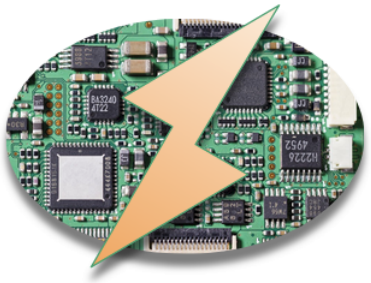
Team 24 - Robo Power



Operating Manual
for
Power Distribution PCB

Team Members

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Github Repository

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Introduction

Our team, Robo Power, was given the task of designing a printed circuit board that operates as a power distribution system for the KORA team's existing Intelligent Ground Vehicle. The purpose of this manual is to inform the KORA team of the uses and functionality of the designed power distribution board so that once we pass off the board they will be able to successfully integrate it into their robot. In this manual, we will define the overall functionality of the board, the roles of the individual subsystems that contribute to the functionality of the board, and how the board should be interfaced with the host robot.

Background

The Kentucky Organization of Robotics and Automation (KORA) is a student organization at the University of Kentucky that designs and develops robots and codes for different competitions around the country. They have decided to participate in the Summer 2022 Intelligent Ground Vehicle Competition (IGVC), a competition that tests autonomous outdoor navigation and obstacle avoidance, and need a suitable power distribution board to properly deliver power to the robot as they currently don't have one. The competition requires an autonomous vehicle to self-navigate an obstacle course while maintaining a minimum speed of one mph and maximum speed of five mph, while remaining within the given track and avoiding the obstacles on the course. All vehicles that participate are ranked by judges based on the completion time around the track and safety elements, such as emergency stop methods, voltage and current regulation, and speed adjustment based on object detection.

Functionality

1. *Overall system*

The designed PCB has seven power rails in total that provide specific regulated outputs to the host robot. There are also current and voltage monitoring hardware that is used to measure each power rail. These measured current and voltage values are displayed on diagnostic displays and other feedback indicators, as well as the temperature of the system measured through the temperature monitoring system. The board also has a wireless and physical emergency stop in case of emergency.

General operation

2. *Communicating with Host*

Given on the top right of the PCB are two I2C connectors that can be used to communicate with the Teensy 4.1 microcontroller. They include 4.7kΩ pull-up resistors at 3.3V logic. Also included is one SPI port. This is normally reserved for the wireless receiver but if the wireless receiver is removed or is not needed then this port can be utilized.

3. *Power Rails and Overcurrent Protection*

There are two 3.3V rails at 500mA, three 5V rails at 5A, two screw terminals and one barrel jack with the sleeve as the ground, and two 1.25-12V variable rails at 1A. To change the voltage of the variable supplies two feedback knobs are located on the top of the enclosure which vary the output voltage when turned.

The 3.3V and 5V buck converters include overcurrent and short circuit protection. The 1.25-12V rails include an over current protection scheme that utilizes the current monitoring system and a relay to open the connection when overcurrent is detected and stays off until the external push button, located at the top of the enclosure, is held for approximately 1 second. This will reset the relay and reconnect the load to the converter. DO NOT HOLD THE BUTTON IF AN OVERCURRENT CONDITION PERSIST. This will cause damage to internal and external components. If an overcurrent condition occurs, safely remove the load from the screw terminals and then reset the relay with the pushbutton.

4. Voltage/ Current Monitoring Systems / LEDs / Oled Displays

4.1 Voltage / Current Monitoring System

The voltage and current monitoring hardware will be used to measure the voltage and current of each power rail and send this data to the microcontroller that has an onboard ADC (analog to digital converter) to calculate values of voltage and current and send this to the diagnostic displays. The data collected from the current monitoring hardware is also used to trigger the overcurrent protection of the 1.25-12V power rail.

4.2 LEDs

The RGB LEDs serve as a feedback system for the operators. The LED strip consists of fourteen WS2812 LED bulbs where every two bulbs represent one power rail: bulbs 0 and 1 are for the first 3.3V rail at 0.5A, bulbs 2 and 3 are for the first 5V rail at 5A, bulbs 4 and 5 are for the first 1.25-12V rail at 1A, bulbs 6 and 7 are for the second 3.3V rail at 0.5A, bulbs 8 and 9 are for the second 5V rail at 5A, bulbs 10 and 11 are for the second variable voltage rail 1.25-12V at 1A, and bulbs 12 and 13 are for the third 5V at 5A rail. The first bulb for each rail represents the measured voltage, the second bulb represents the measured current. The color of the bulbs will represent the following: green means that the measured voltage or current is within five percent of the required value for that rail, red means that the measured voltage or current is above five percent of the required value for that rail, and blue means that the voltage is below five percent of the required value (note that current measurement bulbs should never turn blue). The LEDs will turn white when the measured value is zero.

