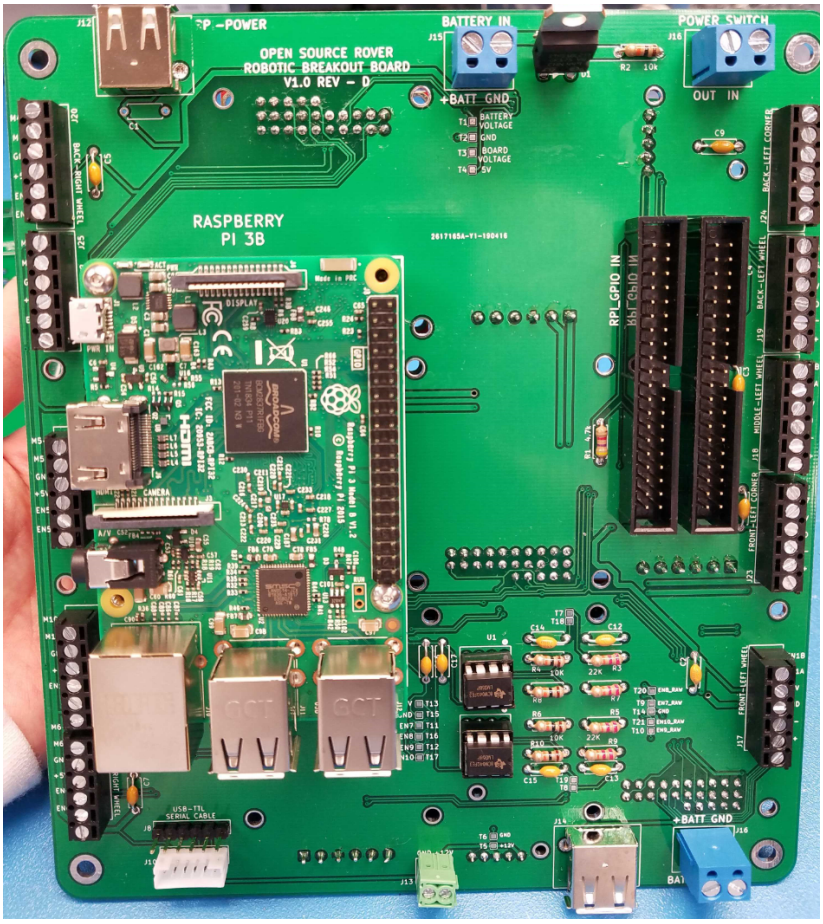


Open Source Rover: PCB Assembly Instructions

Authors: Michael Cox, Eric Junkins

Jet Propulsion Laboratory
California Institute of Technology

Contents

1 PCB Assembly

This document goes through the process of assembling and testing the custom Printed Circuit Boards for the project. One thing you might notice is the boards have reference designators on them that do not match the reference designators used in the parts lists. The board components mapping between these can be found below:

Control Board References

Component	Parts list Ref	Schematic Ref
Terminal block 6 pos top entry	E4	J1-5
Terminal block 6 pos side entry	E3	J17-26
Term block 2p side entry (5.08mm)	E12	J13,15,16
Connector Header pin 40P 40x1	E15	J8,9,11
Connector Header pin 6P 6x1	E14	J10
Connector Header socket 5P 5x1	E6	RC1-5
Connector Header socket 40P 2x20	E13	J6,7
Connector Header socket 20 2x10	E5	RC1-5
Capacitor 100nF	E11	C1-17
Resistor 4.7K 1/4 Watt	E7	R1
Resistor 10K 1/4 Watt	E8	R4,6,8,10
Resistor 22K 1/4 Watt	E9	R3,5,7,9
Resistor 10K 1/2 Watt	E10	R2
LM358 Op Amp	E25	U1,2
DIP IC socket 8 Pos	E33	U1,2
Power Diode	E17	D1
10A Fuse	E16	F1
USB A Connector	E34	J12,14

Arduino Board References

Component	Parts list Ref	Schematic Ref
Term block 2P side entry	E16	J6
Connector Header pin 40P 40x1	E15	J2,3,4
Connecor Header 16P 2x8	E30	J1
Connecor Header 6P 6x1	E14	J5

1.1 Control Board Assembly

1.1.1 Motor & RoboClaw Connectors

Table 1: Parts/Tools Necessary

Item	Ref	Qty	Image	Item	Ref	Qty	Image
OSR Control Board	E1	1		6 Pos Side Term Block	E3	10	
6 Pos Top Term Block	E4	5		5 Pos Header socket	E5	5	
5 Pos Header socket	E6	5		Soder Iron	N/A		

1. Begin by soldering the 6 Position Side entry terminal blocks **E3** into the **top** side of the PCB, on the edge of the board as shown in Figure 1. These terminal blocks will run motor power, encoder power, and encoder signals between the motors/encoders and the RoboClaw motor controllers. The 6 terminal blocks will each be labeled with schematic reference designators J17-J26 on the PCB. Be sure that the wire terminals face **OUTWARD** (away from the center of the board) on all of these connectors.

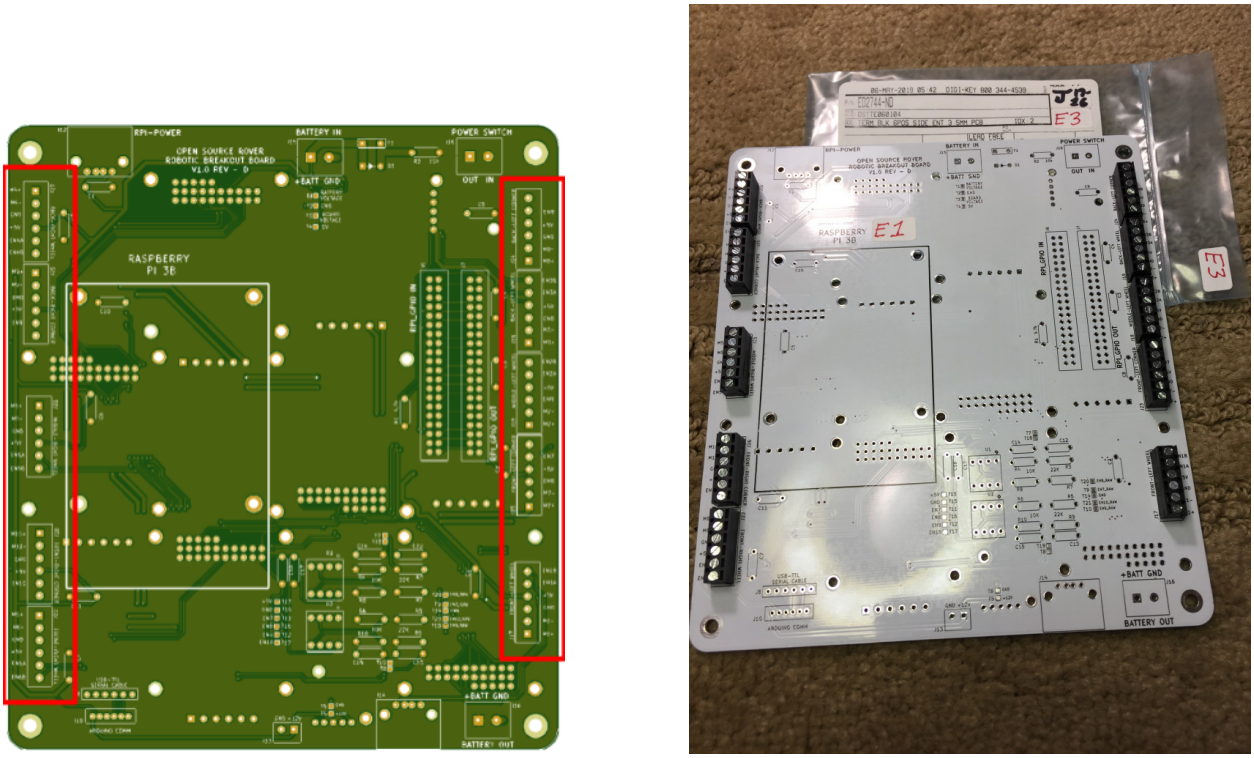


Figure 1: Assembly Step 1

2. On the **bottom** of the board, solder the 6 Position top entry terminal blocks **E4**. They will be labeled with schematic reference designators J1-5. The orientation of the wire terminal face should be AWAY from the each of RoboClaw outlines (see Figure 2). These terminals will run battery power and +/- motor signals to the RoboClaw motor controllers from the PCB.

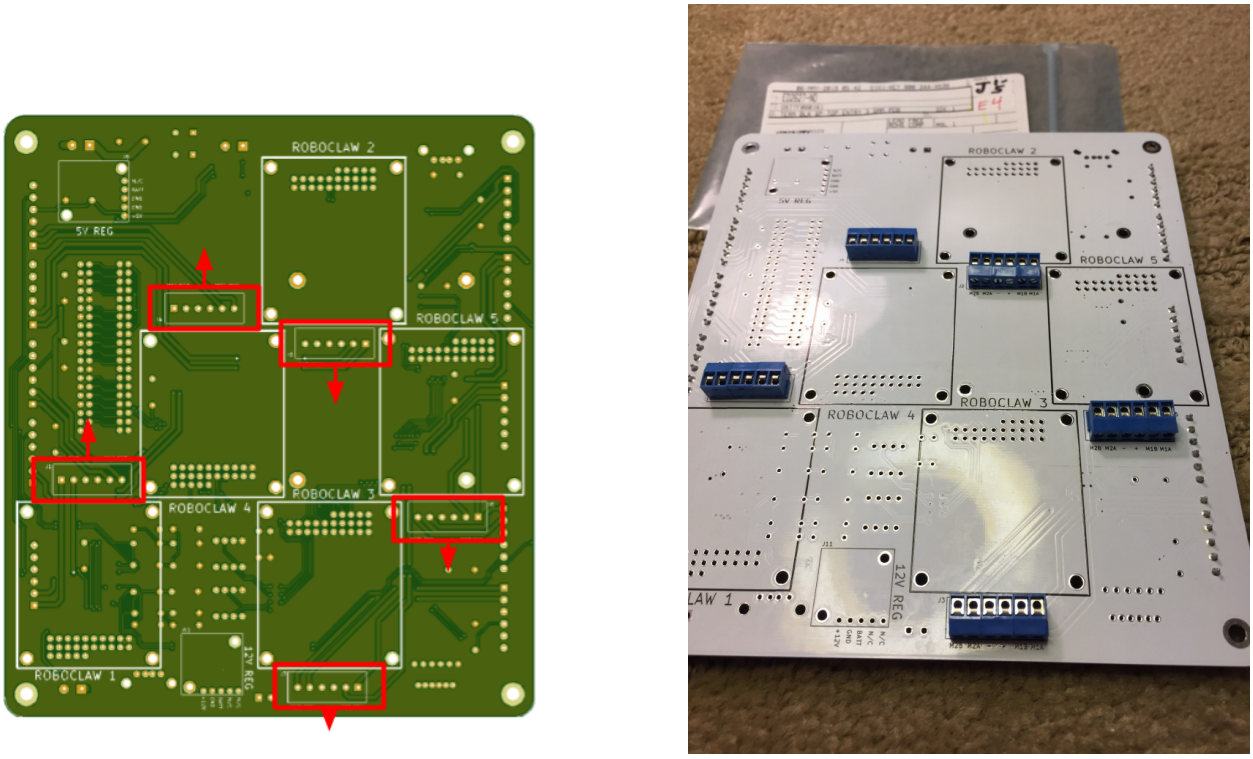
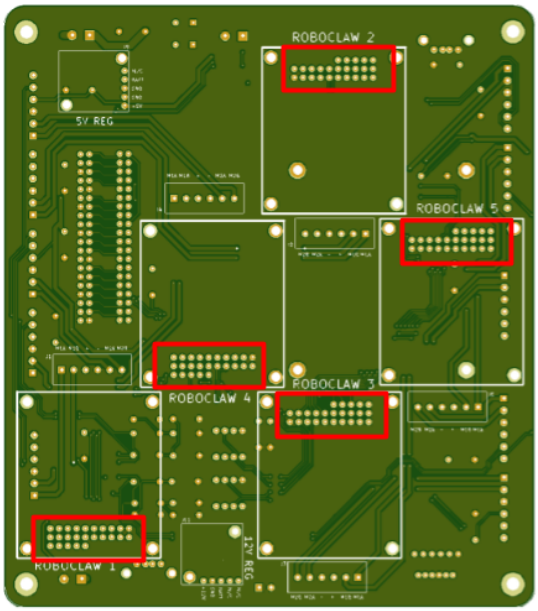


Figure 2: Assembly Step 2

3. On the **bottom** of the board, solder the 20-position female socket header connector **E5** and the 5-position female socket header connector **E6**. They will be labeled with reference designators RoboClaw 1-5. These are the digital signal pins for the RoboClaw motor controllers.



