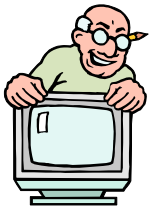
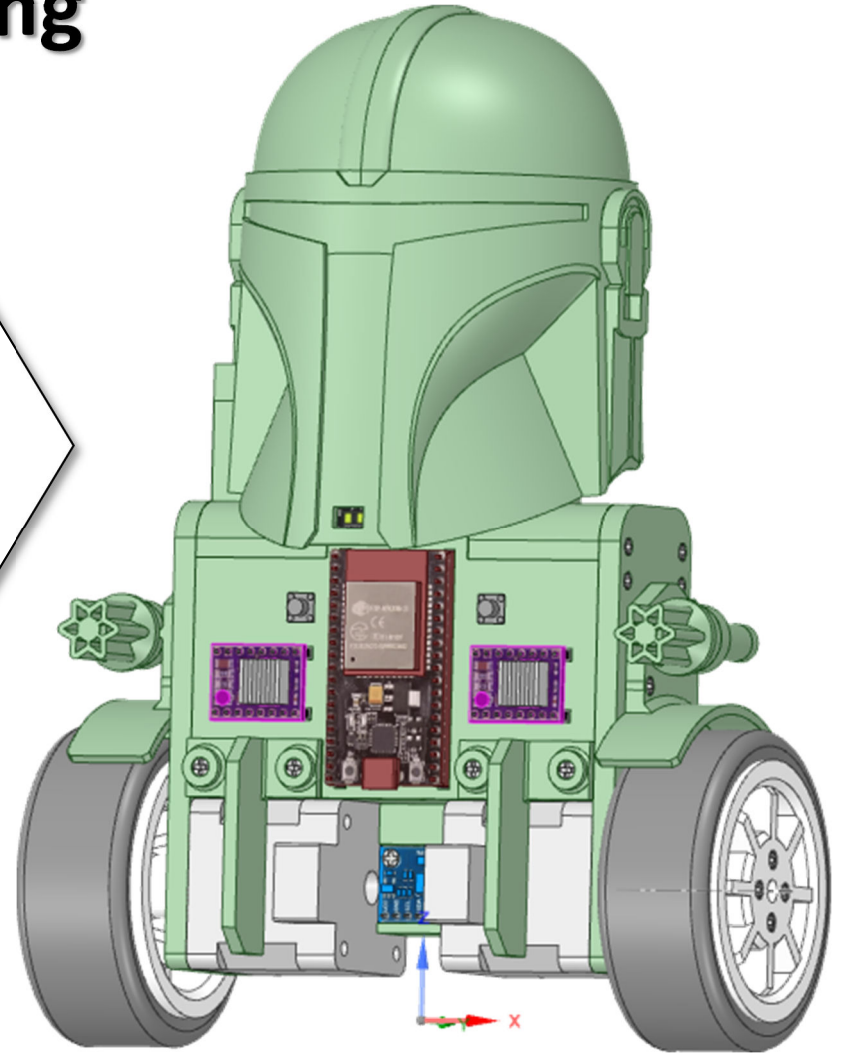
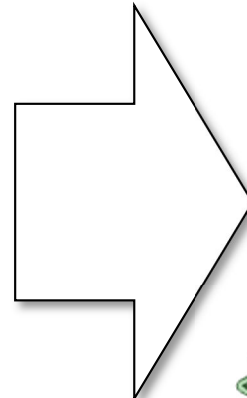
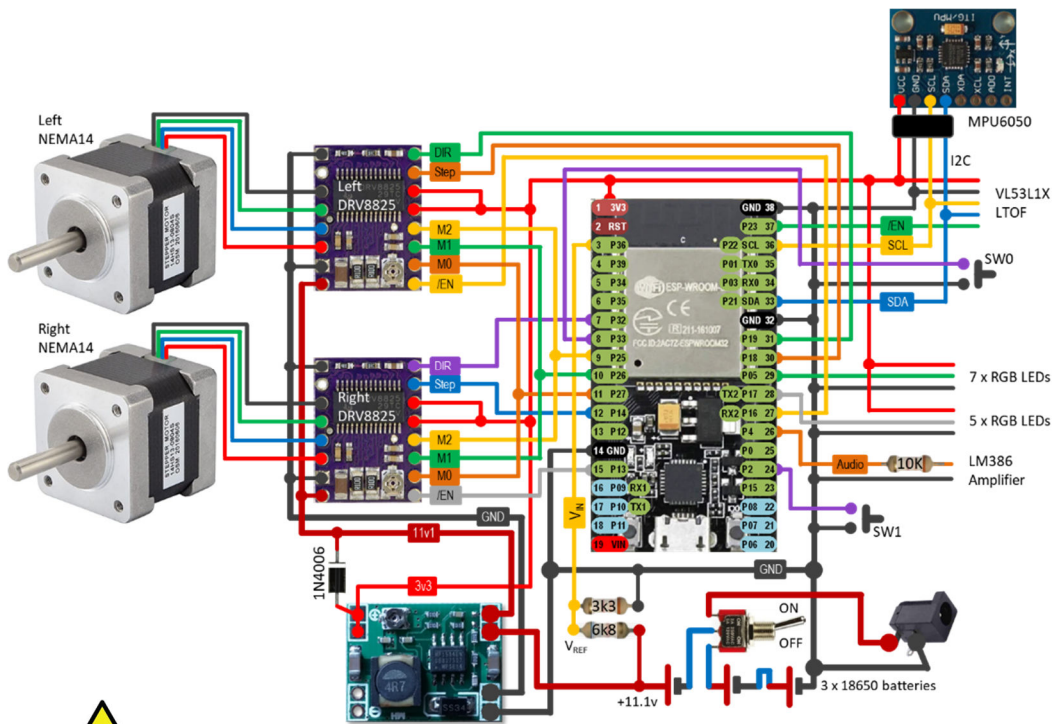


# Project MandalBot BLE

## Circuits & Wiring



Read through this documentation completely before attempting this project.

# 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 damaged, or discharged below their critical voltage.



# Hand Tools:

## Recommended:

- Fine Nosed Pliers
- Side Cutters
- 1.5 mm Drill
- 2.0 mm Drill
- 2.4 mm Drill
- 4.0 mm Drill
- M3 Tap
- Needle Files
- Screwdrivers
- Craft Knife



**Note:** Not all items needed are shown here.

# Tools & Materials:

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

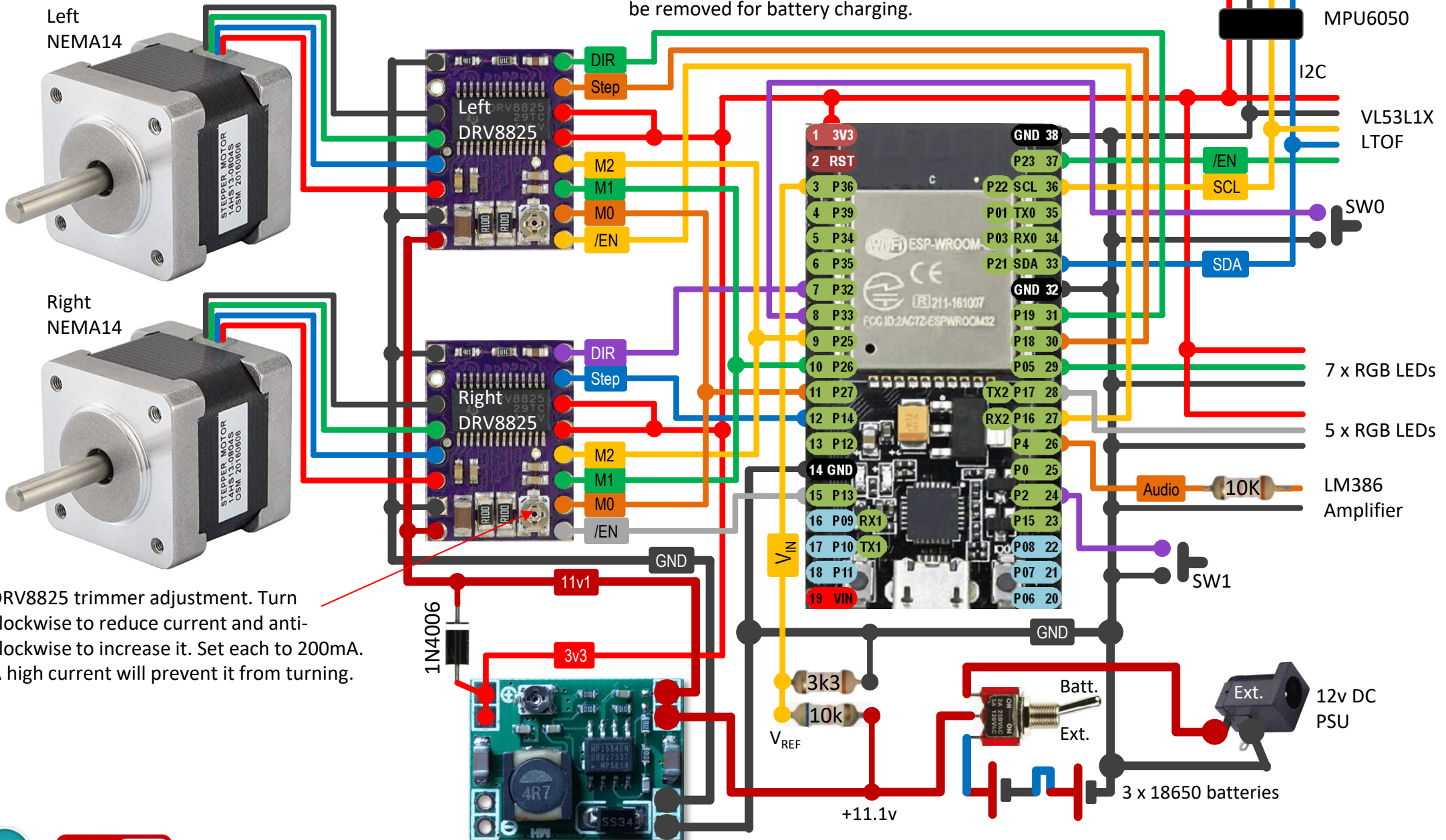


# Schematic A

Using coloured wire will make the task much easier to complete and aid visual checking.



The laser range finder, LEDs and speakers are mounted in the helmet, with the connections being brought from the Micro Plate to the Helmet using 2 x 14 socket strips. Refer to the next sheet for the remaining schematic. Each pin is duplicated for increased connectivity, and the socket and plug arrange allows the head to be removed for battery charging.



DRV8825 trimmer adjustment. Turn clockwise to reduce current and anti-clockwise to increase it. Set each to 200mA. A high current will prevent it from turning.

## Schematic B

A number of components are mounted within the Mandalorian helmet. They are fed from a connector, which concentrates all of the wires coming up through the micro plate.

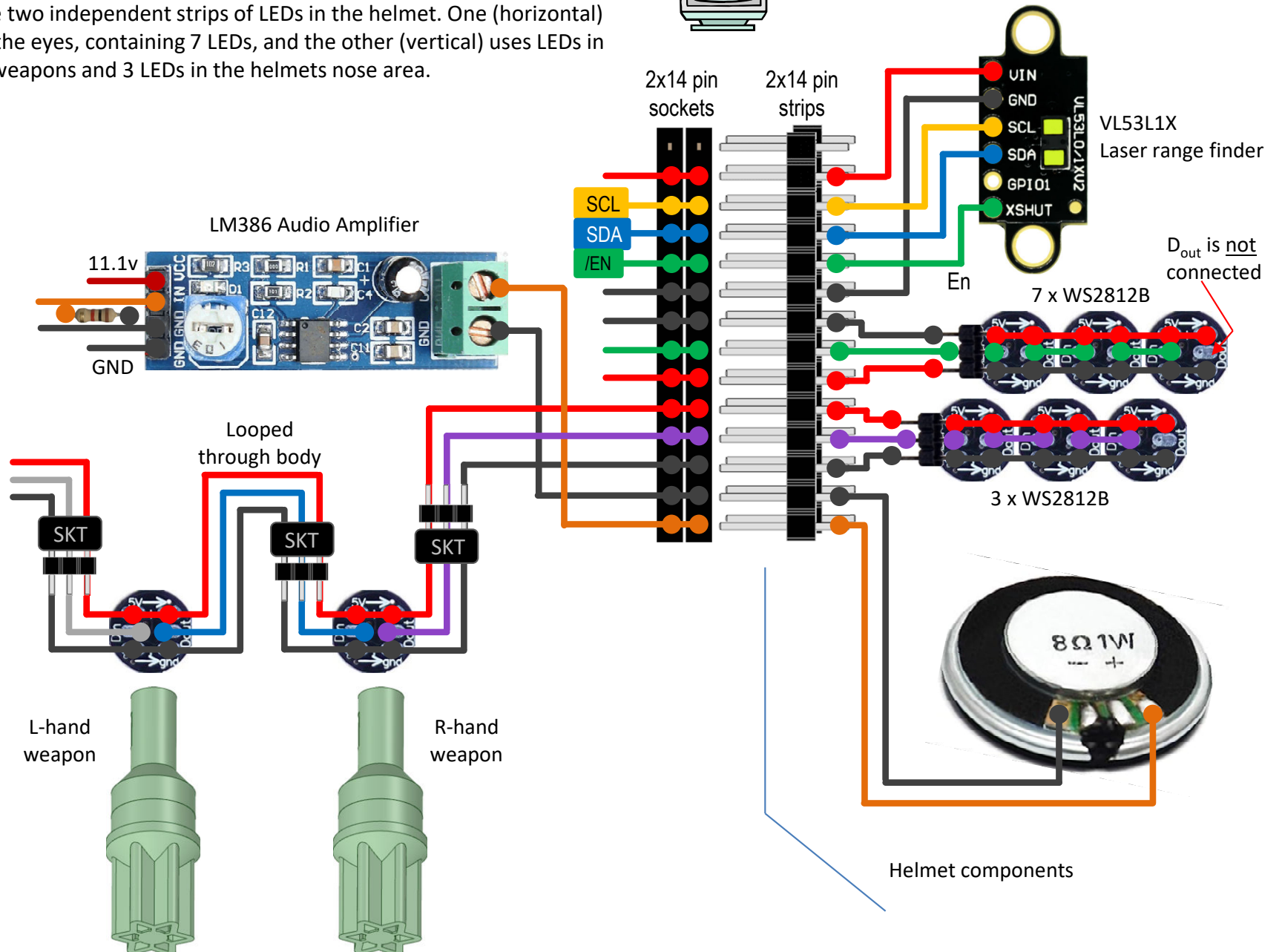
There are two independent strips of LEDs in the helmet. One (horizontal) used for the eyes, containing 7 LEDs, and the other (vertical) uses LEDs in the side weapons and 3 LEDs in the helmets nose area.