4.3 OLEDs

There are three OLED displays that are used to display the measured values from the current and voltage monitoring system of the different power rails. The OLED displays are also used to display the measured temperatures from the two temperature sensors. These displays use an I2C multiplexor that communicates with the microcontroller where the screens are updated as the microcontroller receives new measurements.

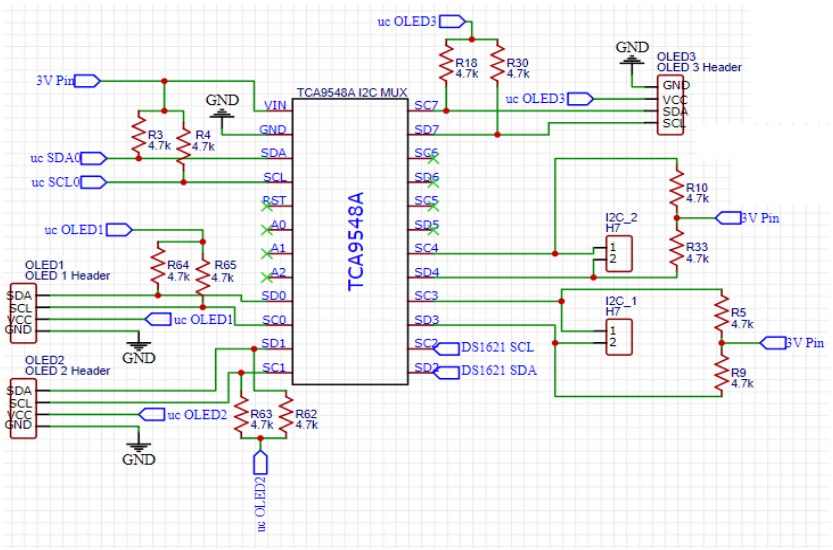

Figure 1: OLED Displays Schematic

5. *Temperature System / Beeper / Fan*

The temperature monitoring system consists of two temperature sensors, a cooling fan, and a beeper. One of the temperature sensors is the DS18B20 which is used to measure the ambient temperature inside the enclosure. The second temperature sensor is the DS1621 in the surface mount package to measure the temperature of the board. These sensors are continuously measuring the temperature and sending the measured values to the microcontroller where it is determined if the board temperature is getting too hot. If the micro determines that the system is getting too hot, it will activate the beeper to turn on. There will be a warning beep at 70C, a second warning beep at 75C, and then continuous beeping at 80C. This will alert the users that the board is getting too hot and gives the users a chance to power down the robot to prevent the system from overheating. This maximum operating temperature of our PCB was determined by finding the lowest maximum operating temperature of the components on the board.

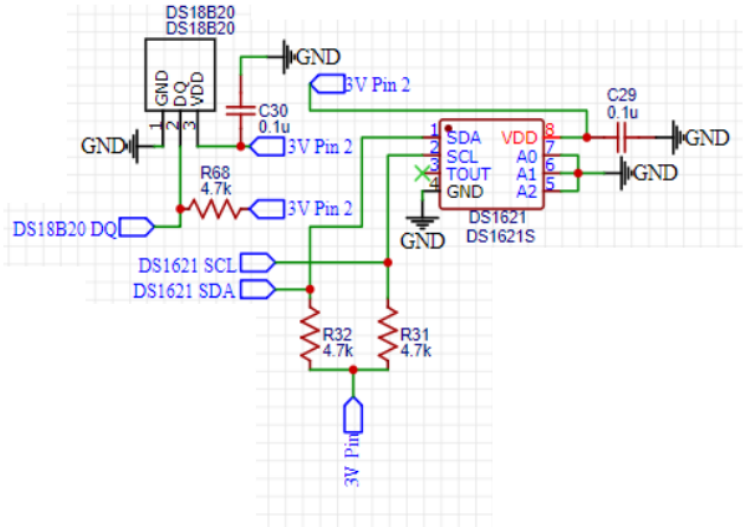

Figure 2: Temperature Sensor Schematic

The fan is a 12V fan that will be turned on once power to the board is activated. It will remain on until the board is powered off, and will aid in keeping the components cool.