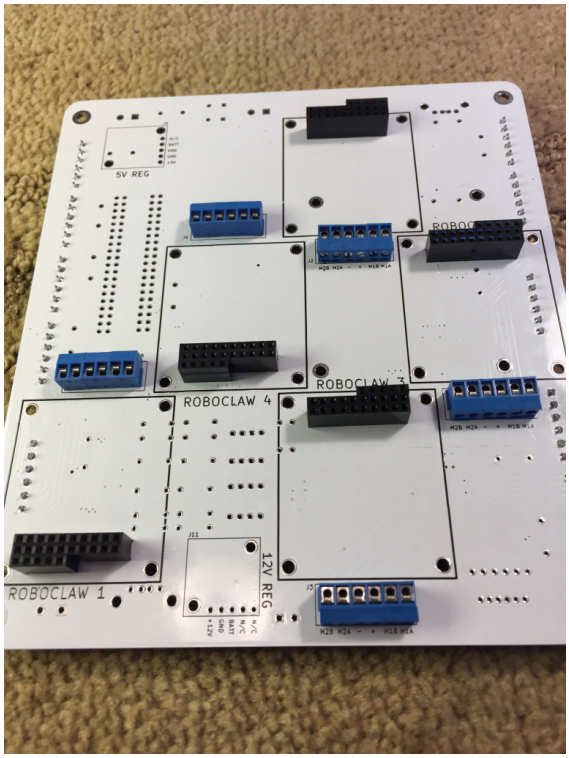


Figure 3: Assembly Step 3

1.1.2 Resistors and Capacitors

Table 2: Parts/Tools Necessary

Item	Ref	Qty	Image	Item	Ref	Qty	Image
OSR Control Board	E1	1		4.7K 1/4 Watt Resistor	E7	1	
10K 1/4 Watt Resistor	E8	4		22K 1/4 Watt Resistor	E9	4	
10K 1/2 Watt Resistor	E10	1		100nF Capacitor	E11	16	

1. On the **top** of the board, solder the resistors and capacitors by comparing the reference designator on the board to the part number listed in the table below. Some of these capacitors are used to store energy for powering components (to help protect against voltage fluctuations). Others are used as noise filtering mechanisms on analog signals (particularly to smooth the encoder signals). The resistors are needed to control the voltage across various components.

Table 3: Resistor/Capacitor reference

Item	Parts list Ref	Schematic/Board Ref
4.7K 1/4 Watt Res	E7	R1
10K 1/4 Watt Res	E8	R4,6,8,10
22K 1/4 Watt Res	E9	R3,5,7,9
10K 1/2 Watt Res	E10	R2
100nF Cap	E11	C1-17

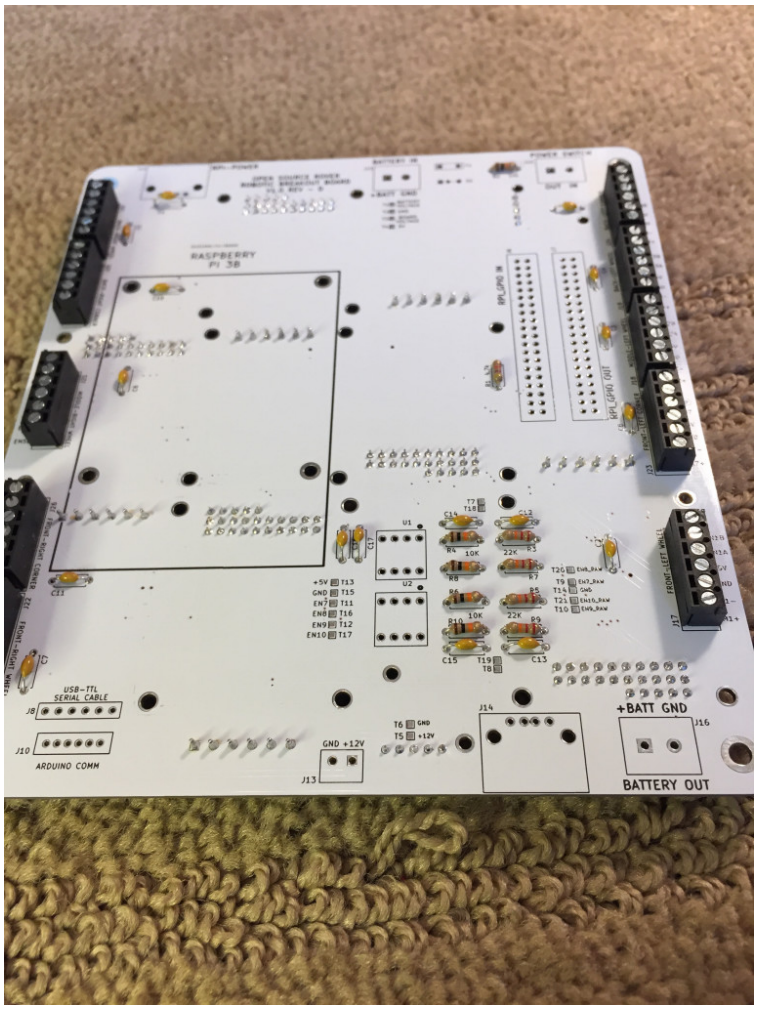


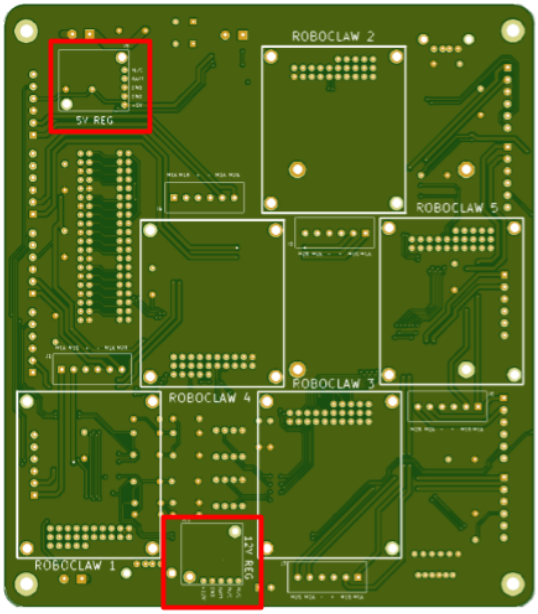
Figure 4: Resistor and Capacitor soldering

1.1.3 Voltage Regulator connectors

Table 4: Parts/Tools Necessary

Item	Ref	Qty	Image	Item	Ref	Qty	Image
OSR Control Board	E1	1		5 Pos Header socket	E6	2	
				Soder Iron	N/A		

1. On the **bottom** of the board, solder the 5-position female header sockets **E6**. The sockets will have schematic reference designators of J9 and J11. These connectors are what the 12V and 5V voltage regulators will slot into.



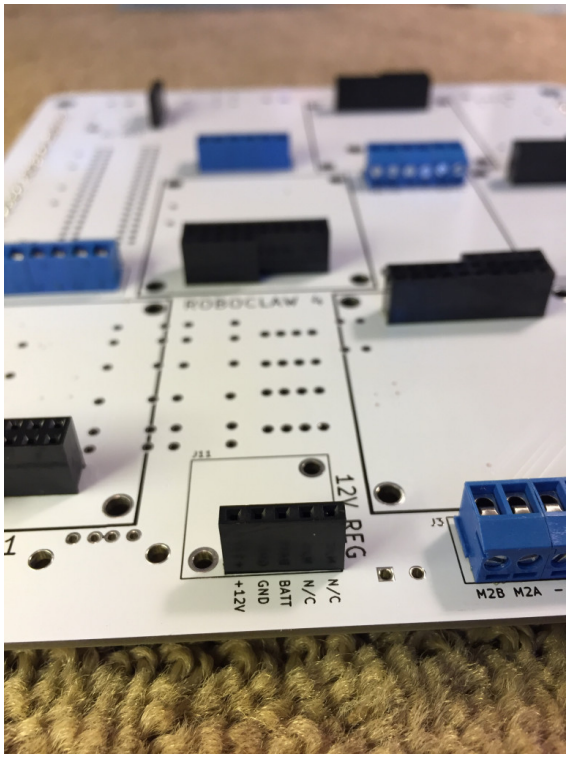


Figure 5: Assembly Step 5

1.1.4 Power Connectors

Table 5: Parts/Tools Necessary

Item	Ref	Qty	Image	Item	Ref	Qty	Image
OSR Control Board	E1	1		2 Pos Side Terminal Block	E12	3	
2 Position 2.5mm Terminal Block	E18	1		Soder Iron	N/A		

1. On the **top** of the board, solder the 2-position side entry terminal blocks **E13**. These will have schematic reference designators J14-16. Ensure that the wire terminals on these componenets face **OUTWARDS**. Also on the **top** of the board, solder the remaining 2-position 2.5mm terminal block **E18** (schematic reference designator J12).

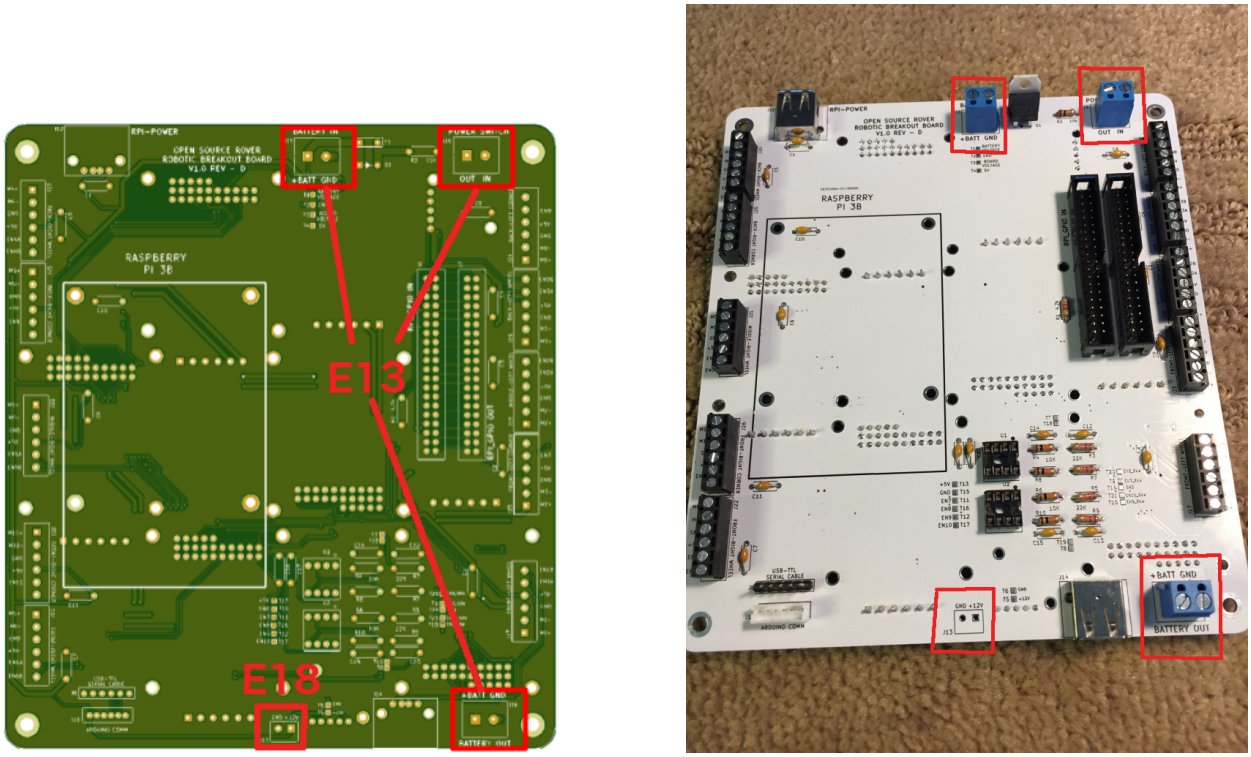


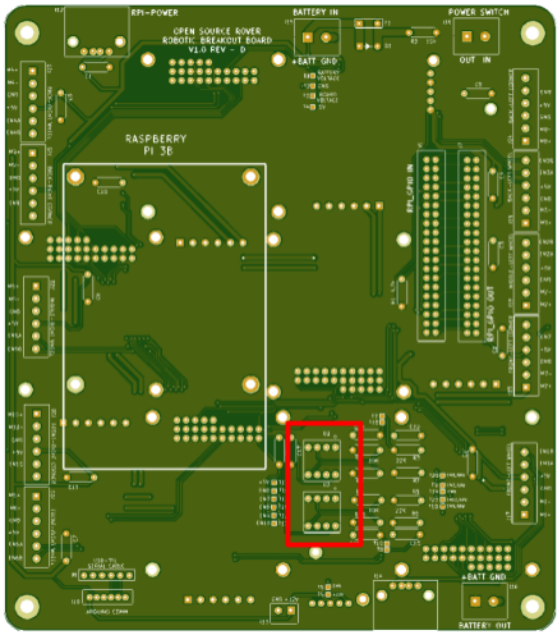
Figure 6: Assembly Step 6

1.1.5 Op amp DIP socket

Table 6: Parts/Tools Necessary

Item	Ref	Qty	Image	Item	Ref	Qty	Image
OSR Control Board	E1	1		8 Pin DIP Socket	E33	2	
				Soder Iron	N/A		

1. On the **top** of the board, solder the 8 Pin DIP sockets **E33**. They will have schematic reference designators U1-2. Orientation of these sockets does not matter, but note that you WILL (later, in another document) need to plug in the Op-Amp chips themselves, and orientation of those chips is important when you eventually complete that step.



