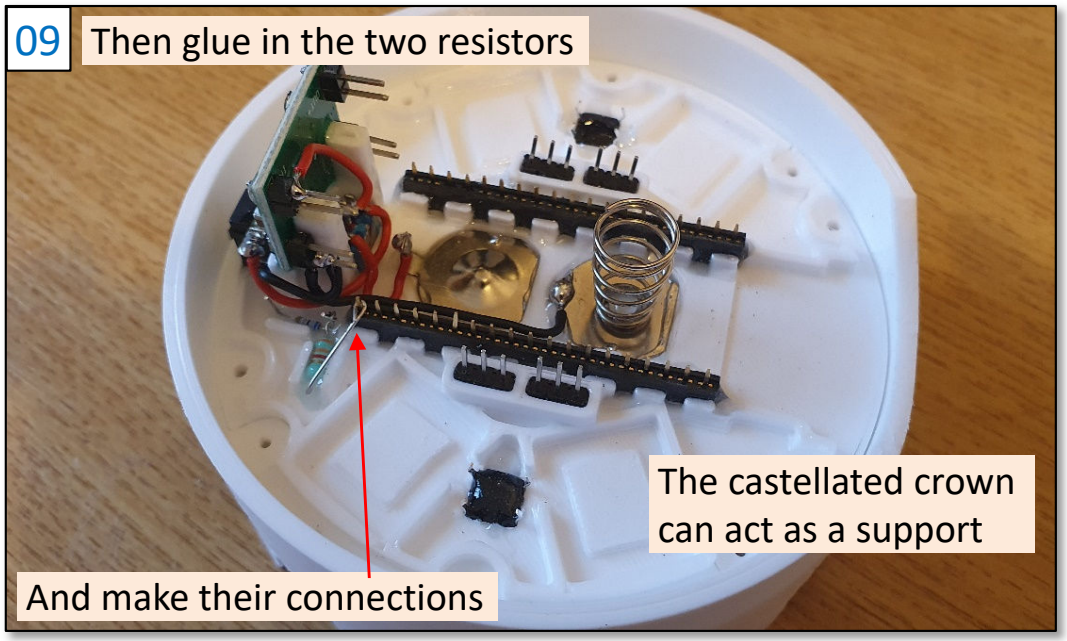


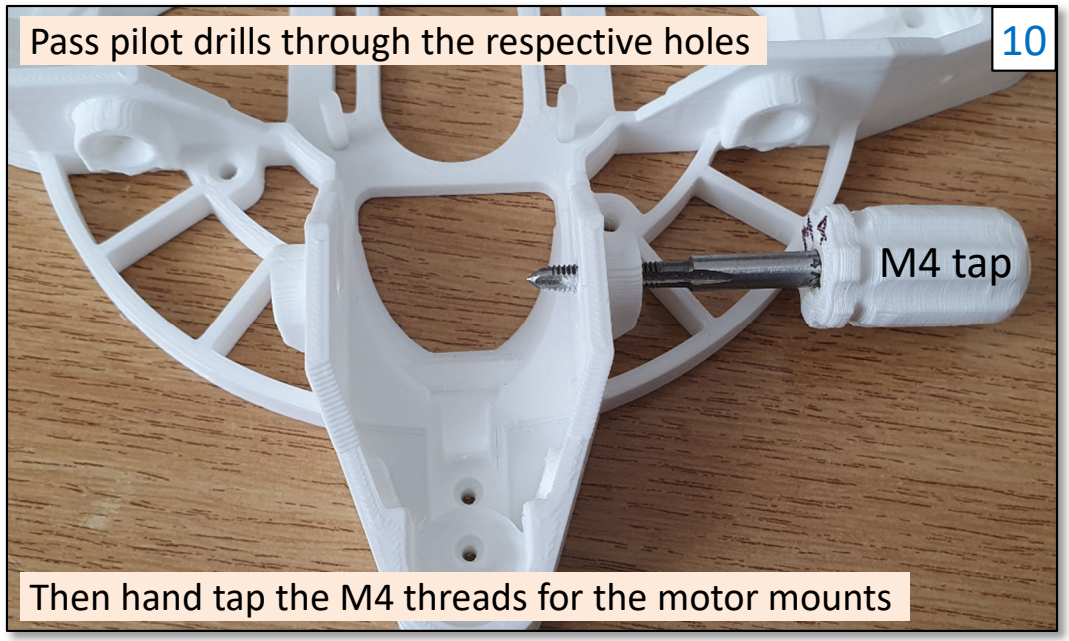


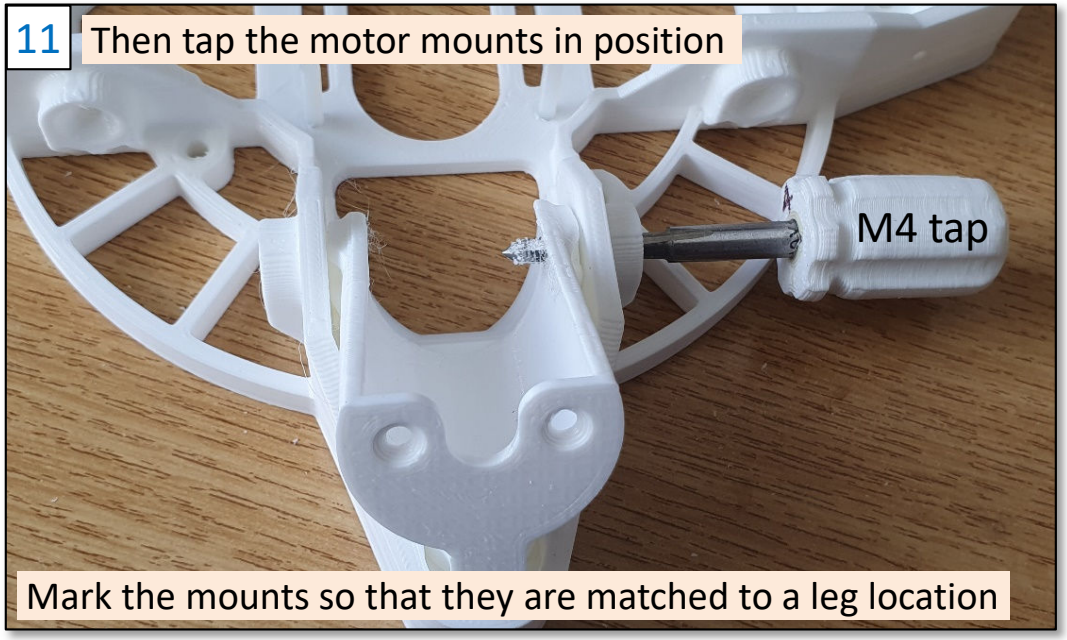


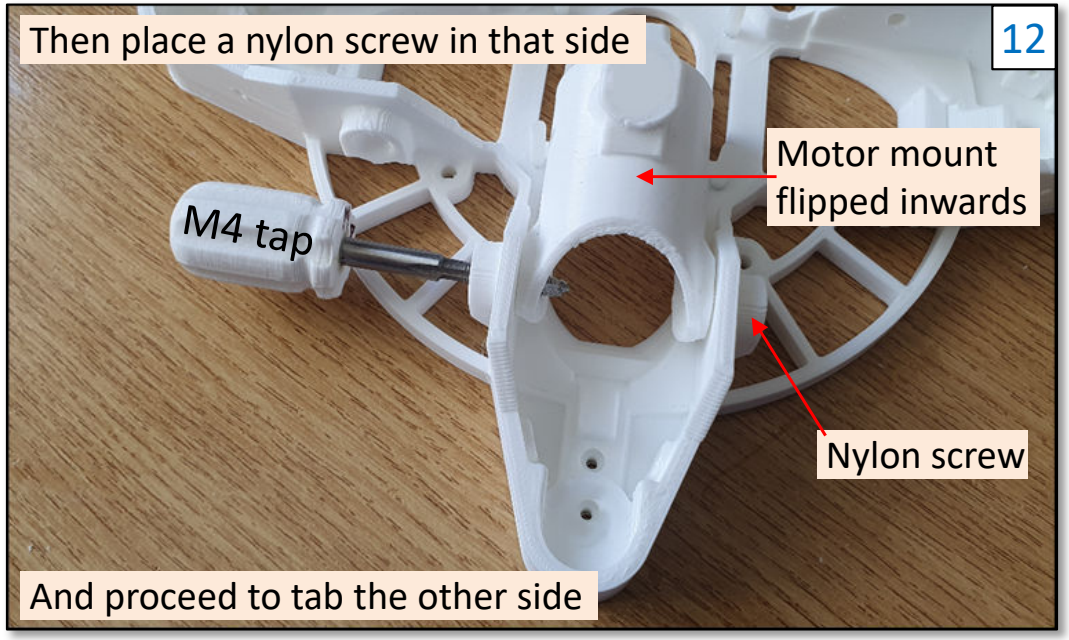


Build Images



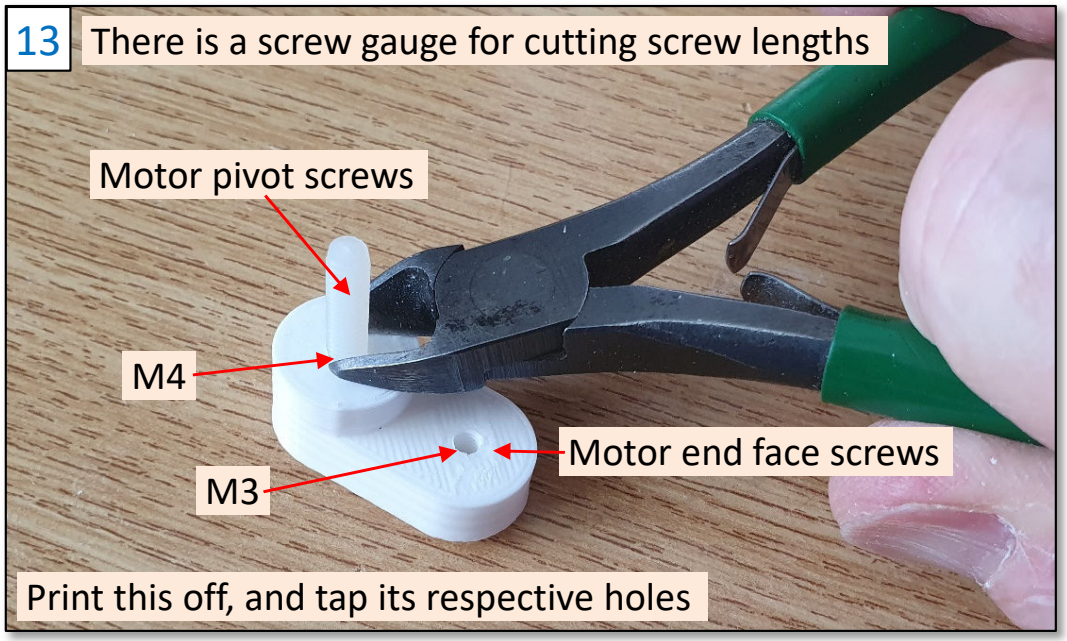






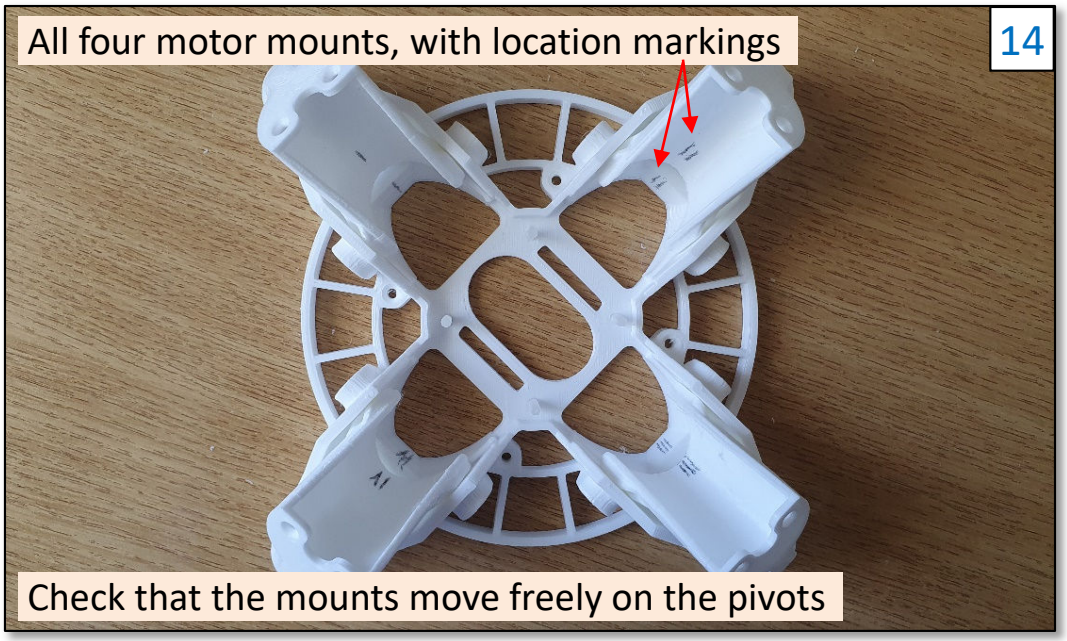
Build Images

13 There is a screw gauge for cutting screw lengths



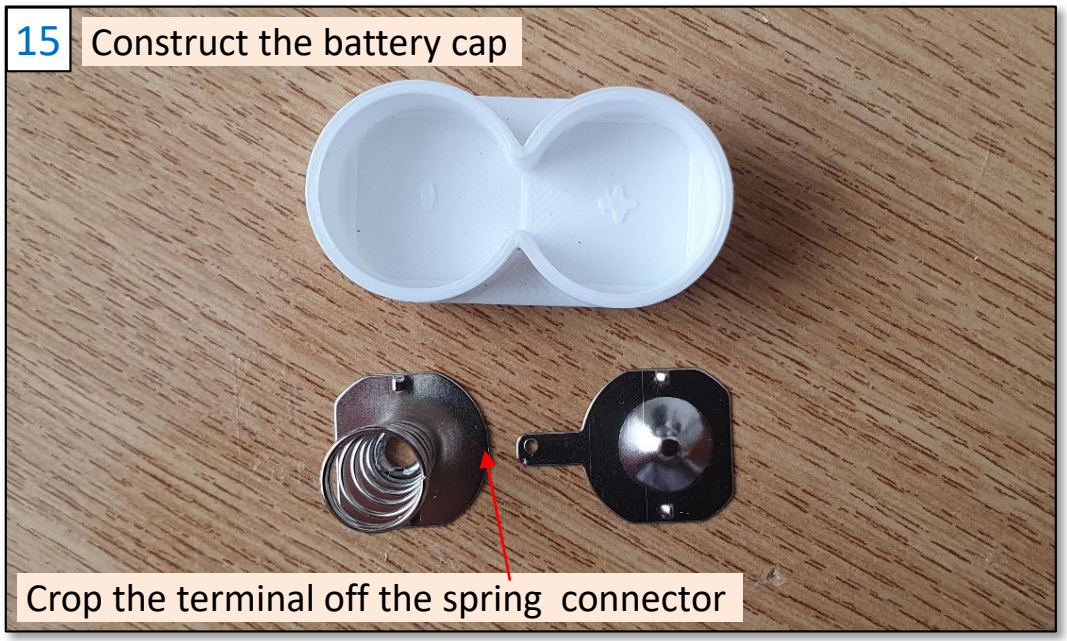
Print this off, and tap its respective holes

All four motor mounts, with location markings 14



Check that the mounts move freely on the pivots

15 Construct the battery cap



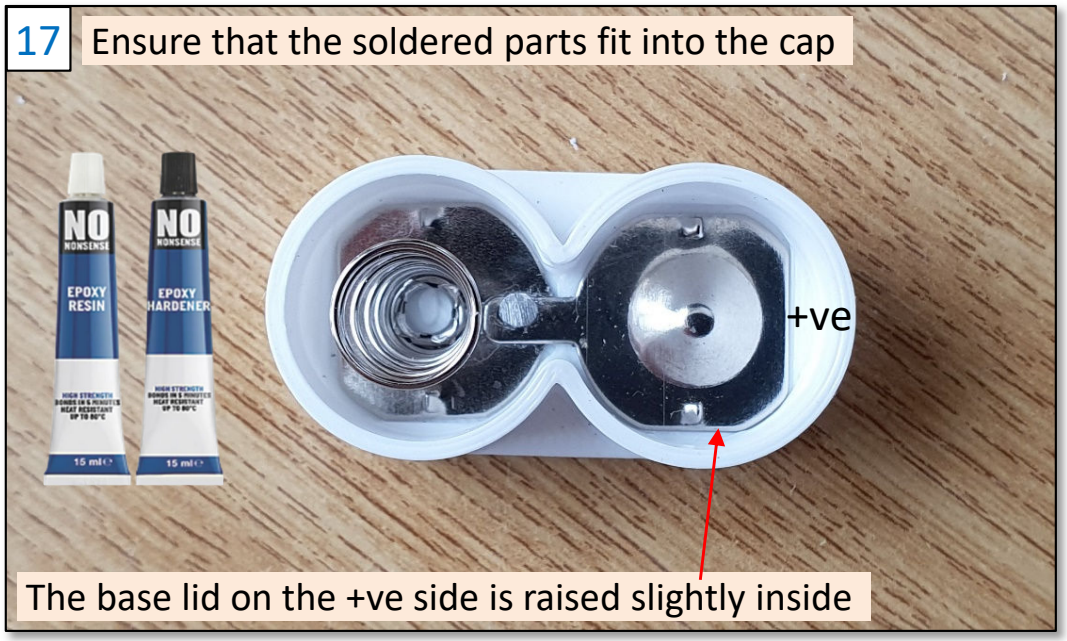
Crop the terminal off the spring connector