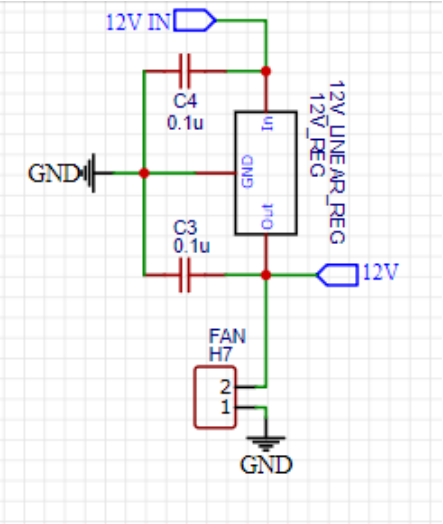

Figure 3: Fan Schematic

6. *E Stop (wireless and physical)*

6.1 Physical

The physical emergency stop button consists of an HW1X-BV402-R emergency stop mushroom button. Pressing this button electrically disconnects the battery from all components on the PCB including any attached loads. The button operates by locking when pushed. To reset just twist the button until it pops up.

6.2 Wireless E Stop

The wireless emergency stop utilizes a receiver antenna which is linked to the transmitter remote. When the Set button is pressed it switches the relay off and electrically disconnects the battery from the rest of the PCB. The Reset button resets the relay.

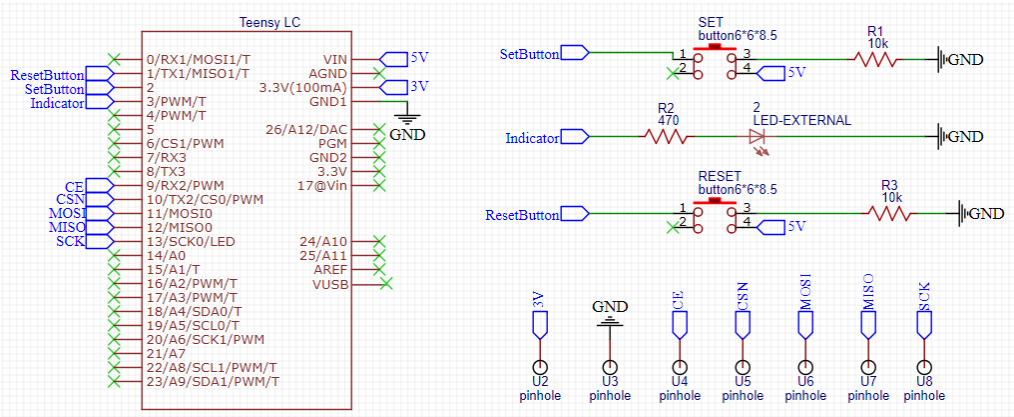

Figure 4: Wireless E-stop Schematic

7. Enclosure

The enclosure for the PCB is 3D printed to be 8” x 6” x 3” with mounting brackets on the bottom bottom for 7” x 5” or smaller PCBs. There are slits on the sides and the middle sections to enable airflow into the enclosure as well as allow for wire routing around the bottom on all sides. On the top of the enclosure, there are mounting holes for the fan, potentiometer, and the circuit reset switch. There are also mounting holes on the bottom to mount to the robot. The CAD files for the enclosure are given in the github link.