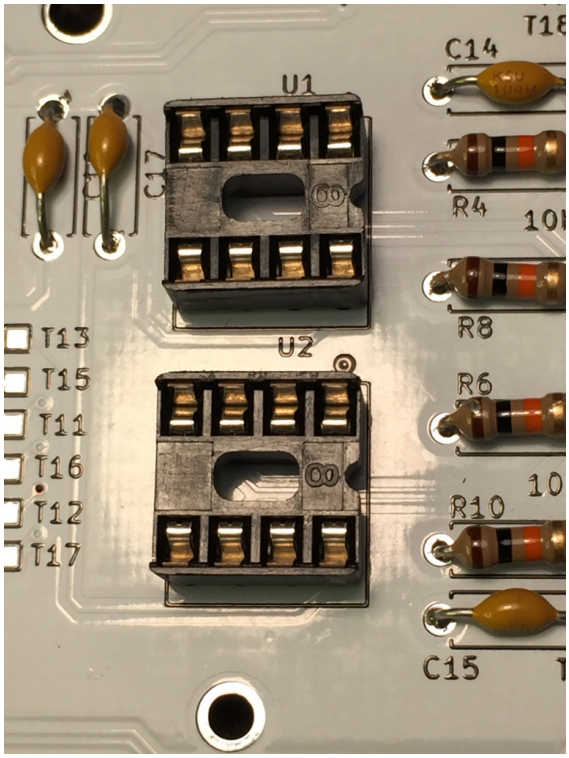


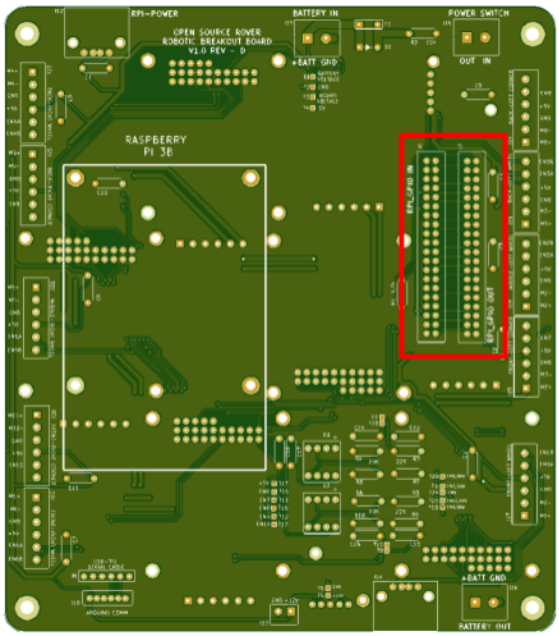
Figure 7: Assembly Step 7

1.1.6 RPi GPIO connector and misc headers

Table 7: Parts/Tools Necessary

Item	Ref	Qty	Image	Item	Ref	Qty	Image
OSR Control Board	E1	1		40 Pin Header connector	E13	2	
40 Position Header Pins	E15	1		6 Position JST Connector	E14	1	
				Soder Iron	N/A		

1. On the **top** of the board, solder the 40-position header connectors **E13**. The clocking notch on the headers should face **OUTWARD** as shown in Figure 7. The schematic reference designators are J6 and J7.



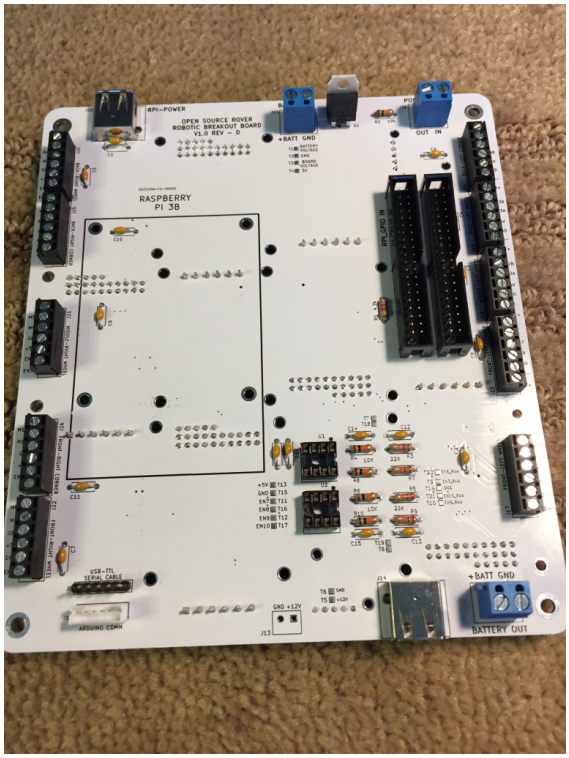


Figure 8: Assembly Step 8

2. Take the 40 pin header pins **E15** and break off a 6-pin segment. On the **top** of the board, solder the 6-pin segment into schematic reference designator J8. Then, solder the JST connector **E14** into the J10 schematic reference designator. The opening in the pins on the JST connector should face **INWARD** as shown in Figure 9.

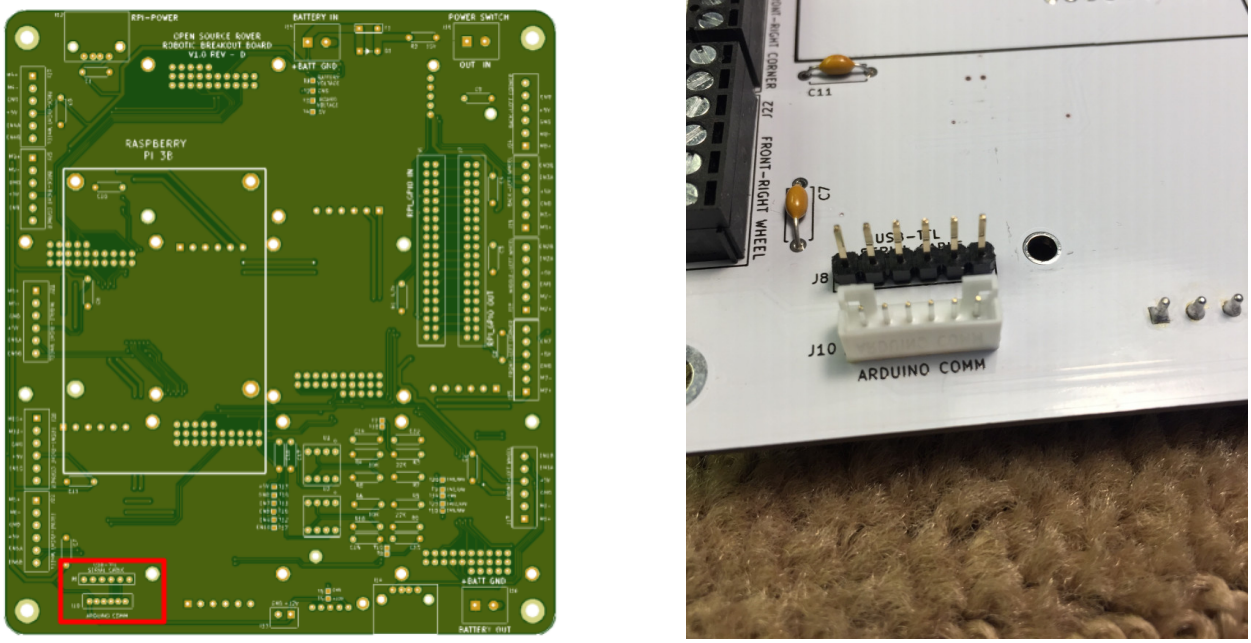


Figure 9: Assembly Step 9

1.1.7 Fuse and Diode

Table 8: Parts/Tools Necessary

Item	Ref	Qty	Image	Item	Ref	Qty	Image
OSR Control Board	E1	1		10 Amp Fuse	E16	1	
Diode	E17	1		Soder Iron	N/A		

1. Solder the fuse **E16** and diode **E17** onto the top of the board into schematic reference designators F1 (fuse) and D1 (diode). **Pay careful attention to the direction that the Diode is mounted on the board**, as it will only work in one direction!

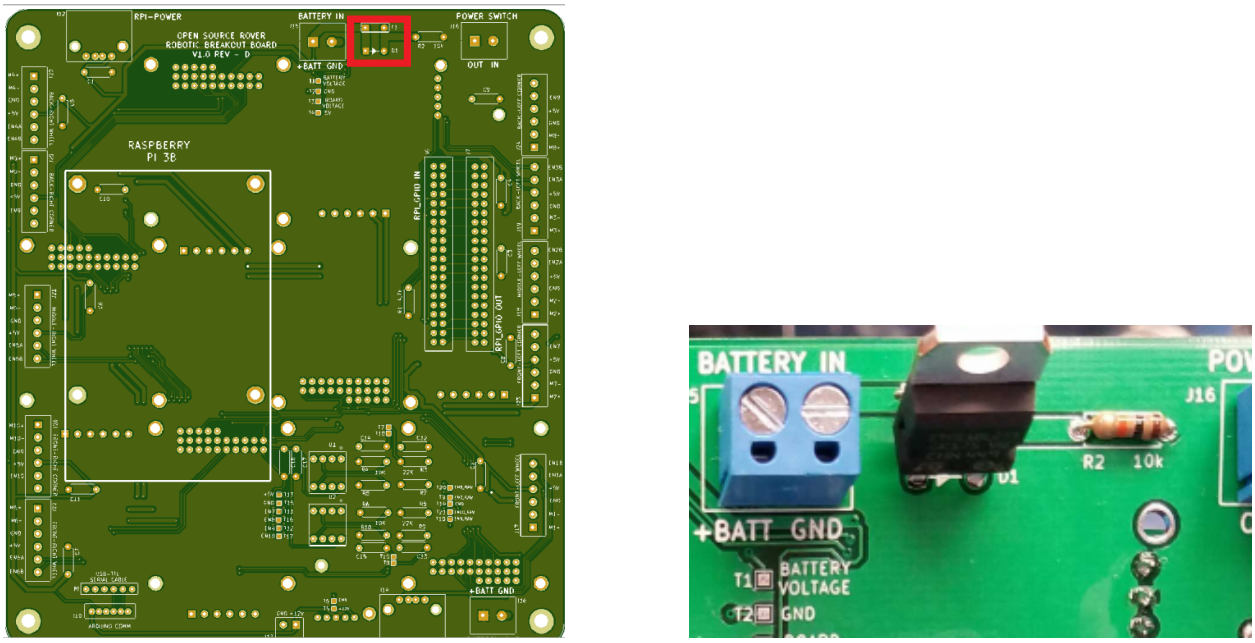


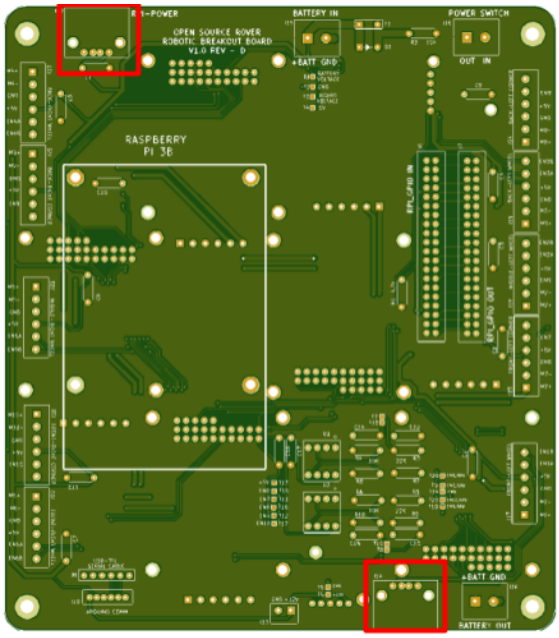
Figure 10: Fuse and Diode Soldering

1.1.8 USB connectors

Table 9: Parts/Tools Necessary

Item	Ref	Qty	Image	Item	Ref	Qty	Image
OSR Control Board	E1	1		USB Connector	E34	2	
				Soder Iron	N/A		