Then apply solder to each parts surface 16

Then apply heat to sweat them together

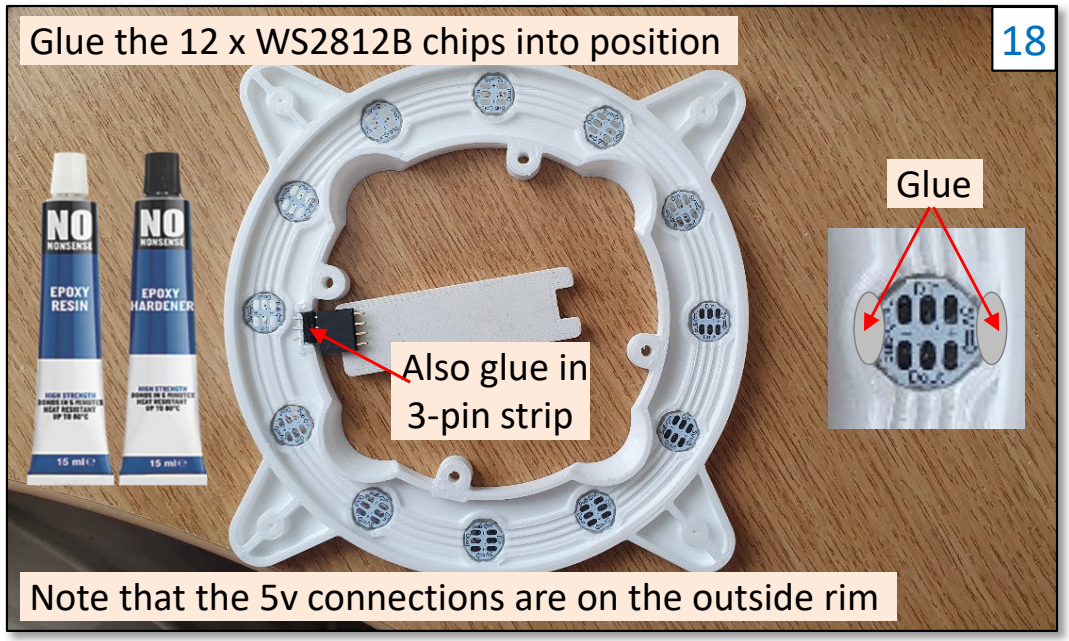
Build Images

17 Ensure that the soldered parts fit into the cap



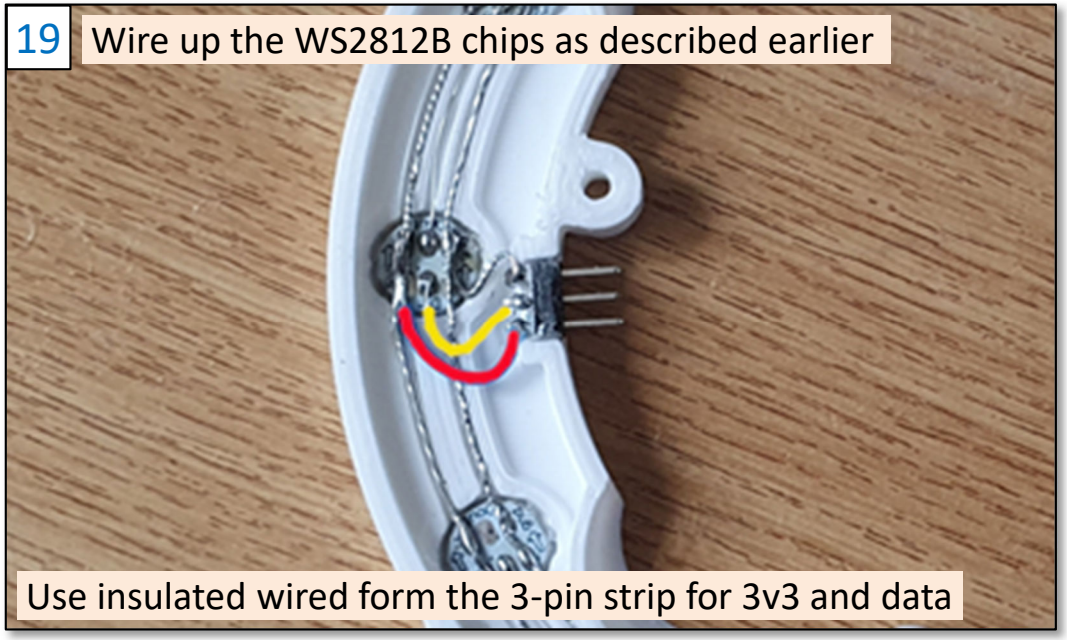
The base lid on the +ve side is raised slightly inside

Glue the 12 x WS2812B chips into position 18



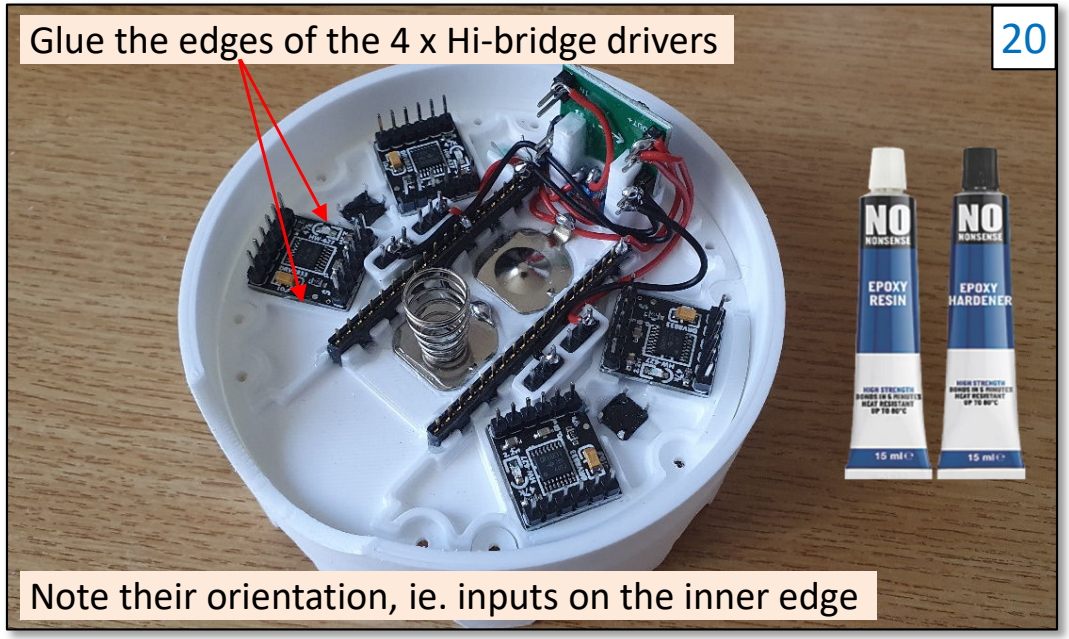
Note that the 5v connections are on the outside rim

19 Wire up the WS2812B chips as described earlier



Use insulated wired form the 3-pin strip for 3v3 and data

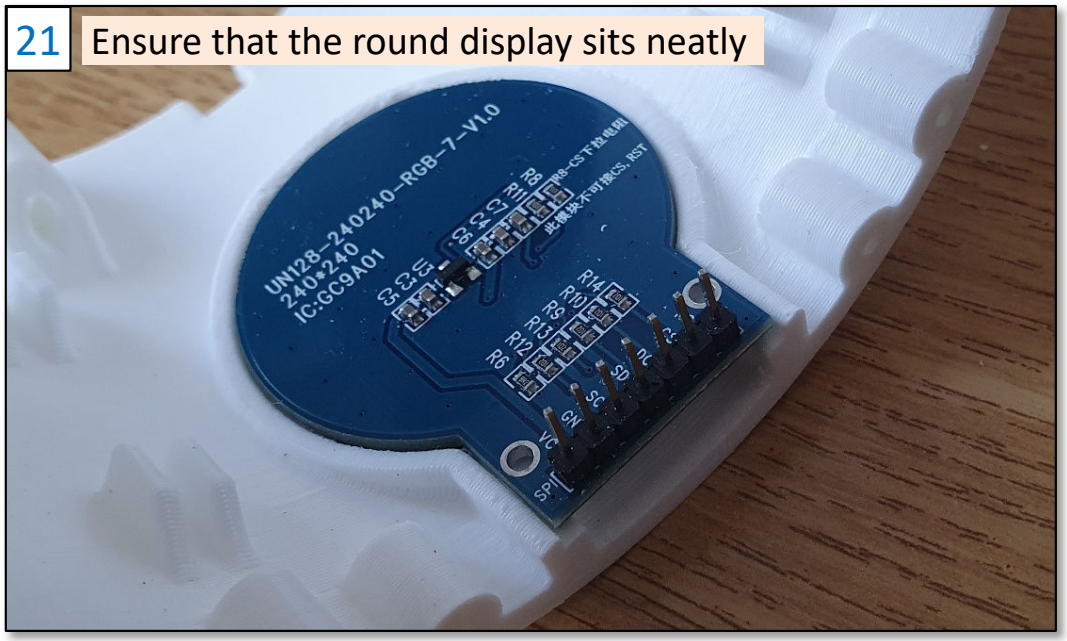
Glue the edges of the 4 x Hi-bridge drivers 20