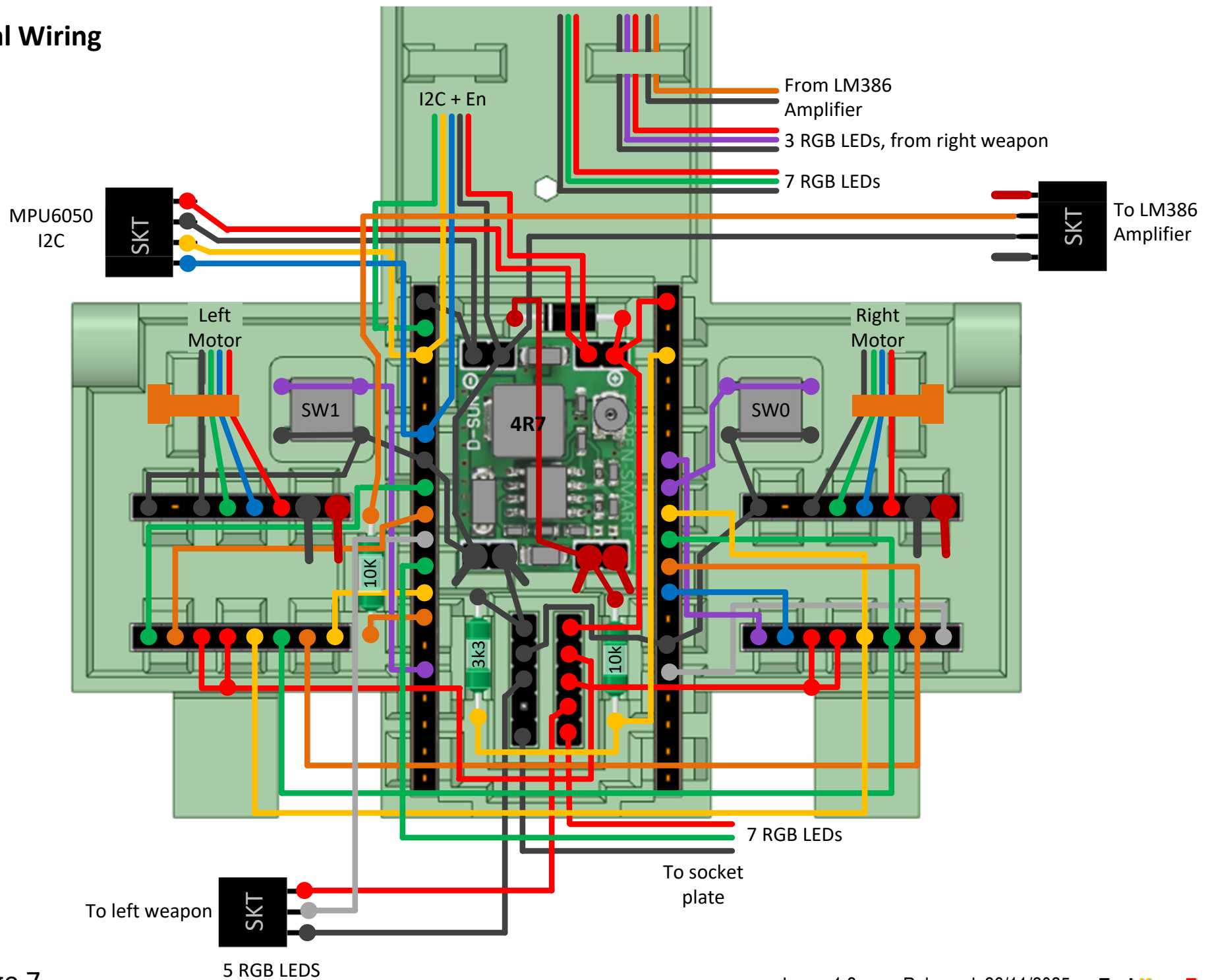
Previous schematic

- VL53L1X
- LTOF
- LTOF
- RGB LEDs
- LM386 amplifier
- RGB LEDs
- RGB LEDs

From micro



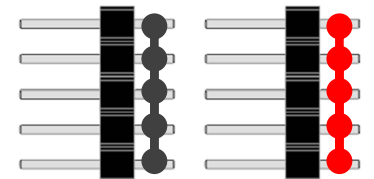
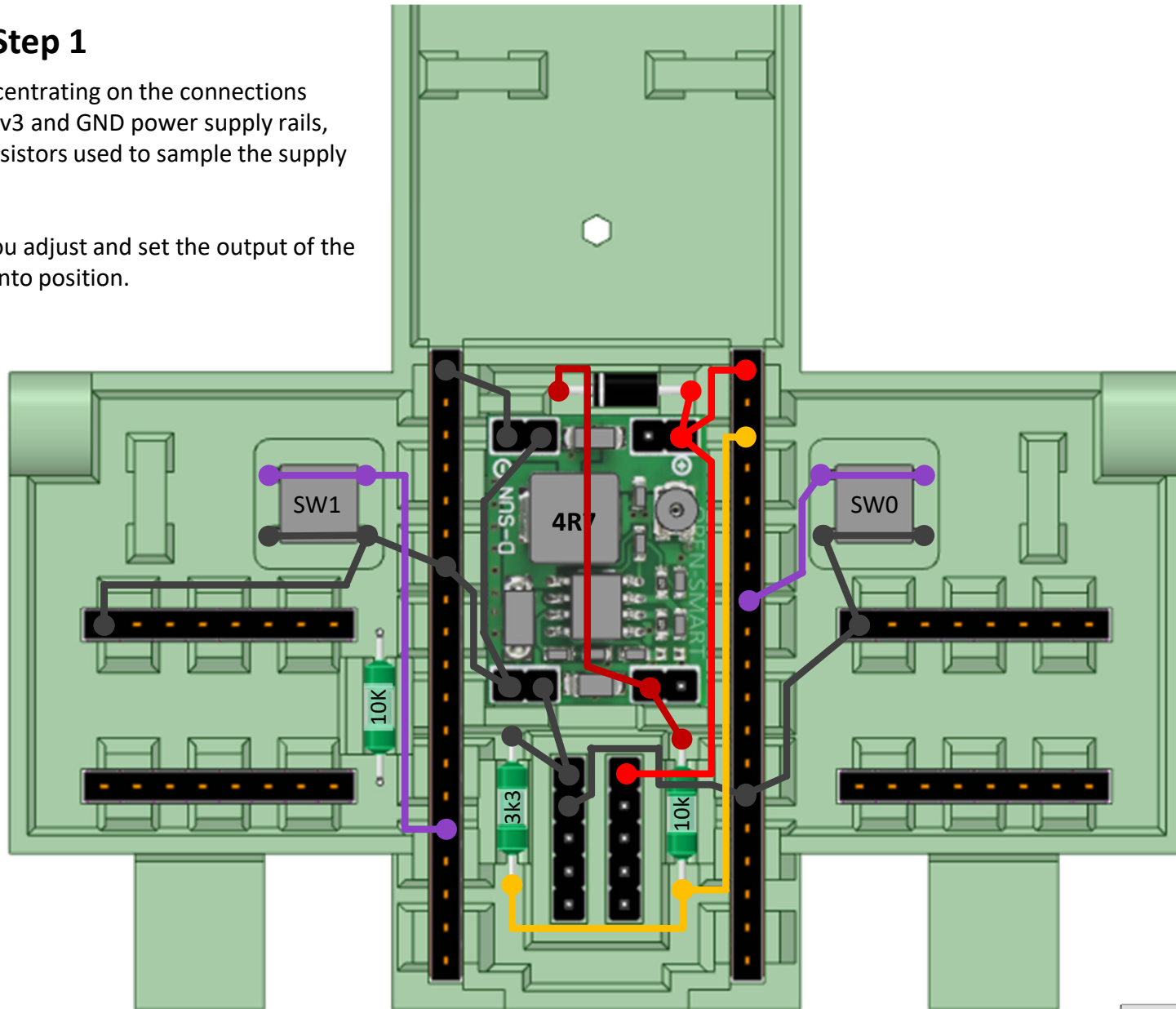
# Micro Plate Total Wiring



## Micro Plate Wiring - Step 1

Start the wiring process by concentrating on the connections shown here. This includes the 3v3 and GND power supply rails, plus the button switches and resistors used to sample the supply voltage.

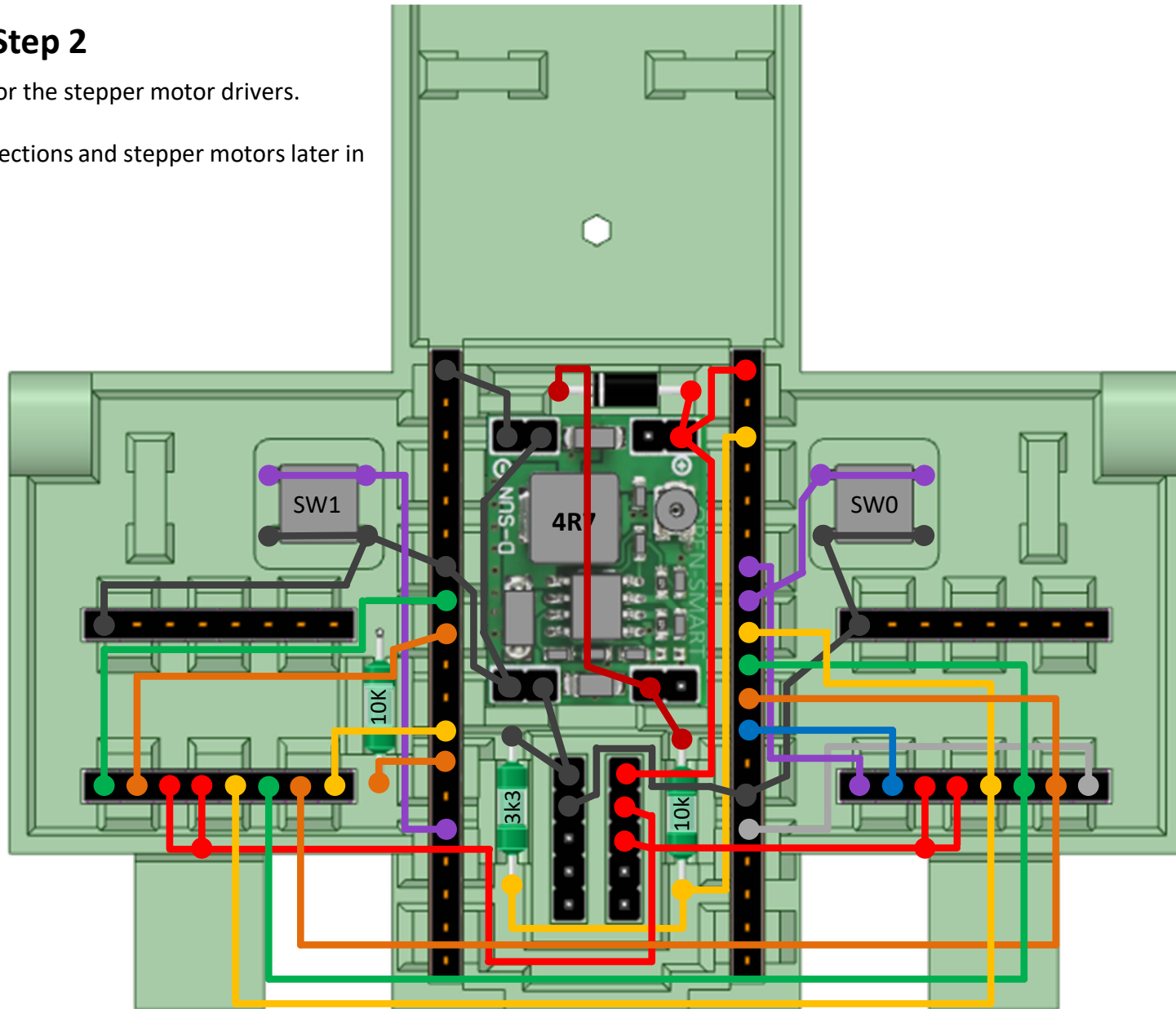
Note it is recommended that you adjust and set the output of the 3v3 regulator prior to gluing it into position.



## Micro Plate Wiring - Step 2

Now wire in the control wires for the stepper motor drivers.

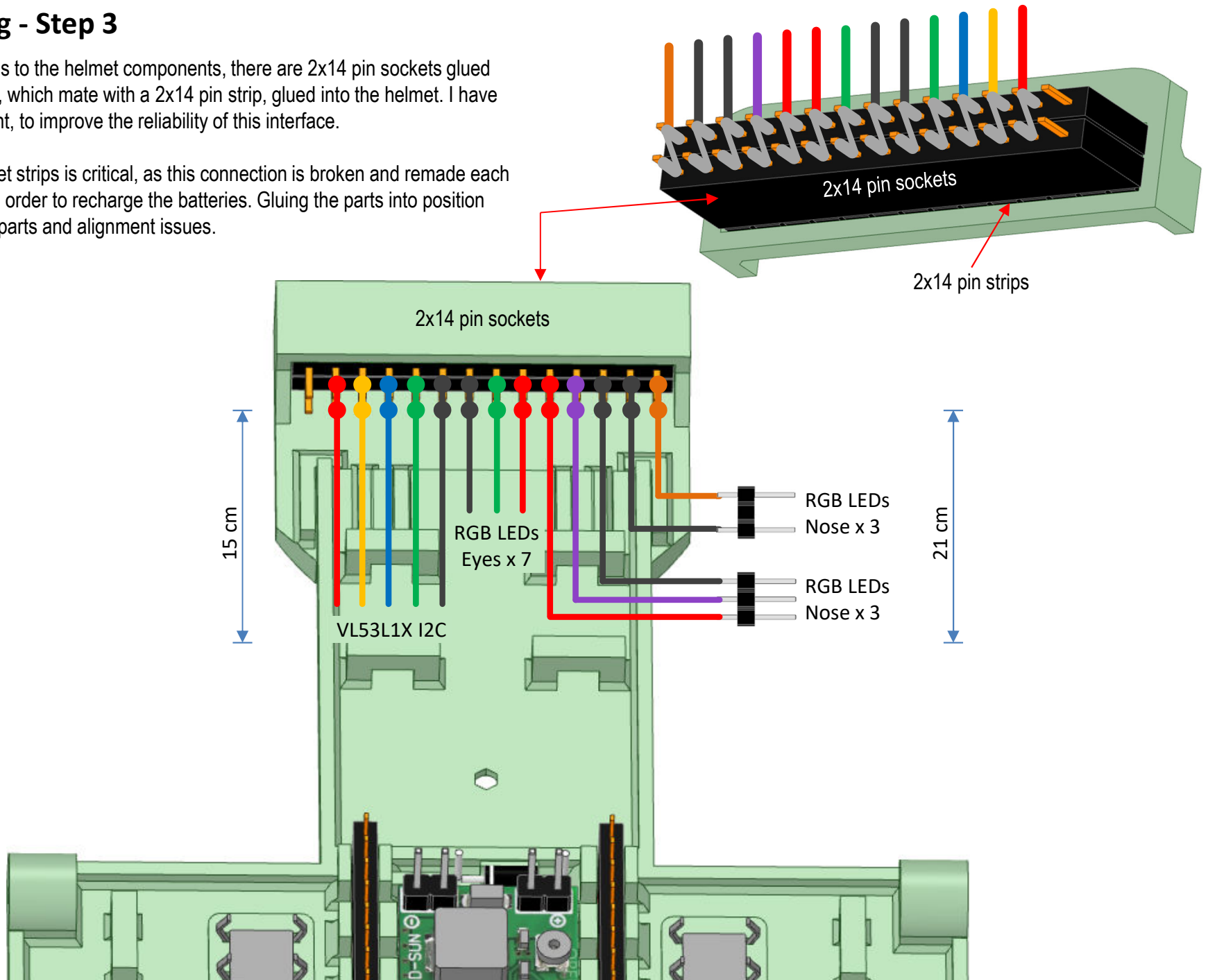
We will wire in the power connections and stepper motors later in the process.



## Micro Plate Wiring - Step 3

To carry the circuit connections to the helmet components, there are 2x14 pin sockets glued into the end of the micro plate, which mate with a 2x14 pin strip, glued into the helmet. I have used a double pin arrangement, to improve the reliability of this interface.

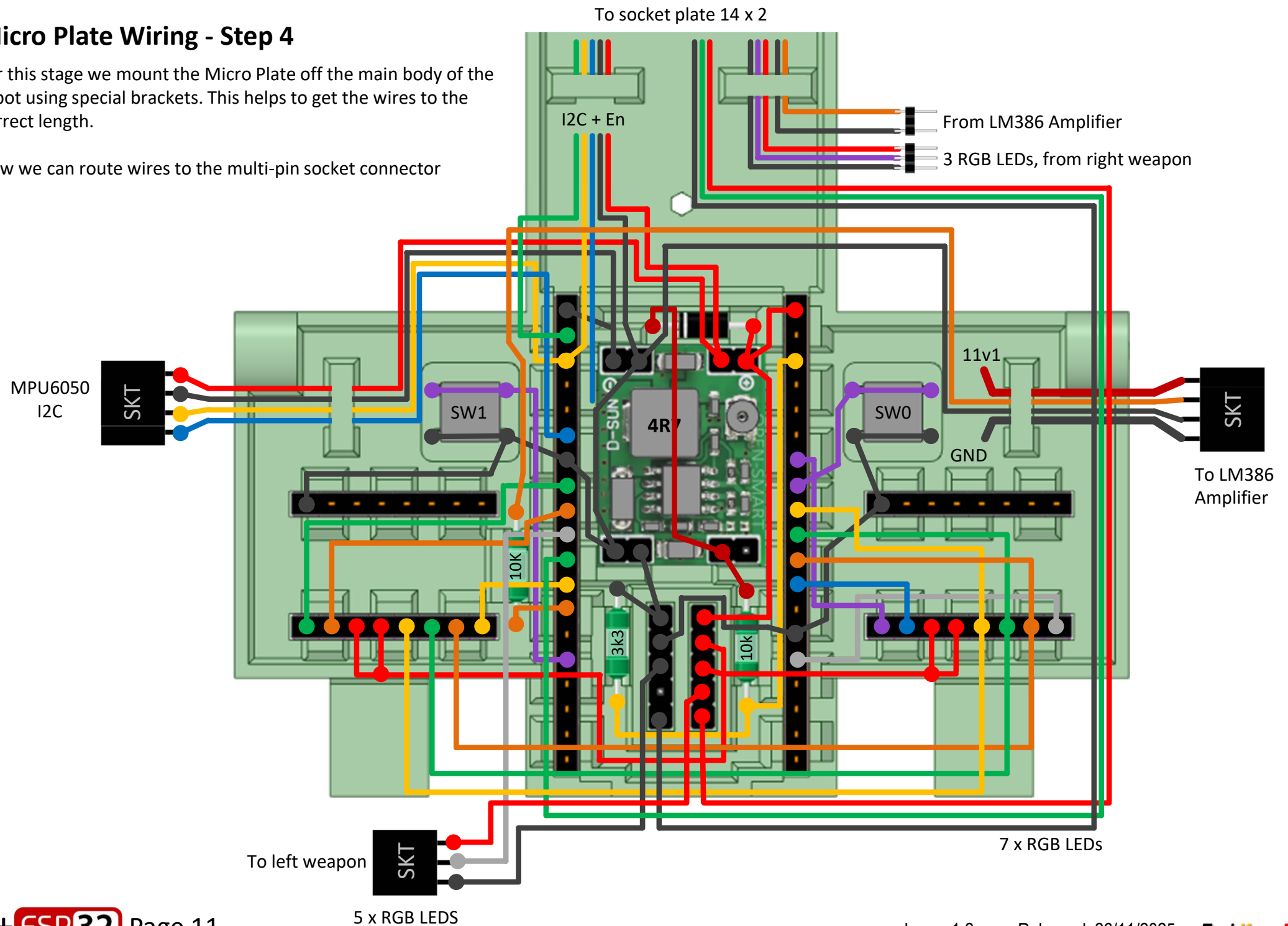
Alignment of the pin and socket strips is critical, as this connection is broken and remade each time the helmet is removed, in order to recharge the batteries. Gluing the parts into position allows for overall tolerance in parts and alignment issues.



## Micro Plate Wiring - Step 4

For this stage we mount the Micro Plate off the main body of the robot using special brackets. This helps to get the wires to the correct length.