1. On the **top** of the board, solder the two USB Connectors **E34**. They will have reference designators J12 and J14.



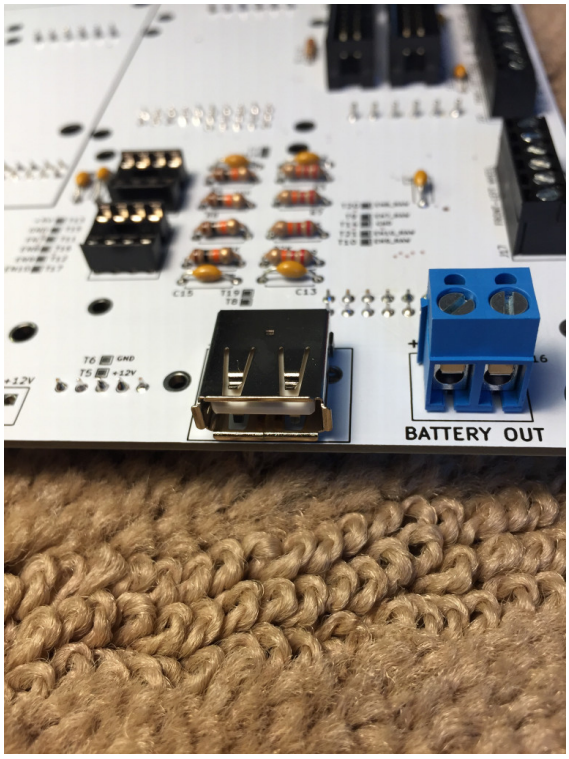


Figure 11: Assembly Step 10

1.1.9 Standoffs

Table 10: Parts/Tools Necessary

Item	Ref	Qty	Image	Item	Ref	Qty	Image
#6-32 x 3/4" Threaded Standoff	T3	4		#4-40 x 1/2 " Threaded Standoff	T11	20	
#2-56 x 1/2" Threaded Standoff	T8	4		M2.5 x 10mm Threaded Standoff	T10	4	
#6-32 3/8" Button Head Screw	B2	8		#4-40 1/4" Button head Screw	B8	40	
#2-56 1/4" Button head Screw	B13	8		M2.5 x 6mm	B10	8	

1. **Board mounting Standoffs:** On the **BOTTOM** side of the board, attach the four #6-32 Standoffs **T4** on the outermost corner four mounting holes using screws **B2**. These standoffs will be used to attach the board to the robot chassis.

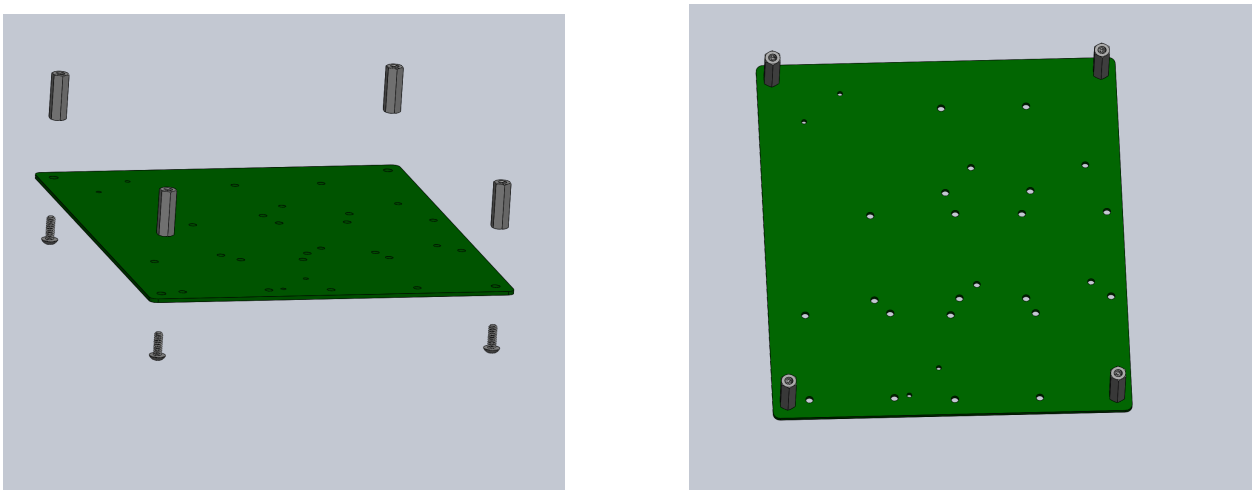


Figure 12: Mounting Standoffs

2. **RoboClaw mounting Standoffs:** On the **BOTTOM** side of the board, attach the twenty #4-40 Standoffs **T5** using screws **B8** as shown in Figure 13. You can identify the RoboClaw mounting holes as the ones that are inside the RoboClaw rectangles on the silk screen.

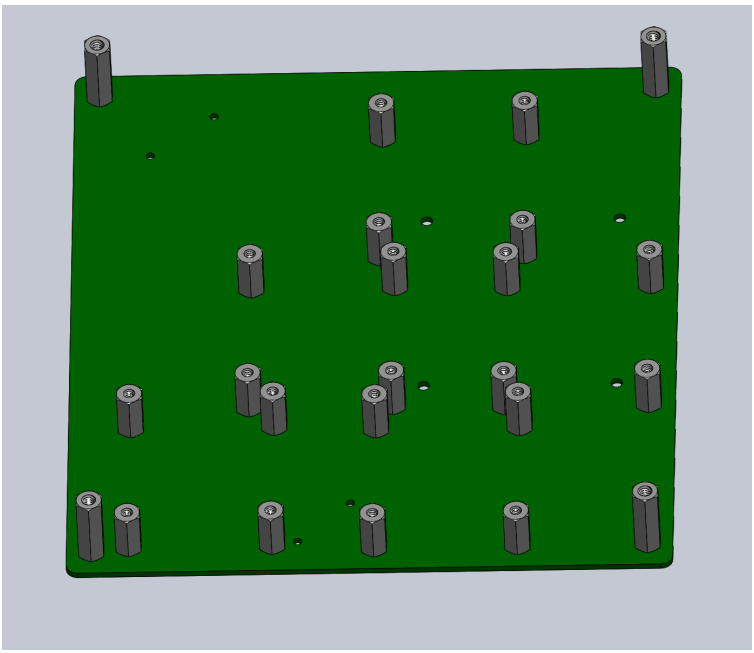


Figure 13: RoboClaw Mounting Standoffs

3. **Voltage Regulator Standoffs:** On the **BOTTOM** side of the board, attach the four #2-56 Standoffs **T6** using screws **B13** as shown in Figure 14.

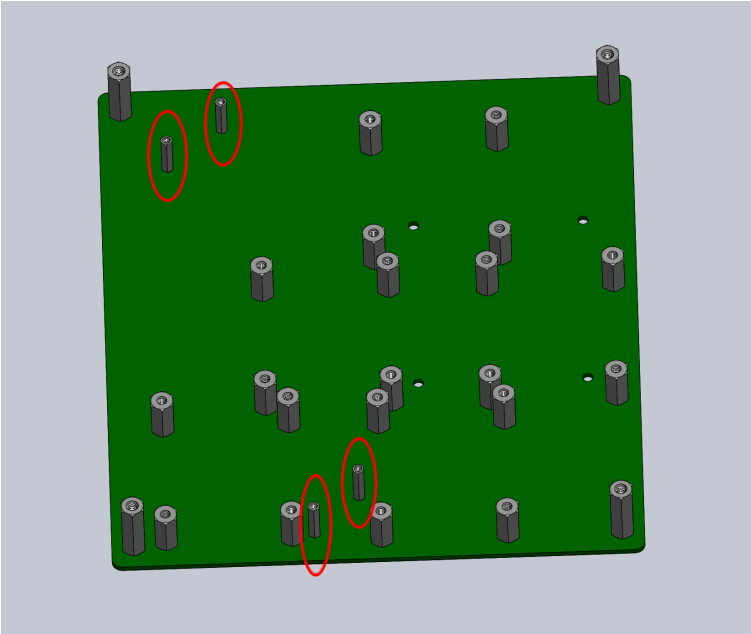


Figure 14: Voltage regulator Mounting Standoffs

4. **Raspberry Pi Standoffs:** On the **TOP** side of the board, attach the four M2.5 Standoffs **T7** using screws **B10** as shown in Figure 15.

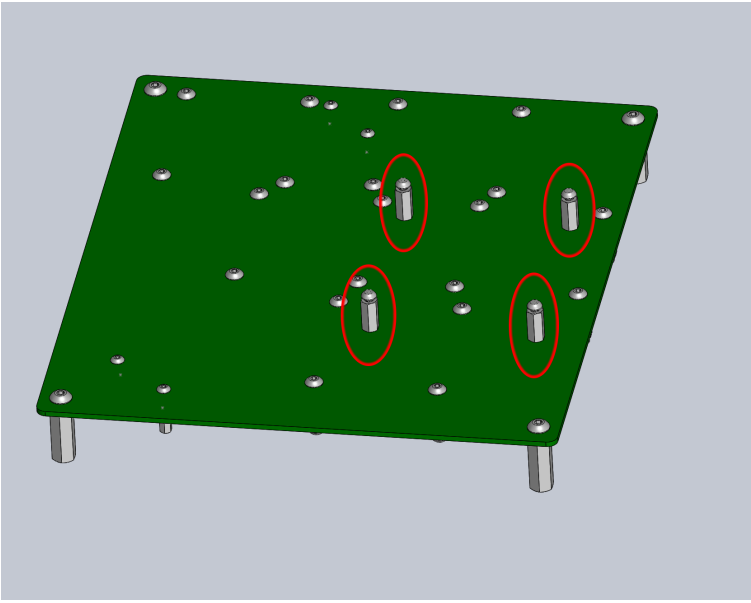


Figure 15: Raspberry Pi Standoffs

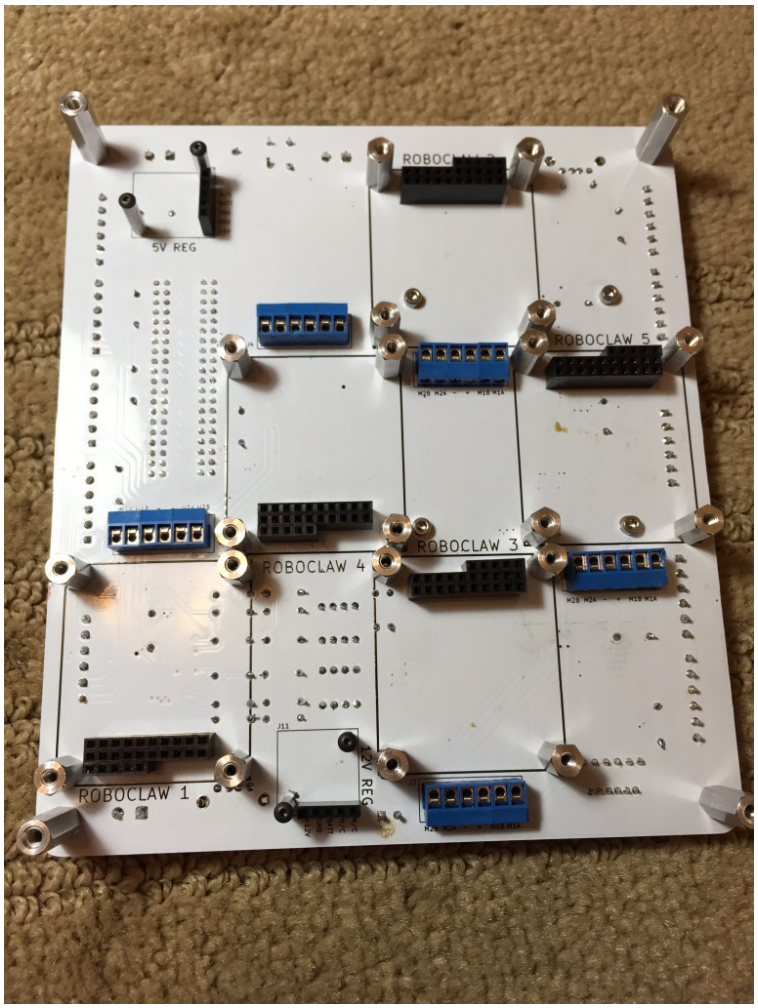
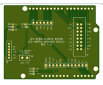


Figure 16: Standoffs Installed (Bottom View)

1.2 Arduino Sheild Assembly

Table 11: Parts/Tools Necessary

Item	Ref	Qty	Image	Item	Ref	Qty	Image
Arduino Sheild	E2	1		2 Position Term Block	E18	1	
2x8 Shrouded Header pins	E19	1		1x6 JST header pins	E14	1	
1x40 0.1 Pitch Header pins	E15	1					

Now, we will assemble the Arduino shield that will sit in the rover's head and control the face. We will start with the **TOP** side of the Arduino board. The final product is shown in Figure 17.