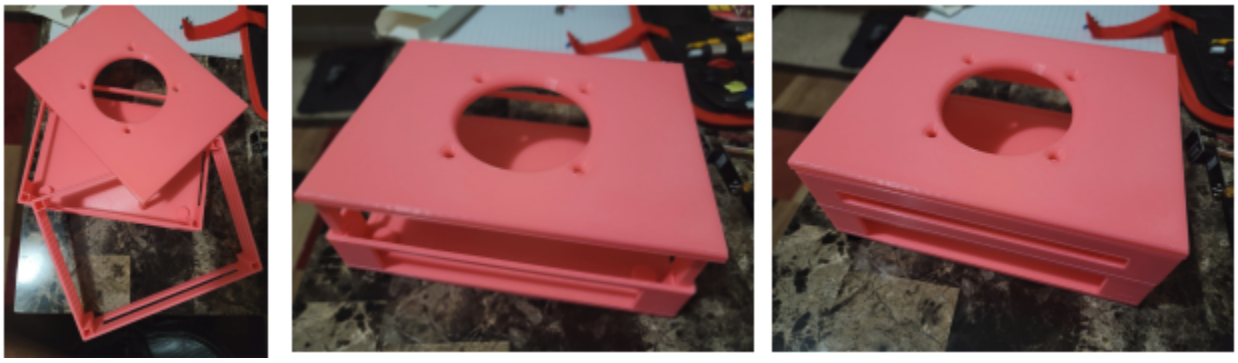

Figure 5: Enclosure

8. PCB

Given below are 3D models of the front and back of the PCB. Every part is labeled on the PCB. Most of the space is taken up by the voltage regulators which are located on the bottom, the bottom left, and the bottom right. The I2C connections are located at the top right of the PCB. The battery screw terminals are located at the top right of the board. The microcontroller is powered with a live and ground only micro USB cable to improve the stability of the power supply for the ADC since the Teensy 4.1 does not have a dedicated voltage reference for the ADC. The schematic for the overall design is given in the github link. The Gerber files for the PCB are also given in the github link.