Now we can route wires to the multi-pin socket connector

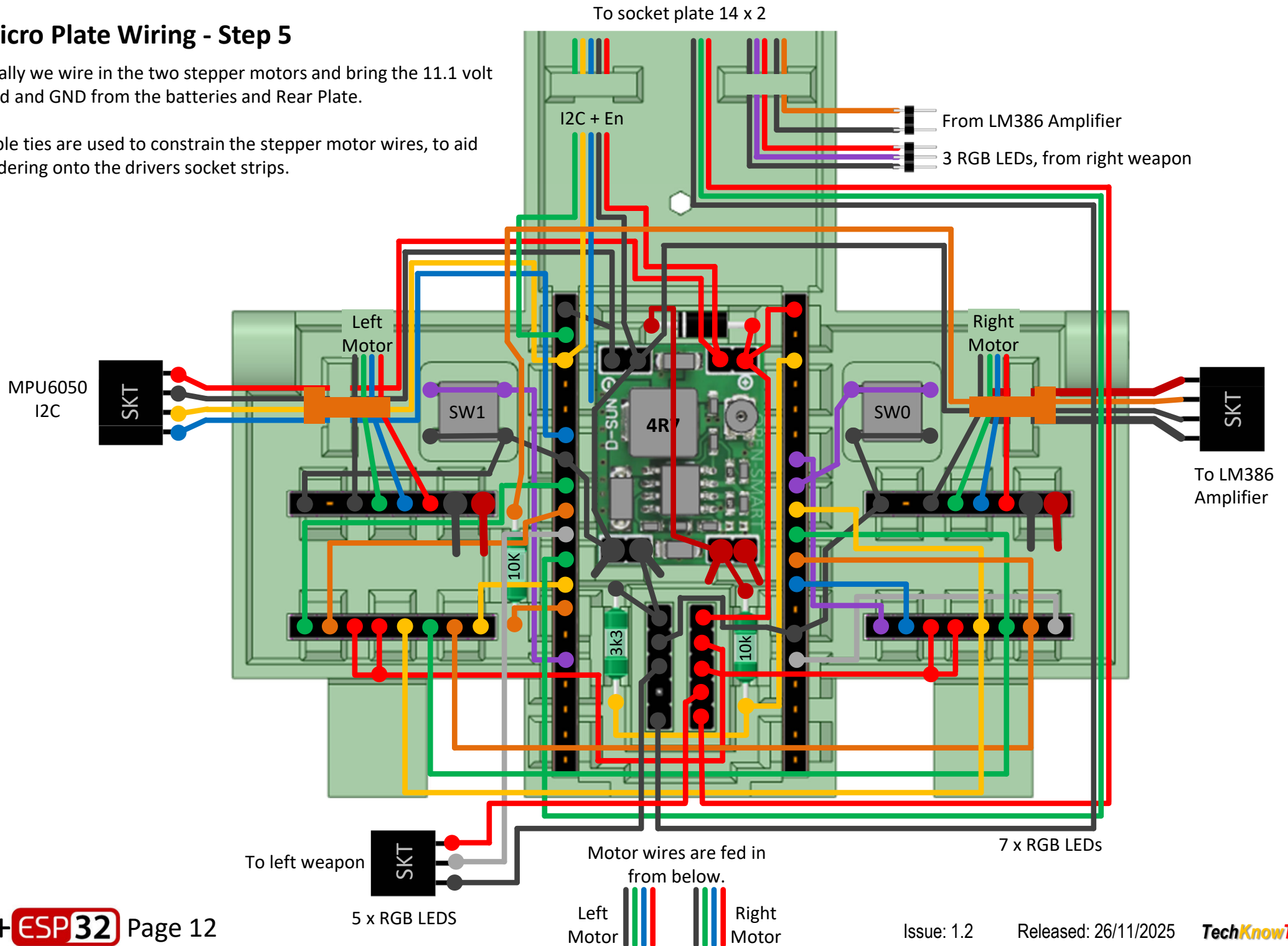


# Micro Plate Wiring - Step 5

Finally we wire in the two stepper motors and bring the 11.1 volt feed and GND from the batteries and Rear Plate.

Cable ties are used to constrain the stepper motor wires, to aid soldering onto the drivers socket strips.

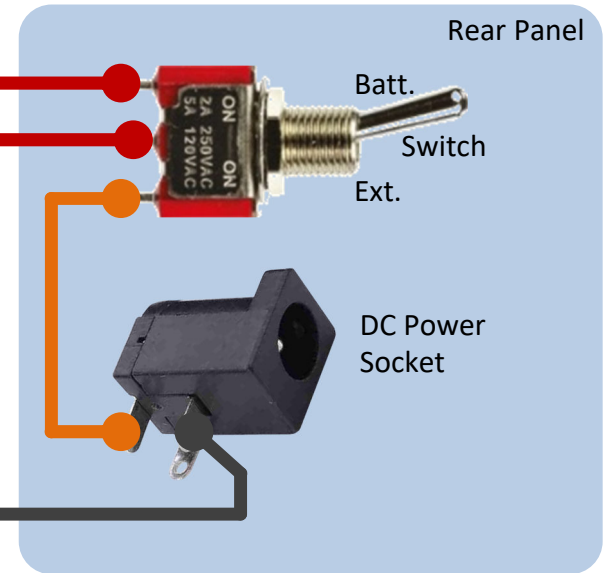
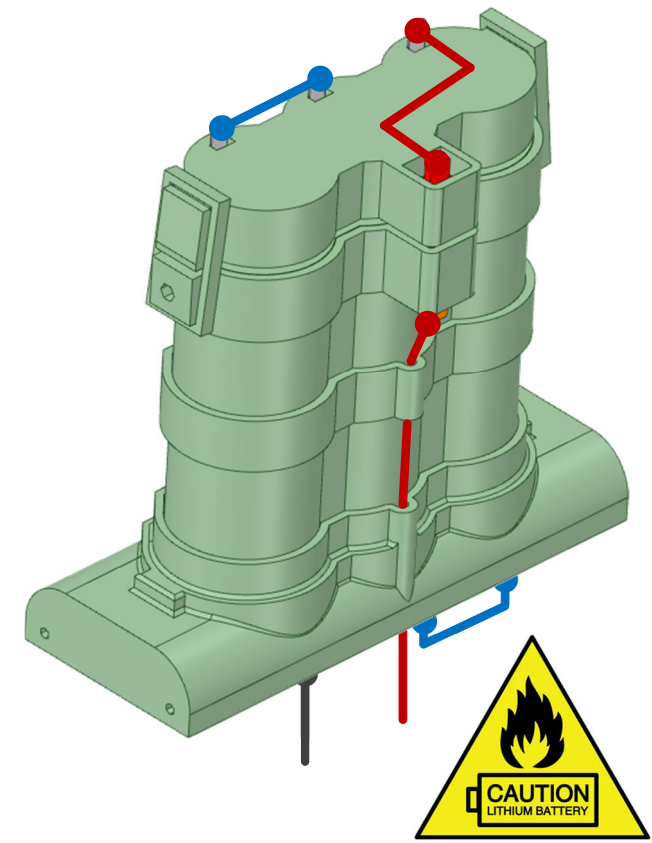
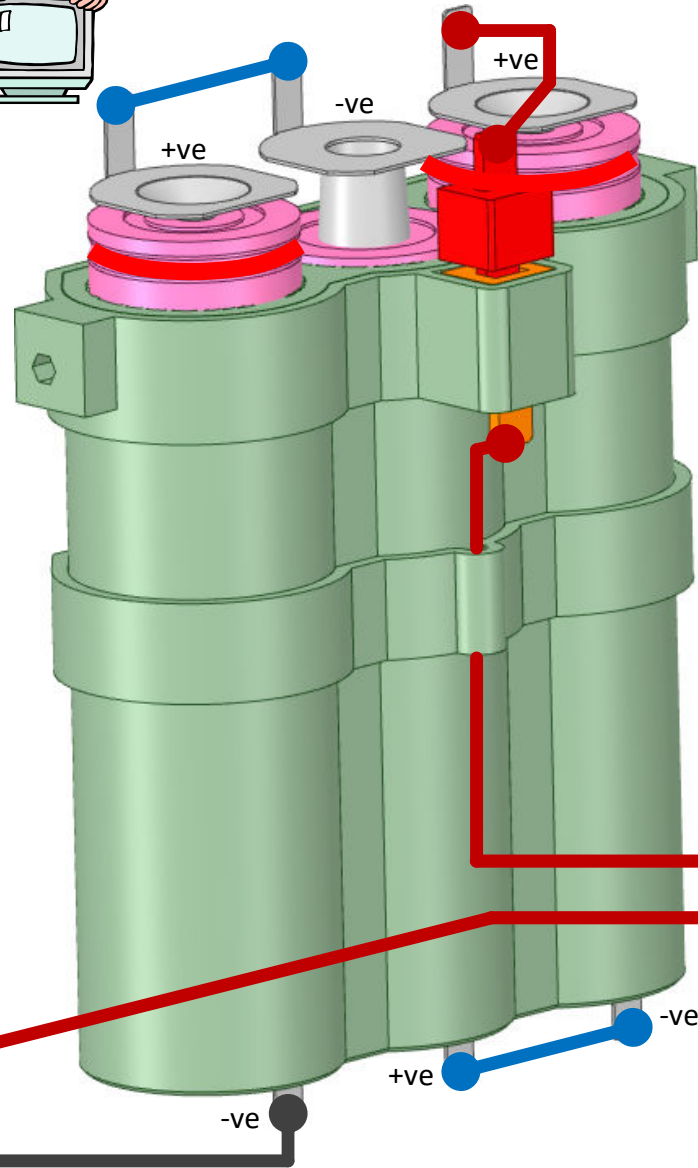
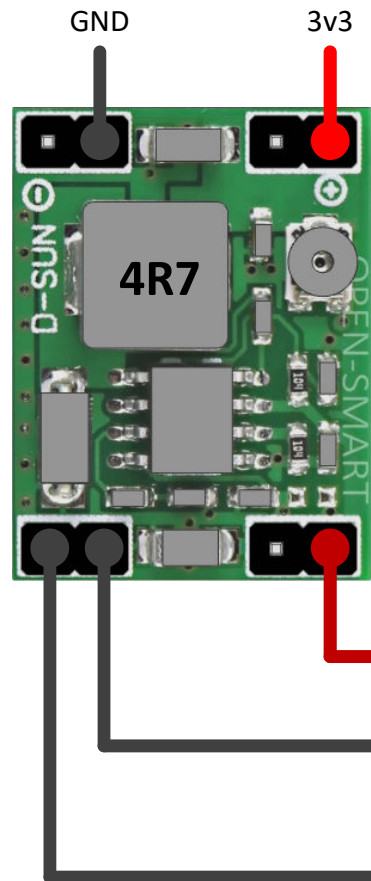
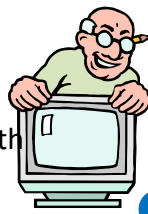
To socket plate 14 x 2



# Battery Pack Wiring

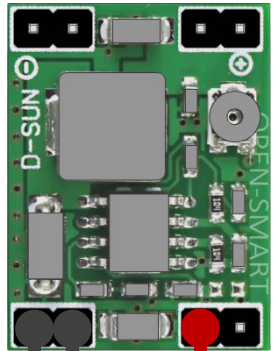
This slide show the wiring of the 11.1v battery pack, with and without the cover included for clarity.

**WARNING** – this design does not include any form of circuit protection, like a fuse. You should therefore take great care in ensuring that the batteries are wired correctly and inserted into the tubes with the correct polarity.

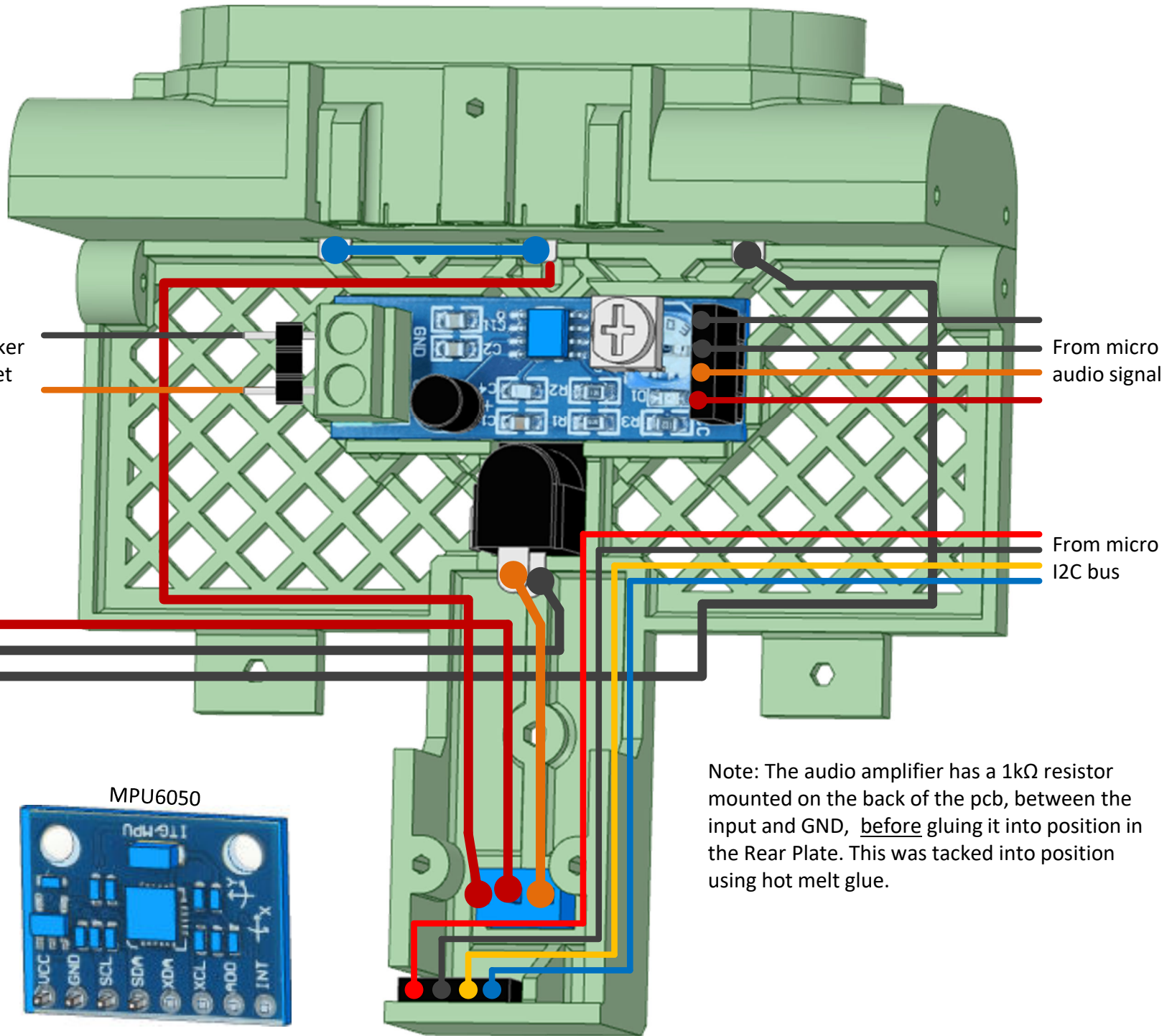


# Rear Plate Wiring

Voltage regulator  
On Micro Plate

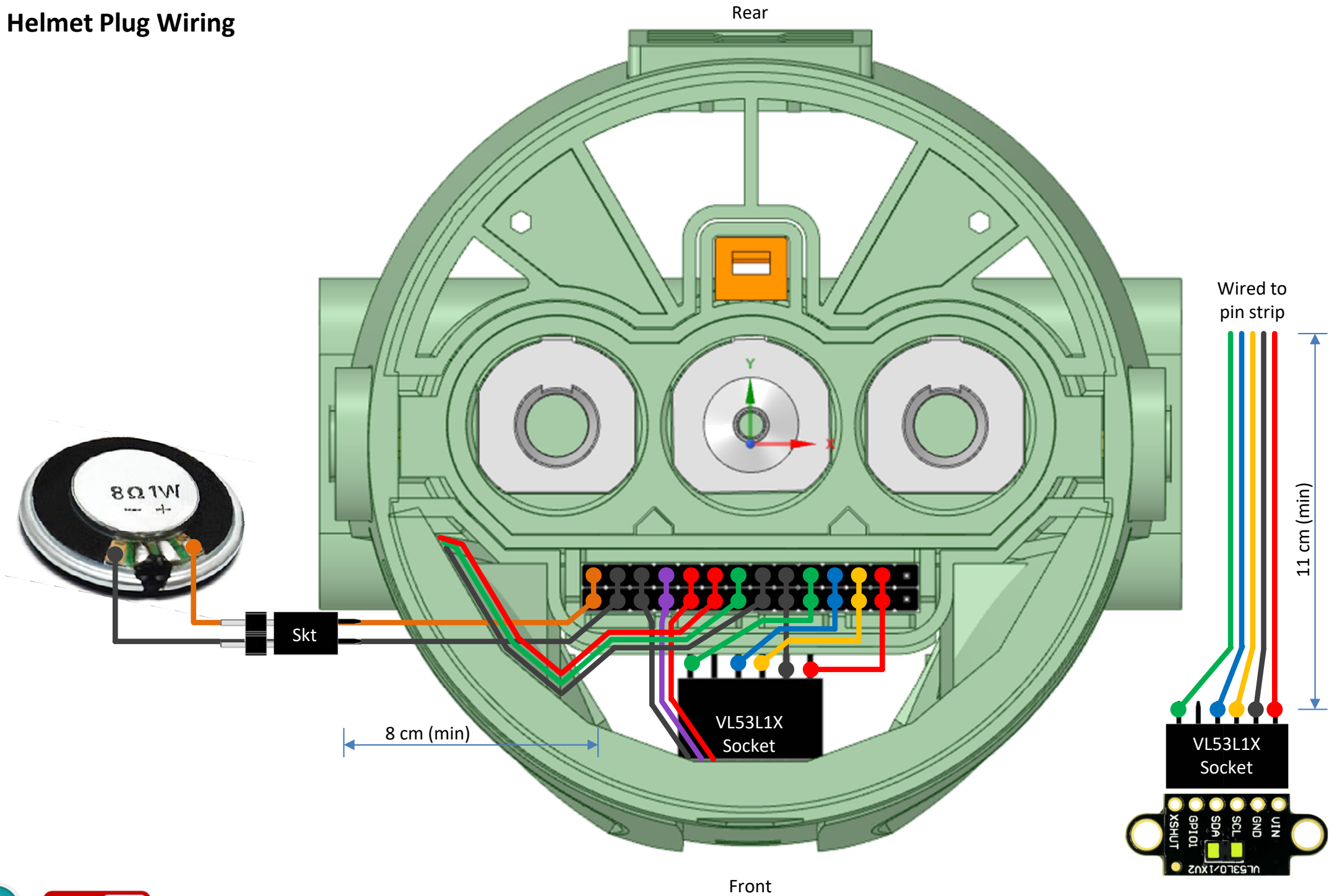


To speaker  
In helmet



Note: The audio amplifier has a 1kΩ resistor mounted on the back of the pcb, between the input and GND, before gluing it into position in the Rear Plate. This was tacked into position using hot melt glue.