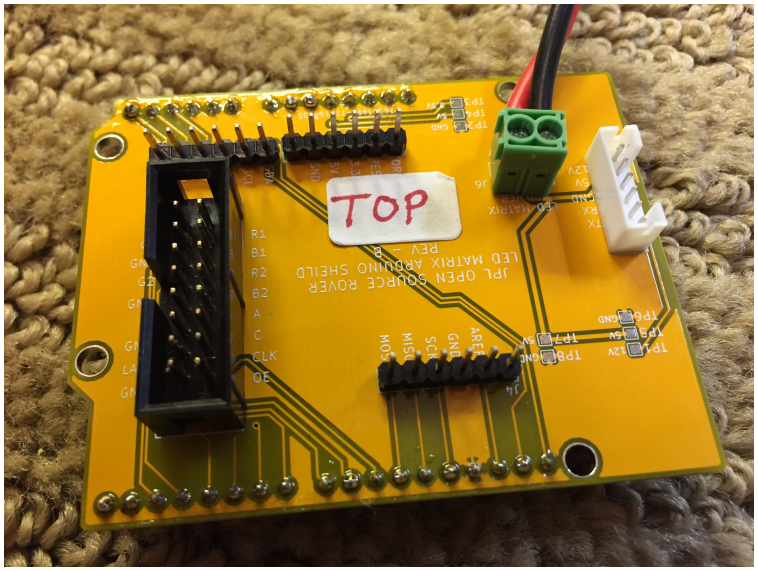


Figure 17: Assembled Arduino Sheild

1. Begin by taking the 2-position terminal block **E18** and soldering it to top of the board at the J6 connector, such that the screw terminals face outwards as shown in Figure 17:

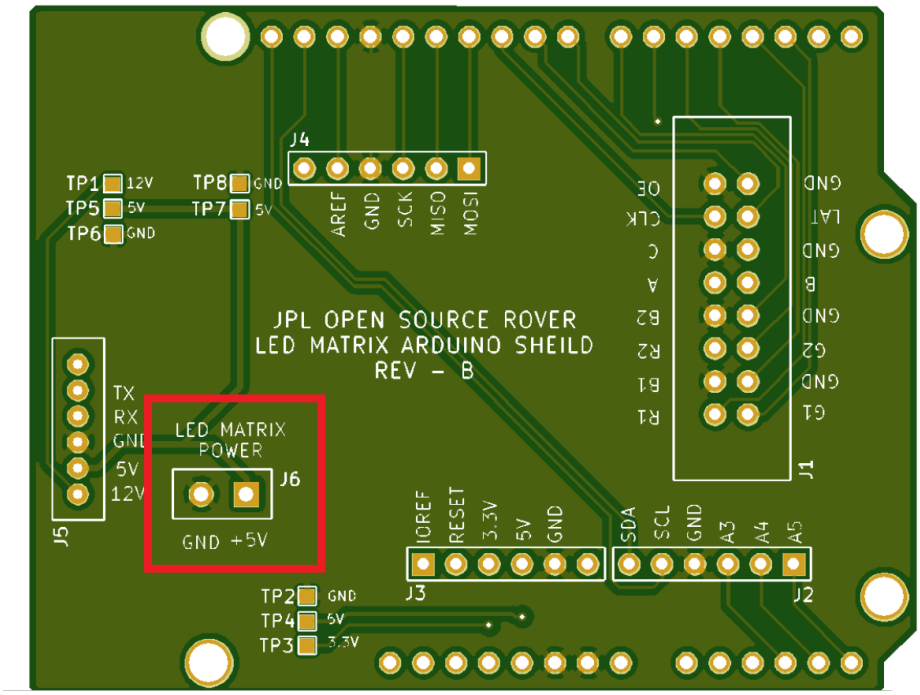


Figure 18: Terminal Block assembly

2. Solder the 1x6 JST connector **E14** onto the top of the board at the J5 connector such that the notch in the connector faces **OUTWARDS** as shown in Figure 17:

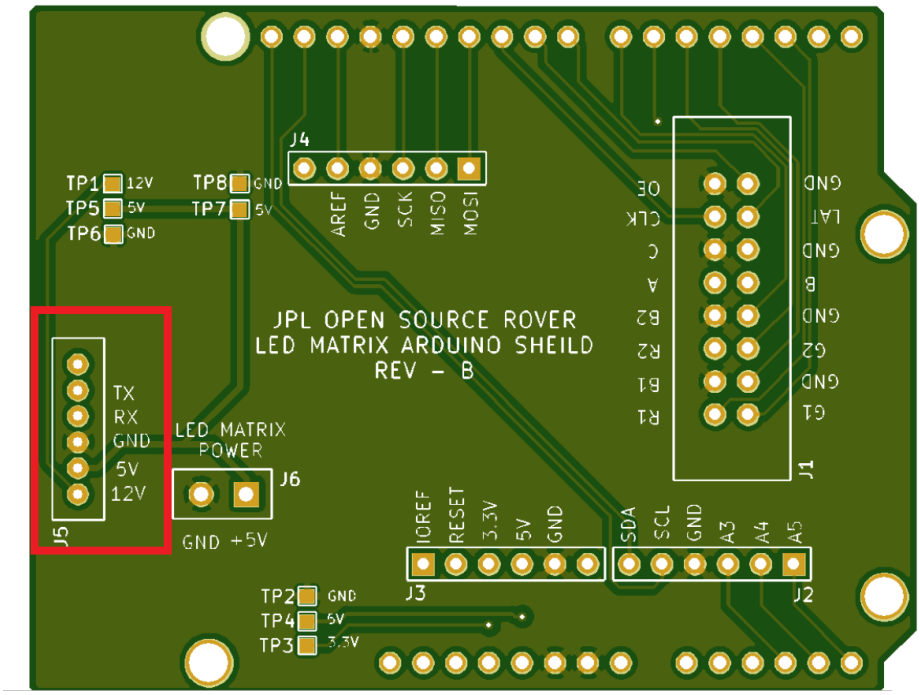


Figure 19: JST assembly

3. Solder the 2x8 shrouded header pin connector **E19** to the top of the board at connector J1 such that the notch faces **OUTWARDS** as shown in Figure 17.

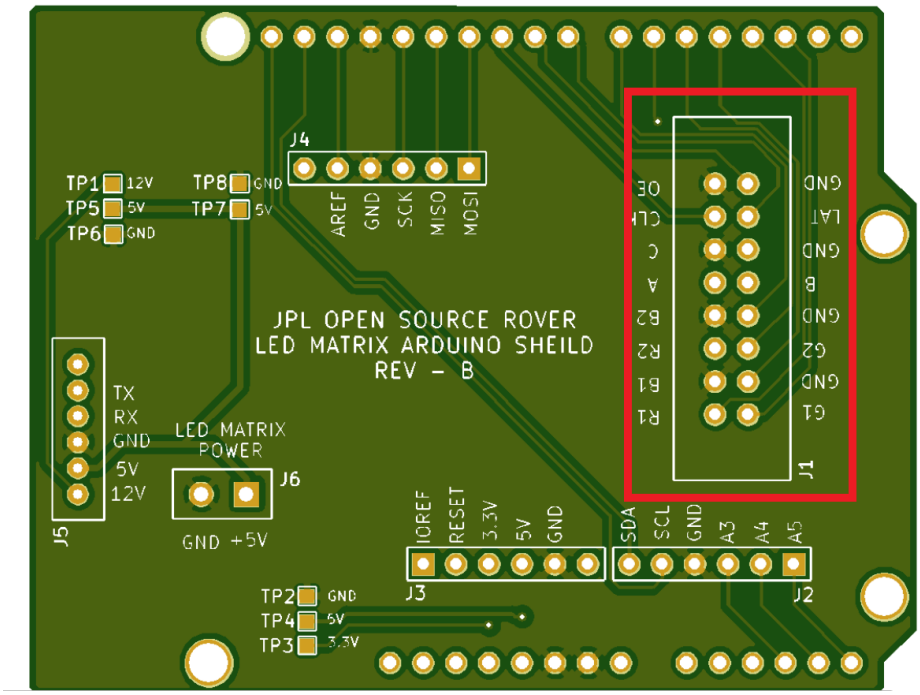


Figure 20: Terminal Block assembly

4. Solder the 0.1 pitch header pins **E15** to connectors J2-4 on the top side of the board:

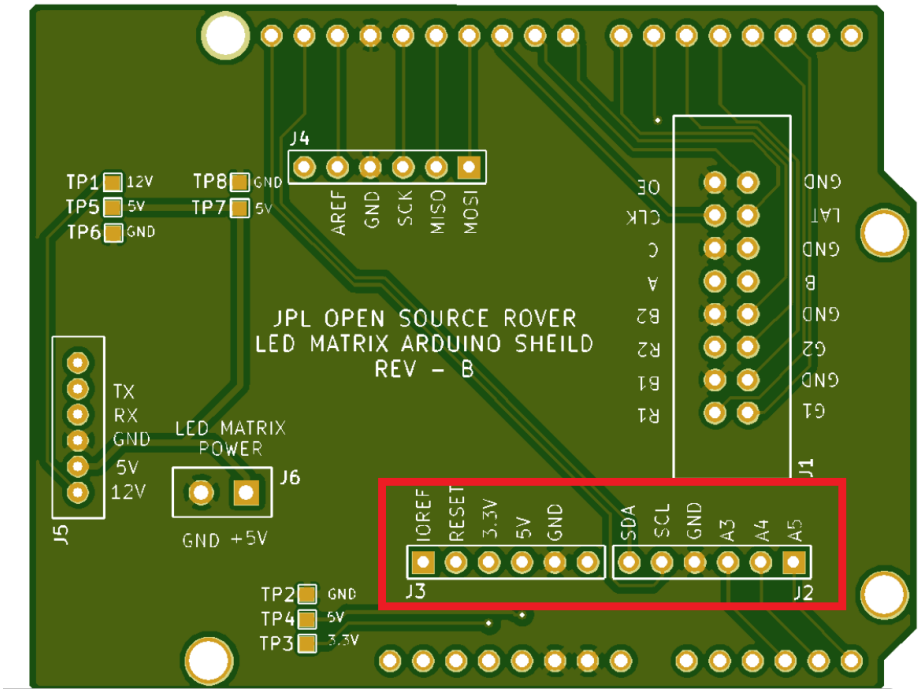


Figure 21: 0.1 Pitch headers

Flip the Arduino board over to the **BOTTOM** side where we will now install the remaining headers. The final product is shown in Figure 23.