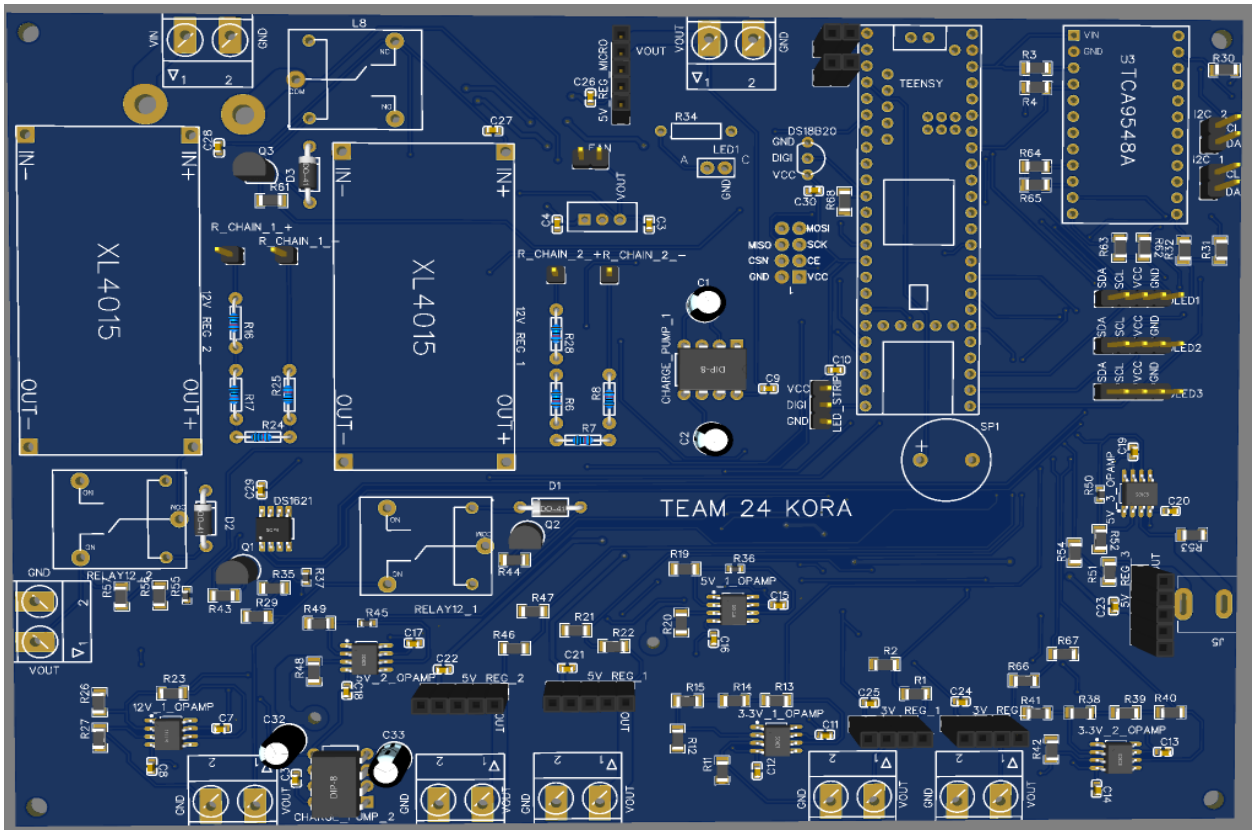

Figure 6: Front of the PCB

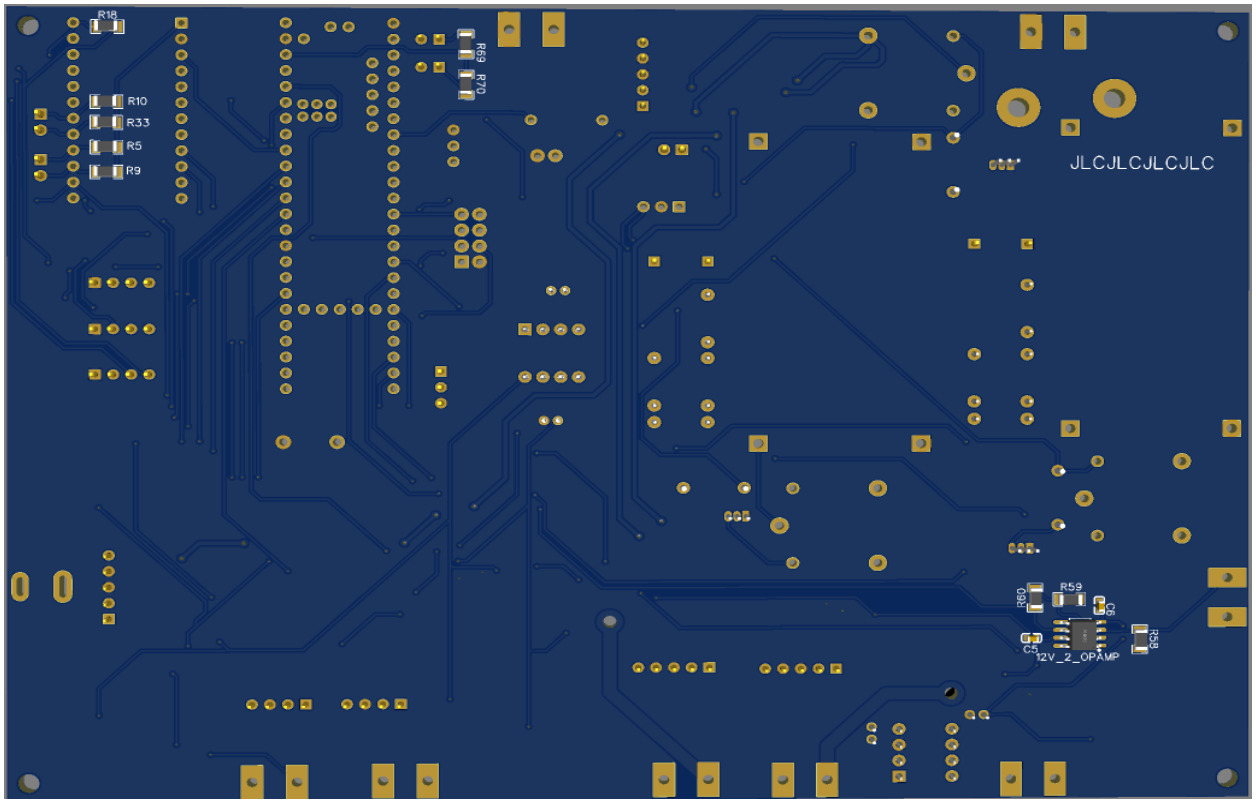

Figure 7: Back of the PCB

9. *Code*

9.1 Overview

Overall, the main code is C++ and uses the Arduino IDE with the Teensyduino add-on for the IDE to be able to connect and compile code to the Teensy 4.1. It includes several functions which are used to take analog reading, communicate with onboard sensors, and display measured values. Given below is the list of all functions and their general purpose.

9.2 TCA9548A

This function's main purpose is for the I2C multiplexor. It accepts a number between 0 and 7 and will set up a communication line to the port with that number. For more information on the I2C multiplexor and its code please visit this website for more details.

9.3 Setup

The setup function includes lines to start communications between different sensors and subsystems to the microcontroller. It also includes lines to set input and output pins for all functions.