# Helmet Plug Wiring

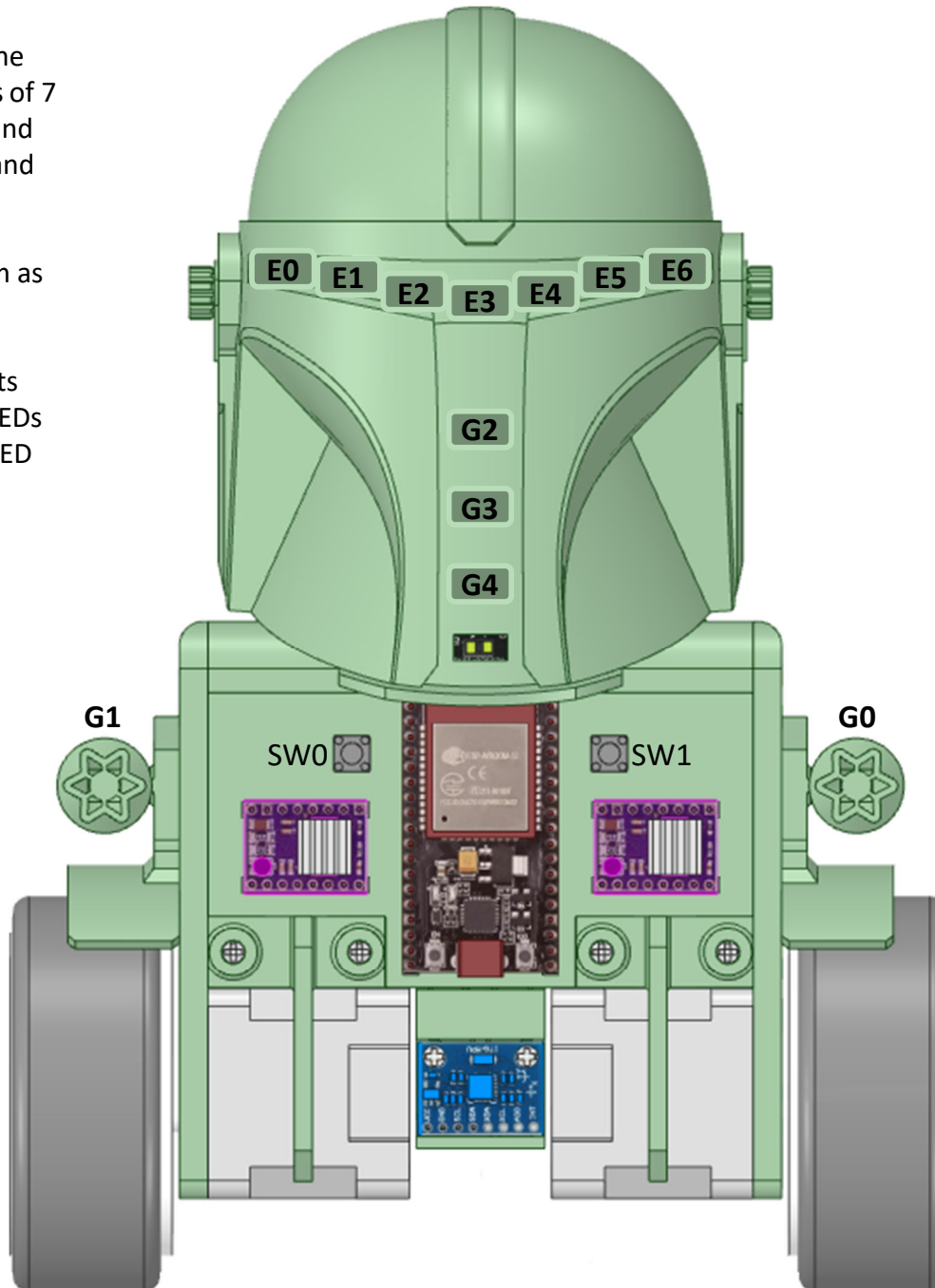


## LED Assignments

The LED strips are driven by the ESP32 code as two separate FastLED entities, albeit normally updated at the same time; but not always. The code defines two strips of 7 LEDs in each. One is defined as the Guns\_LED[] array, and the other as the Eyes\_LED[] array. The left and right-hand gun LEDs are in the same strip as are those in the nose/mouth region. And the Guns\_LED[] strip is only 5 LEDs long, not 7; but for simplicity the code treats them as if there were 7 LEDs in that strip.

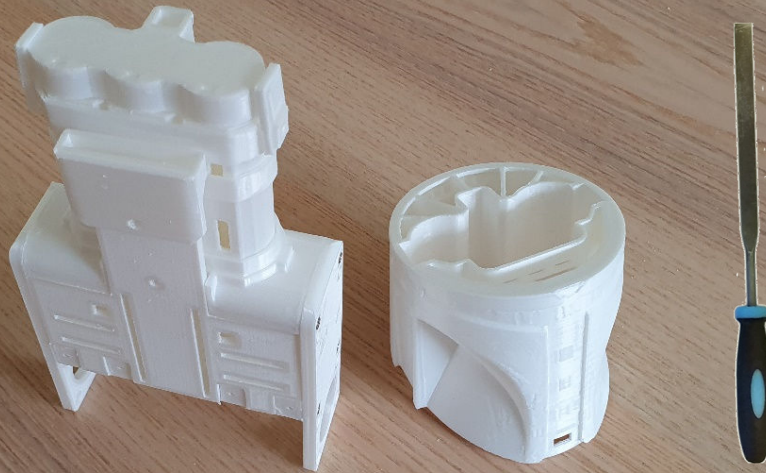
Given the wiring inside the helmet, the LED assignments are as shown here. Where En references refer to eye LEDs and Gn references refer to gun references. So the G0 LED refers to the FastLED reference Guns\_LED[0].

It is important that you understand this, if you wish to write LED sequences for your robot.



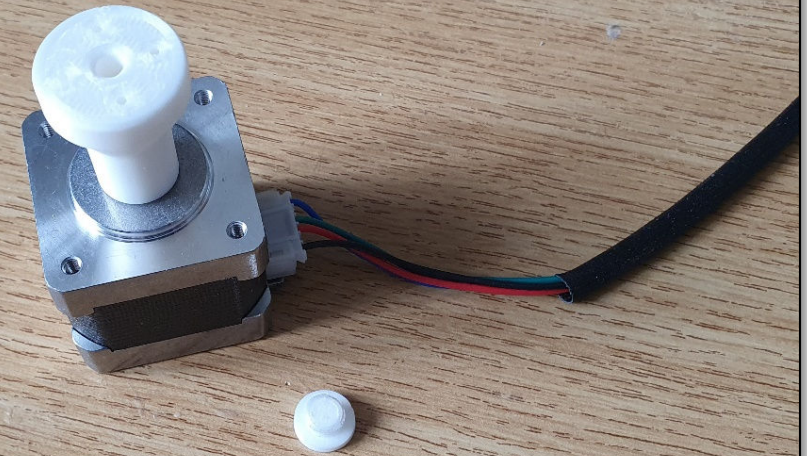
## Build Images

01 Print off your 3D parts and check that they go together.



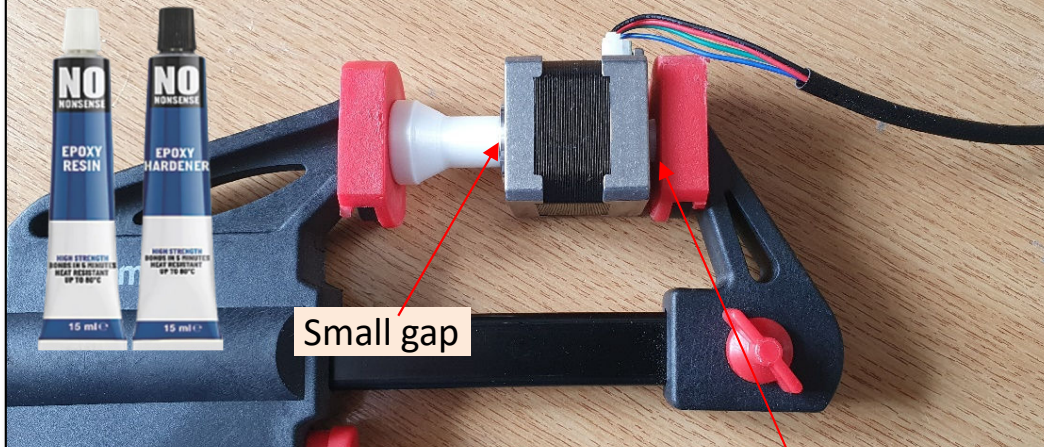
Low quality of prints, can be dressed with a needle file

02 The motor shafts should be a good fit on the shafts



The small spacer issued during the clamping process.

03 Put glue inside the plastic drive shaft, using a toothpick.



Small gap

The spacer is placed at the rear of the motor, here

04 Once pressed into position, put extra glue in the end

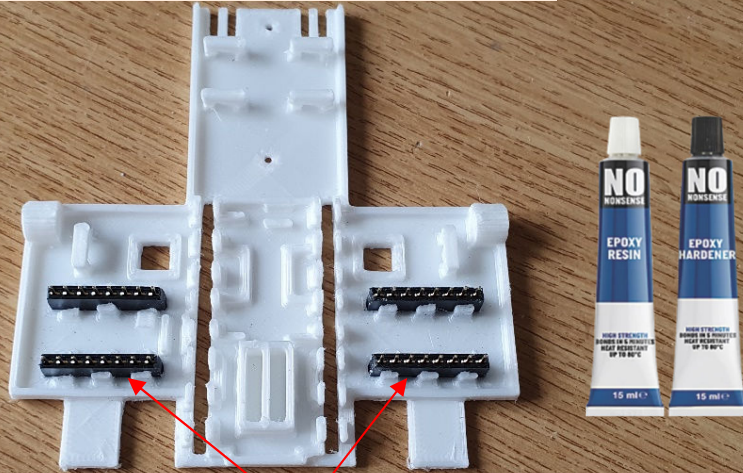


Small gap

This glue sets rapidly, within 5 minutes. Be quick!

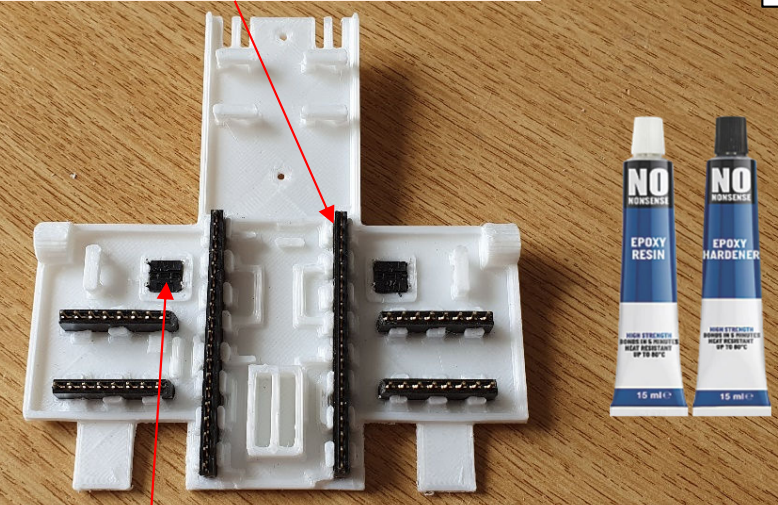
## Build Images

05 Cut the socket strips to the required lengths



Chamfer the ends slightly, and glue into position

Repeat this for the microcontroller pin strips



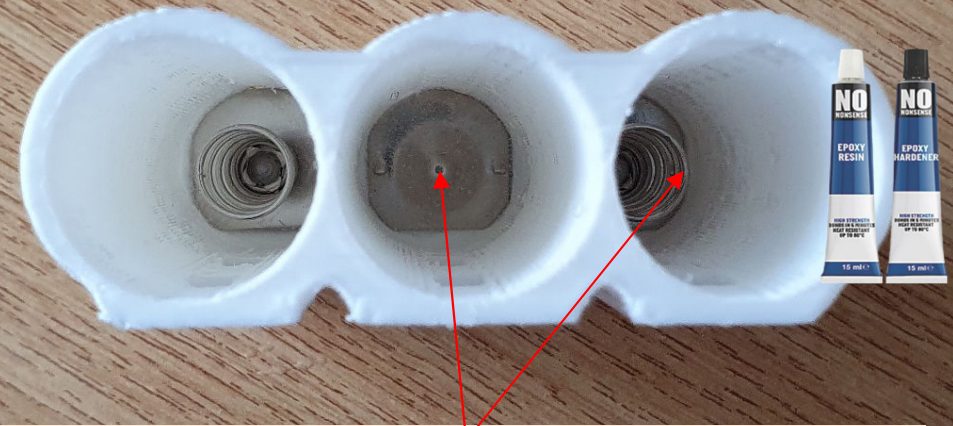
And the two button switches

07 Attach the small rod to the end of a screwdriver



This helps you get the battery springs into the tubes

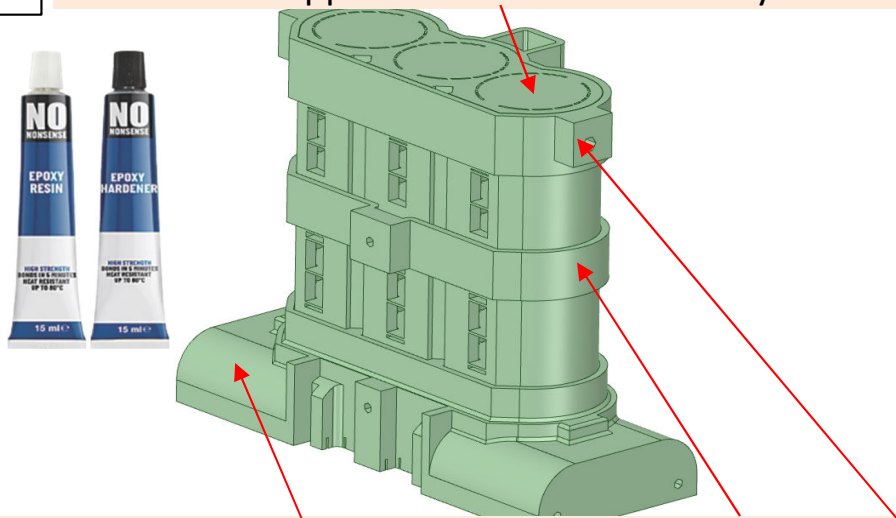
08 The two springs and end cap are glued into position



Avoid getting glue on the surface of the end cap & springs

## Build Images

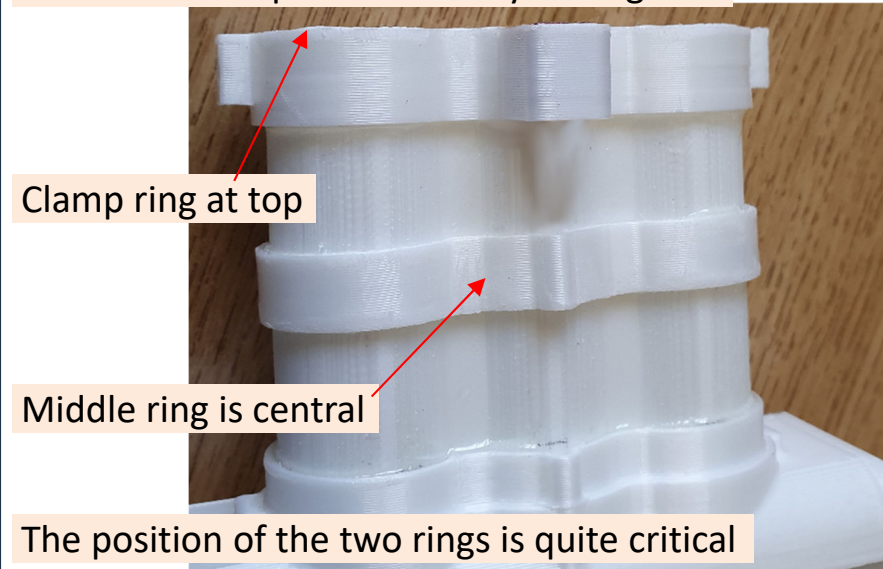
09 Remove the support material in the battery tubes