5. Solder the 0.1 pitch header pins **E15** to the bottom side of the board in the remaining hole sets.

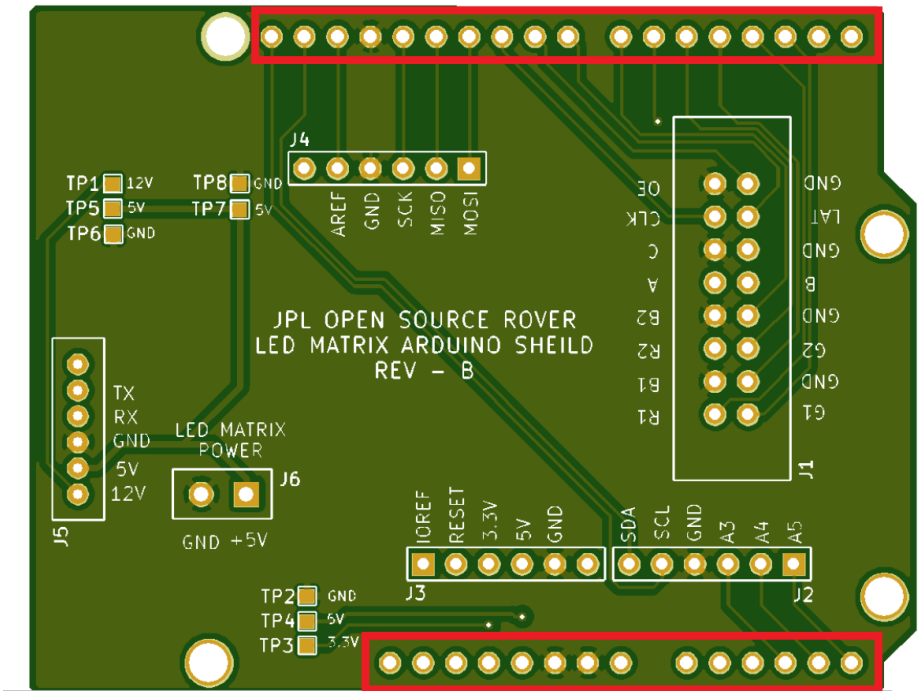


Figure 22: 0.1 Pitch headers

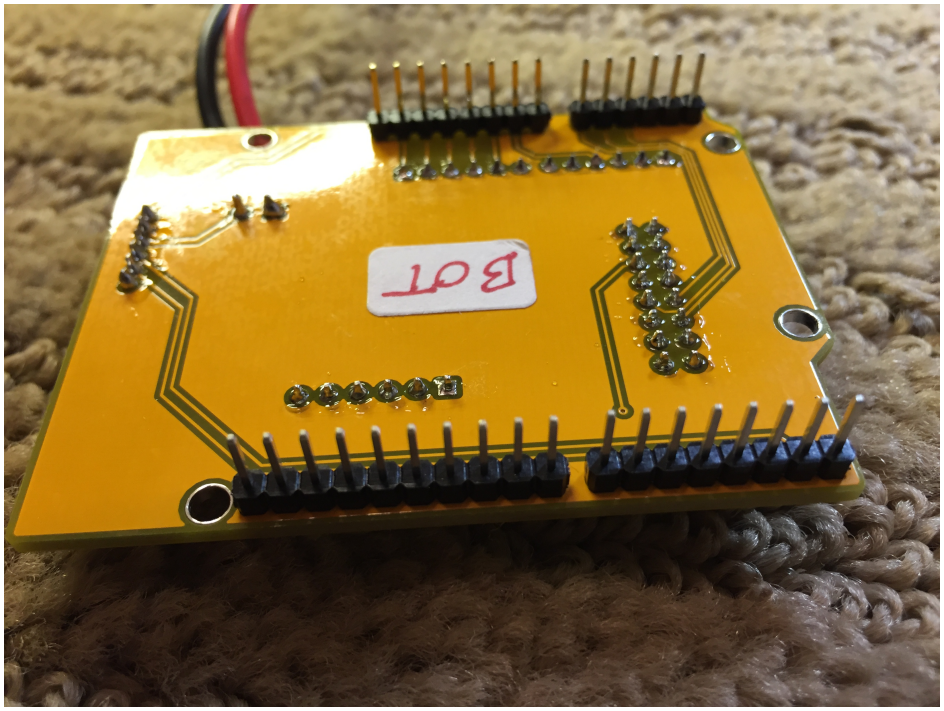


Figure 23: Assembled Arduino Sheild

2 Component Integration and Testing

This next section will go over the process of integrating the electronics onto the Control Board and the testing to verify that the board and components are working as expected at each step. You should perform this section with the board **outside** of the robot chassis in case you need to replace components or fix any mistakes. It is important to do the following steps **one at time** so you can verify that electronics are working as intended. These tests will save you from accidentally breaking one or more of your components if something else is plugged in incorrectly or shorted.

2.1 Testing the Control Board

2.1.1 Power Distribution System

Table 12: Parts/Tools Necessary

Item	Ref	Qty	Image	Item	Ref	Qty	Image
OSR Control Board	E1	1		Battery	E36	1	
Tamiya Battery Connectors	E35	1		Red 20 AWG	X1	1	
Black 20 AWG	X2	1		5V Regulator	E22	1	
12V Regulator	E23	1		RoboClaw Motor Controller	E20	5	
Op-Amp LM358P	E25	2		Micro USB Cable	E28	1	

1. Begin by powering the board. For testing purposes, we will plug the battery directly into the board, bypassing the switch and volt meter. Thus, the connection we use for testing will look a little bit different than when you fully install the board into the rover. Insert the red wire on the Tamiya Battery Connector **E35** into the IN terminal on connector **J16 / POWER SWITCH**, and the black wire to the GND terminal on the connector **J15 / BATTERY IN**.

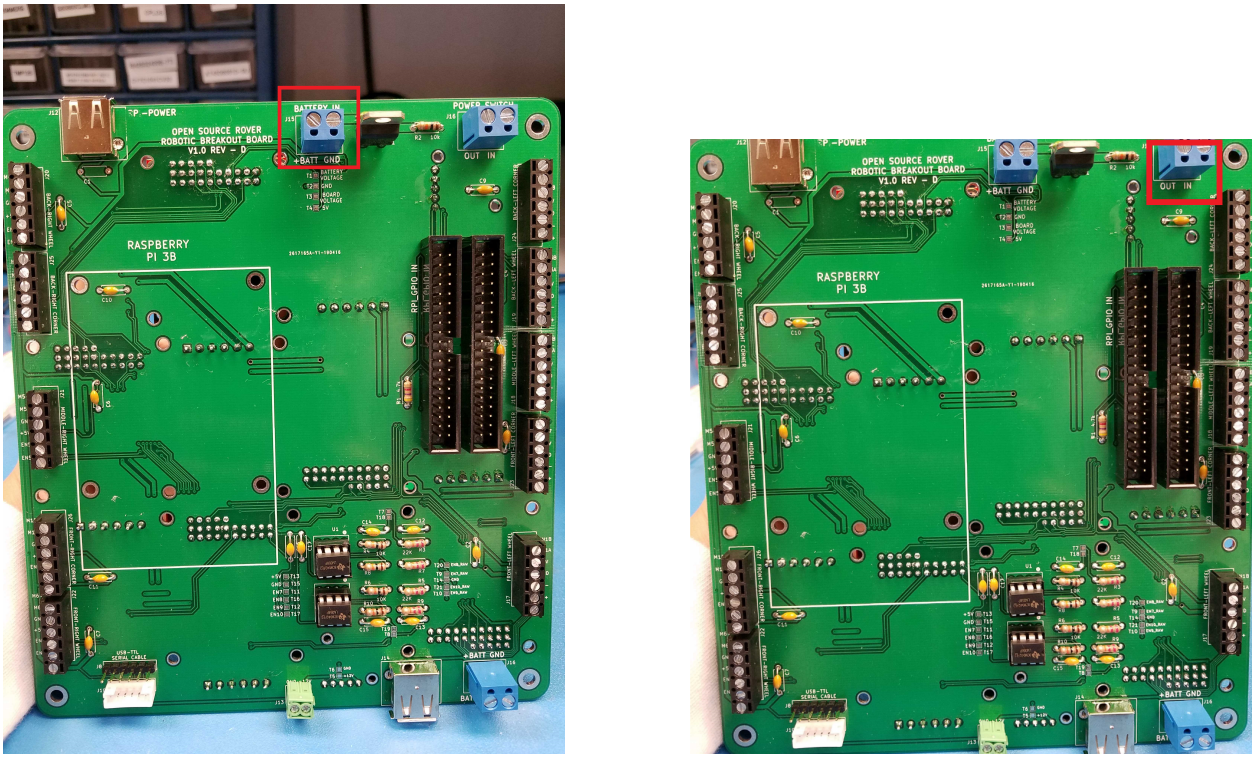


Figure 24: Test Step 1

2. Using a Digital Multimeter (DMM), probe the voltage across the test points T1 and T2. These will tell you the voltage at which the board power rails are, which should be the direct voltage of the battery. Verify that from T1 to T2 reads a positive number, and is between 12V and 16.7V depending on the charge state of your battery.

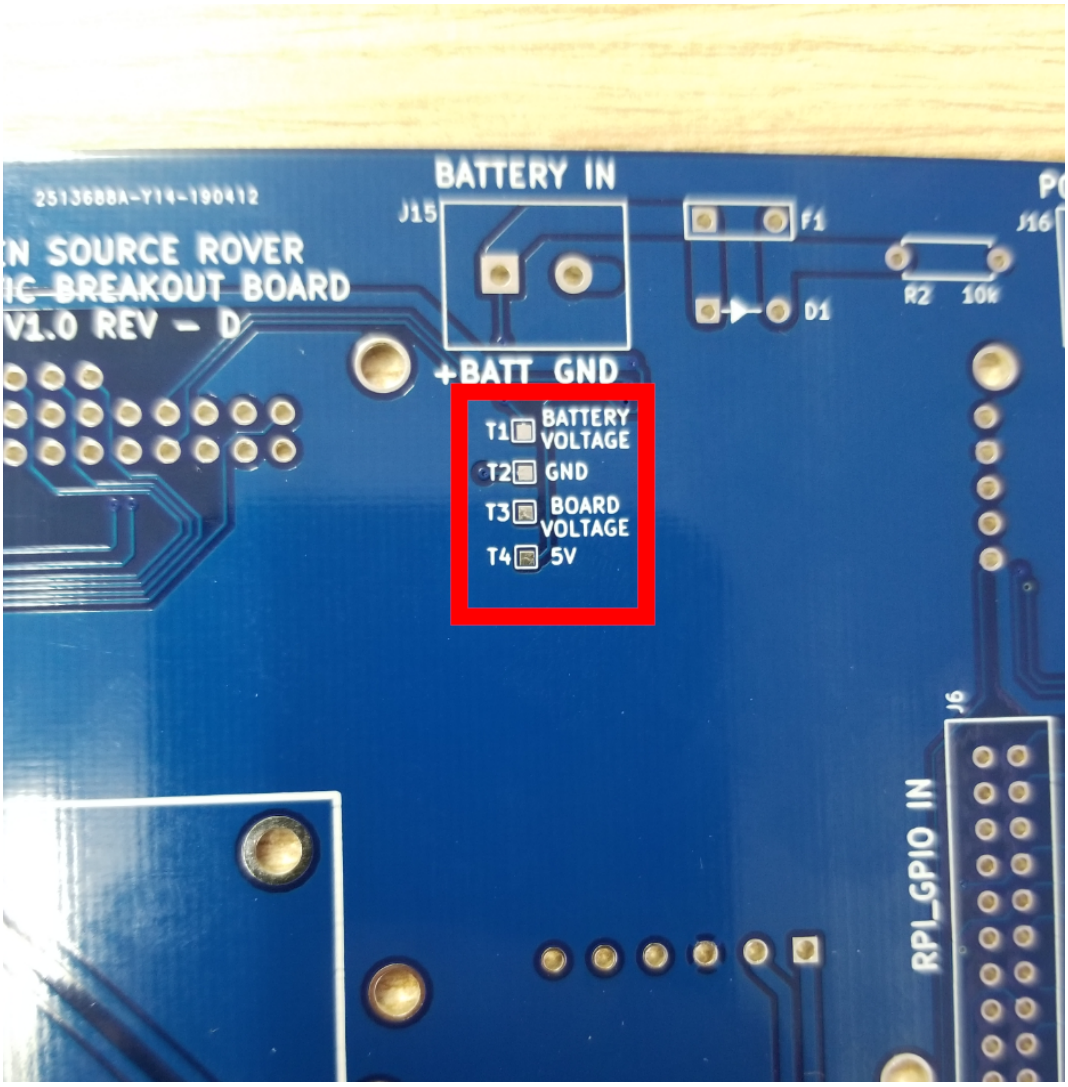


Figure 25: Test pads

3. Next, you will need to create jumper wires that will connect the RoboClaw motor controller power terminals to the RoboClaws. **Unplug the Tamiya battery connector before plugging in or unplugging ANY components, or before inserting components!!!** (in future steps, we will not explicity say to unplug the battery, but **you should disconnect the battery at each step BEFORE inserting components or working on the board!**). Take the red and black 24 AWG wires **W1 and W2** and cut 15 2-inch long segments of each color (you should have 15 red and 15 black pieces). Using wire strippers, strip the ends about 0.1 inches at each end. Insert these jumper wires into the terminal blocks on the RoboClaw Motor Controllers **E20** in the following way:

Table 13: Parts/Tools Necessary

Terminal	Wire Color
M1A	Red
M1B	Black
+	Red
-	Black
M2A	Red
M2B	Black

4. Start by inserting one of the RoboClaws into the slot on the bottom of the board labeled ROBOCLAW 2. Connect the wires directly across from RoboClaw motor terminal block to the terminal block on the control board as shown in Figure 26.