9.4 Loop

The main purpose of this function is to call the other functions and execute them while continuously looping until power is turned off. If new functions are added to the program then they should be called here.

9.5 readVoltage

The function readVoltage is a function that will read the voltage at an analog pin and return the voltage of the load. It has inputs of pinNum, the analog pin we want to read, R1, the first resistor in the voltage divider network, and R2, the second resistor in the voltage divider network. More information about the voltage monitoring hardware is provided in the voltage/current monitoring system section.

9.6 readCurrent

The function readCurrent is a function that will read the voltage at an analog pin and return the current of the load. It has inputs of pinNum, the analog pin we want to read, R_shunt, the shunt resistor we are reading the voltage of, R1 and R2, the resistor that make up the network for the gain of the Op amp, and a voltage that is there to set the current to zero if the voltage of that bus is zero. More information about the voltage monitoring hardware is provided in the voltage/current monitoring system section.

9.7 display_1

The function display_1 is a function that displays the currents and voltages of the first three power rails and displays them on the first OLED display which is connected to port 0 of the I2C multiplexor. More information about the OLEDs are provided in the OLED displays section.

9.8 display_2

The function display_2 is a function that displays the currents and voltages of the last four power rails and displays them on the second OLED display which is connected to port 1 of the I2C multiplexor. More information about the OLEDs are provided in the OLED displays section.

9.9 display_3Temp

The function display_3Temp is a function that displays the measured temperatures on the third OLED display which is connected to port 7 of the I2C multiplexor. More information about the OLEDs are provided in the OLED displays section.

9.10 LEDs and LEDs2

These two functions are used to change the colors of the LEDs based on the voltage and current of the individual buses. More information about how they work is provided in the LEDs section.

9.11 sensor1

Function for the ambient temperature sensor that returns the temperature as a float when called. Gives the temperature in celsius. More information about the sensor can be found in the temperature system/beeper/fan section.

9.12 sensor2

Function for the onboard temperature sensor that returns the temperature in celsius as a float when called. It uses the I2C multiplexor port 2. More information about the sensor can be found in the temperature system/beeper/fan section.

9.13 warning_One, warning_Two, and Continuous

Functions that trigger the onboard speaker once when the temperature of the system surpasses 70 C for the first function, 75 C for the second function, and continuously beeps when the system surpasses 80 C. These limits can be changed in the code. More information about the speaker can be found in the temperature system/beeper/fan section.

9.14 latch and latch2

Functions that control the overcurrent relays of the 1.25-12V buck convertors. When the system detects that the current of a rail is over 1 amp and switches the relay to the normal open pin. The function then keeps the relay switched until an external push button is pressed which resets it. More information about the push button and overcurrent protection is given in the power rails and overcurrent protection section.

10. Potential Improvements

Given in these section is a list of potential improvements that can be added to make the system more accurate and easier to use.

- The main code could be heavily optimized.

- Improvements include making the overcurrent protection function, latch and latch2, as interrupts to improve response of the overcurrent protection.
- Configuring the analog to digital converter to run faster.
- Temperature sensors could be optimized to show more digits and accuracy could be improved.

- Addition of low pass filters to outputs of each Op amp to improve analog readings.
- Control system for fan.

11. Subsystem Schematics

Given in this section are the schematics for each of the individual subsystems. The schematic for the overall design is given in the github link.