Glue tubes into shoulder, & glue on the middle & clamp rings

This shows the parts after they were glued

10

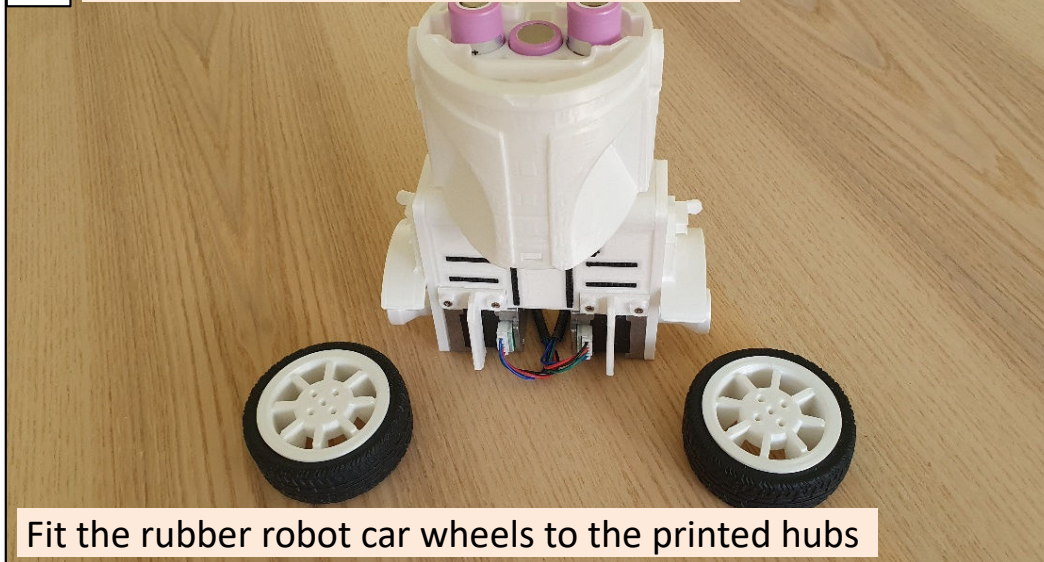


Clamp ring at top

Middle ring is central

The position of the two rings is quite critical

11 Regularly check the assembly of parts



Fit the rubber robot car wheels to the printed hubs

Thread the motor depth gauge. Use to set screw lengths

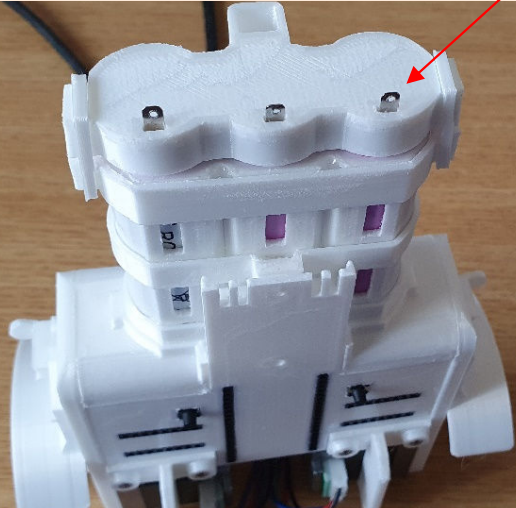
12



The M3 nylon screws are easily cropped with side cutters

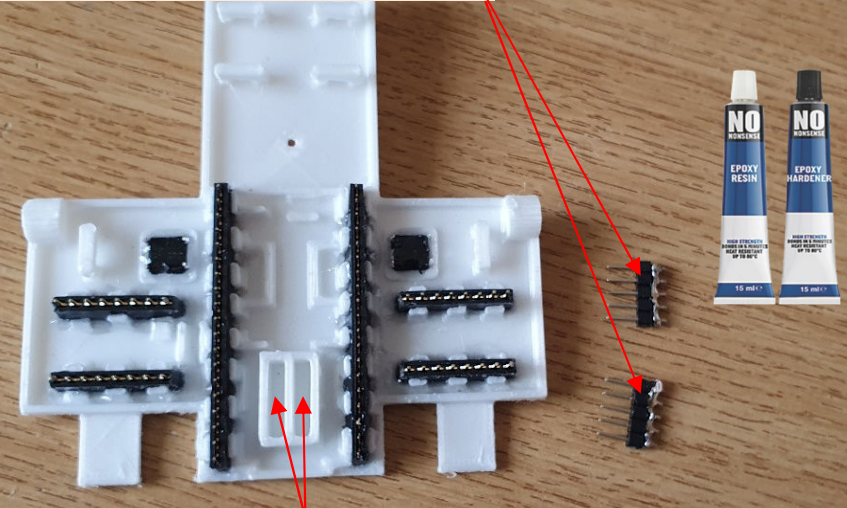
## Build Images

13 Glue the two caps and spring into the battery cover



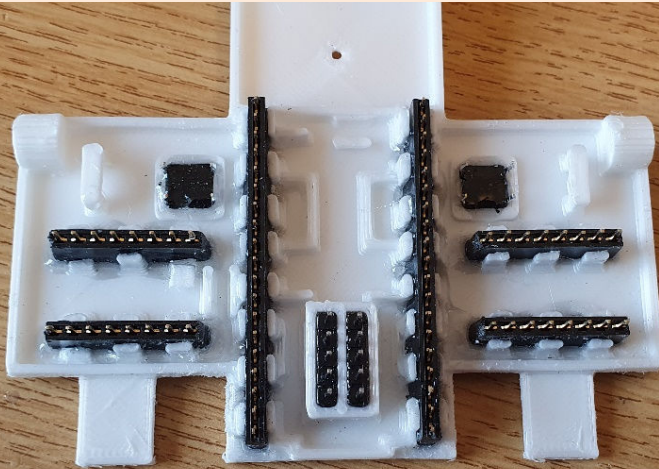
Then trial fits the parts to check everything fits well

14 Wire and solder the two 5-pin strips



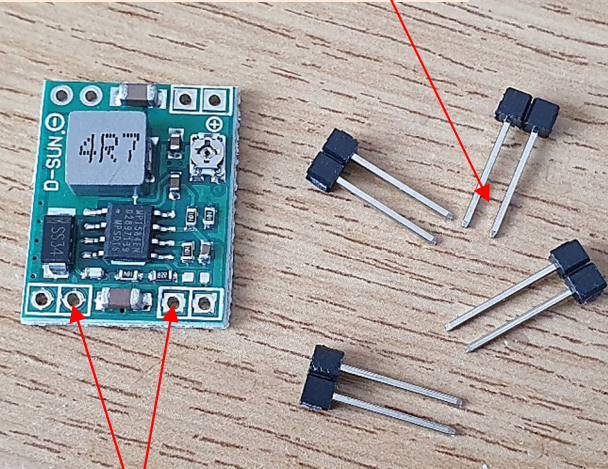
Glue them into the two sockets built into the micro plate

15 He all of the sockets and switches are glued in



Use a single pin and pliers to check the insertion of each

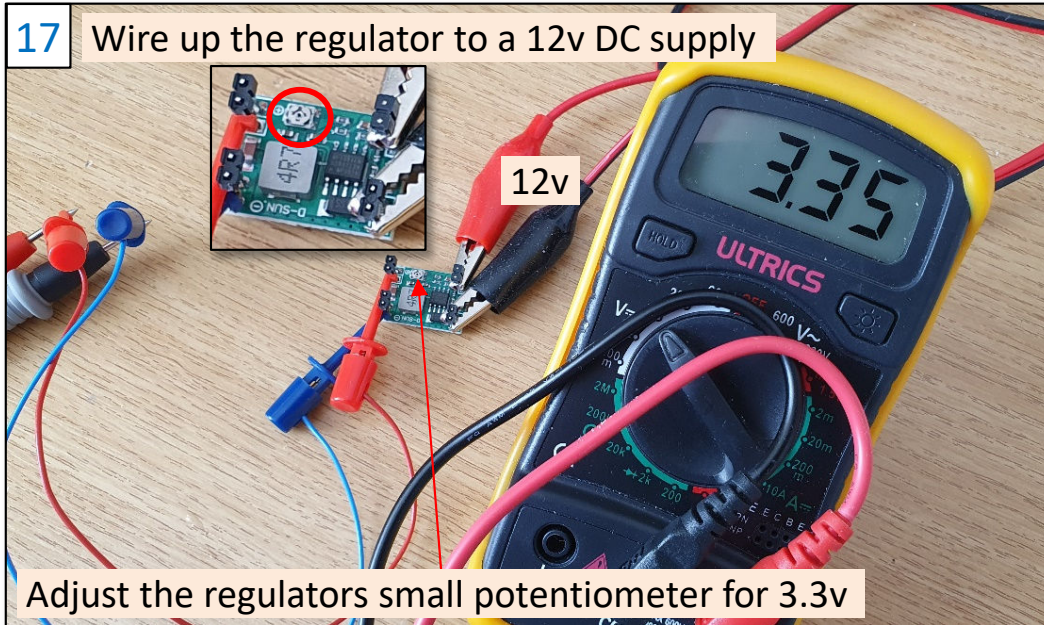
16 Crop four 2-pin strips, and adjust like this



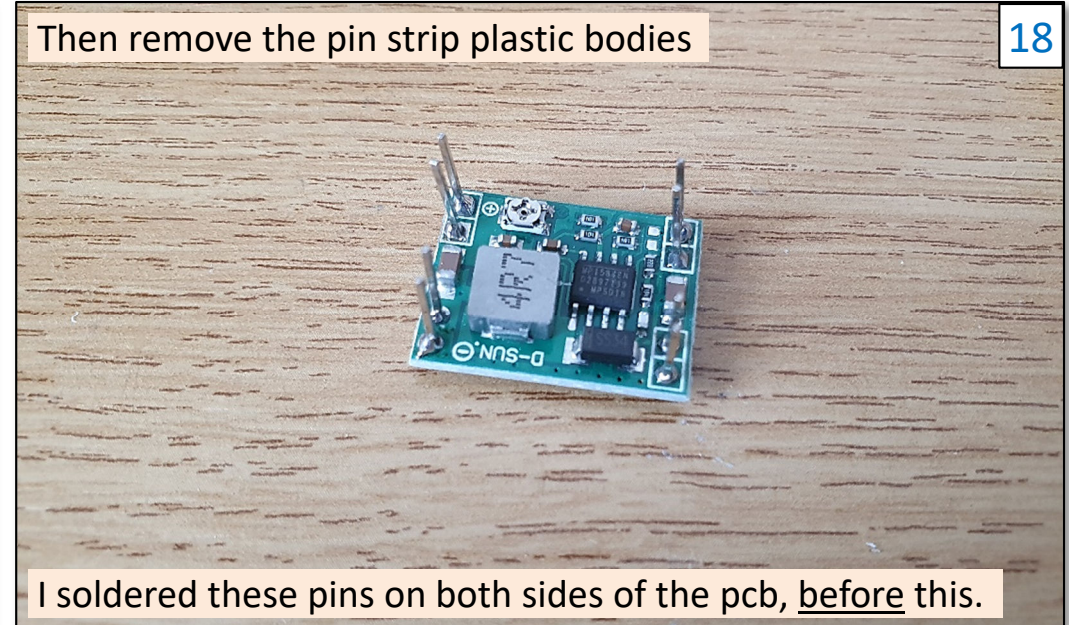
These are soldered in, standing up from the pcb

## Build Images

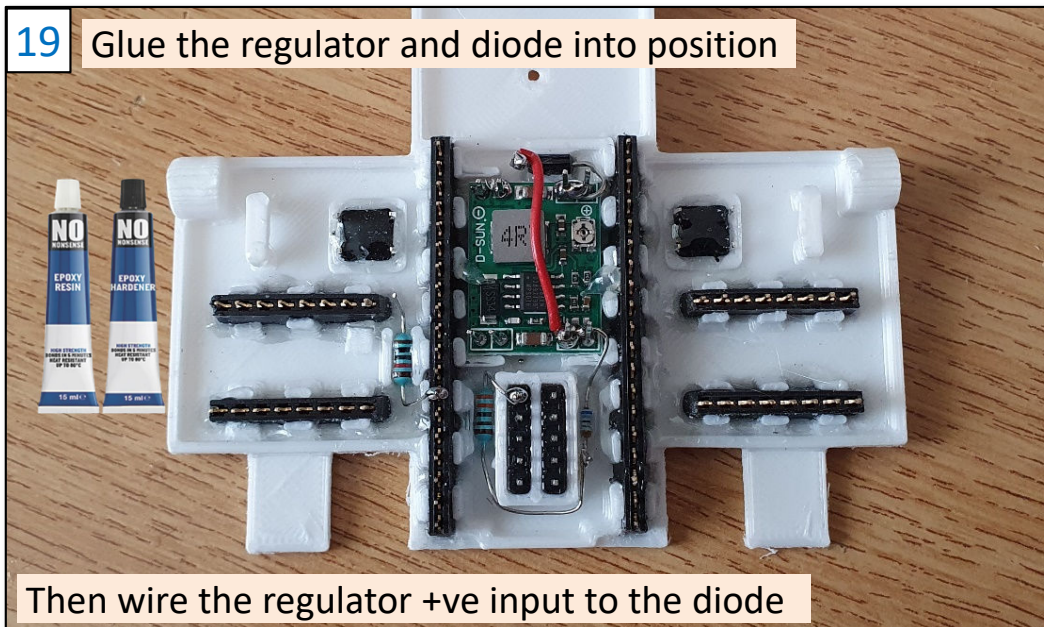
17 Wire up the regulator to a 12v DC supply



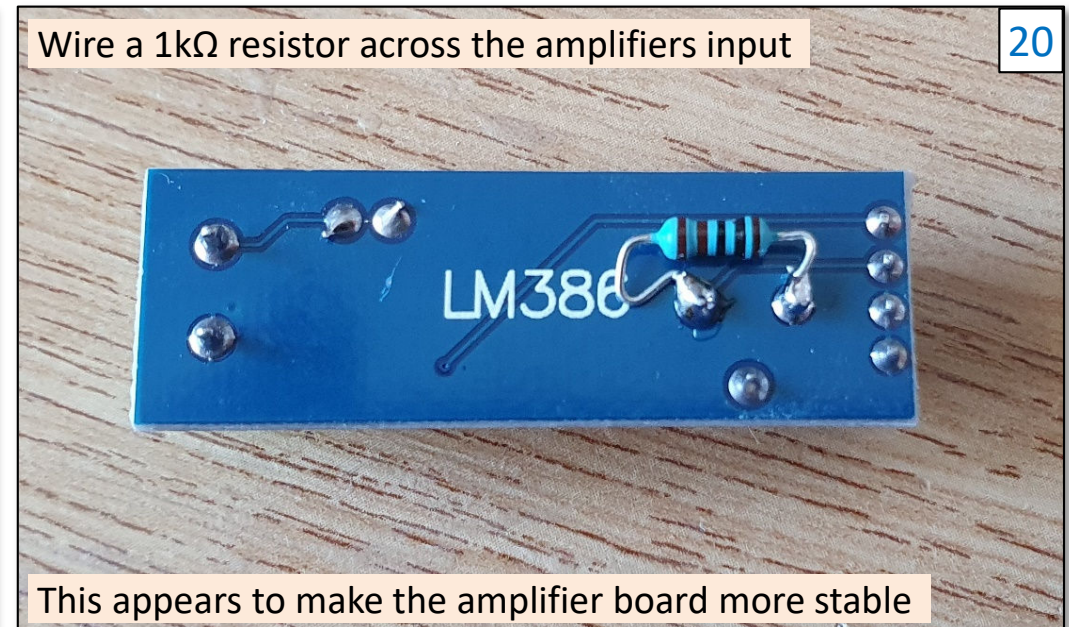
Then remove the pin strip plastic bodies



19 Glue the regulator and diode into position



Wire a 1kΩ resistor across the amplifiers input



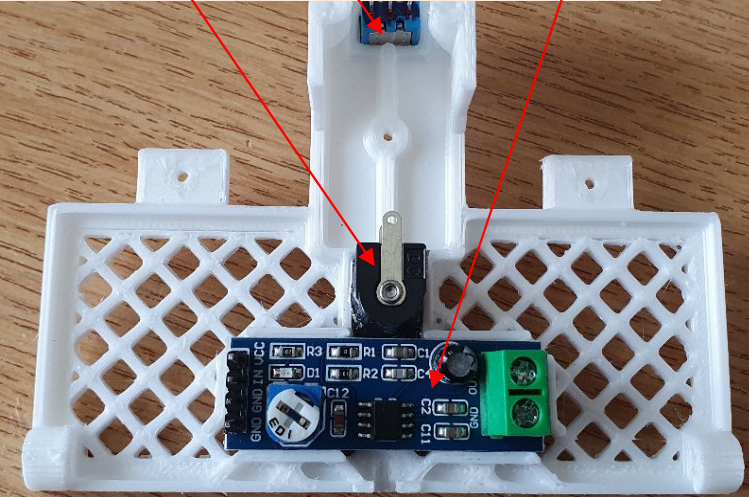
## Build Images

21 Glue in the female part of the cropped connector



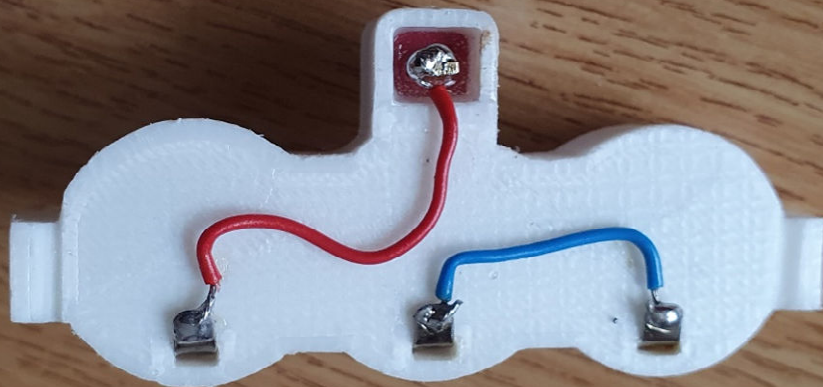
Then position the battery cover and glue in the male part

22 Glue in the power socket, switch, and amplifier.



Wire up the switch and power socket

23 Wire up the battery cover like this:



This is done before gluing on the cover top

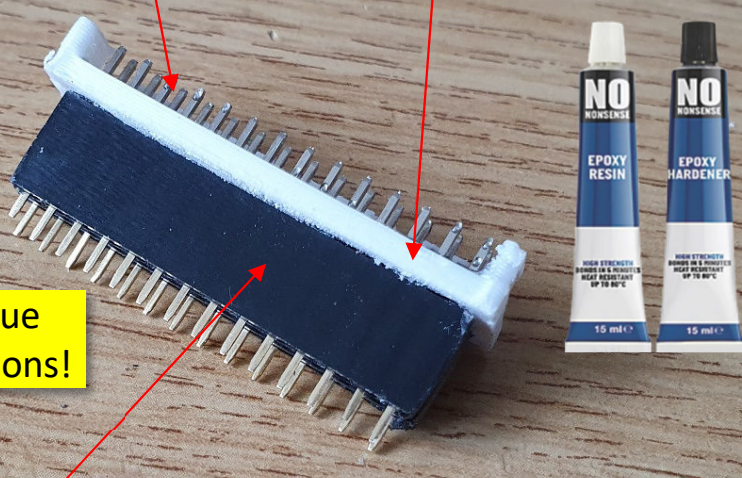
24 The finished component will then look like this:



The cover top has been glued into position .