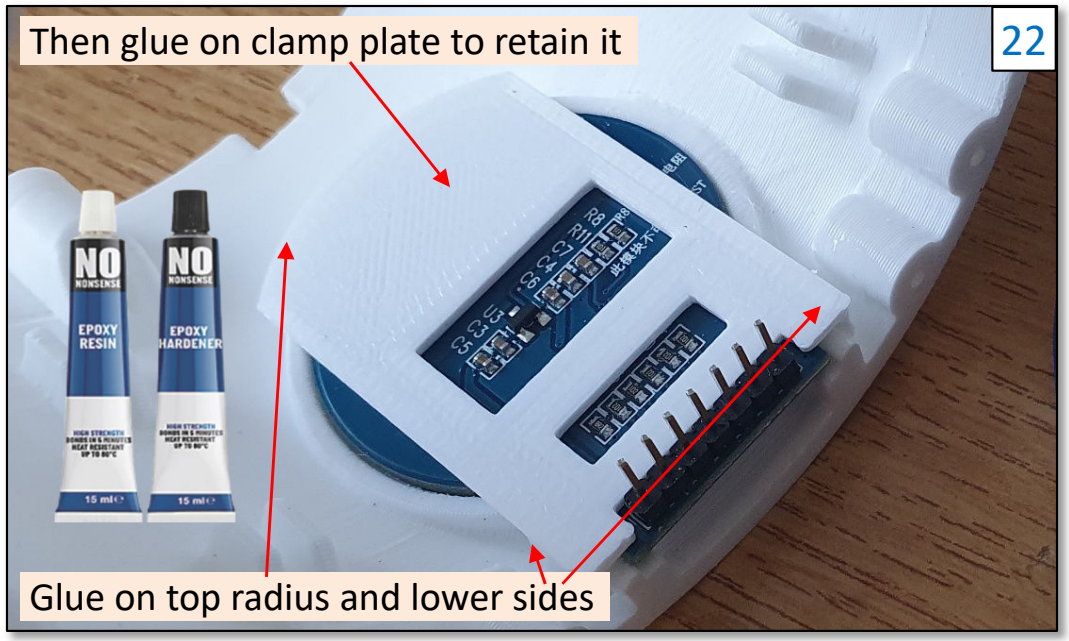
Note their orientation, ie. inputs on the inner edge

Build Images

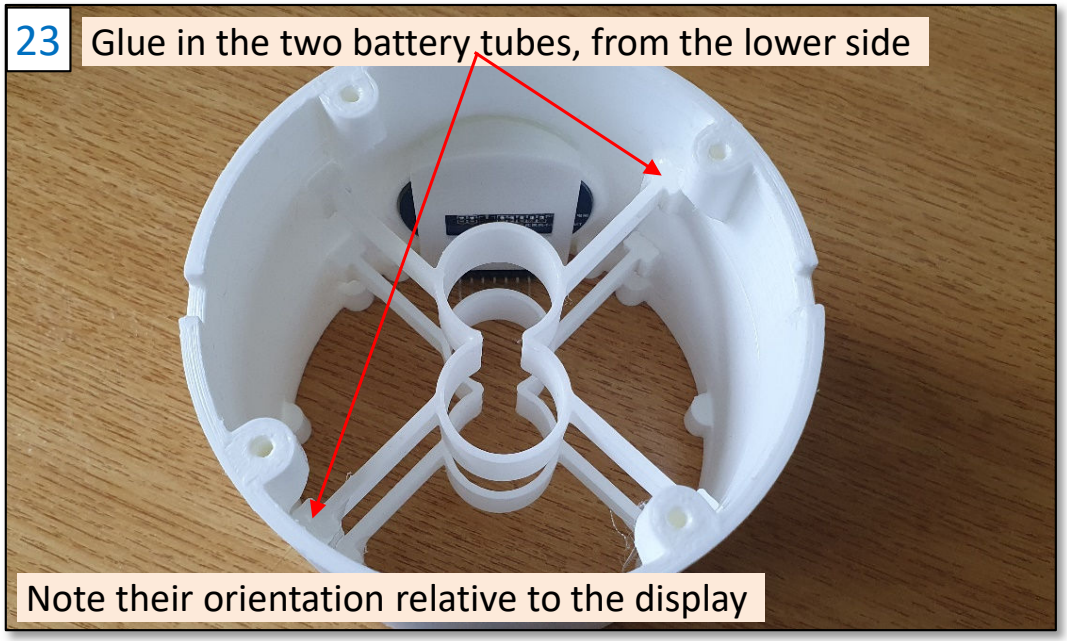
21 Ensure that the round display sits neatly



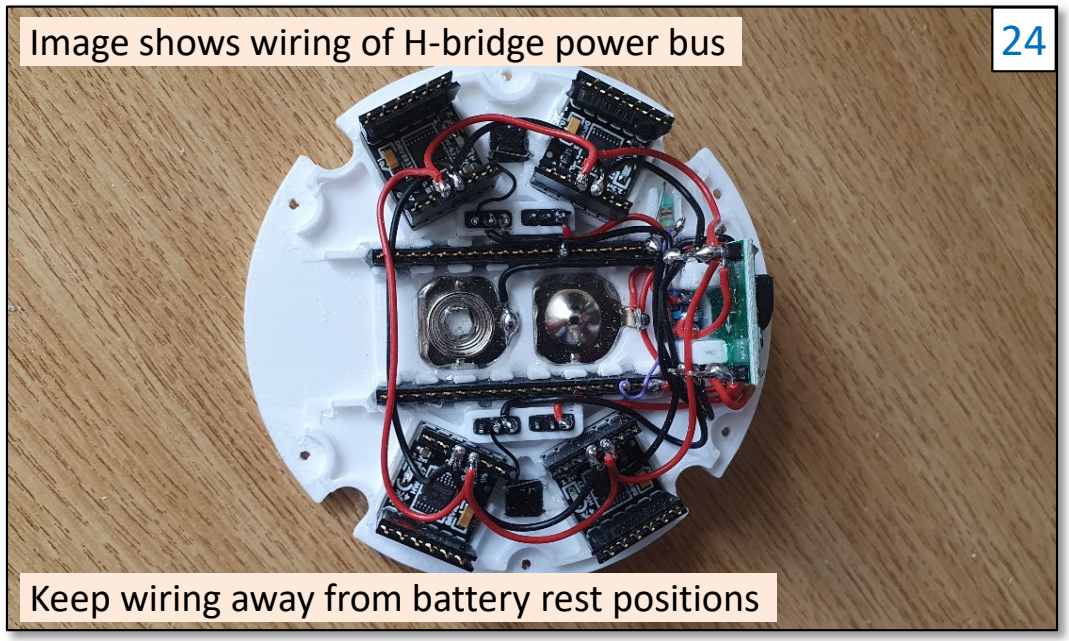
22 Then glue on clamp plate to retain it



23 Glue in the two battery tubes, from the lower side

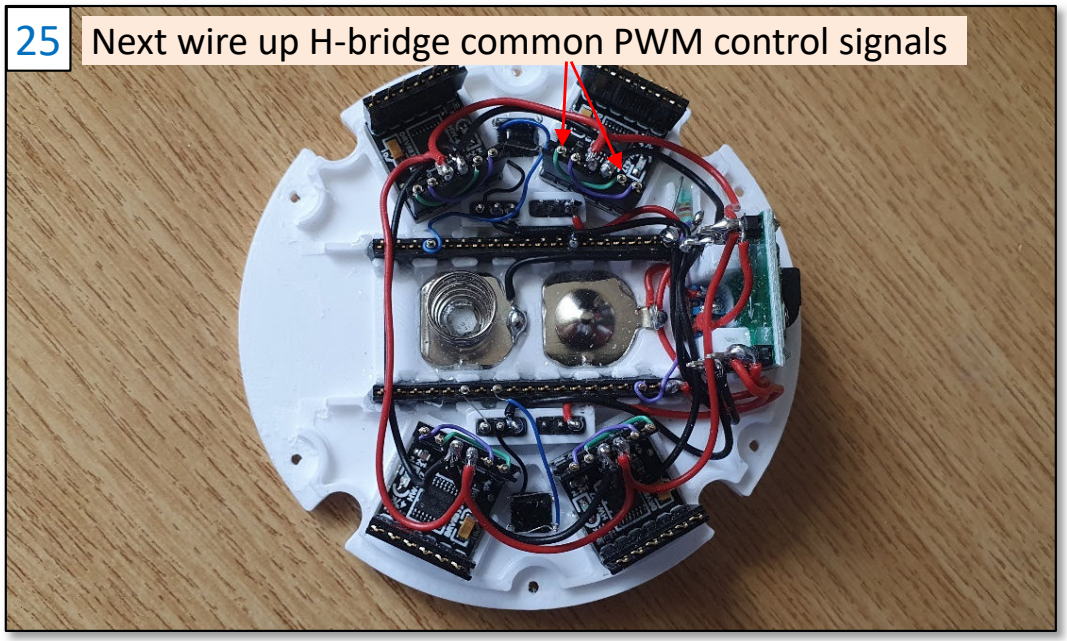


24 Image shows wiring of H-bridge power bus

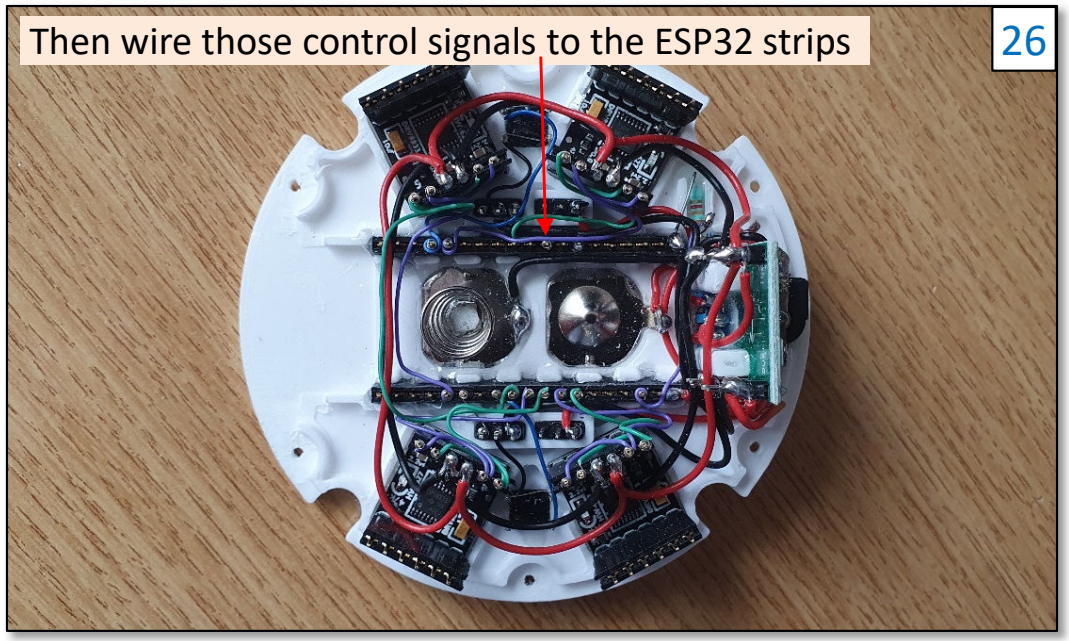


Build Images

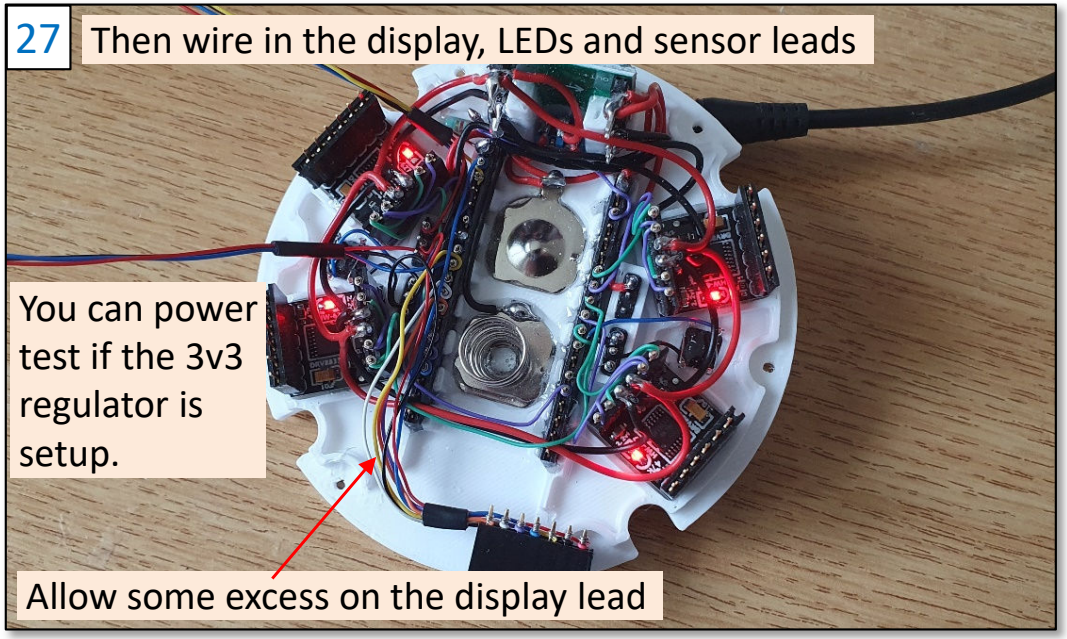
25 Next wire up H-bridge common PWM control signals