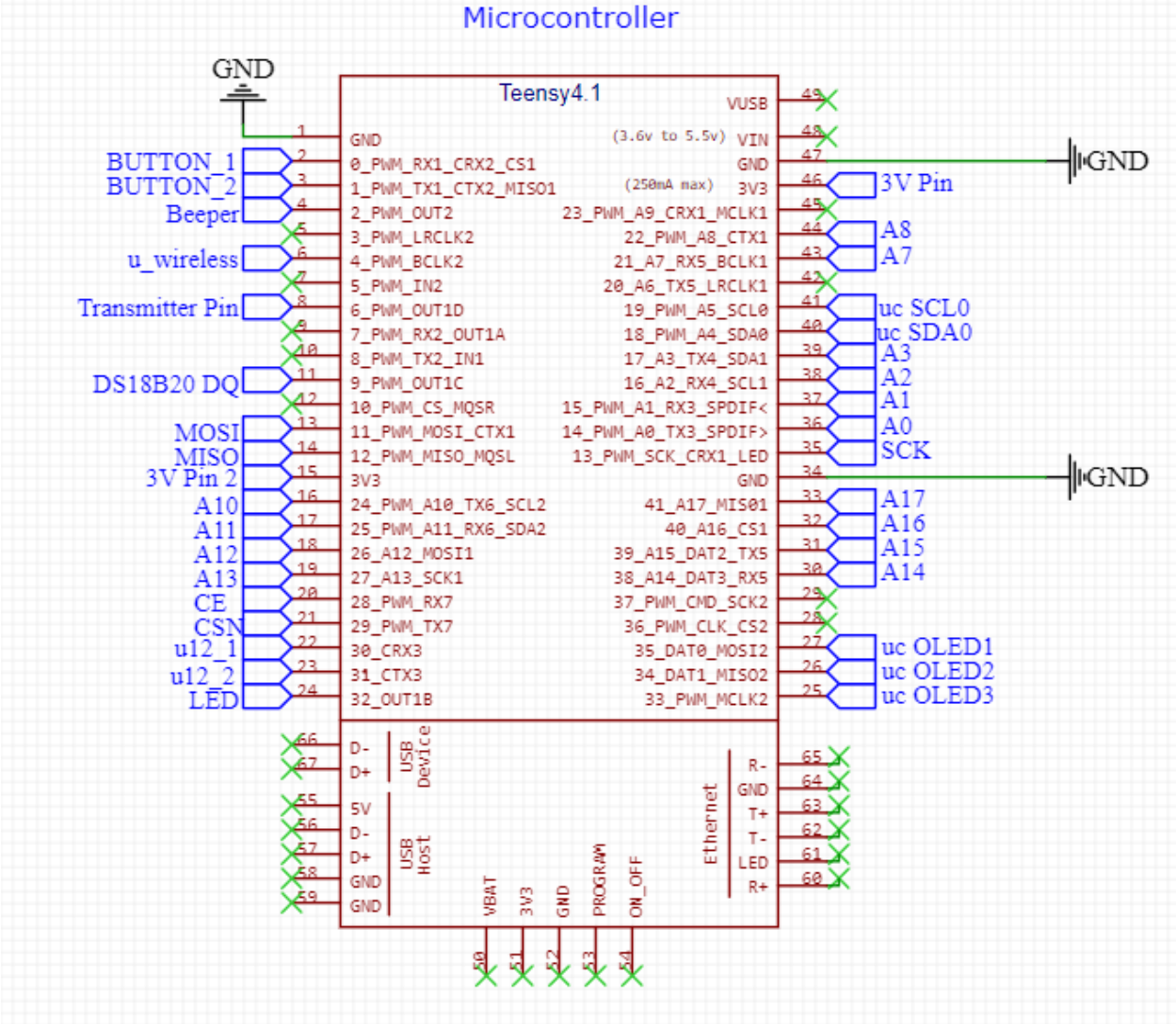

Figure 8: Microcontroller Pinout

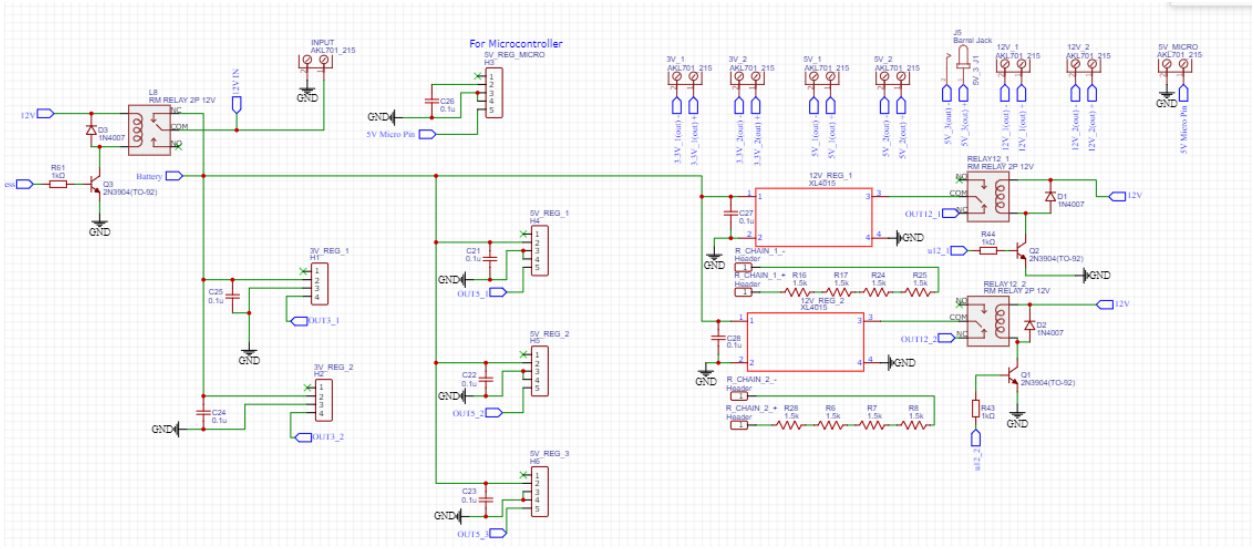

Figure 9: Power Rails with