## Build Images

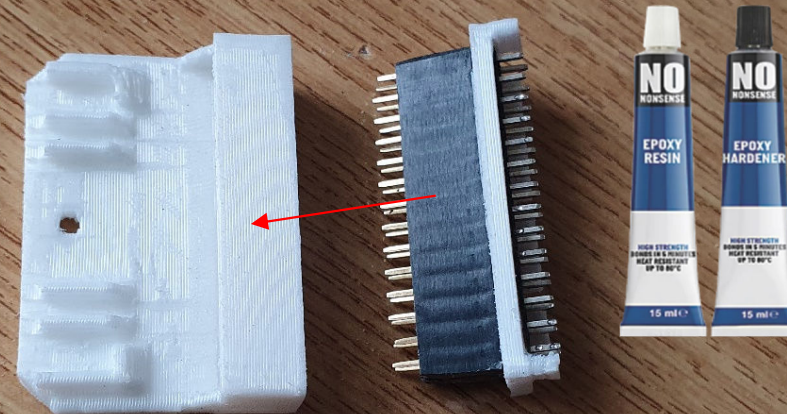
25 Glue the 2x14 pin strips into the connector plate.



Avoid getting glue on the connections!


Use the 2x14 sockets to hold and guide the pin strips.

Carefully glue the 2x14 sockets into the socket plate: 26



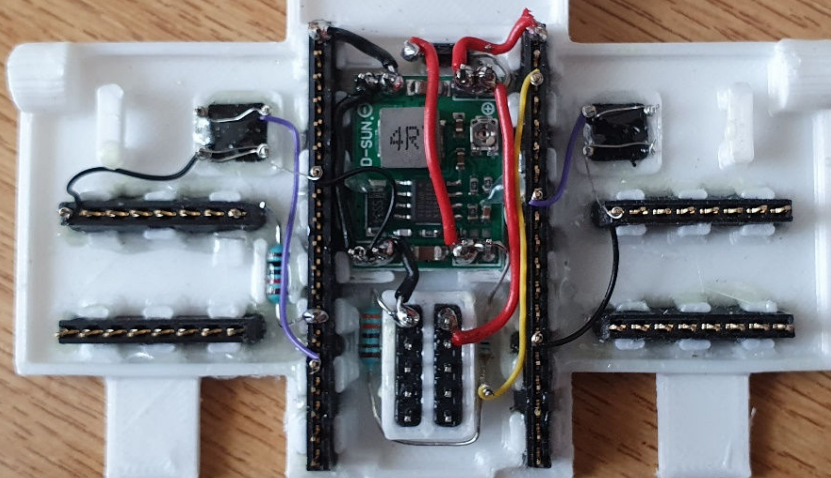
The connector plate pin strips will help with this.

27 The two parts should then push together like this.



The lower socket plate is later attached to the micro plate.

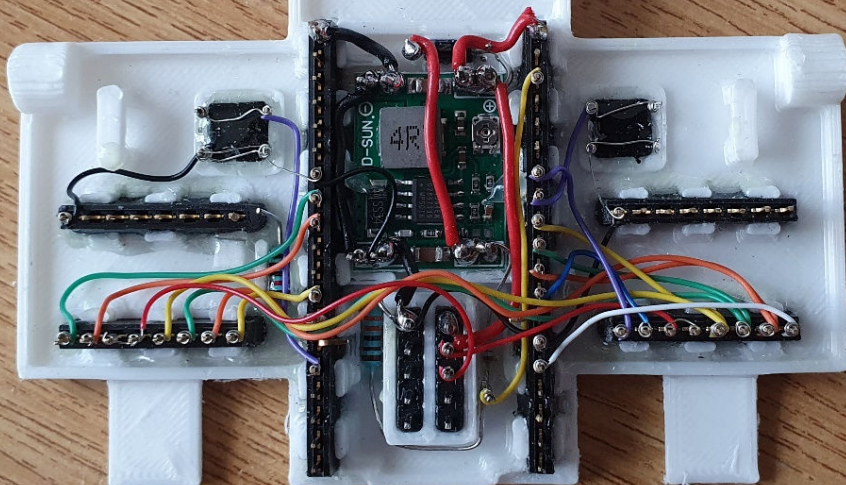
28 Then we continue wiring up the micro plate:



Use the earlier diagrams to guide this work.

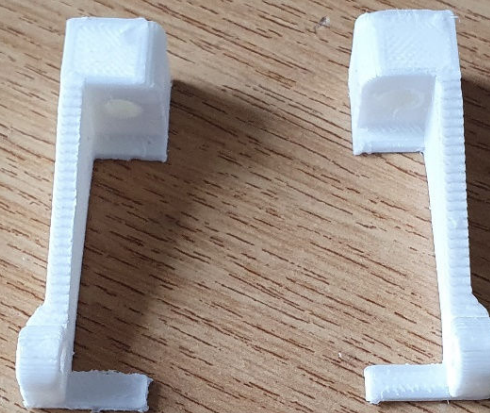
## Build Images

29 Next we wire in connections to the motor drivers:



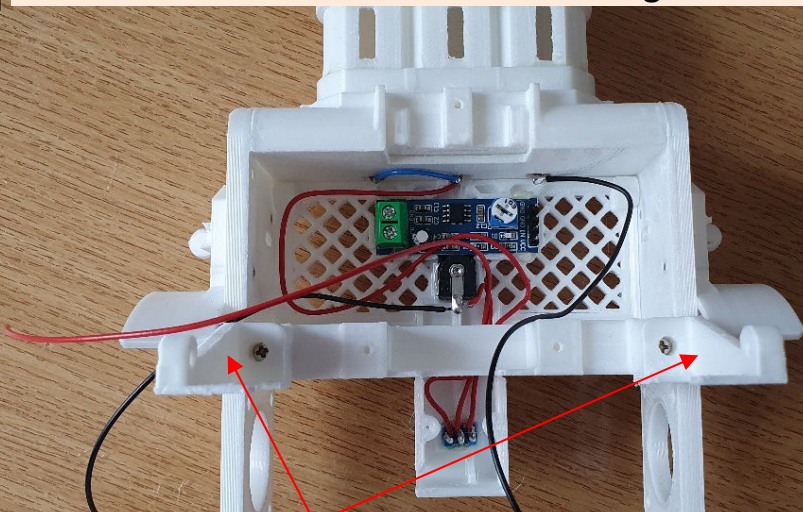
Colour coded wire wrapping makes this much easier.

30 We now attach the micro plate support brackets:



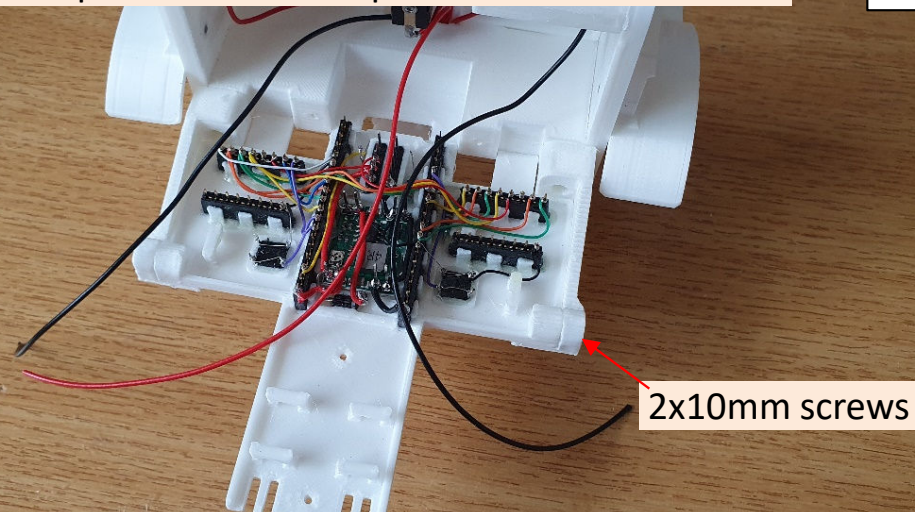
These position the micro plate at a right angle.

31 These brackets attach to the base bridge as shown:



The brackets are facing out towards you.

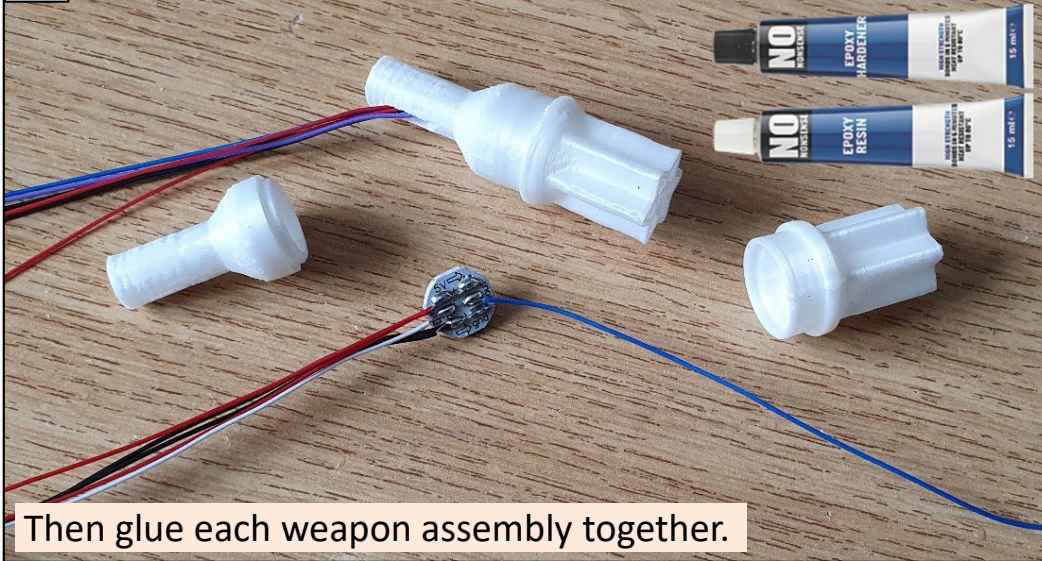
32 The micro plate can then be placed into the brackets:



This greatly assists the final wiring phase.

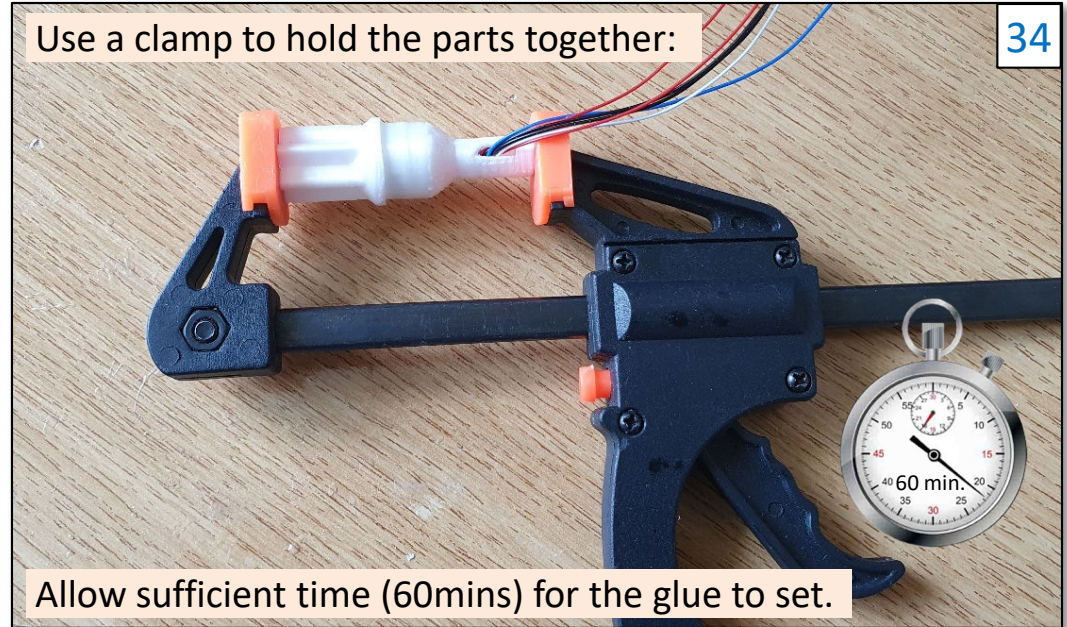
## Build Images

33 Pre-wire the RGB LED chips and test them



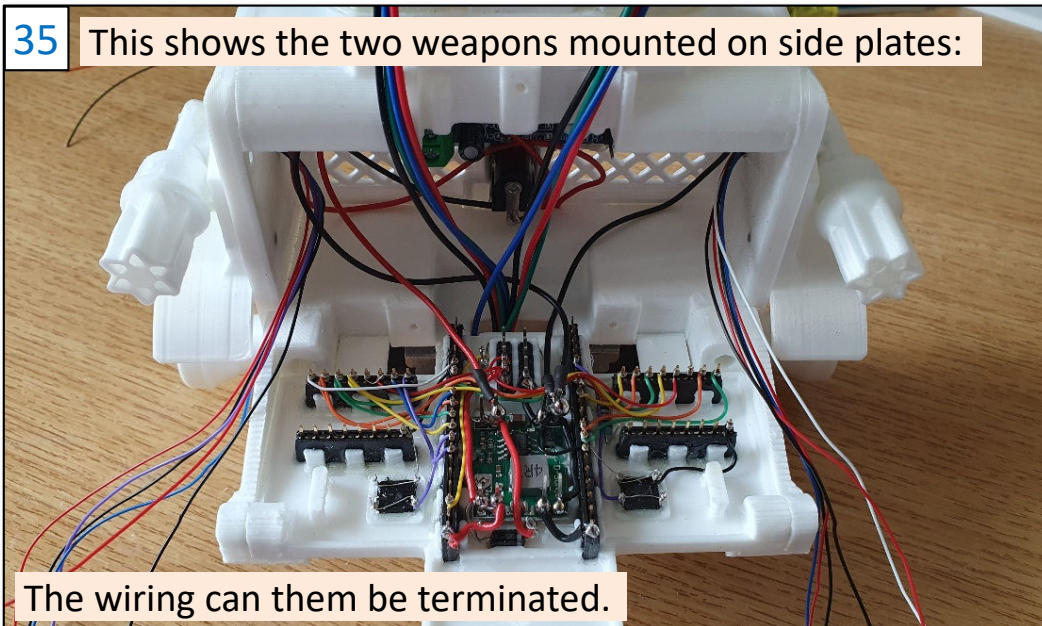
Then glue each weapon assembly together.