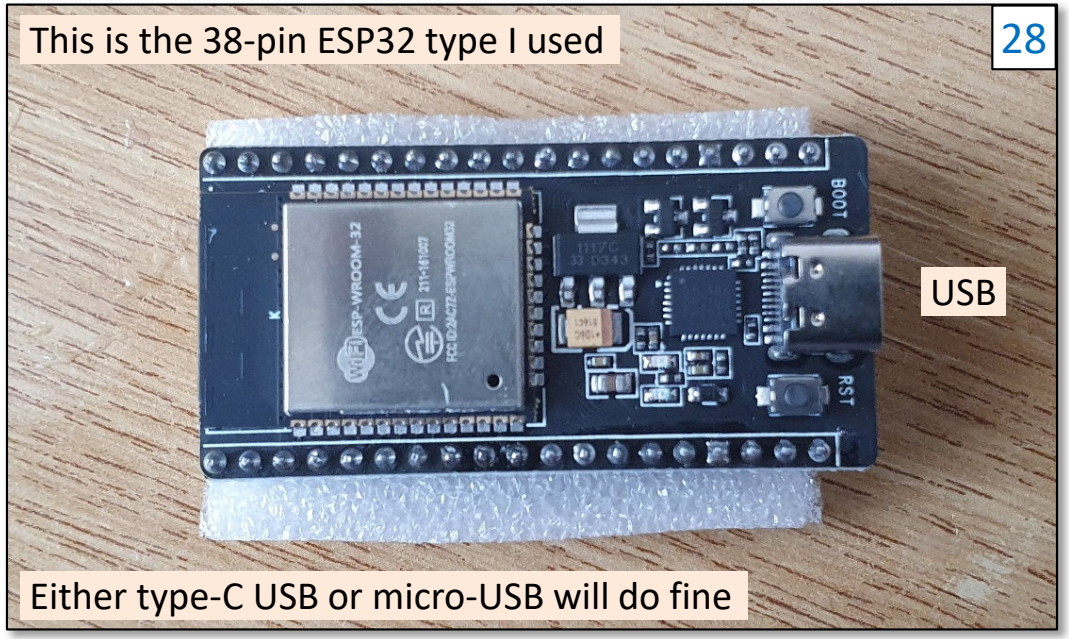
Then wire those control signals to the ESP32 strips 26



27 Then wire in the display, LEDs and sensor leads

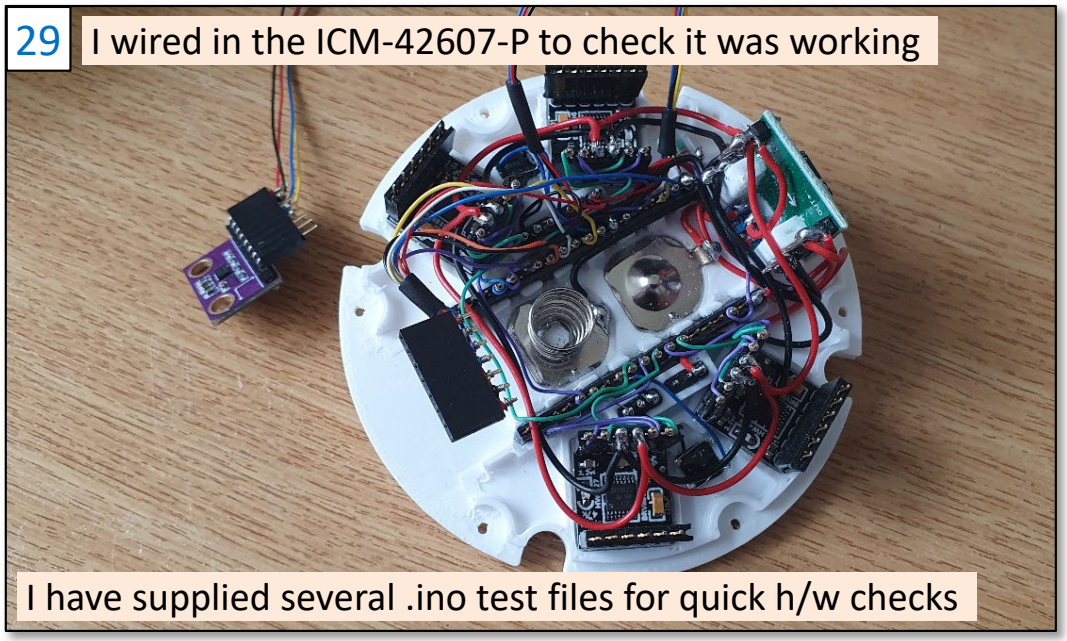


This is the 38-pin ESP32 type I used 28



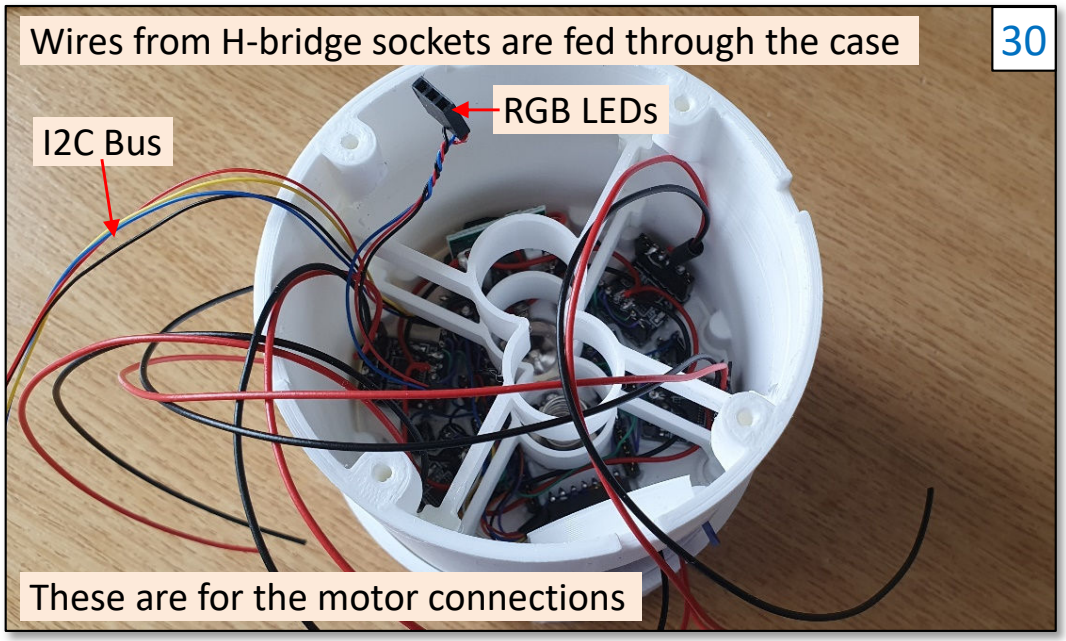
Build Images

29 I wired in the ICM-42607-P to check it was working



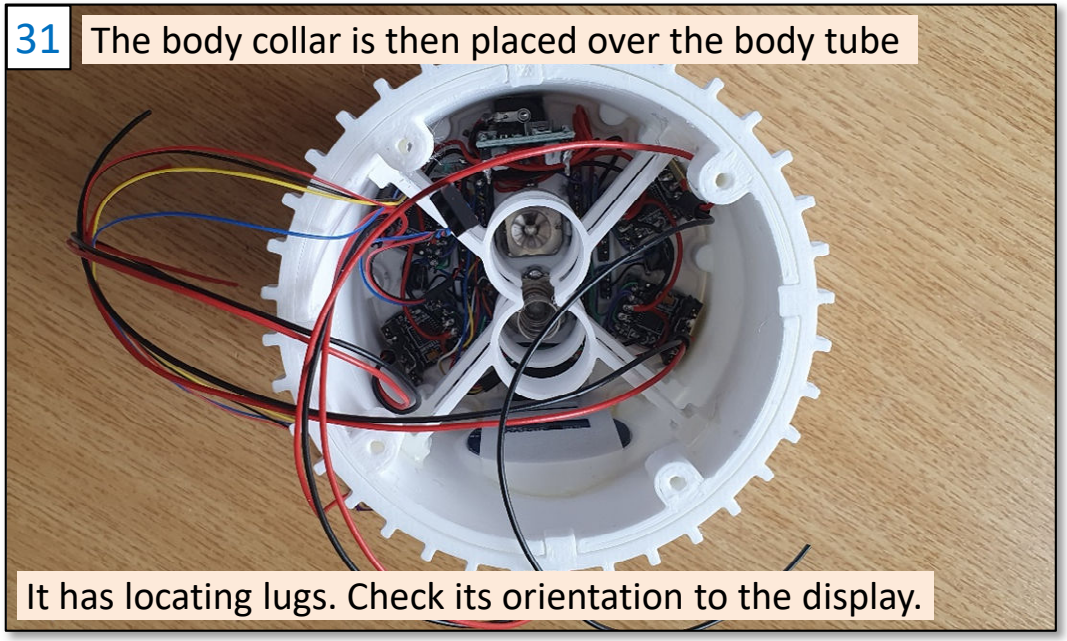
I have supplied several .ino test files for quick h/w checks

Wires from H-bridge sockets are fed through the case 30



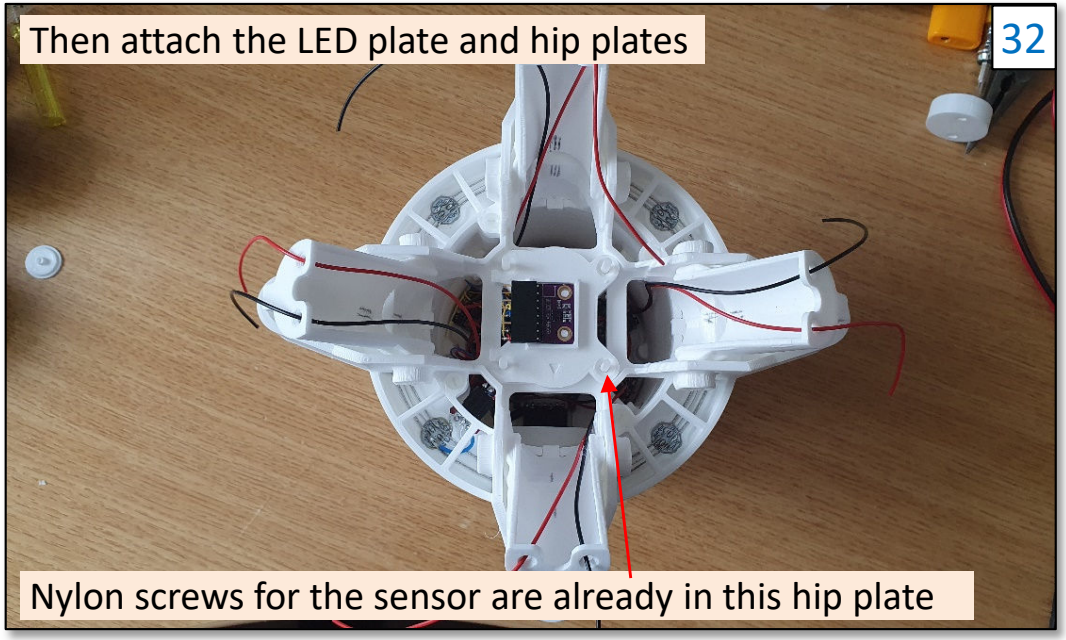
These are for the motor connections

31 The body collar is then placed over the body tube



It has locating lugs. Check its orientation to the display.