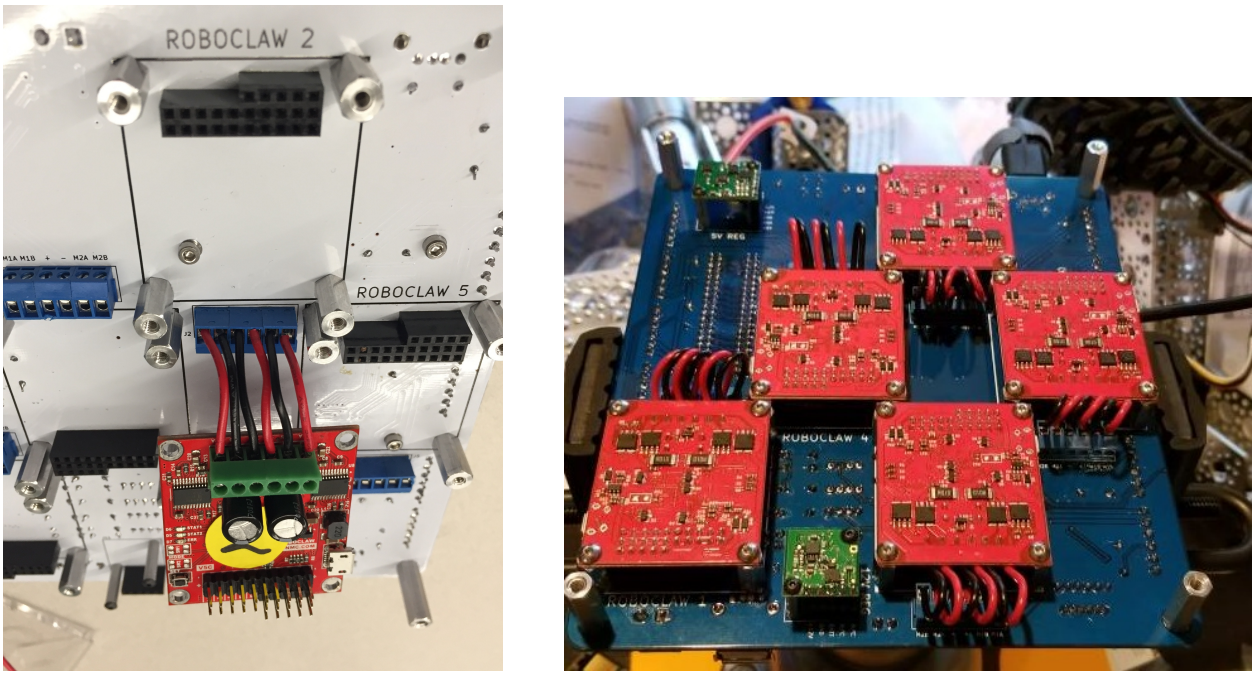


Figure 26: RoboClaw power/motor wires

5. Plug in the battery. An LED on the RoboClaw will turn on; verify that it is green. If the LED is red, it means there is an error. Error codes can be traced by looking at the RoboClaw user manual:

   - https://www.basicmicro.com/downloads

6. Repeat this process one RoboClaw at a time **following the order of 2, 3, 4, 1, 5** (testing each RoboClaw after you plug it in) until all 5 RoboClaws have been plugged into the board.

7. Take the two voltage regulators **E23 and 24** and solder their header pins to the bottom side of the board. Note that you will be soldering the back side of the pins on the top side of the board (the side with large capacitors on it).

8. Insert the 5V regulator into the control board as shown in Figure 27. Power your board and probe between test points T4 and T2 on the top of the board (Figure 27) with your DMM and verify that it reads 5V. If it does not, make sure that the 5V regulator is slotted in properly and that your solder connections are solid.

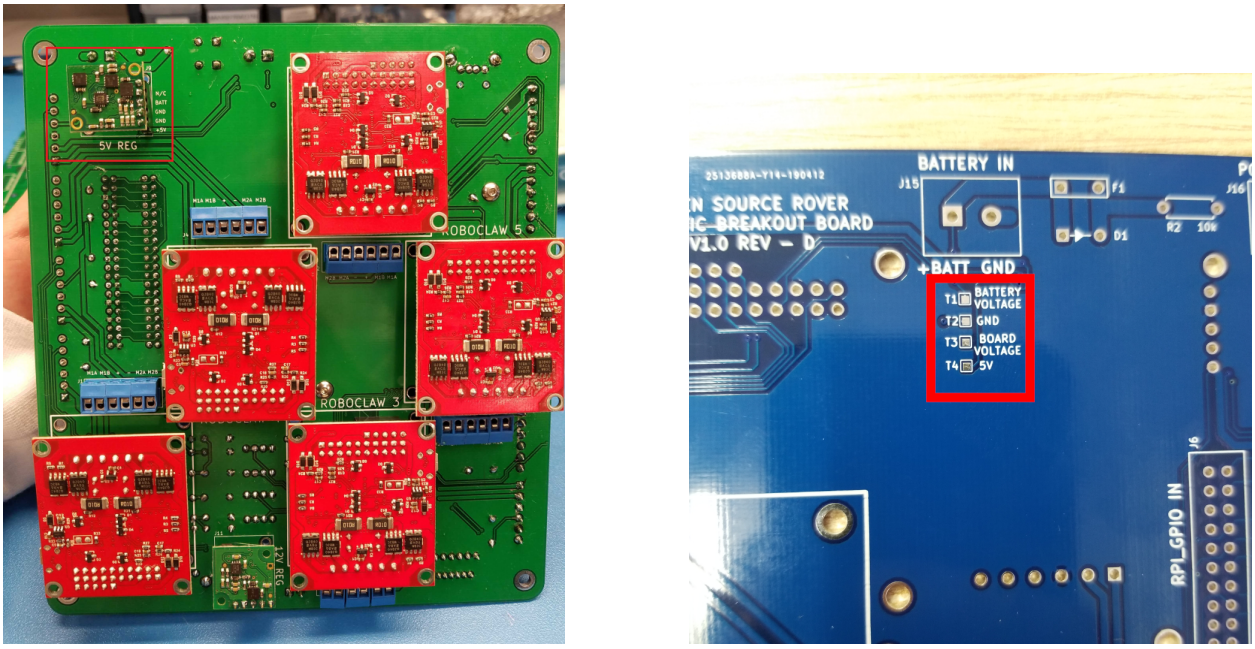


Figure 27: 5V Regulator & Test Pads

9. Insert the 12V regulator into the control board. Power your board and probe between test point T5 and T6 on the top of the board with your DMM and verify that it reads 12V. If it does not, make sure the 12V regulator is slotted in properly and that your solder connections are solid.

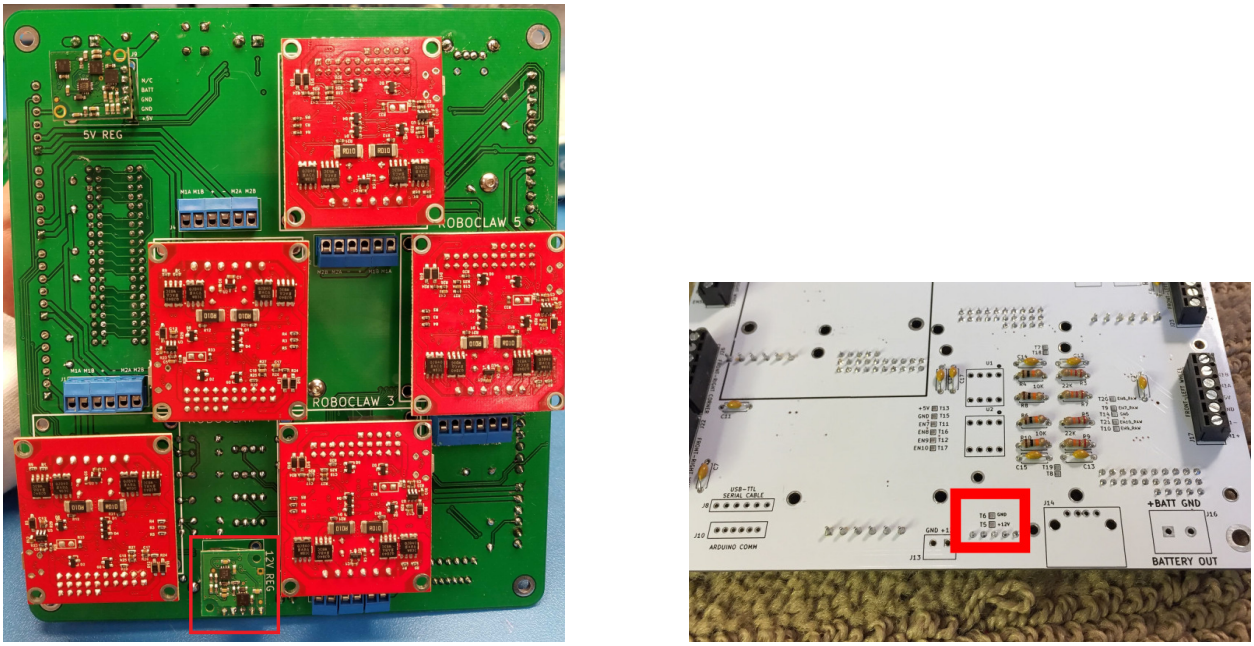


Figure 28: 12V Regulator & Test Pads

If all voltage test points read expected values and all the RoboClaw motor Controllers have green LEDs, the power system has been verified!

2.2 Op-Amp Integration

Press the Op-Amp LM358P **E25** into the slots in the 8 Position DIP socket. Take careful note of the direction of the chip in the DIP socket, as the notch **MUST** face the correct direction.

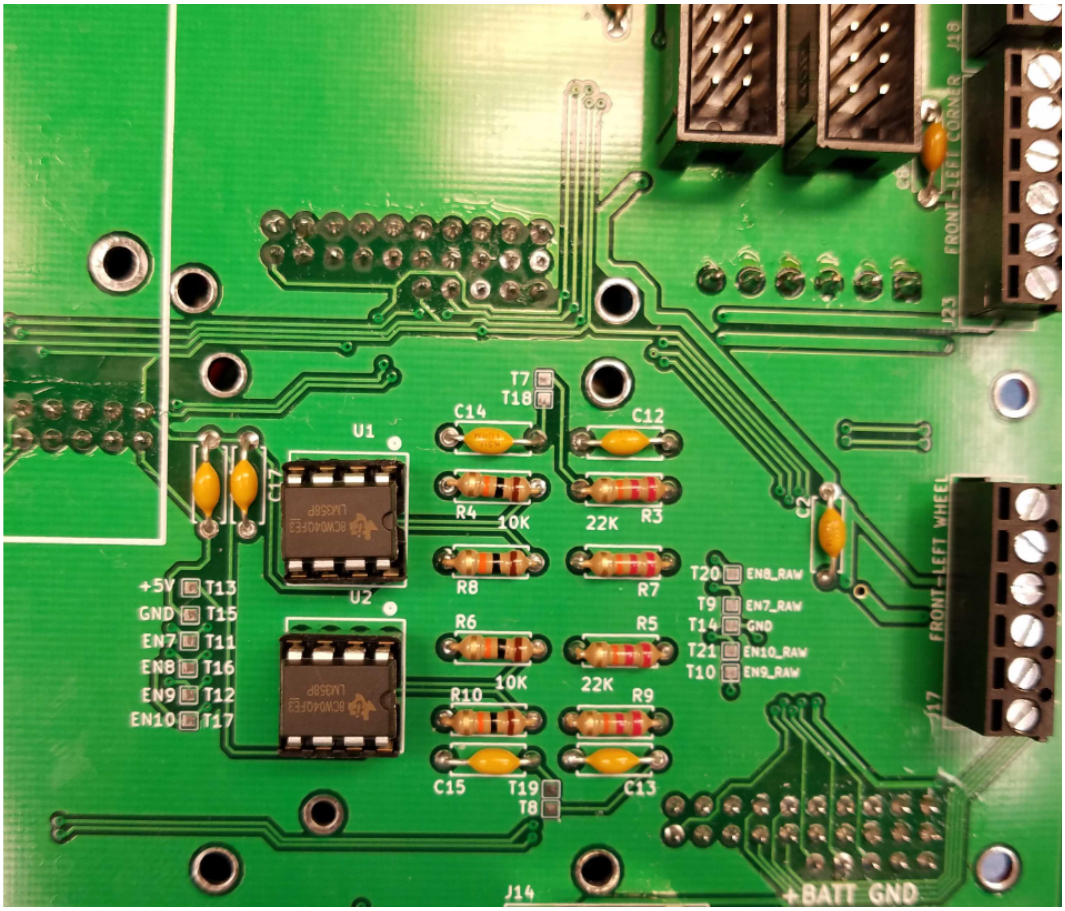


Figure 29: Op-amp integration

2.2.1 Voltage Divider Verification

Now that the Op-amps are installed we want to check and make sure the voltage dividers are working correctly. To do this, we will run power from the motors directly back into the analog read signal, and see what voltage it gets divided down to. On the motor connectors for each corner motor (J23-26), use a jumper wire to connect the 5V signal line to the ENx line. Then, use a DMM to measure the voltage between each of the following test pads and GND and compare the values to the expected voltage ranges in Table 14:

Table 14: Parts/Tools Necessary

Signal	Test Pad	Voltage (to ground, in Volts)
OP amp Power	T13	5
M7 Encoder signal divided	T7	1.5 - 2.0
M7 Encoder raw	T9	5
M7 Encoder after Op-amp	T11	1.5 - 2.0
M8 Encoder signal divided	T18	1.5 - 2.0
M8 Encoder raw	T20	5
M8 Encoder after Op-amp	T16	1.5 - 2.0
M9 Encoder signal divided	T8	1.5 - 2.0
M9 Encoder raw	T10	5
M9 Encoder after Op-amp	T12	1.5 - 2.0
M10 Encoder signal divided	T19	1.5 - 2.0
M10 Encoder raw	T21	5
M10 Encoder after Op-amp	T17	1.5 - 2.0

2.2.2 RoboClaw Testing and Verification

In this section you will be going one by and and testing the operation of the RoboClaw Motor controllers. You will be doing this by using the GUI provided by the manufacturer of the motor contollers. The GUI can be found at the following link, under general downloads, then BasicMicro Motion Studio

- https://www.basicmicro.com/downloads

To use the GUI, insert a USB to micro USB cable from your computer to the motor controller you are going to be testing.

You must now make a temporary connection between the motor controllers and your motors. We found it easiest to test using a set of male-male jumper wires connected between the motor terminal being tested and a test motor.

2.2.3 Drive Motor Blocks

Do each of the steps below for the terminal blocks labeled J17-22; these terminal blocks correspond to the driving motors for the rover. **Make sure that while you are plugging in connections, your board is powered off!** The terminal blocks correspond to the motor controller outputs in the following manner:

Table 15: Parts/Tools Necessary

Terminal Block Label	RoboClaw Board Label	Motor Output Channel
J17	RC1	M1
J18	RC1	M2
J19	RC2	M1
J20	RC2	M2
J21	RC3	M1
J22	RC3	M2

1. First, connect the wires in the following manner:

Table 16: Parts/Tools Necessary

Signal	Terminal Block Label	Motor Connector Wire Color
Motor (+)	M+	Red
Motor (-)	M-	Black
Ground	GND	Green
+5V	+5V	Blue
Encoder A	ENA	Yellow
Encoder B	ENB	White

2. Power on the board. After a minute or so, in the Basic Motion GUI you should see an available device appear. It might require an update to proceed; install the latest firmware update and then connect to the device.

3. Click on the PWM tab. We will now send a PWM signal to the motor and test that connections are all made correctly to the motor and encoder.

4. Slowly move the slide bar for the corresponding motor output channel (Either M1 or M2 from the above table) for the terminal you are testing. Verify that the motor spins (we will worry about direction later), and that the encoder value is also changing (we'll worry about it increasing or decreasing correctly later as well). Switch direction of the slide bar and verify that it spins the other direction and the encoder value does the opposite of previous as well. If these are not happening or are backwards, go back and check that you are using the correct motor controller, terminal block, etc. If all your connections are correct, you may have to test your solder contact between the components on the board itself.

5. Repeat the steps above for each of the drive motor terminal blocks, labeled J17-22.

2.2.4 Corner Motor Blocks

Do the following procedure for the terminal blocks labeled J23-26. These correspond to the corner motors for the rover. Terminal blocks correspond to the motor controller outputs in the following manner:

Table 17: Parts/Tools Necessary

Terminal Block Label	RoboClaw Board Label	Motor Output Channel
J23	RC4	M1
J24	RC4	M2
J25	RC5	M1
J26	RC5	M2

1. Connect the wires to the motor in the following manner

Table 18: Parts/Tools Necessary

Signal	Terminal Block Label	Motor Connector Wire Color
Motor (+)	M+	Red
Motor (-)	M-	Black

2. The main difference between the drive and corner motor systems is that for the corner system, we need to use the encoders. We want to test the voltage division circuit used on the control board; this divider which will expects a 0-5V signal from the absolute Hall effect encoder. To simulate the encoder, connect the +5V terminal on the motor terminal block straight into the ENA signal in the same terminal block.

3. Connect to the motor controller in the Basic Motion GUI. Under the General settings tab (under Encoders), change the type of encoder from Quadrature to Absolute. You should see that the encoder values change to a number somewhere around 1600. As long as it is a fairly constant value and is in the range of 1400-2000 then everything is working. If the value varies wildly or is not in the 1400-2000 range, recheck that the OP-amp is installed in the correct direction. If this number still isn't correct then make sure you correctly installed all the resistors/capacitors in the assembly steps.

4. Under the PWM tab, move the slide bar and verify that the motor spins accordingly.

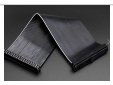
5. Repeat this process for all the corner motor terminal blocks, labeled J23-26.

2.2.5 Raspberry Pi Install

Next up is to verify that power to the Raspberry Pi is working. For this, you'll need a working operating system installed on the SD card. Take a moment now to follow to the Software Install steps to install the rover software on the Raspberry Pi.

https://github.com/nasa-jpl/open-source-rover/blob/master/Software/Software%20Steps.pdf

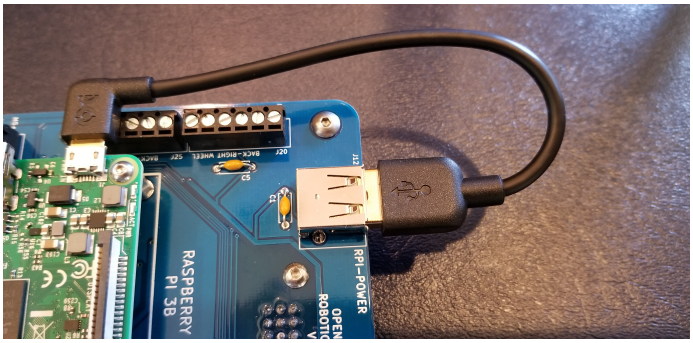
Table 19: Parts/Tools Necessary

Item	Ref	Qty	Image	Item	Ref	Qty	Image
OSR Control Board	E1	1		Raspbery Pi 3B	E21	1	
40 Pin Ribbon Cable	E29	1		USB to Micro USB Cable	E27	1	

ONLY PROCEED WITH THE FOLLOWING ONCE YOU HAVE SUCCESSFULLY FINISHED THE INSTALLATION OF THE ROVER CODE ON YOUR RASPBERRY PI.

1. Attach the Raspberry Pi to the board on top of the standoffs you attached earlier, making sure that the USB ports face downward on the board as shown in Figure 30.

2. Plug in the micro USB cable **E27** to the USB power port labeled J12 and to the **power port** of the Raspberry Pi (labelled 'PWR'). Then, plug in the ribbon Cable **E29** into the Raspberry Pi GPIO header pins and connect the other end to the **J6** 40 pin GPIO connector.



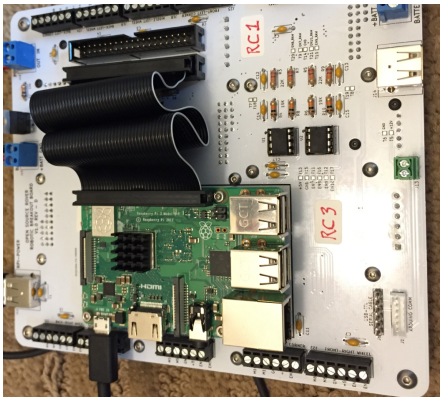
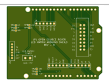


Figure 30: RPi Install

2.3 Arduino Sheild Testing

Table 20: Parts/Tools Necessary

Item	Ref	Qty	Image	Item	Ref	Qty	Image
Arduino Sheild	E2	1		Arduino Uno	E24	1	
1x6 JST Cable	E26	1		16x32 LED Matrix	E37	1	

Note: Testing the arduino board is dependent on finishing the control board and having it tested fully. Do not proceed until you have successfully tested your main control board.

Slot the Arduino Uno onto the bottom of the Arduino shield, matching the footprints on the board.

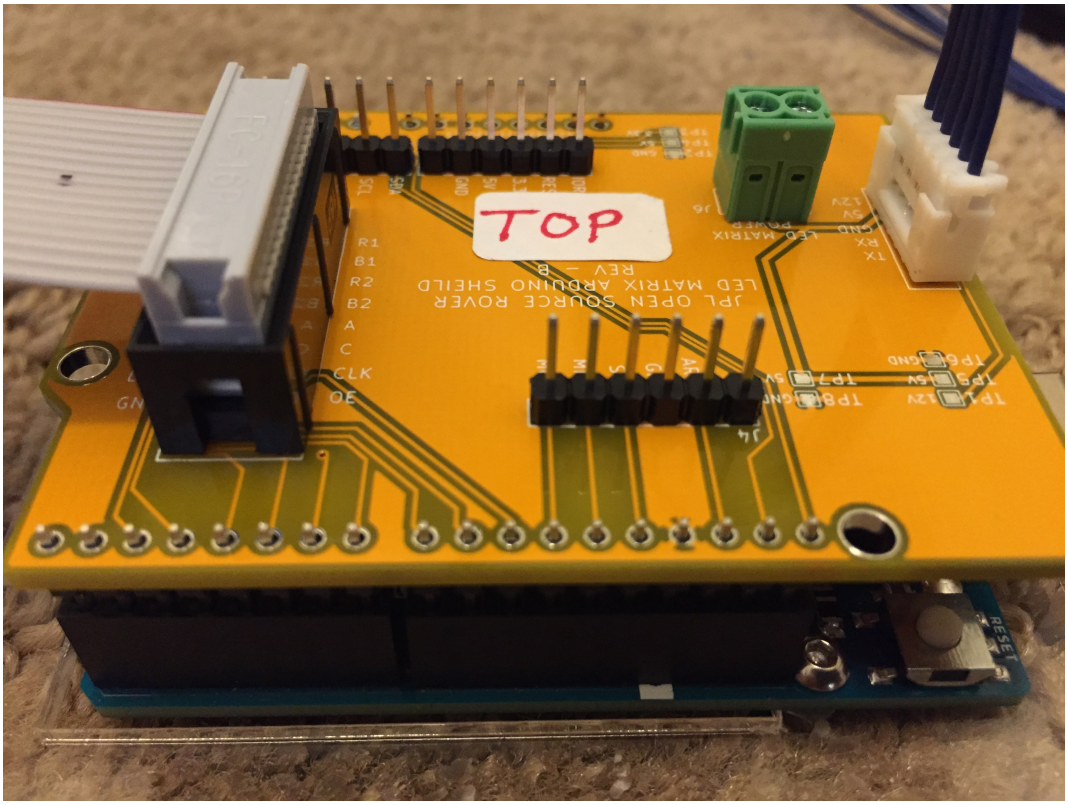


Figure 31: Arduino Sheild Mounted

1. Plug in the 1x6 JST cable **E26** into the Arduino shield and to the Control board. This cable will run 12V, 5V, GND, and two serial communication lines from the main rover to the Arduino shield which runs the screen in the head. This step relies on successful tests of the 5V and 12V regulators on the control board and verifying that they work correctly. If you have not tested the main board

successfully, you may damage the Arduino.

2. Using a Digital Multimeter, probe the following **Arduino shield test pads** and verify their voltages:

   - TP1 to TP6 should read +12V. This voltage powers the Arduino Uno board
   - TP5 to TP6 should read +5V. This voltage powers the LED Matrix and runs the LEDs on it
   - TP4 to TP2 should read +5V. This is the 5V converter on the Arduino board
   - TP3 to TP2 should read +3.3V. This is the 3.3V converter on the Arduino board

If all the above test points read the correct voltages, then the Arduino Sheild board is working correctly! You are now ready to finish the Electrical Assembly of the rover!