34 Use a clamp to hold the parts together:



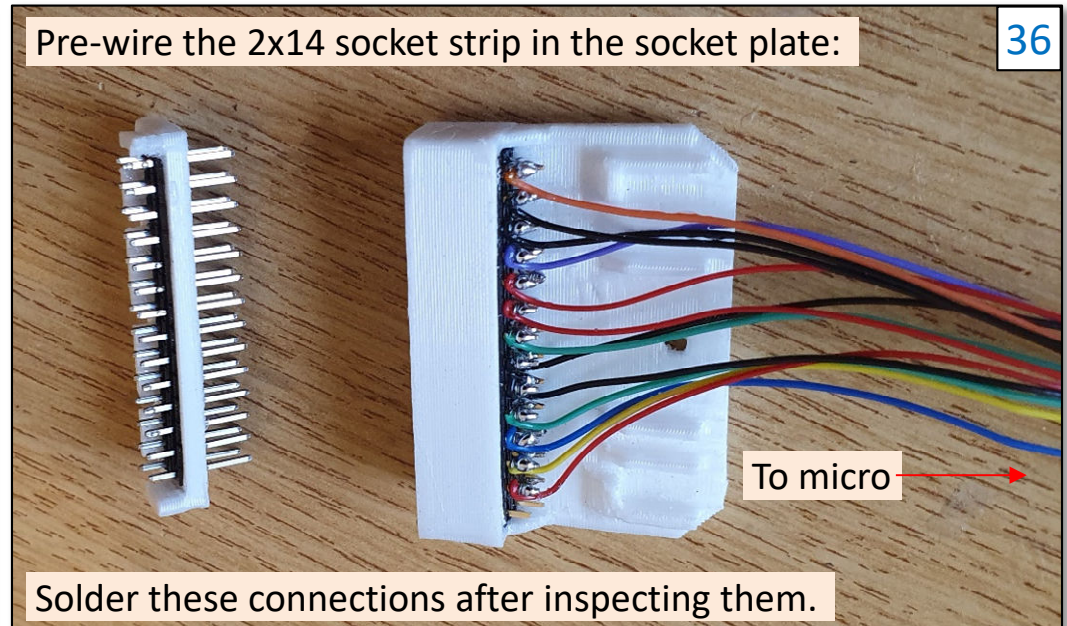
Allow sufficient time (60mins) for the glue to set.

35 This shows the two weapons mounted on side plates:



The wiring can then be terminated.

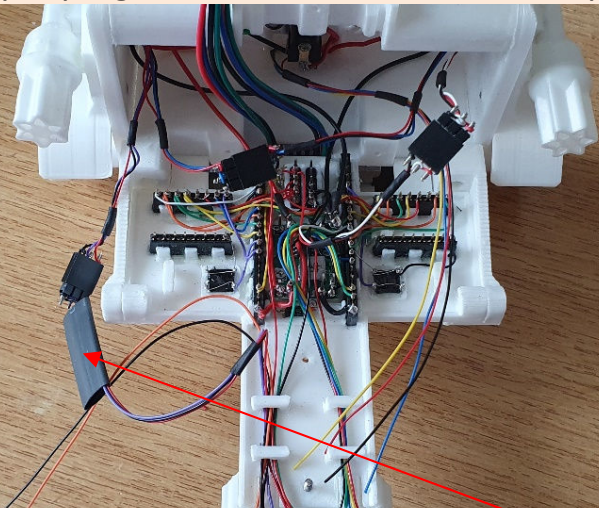
36 Pre-wire the 2x14 socket strip in the socket plate:



Solder these connections after inspecting them.

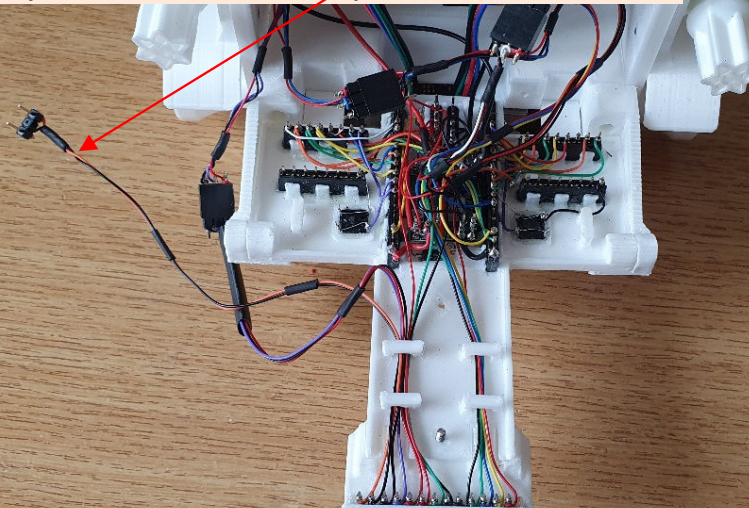
## Build Images

37 I used 3-pin plugs/sockets to wire in the weapons:



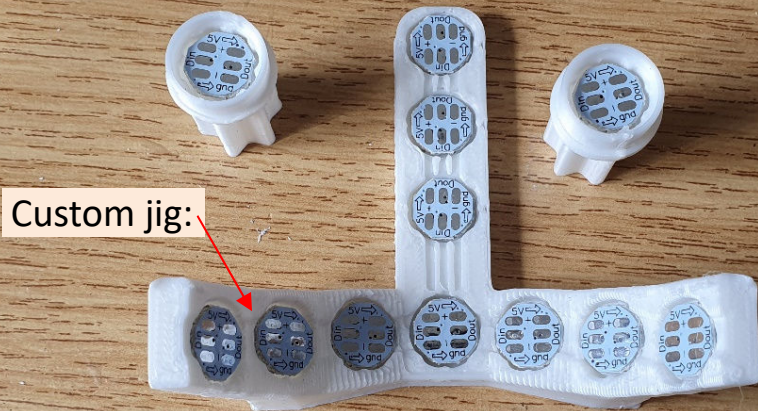
These are soldered and wrapped in heat shrink sleeving.

Here you see the 2-wire speaker connection:



Which connects the socket plate to the LM386 amplifier.

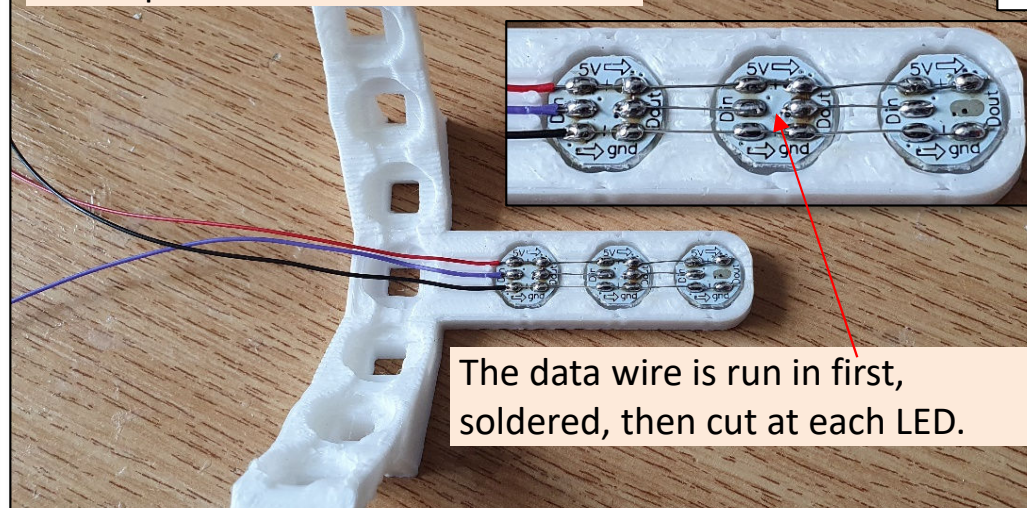
39 Earlier we checked the WS2812B chips fit the mounts:



Custom jig:

This photo is slightly out of sequence.

Wire up the helmets nose LEDs first:



The data wire is run in first, soldered, then cut at each LED.

The jig holds the LEDs in position. They are removed after.

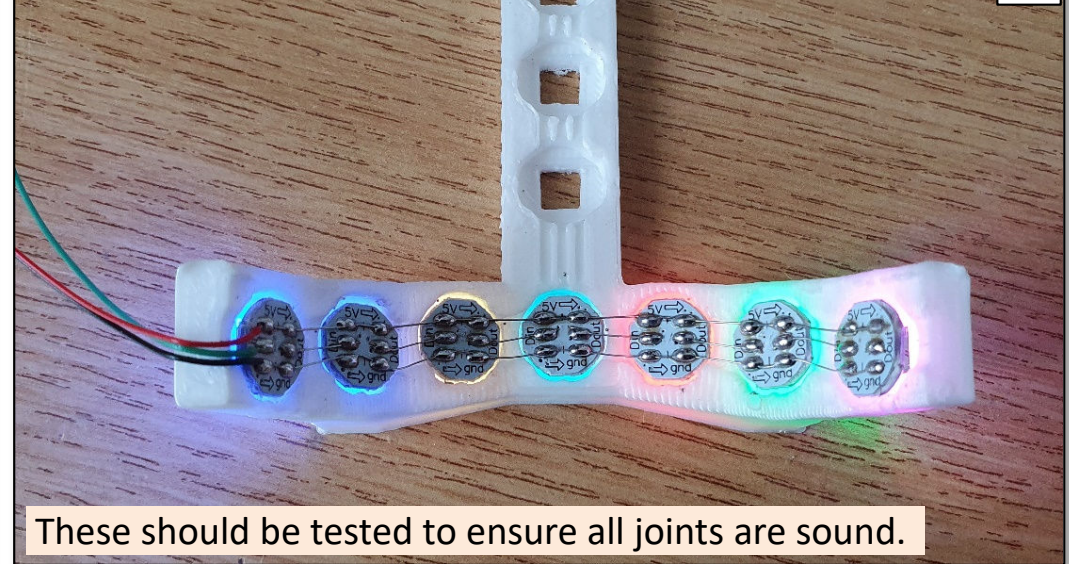
## Build Images

41 The pre-wired LEDs can then be glued into the helmet:

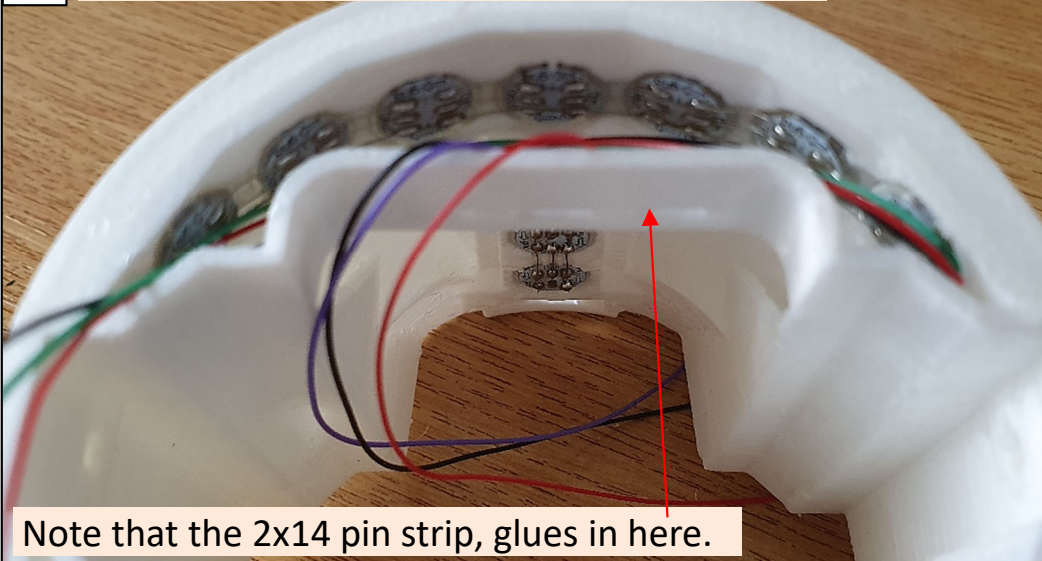


The jig is then used to wire up the eye LEDs:

42

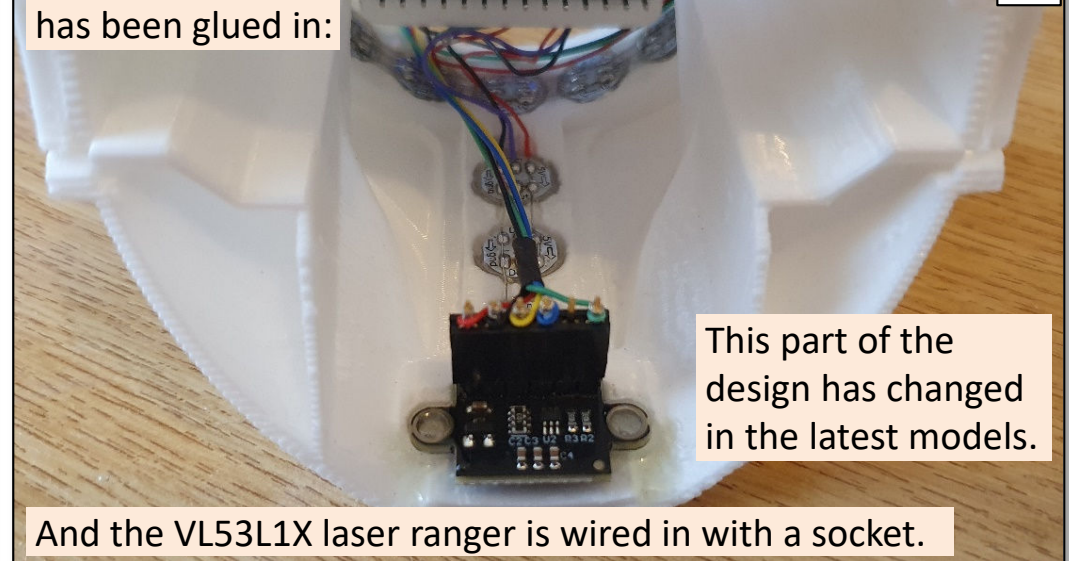


43 The LEDs can then be glued into the helmet:

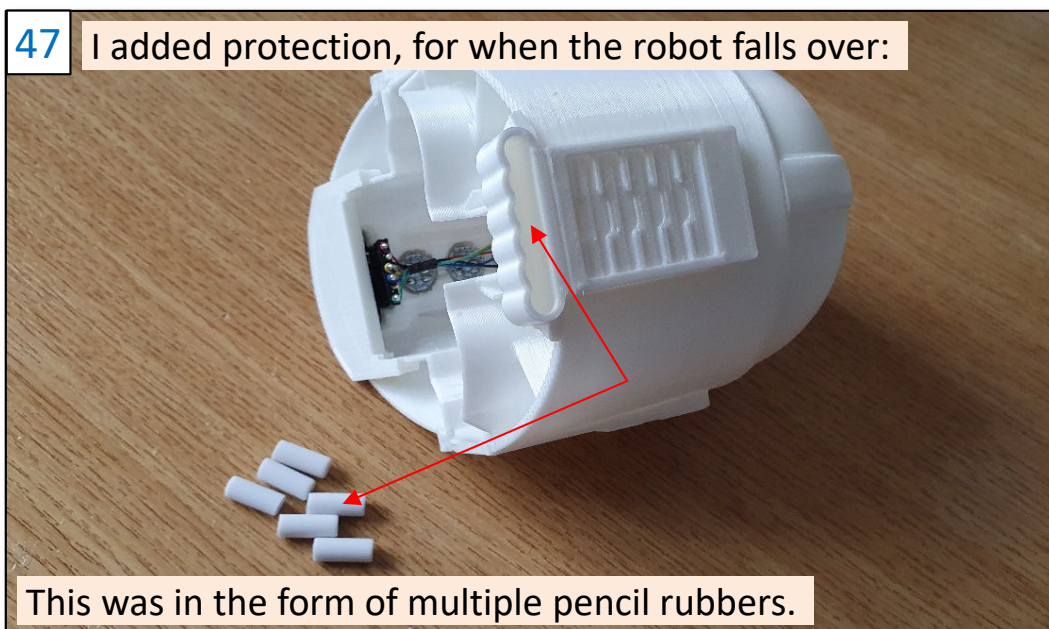
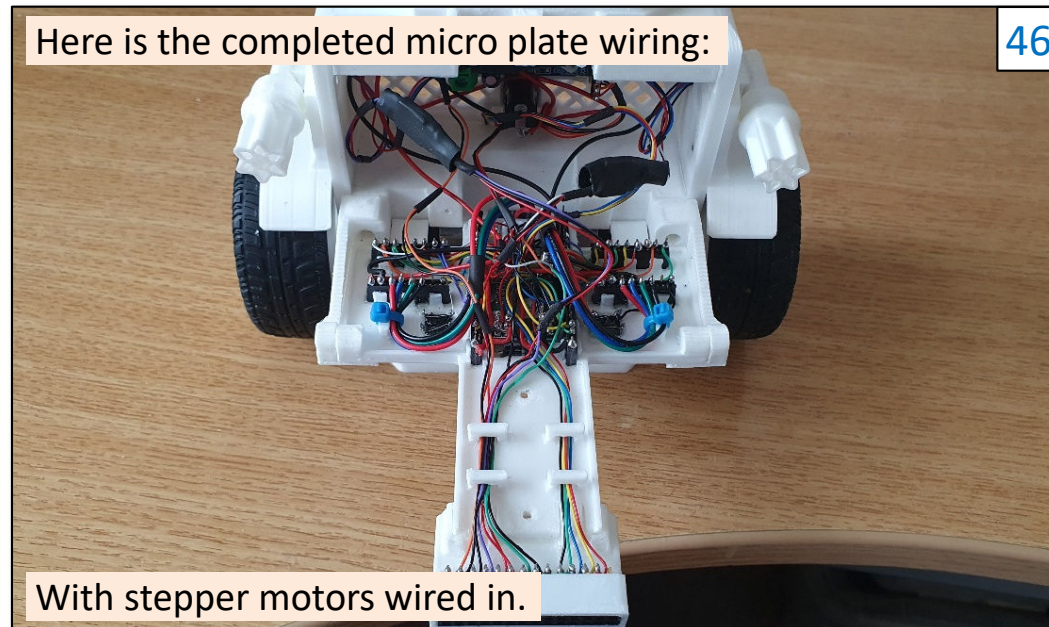
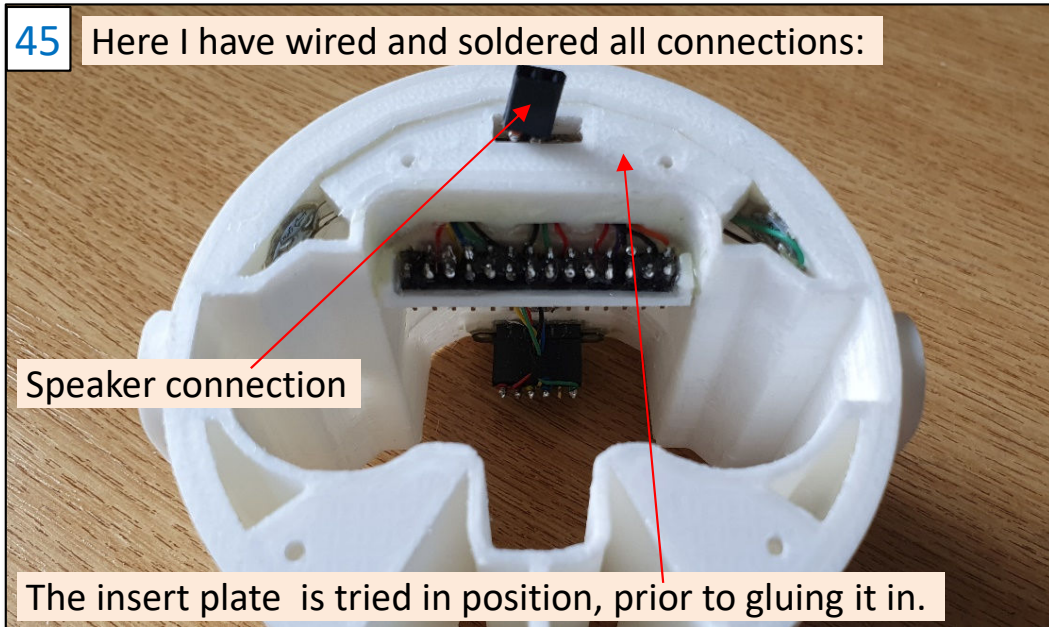