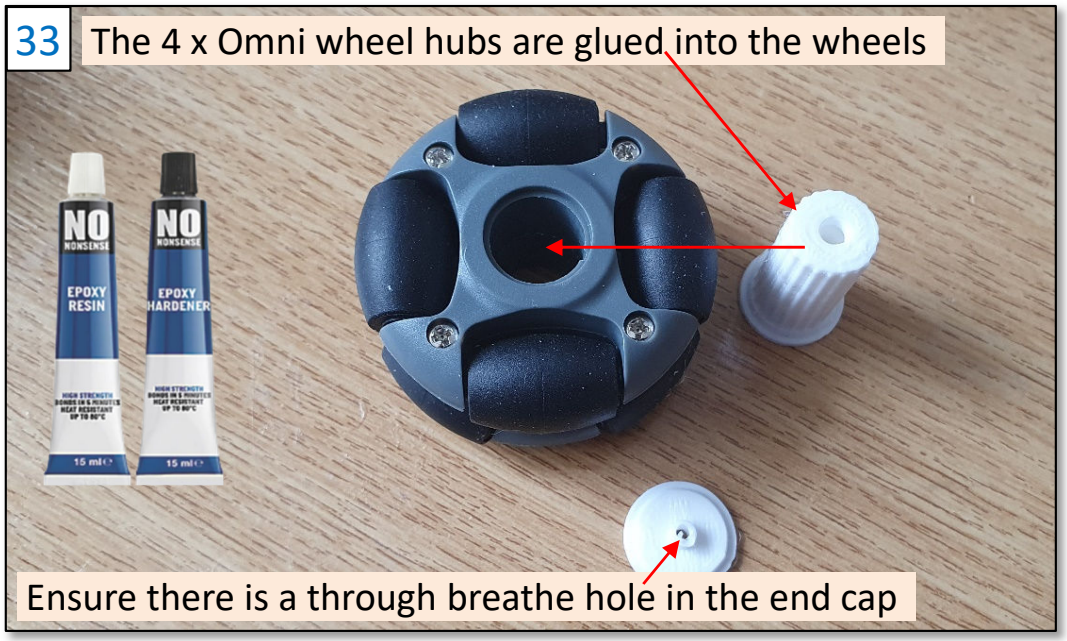
Then attach the LED plate and hip plates 32



Nylon screws for the sensor are already in this hip plate

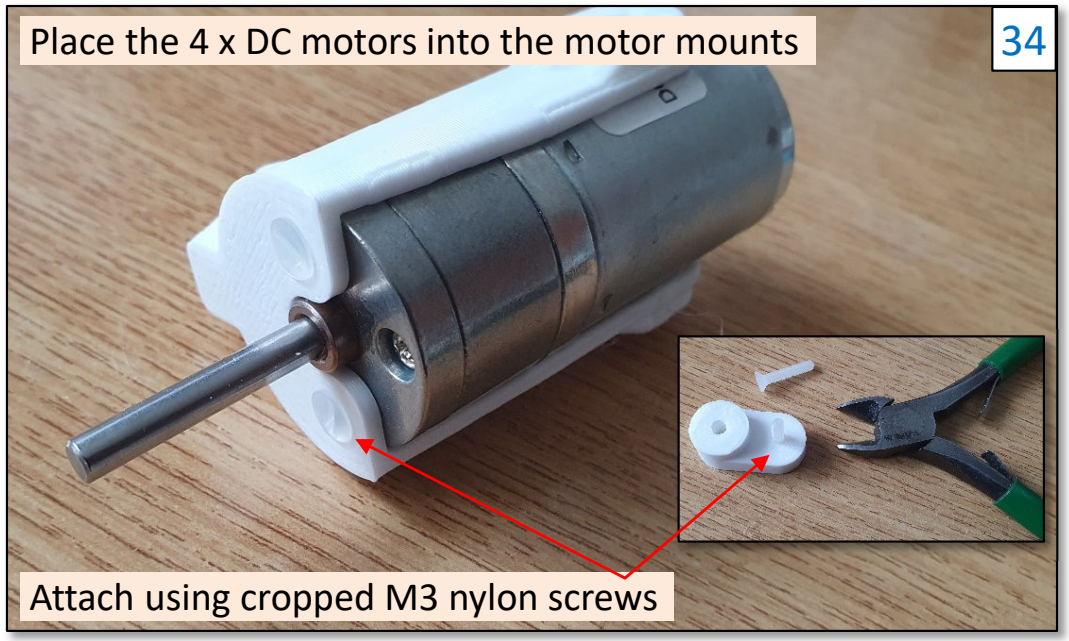
Build Images

33 The 4 x Omni wheel hubs are glued into the wheels



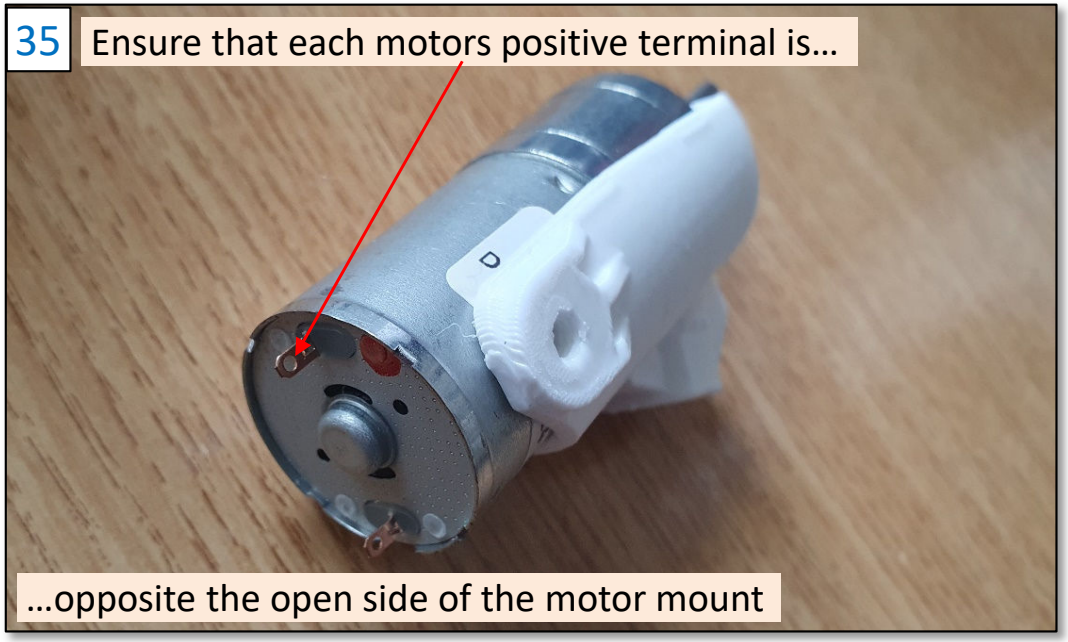
Ensure there is a through breathe hole in the end cap

Place the 4 x DC motors into the motor mounts 34



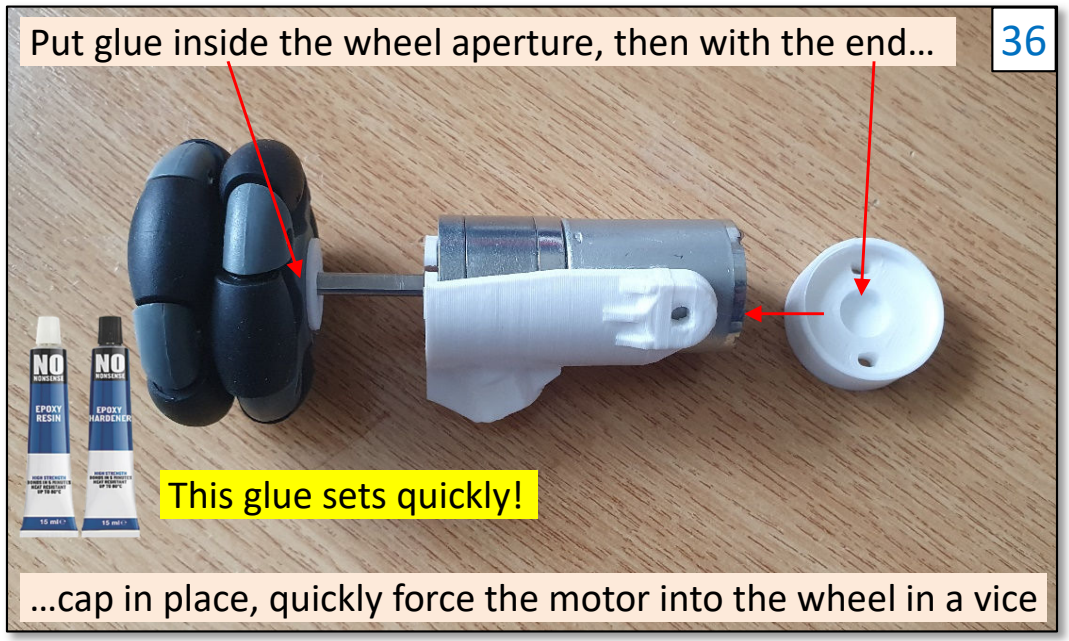
Attach using cropped M3 nylon screws

35 Ensure that each motors positive terminal is…



…opposite the open side of the motor mount

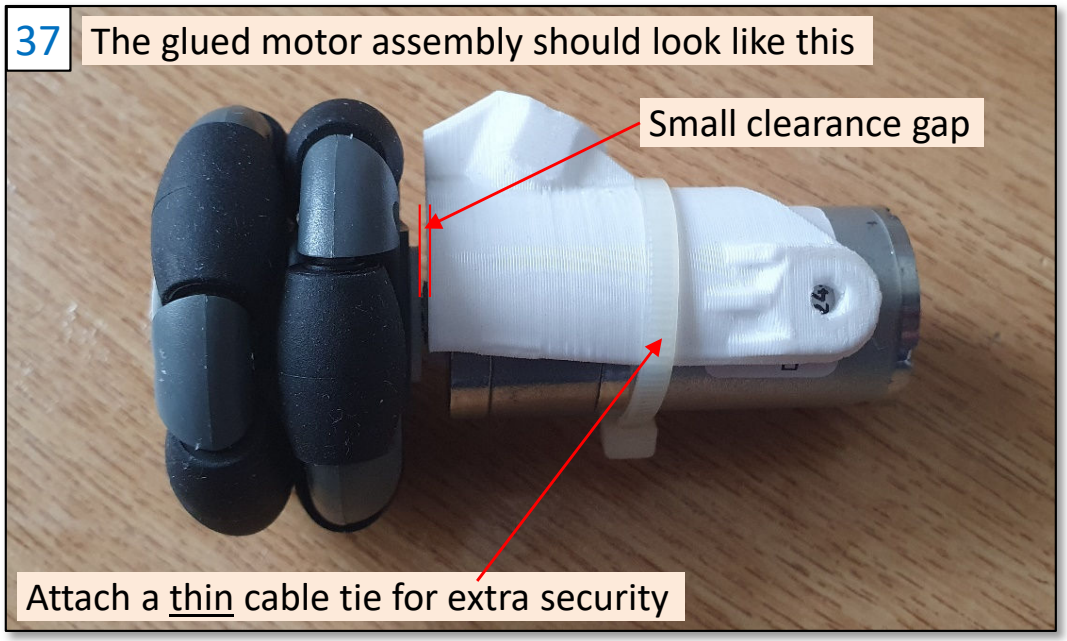
Put glue inside the wheel aperture, then with the end… 36



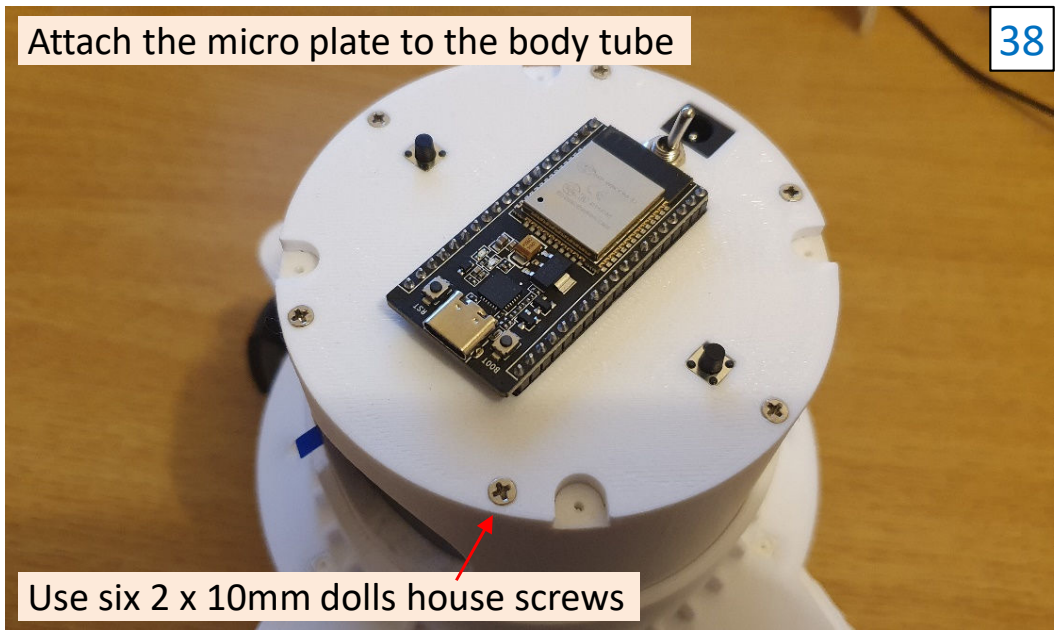
…cap in place, quickly force the motor into the wheel in a vice

Build Images

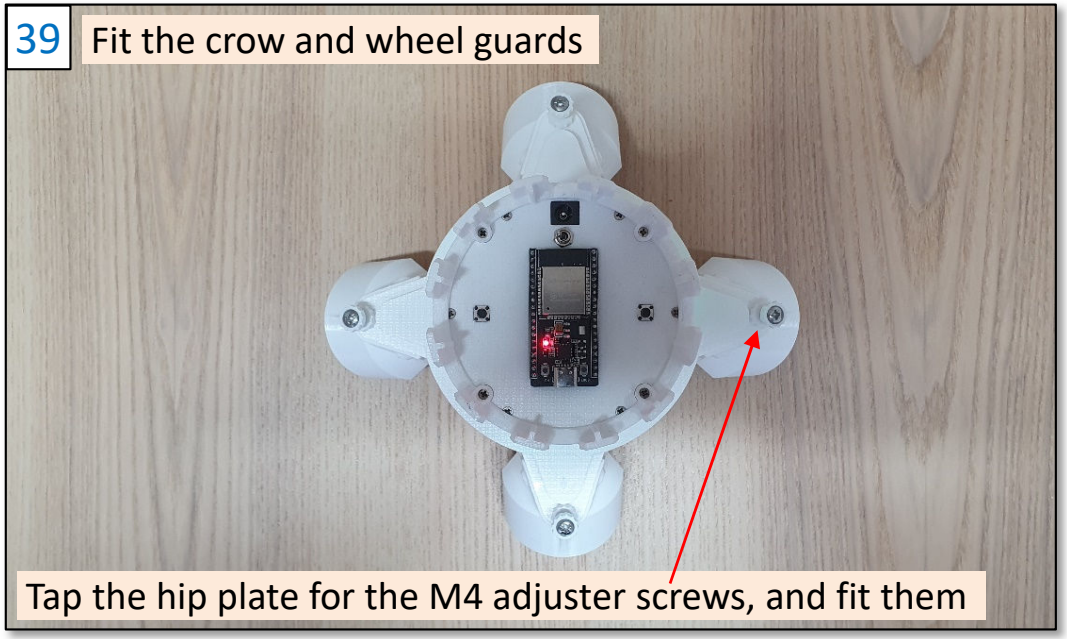
37 The glued motor assembly should look like this



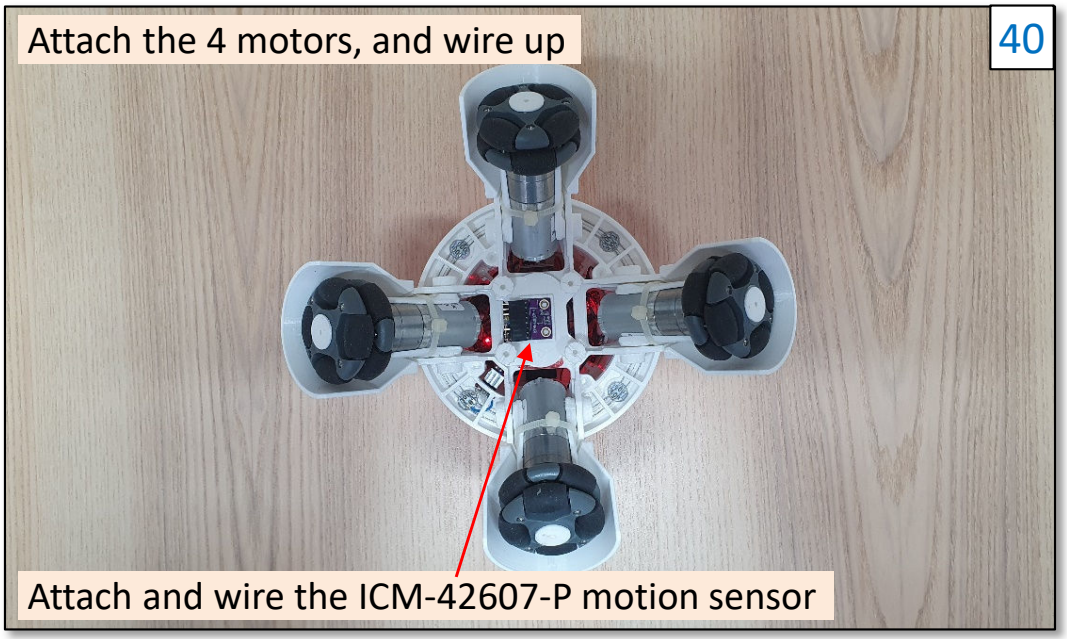
Attach the micro plate to the body tube 38



39 Fit the crow and wheel guards



Attach the 4 motors, and wire up 40



Build Images

41 And you're now ready for testing

This project is designed to work with a WEMOS D1 transceiver

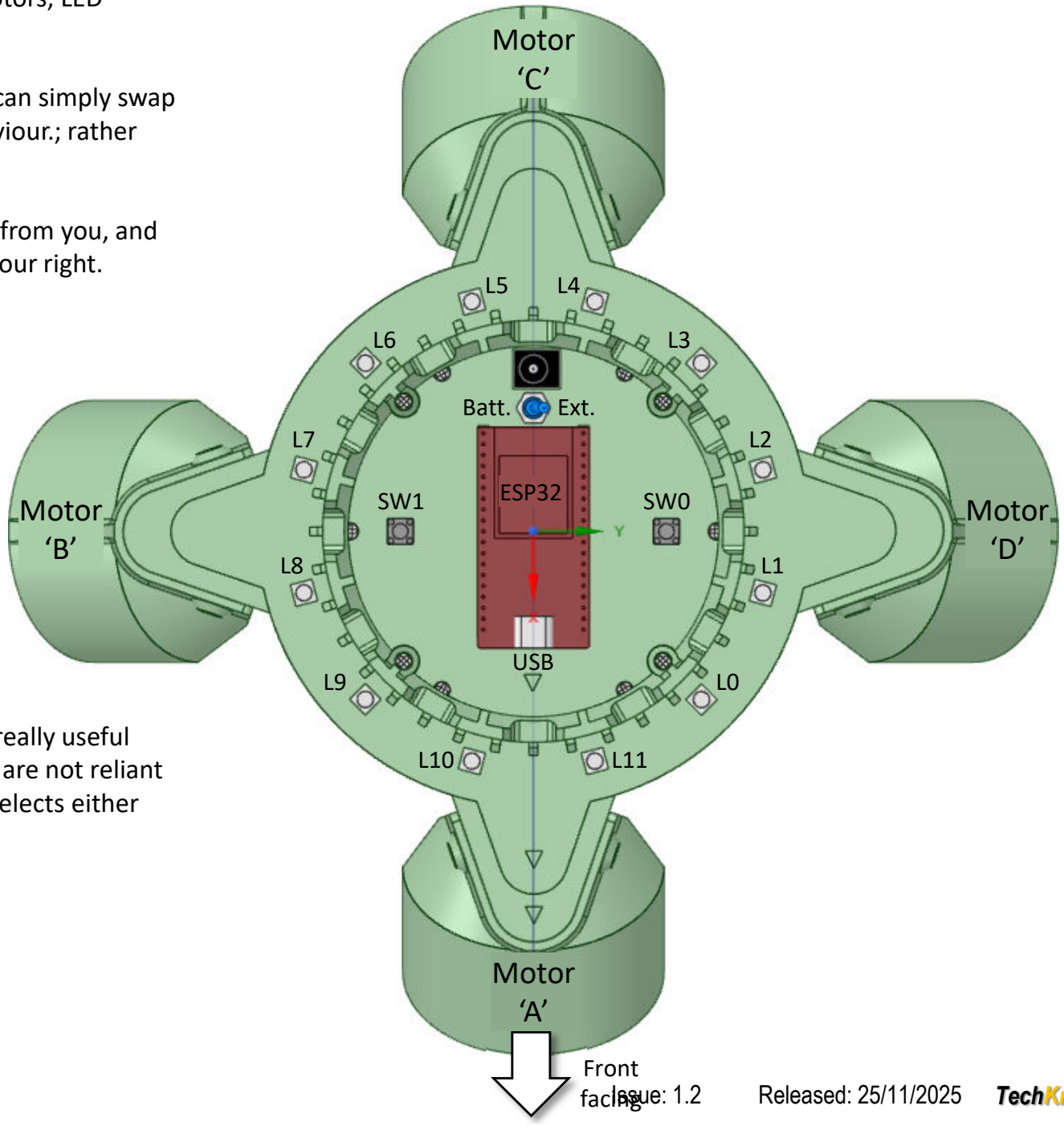
A Wii Nunchuk controller, and the Monitor+ app for tuning the PID controllers

BallBot ESP32 4x4 – top view

This image is included to show the assignment of motors, LED numbers and switches, for coding reference.

If one or more motors turn in the wrong direct, you can simply swap the pin assignments in the code to correct this behaviour.; rather than changing the wiring, if you want.

In demonstrations the robot is normally facing away from you, and this is why SW0 would be on your left, and SW1 on your right.



With the BallBot on a stand, the DC power socket is really useful during code development and testing. Such that you are not reliant on frequently charging batteries. The power switch selects either batteries or the DC socket, as the power source.

6v DC Motor 130 rpm

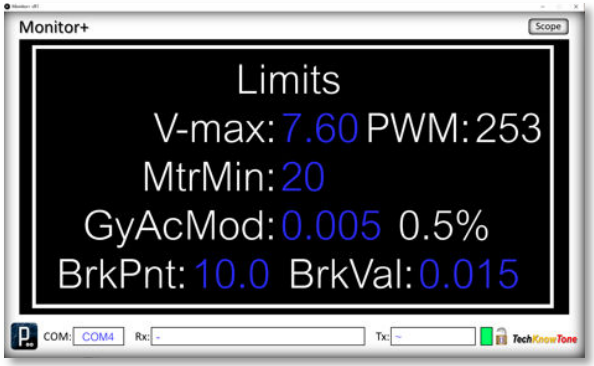
The GA25-370 motors rotate clockwise, when looking at the end of the drive shaft, when a positive voltage is applied to the motor terminals, as shown.

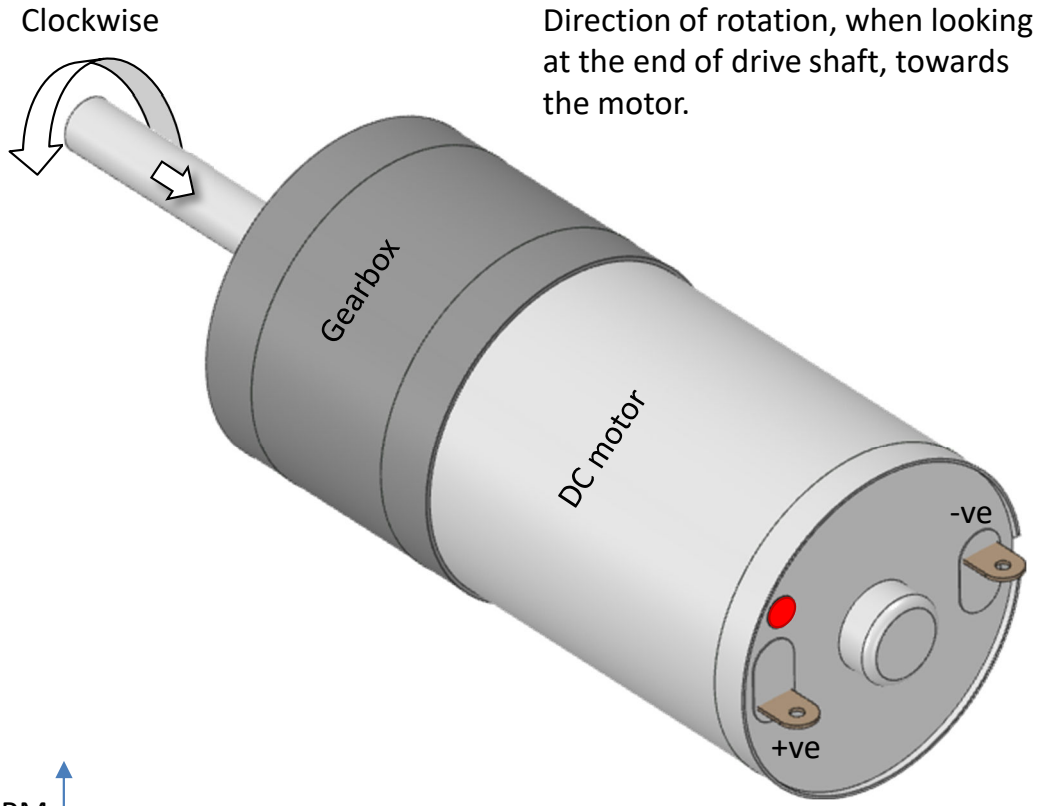
In this project the 7.5v Lithium batteries can have a terminal voltage, ranging from 6.0 – 8.2 volts, depending on the state of charge. Hence the supply voltage is monitored by the code, which then adjusts the applied PWM signals to compensate for this variation.