Here the pin strip has been glued in:

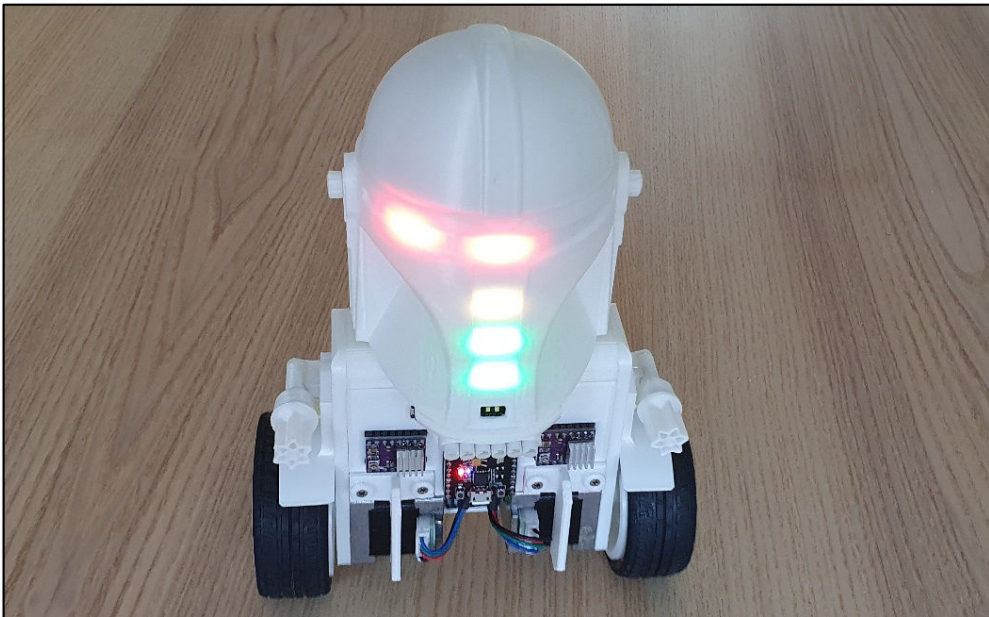
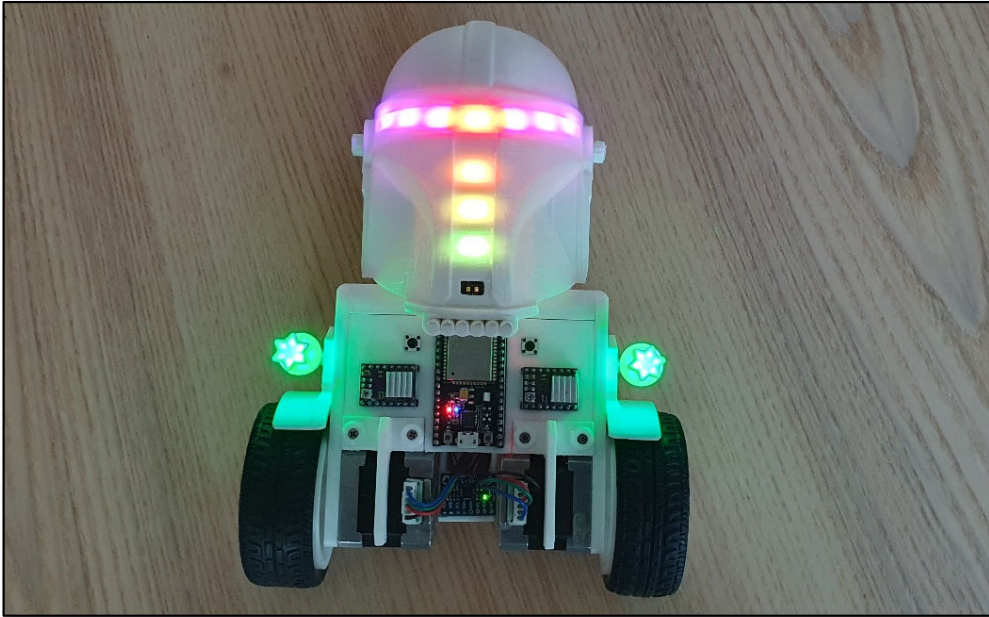
44



## Build Images



It's time for testing!



# NEMA14 Stepper control

Nema14 stepper motor is 1.8° per step, or 200 steps per revolution.

DRV8825 driver is set to 1/4 step(W1-2 phase excitation), giving control resolution of 0.45° per clock pulse.

From DRV8825 datasheet we get the following relationship:

$$f_{step} (\mu\text{steps} / \text{second}) = \frac{120 \left( \frac{\text{rotations}}{\text{minute}} \right) \times 360 \left( \frac{\circ}{\text{rotation}} \right) \times 8 \left( \frac{\mu\text{steps}}{\text{step}} \right)}{60 \left( \frac{\text{seconds}}{\text{minute}} \right) \times 1.8 \left( \frac{\circ}{\text{step}} \right)}$$

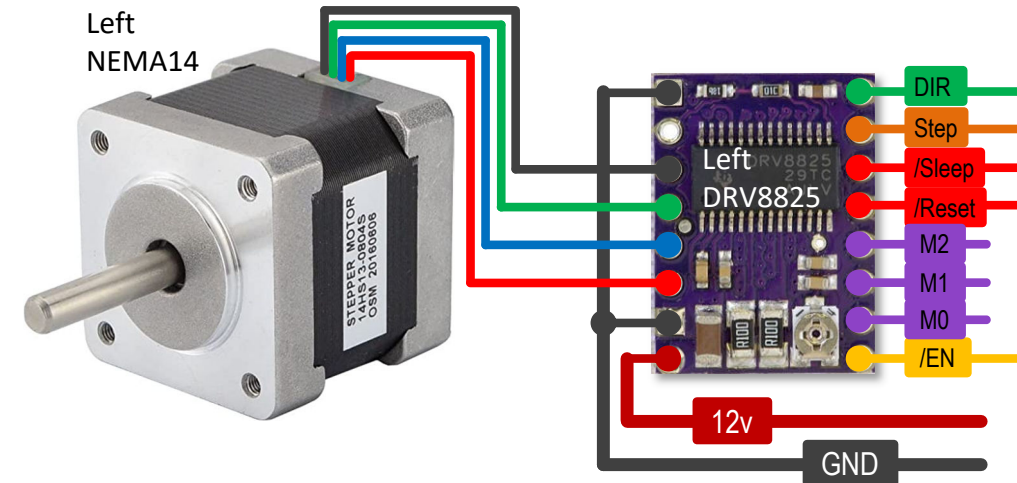
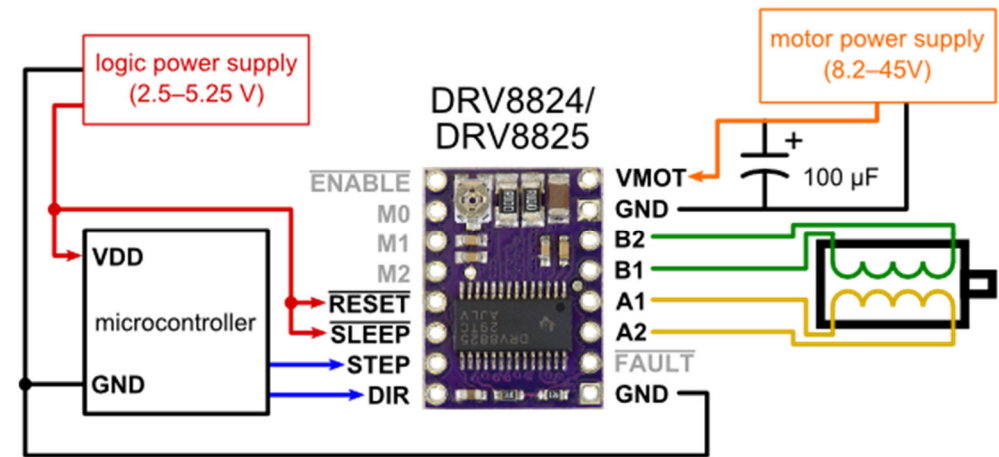
So to run the motor at 3 rev/sec, or 120 rpm, using 1/4 steps, this gives us:

$$F_{step} = 120 * 360 * 4 / 60 * 1.8 = 1,600 \mu\text{steps/sec} (1.6\text{kHz})$$

With a step period of 625 μs

In the NANO BalanceBot the ISR gave a minimum step period of 40 μs, which is 25kHz, means it can achieve a max wheel speed of 47 rpm.

This seems quite high, and puts a heavy load on the code, so will run timers off the micros() timer at a max rate of 10 kHz, or 100 μs period.



MODE2	MODE1	MODE0	STEP MODE
0	0	0	Full step (2-phase excitation) with 71% current
0	0	1	1/2 step (1-2 phase excitation)
0	1	0	1/4 step (W1-2 phase excitation)
0	1	1	8 microsteps/step
1	0	0	16 microsteps/step
1	0	1	32 microsteps/step
1	1	0	32 microsteps/step
1	1	1	32 microsteps/step

# Battery Voltage Health Monitoring

See Lithium discharge curve obtained from the internet. In this analysis the lipo battery consists of three identical batteries connected in series. Assume fully charged 11.1v battery max voltage is  $V_{BM} \geq 12.9v$  max  
 Set battery warning point at  $V_B = 10.5v$  (3 x 3.5v)  
 Set battery critical point at  $V_{BC} = 9.9v$  (3 x 3.3v)

The ESP32 is powered via a voltage regulator connected to the 3.3v pin.  $V_{ADC} == 4095$  on 12-bit converter (4095 max).  
 If we use a 10k resistor feeding A0 and a 3k3 resistor to GND, we get a conversion factor of  $13.3v == 4095$ , or 3.25mV/bit, or 307.9 bit/v  
 Using a Multimeter I determined the following  $V_{ADC}$  values for corresponding threshold voltages:

MAX: (100%)  $V_M = 12.3v$ , gave A0 = 3841 on  $V_{ADC}$  (3 x 4.1v)

HIGH: (80%)  $V_H = 11.4v$ , gave A0 = 3402 on  $V_{ADC}$

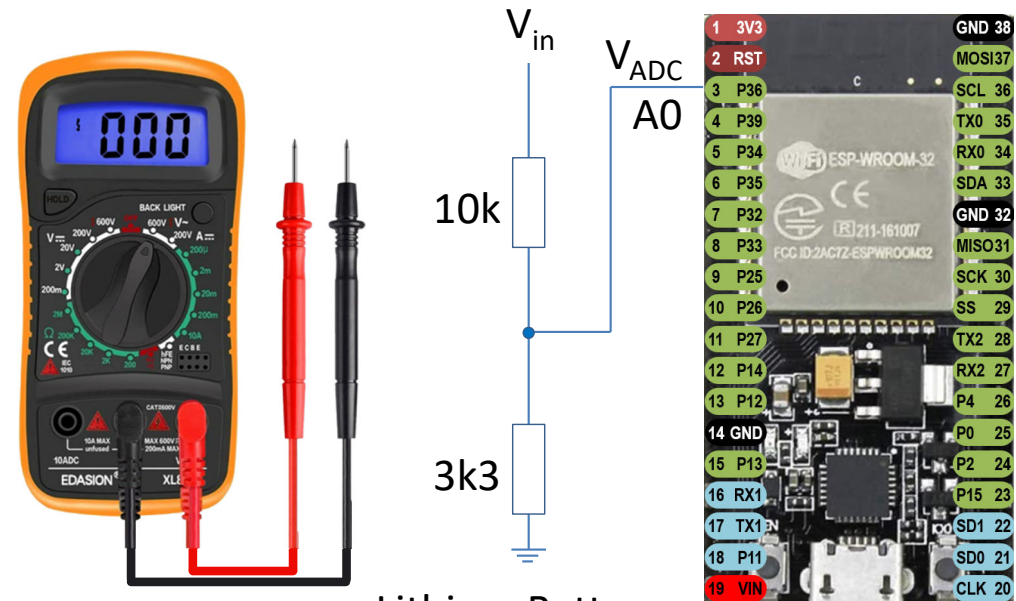
WARNING: (20%)  $V_B = 10.8v$ , gives A0 = 3175 on  $V_{ADC}$

CRITICAL: (0%)  $V_{BC} = 10.0v$ , gives A0 = 2895 on  $V_{ADC}$  (3 x 3.3v+)

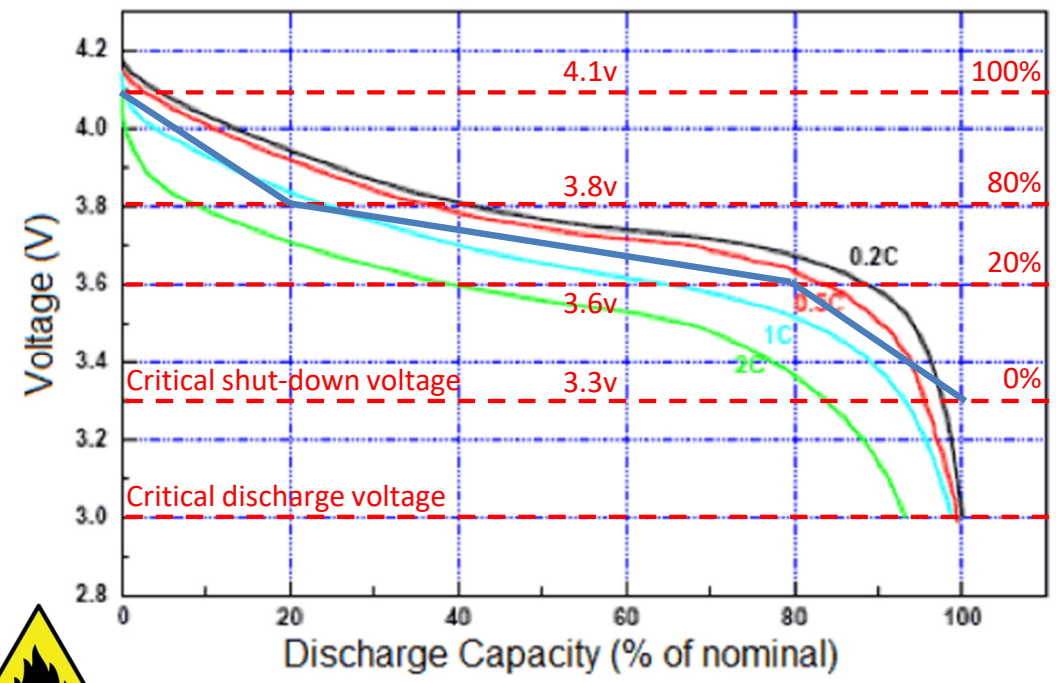
The code will sample the battery voltage on power-up to ensure it is sufficient, then at every 40ms interval, calculating an average (1/20) to remove noise. It also detects no battery as USB mode.

In the code I have assumed a discharge curve ranging from 12.3v (100%) to 10.0v (0%) capacity, using the overlay lines shown. The rate of discharge is monitored and used to predict the life of the battery in use.

Note: If connected to USB port with internal battery switched OFF the ADC will read a value 5 volts (A0 = 1919) or less. So if the micro starts with such a low reading it knows that it is on USB power.



Lithium Battery Discharge Profile



Discharge: 3.0V cutoff at room temperature.