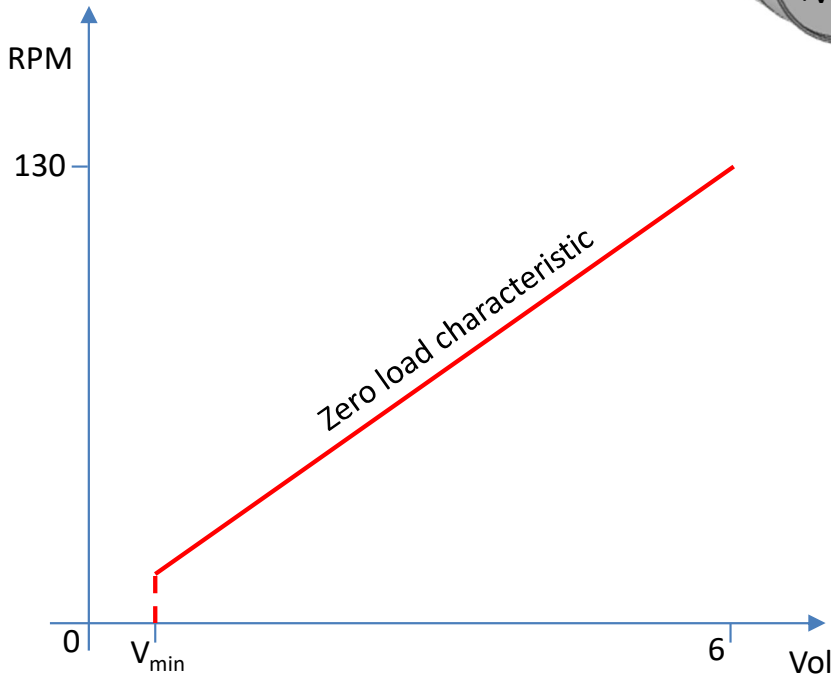
With zero load, the speed of a DC motor is proportional to the applied voltage. However, gearbox friction losses will mean that the motor is always loaded, albeit lightly. It therefore does not turn, until the applied voltage reaches a minimum threshold, V_{min}.

Due to stiction in the gearbox, given the relatively high gear ratio, the drive shaft output will also stall below a minimum voltage. The applied PWM signal code, recognises this deadband, which is set using the Monitor+ application.

In this screen shot, the value of V-max can be adjusted, setting the voltage to which PWM values will be scaled back. And the MtrMin value can be adjusted, setting the lowest value of PW demand being applied:





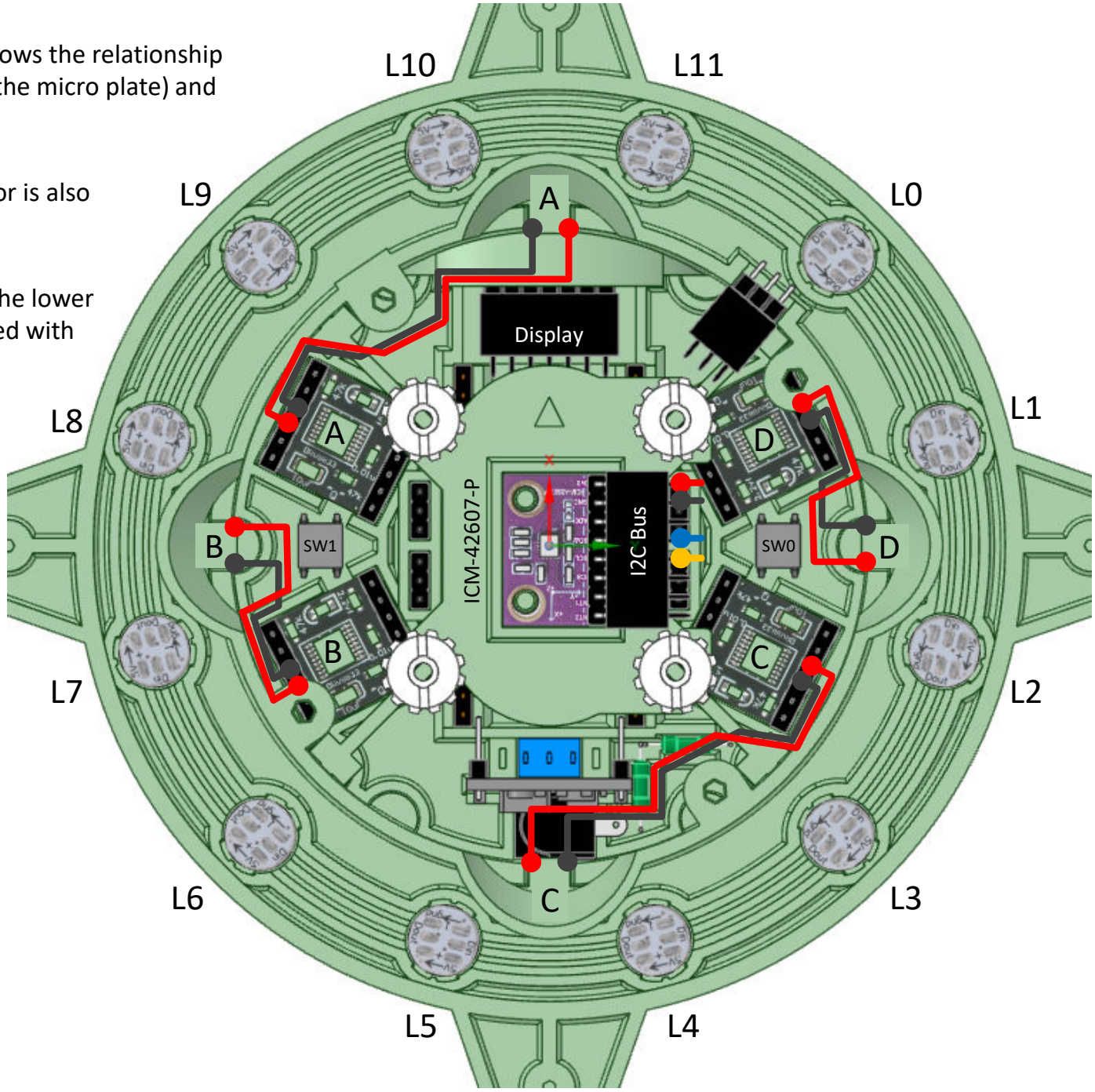


BallBot ESP 4x4 – H-bridge Driver Connections

This view of the underside of the BallBot robot, shows the relationship between the PWM H-bridge drivers (mounted on the micro plate) and their designated motors.

The connections to the ICM-42607-P motion sensor is also shown, along with its orientation.

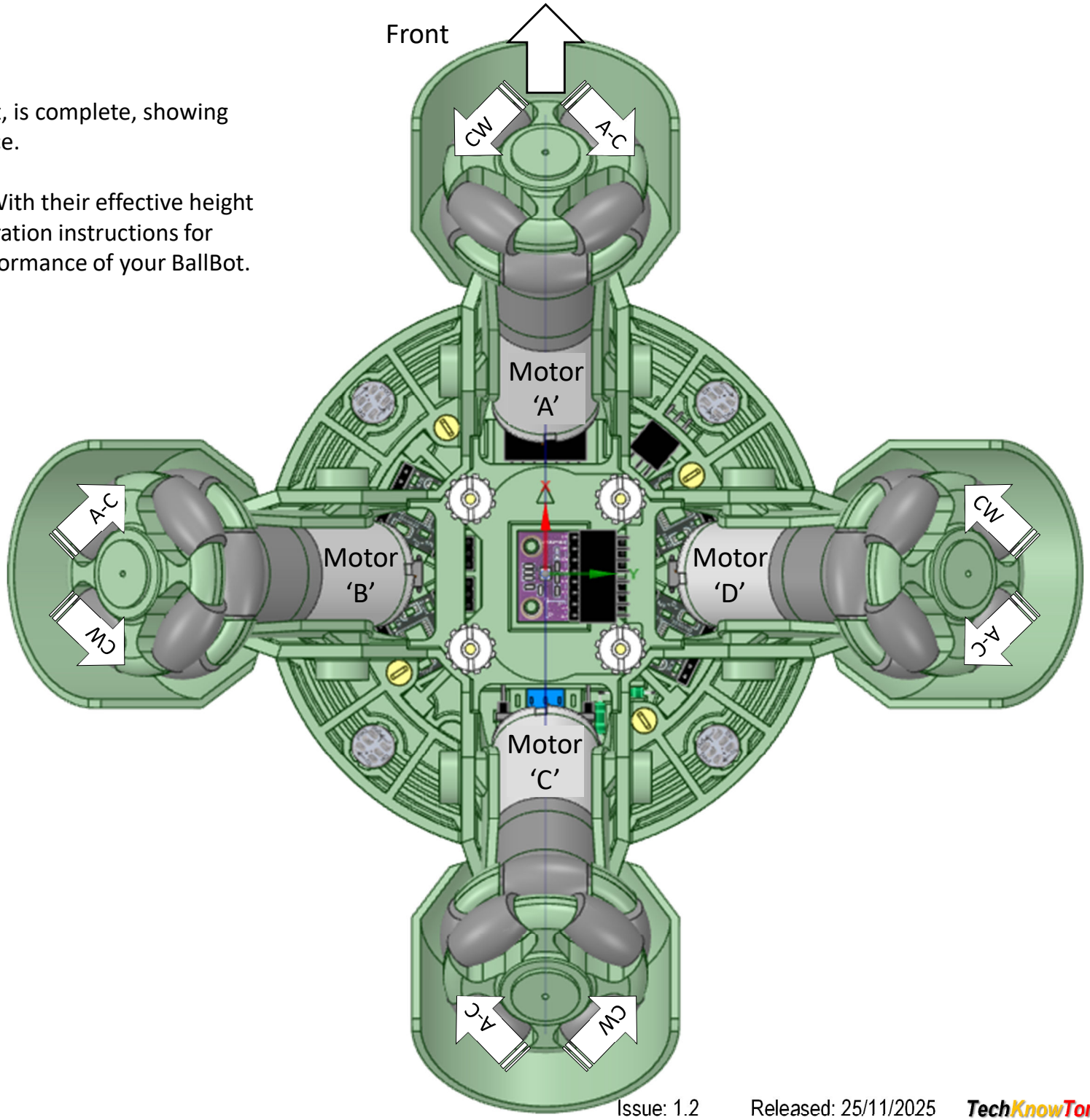
For improved clarity, this image does not include the lower Hip Plate. But the wiring to the motors is completed with that plate in place.



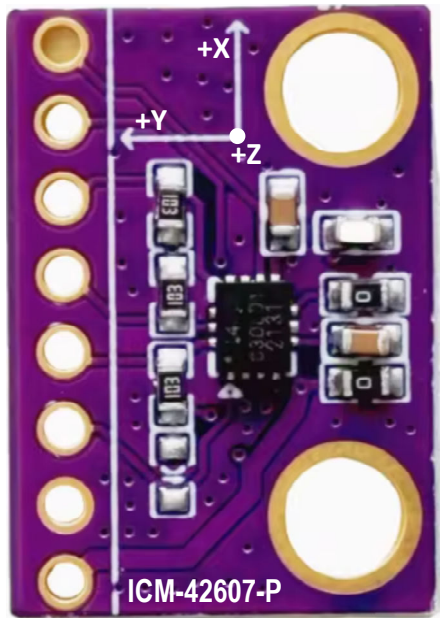
BallBot ESP 4x4 – Hip Plate

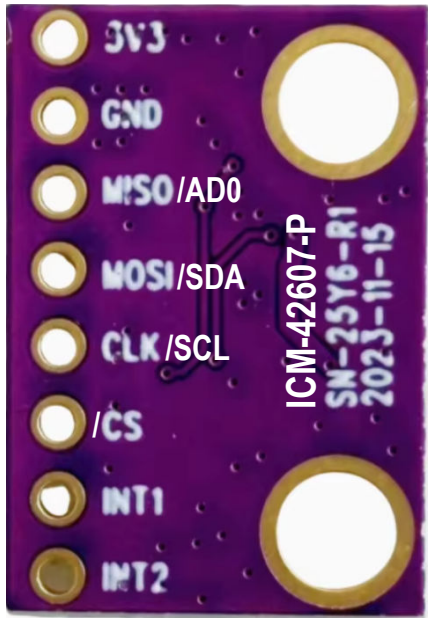
This view of the underside of the BallBot robot, is complete, showing the Hip plate, motors and wheel guards in place.

The motors are pivoted on M4 nylon screws. With their effective height being adjusted via metal M4 screws. See calibration instructions for setting the motors, which is critical to the performance of your BallBot.



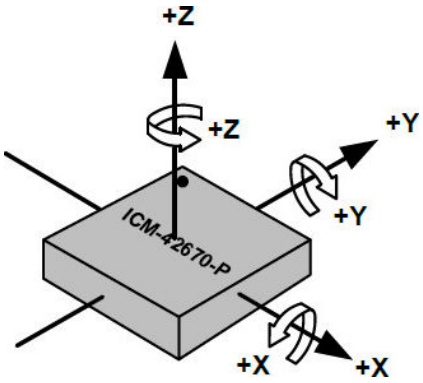
INT2
INT1
/CS
SCL/CLK
SDA/MOSI
AD0/MISO
GND
3v3

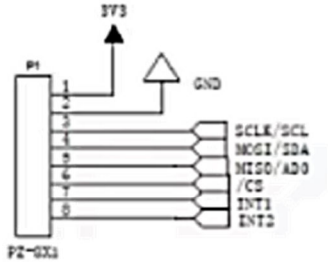


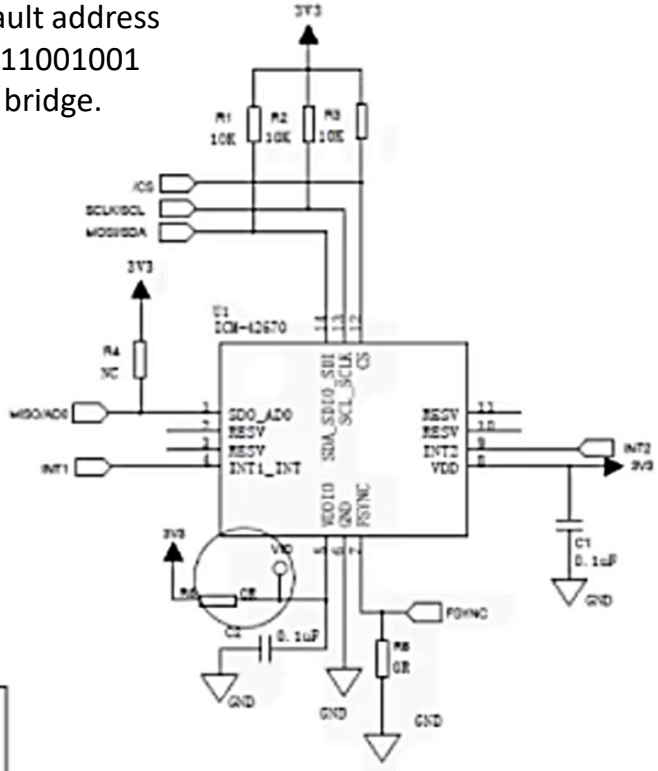


The ICM-42607-P interfaces supports I3C, I²C and SPI modes. With /CS pulled HIGH the device will operate in I3C/I²C mode. This board has /CS pulled HIGH.

The I2C address is 0b110100X, with LSB determined by AD0. In this module AD0 is floating, with the option of pulling it HIGH via a resistor, which is omitted. So the default address is 0b1101000 (0x68), if AD0 is pulled LOW, or 0b11001001 (0x69) if the AD0 line is pulled HIGH via a solder bridge.







I2C Mode

3V3
GND
SCL
SDA
AD0
CS=VDDIO(已经拉高)
INT1
INT2

SPI Mode

3V3
GND
SCLK
MOSI
MISO
CS
INT1
INT2

4x4 Ball Balancing Robot
ICM-42607-P Orientation

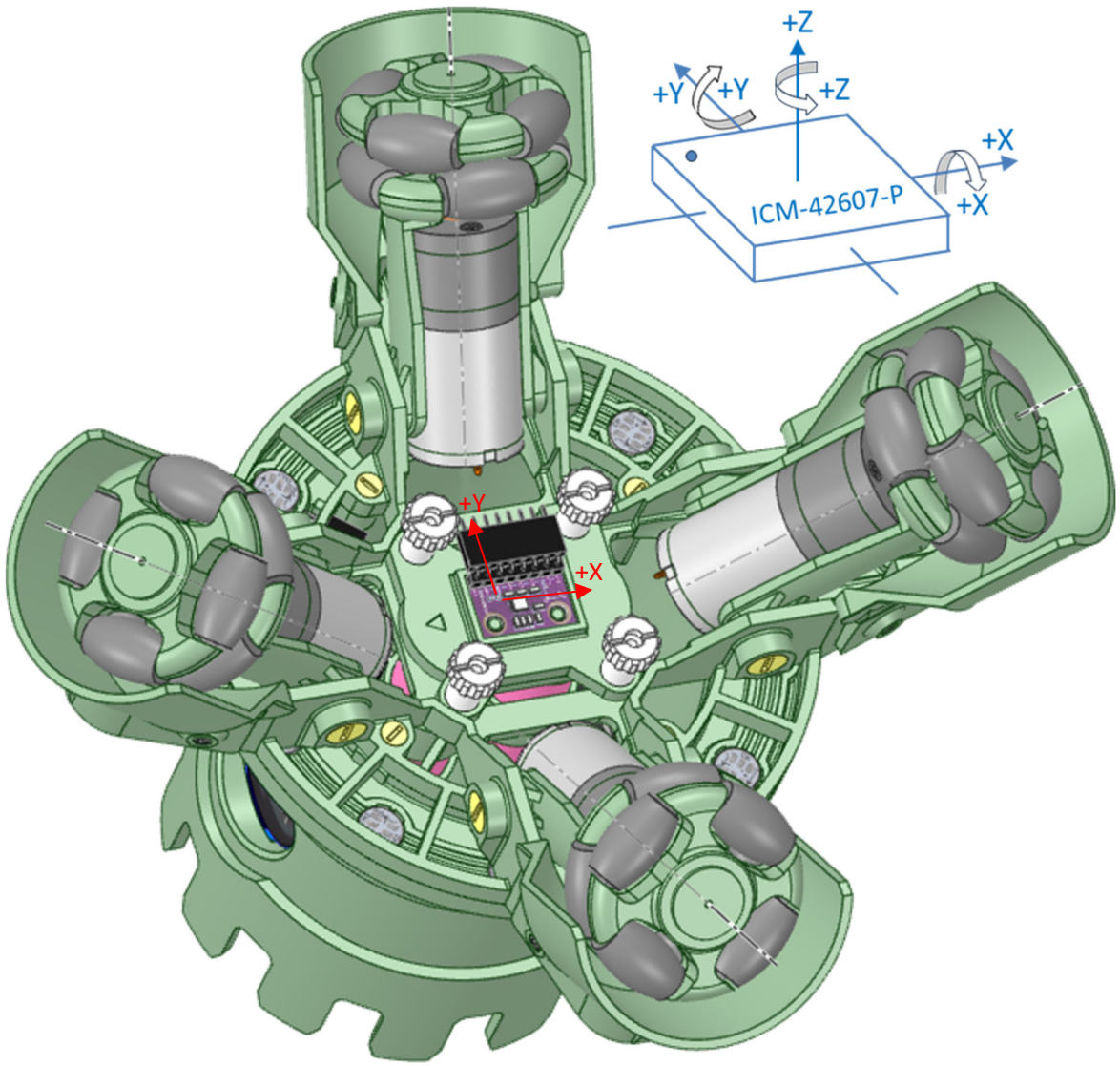
Given the way the ICM device is mounted at the base of the BallBot we can deduce the following:

X-axis is horizontal, feeding front to back, through the robot. When the robot tilts forwards, the X-accelerometer pitch will read positive, due to gravity. The Y-gyro pitch value will be positive when the robot tilts forwards.

Y-axis is horizontal, feeding right to left, through the robot. When the robot rolls to the right, the Y-accelerometer roll will read positive. The X-gyro roll value will be negative when the robot rolls to the right.

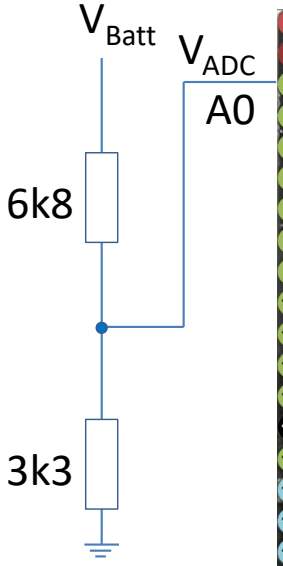
Z-axis is vertical, through the centre of the robot. When the robot is upright, the Z accelerometer will read negative, due to gravity. When turning to the right, the Z-gyro yaw value will be positive.

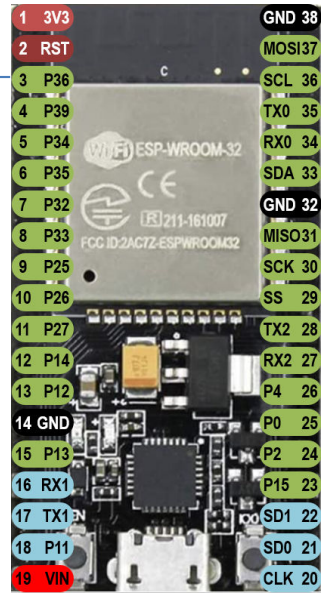
Note that the ICM-42607-P will have small accelerometer offsets, due to the way in which it is mounted, and the gyros will also have a small amount of rate when stationary. These errors are removed in the code, to improve the accuracy of the control system.



Battery Voltage Calibration

See Lithium discharge curve obtained from the internet below. In this analysis the lipo battery consists of two identical batteries connected in series.
Assume fully charged 8.2v battery max voltage is V_{BM} >= 8.4v max (charging)
Set battery warning point Bat7v2 at V_B = 7.2v (2 x 3.6v)
Set battery critical point Bat6v6 at V_{BC} = 6.6v (2 x3.3v)





The ESP32 is powered via a 3.3v voltage regulator, connected to the 3v3 pin, but the 6k8 supply sampling resistor is connected to source V_{Batt}.
For ESP32 V_{ADC} == 4095 on 12-bit converter (4095 max).
If we use a 6k8 resistor feeding A0 and a 3k3 resistor to GND, we get a conversion factor of 10.1v == 4095, or 2.47mV/bit, or 405.4 bit/v
Using a Multimeter and a variable DC supply, I determined the following V_{ADC} values for corresponding threshold voltages:

MAX: (100%) Bat8v2 V_{ADC} = 8.2v, gave A0 = 3032 on V_{ADC} (2 x 4.1v)

HIGH: (80%) Bat7v6 V_{ADC} = 7.6v, gave A0 = 2906 on V_{ADC} (2 x 3.8v)

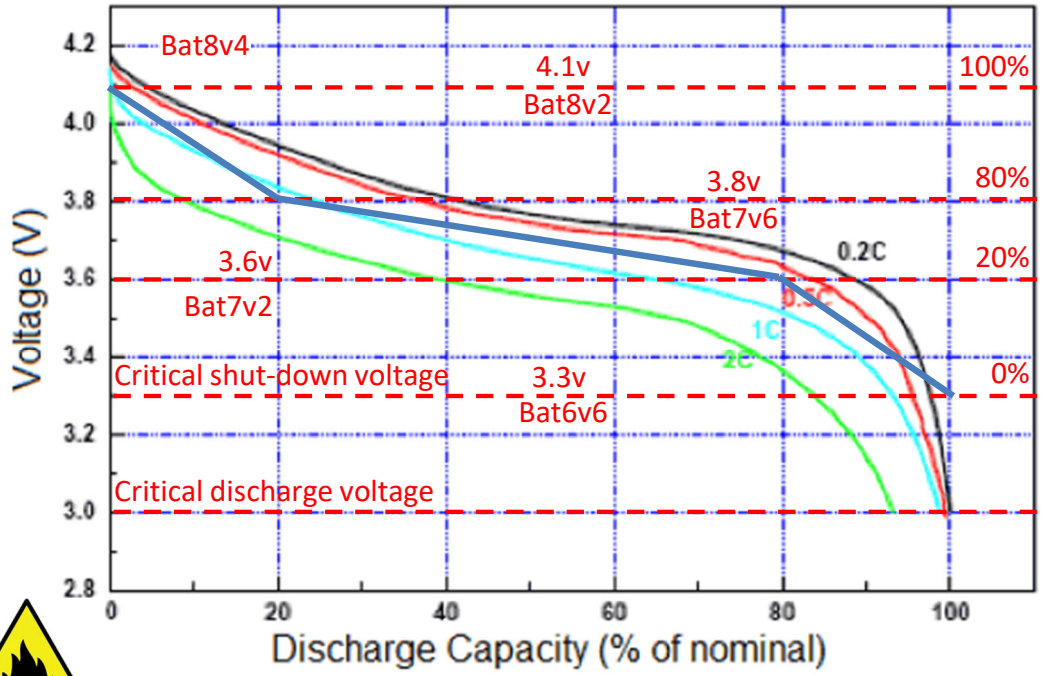
WARNING: (20%) Bat7v2 V_{ADC} = 7.2v, gives A0 = 2734 on V_{ADC} (2 x 3.6v)

CRITICAL: (0%) Bat6v6 V_{ADC} = 6.6.0v, gives A0 = 2482 on V_{ADC} (2 x 3.3v)

The code will sample the battery voltage on power-up to ensure it is sufficient, then at every 8ms interval, calculating an average (1/50) to remove noise. It also detects no battery as being USB mode.

Note: If connected to USB port with internal battery switched OFF the ADC will read a value of A0 = 1500, or less. So, if the micro starts with such a low reading it knows that it is on USB power, and this will limit its behaviour.

Lithium Battery
Discharge Profile



Discharge: 3.0V cutoff at room temperature.