Wireless Estop and Overcurrent Protection

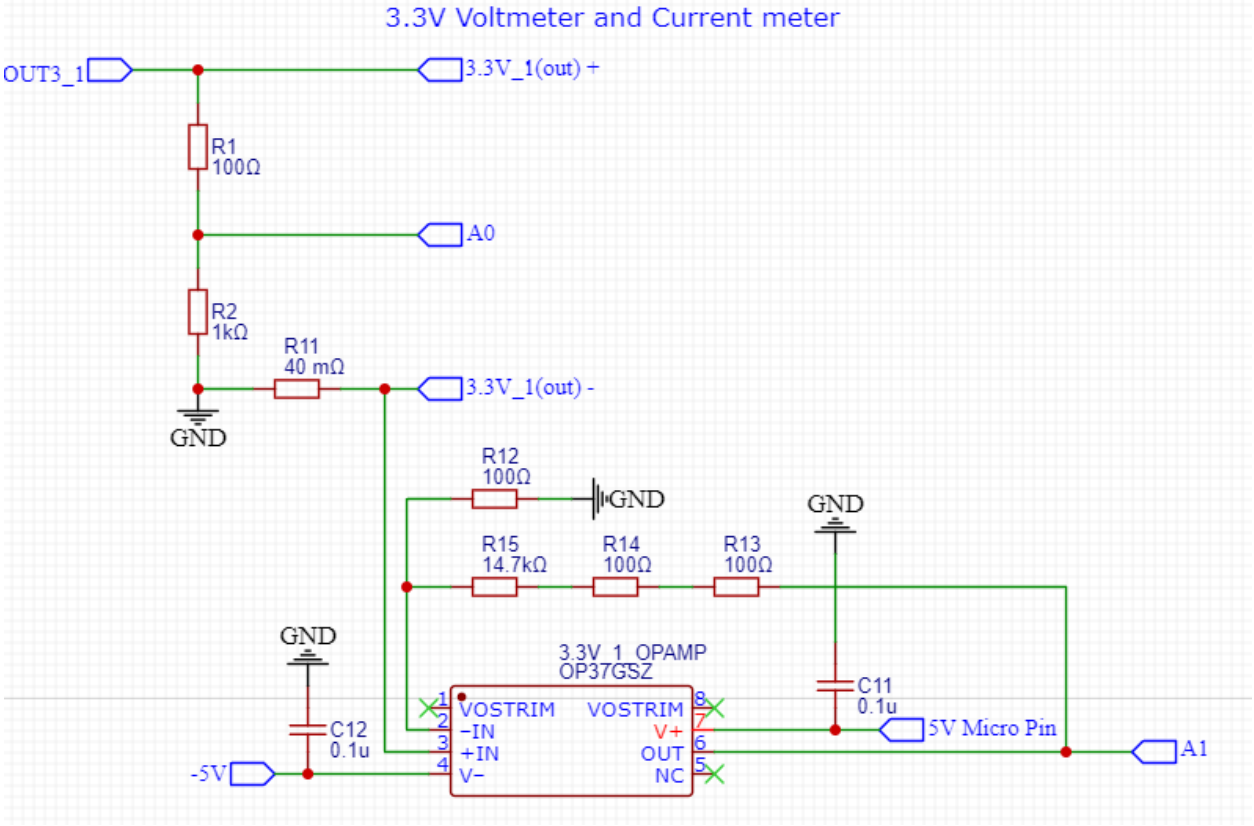

Figure 10: 3.3V Voltage and Current Monitoring Hardware

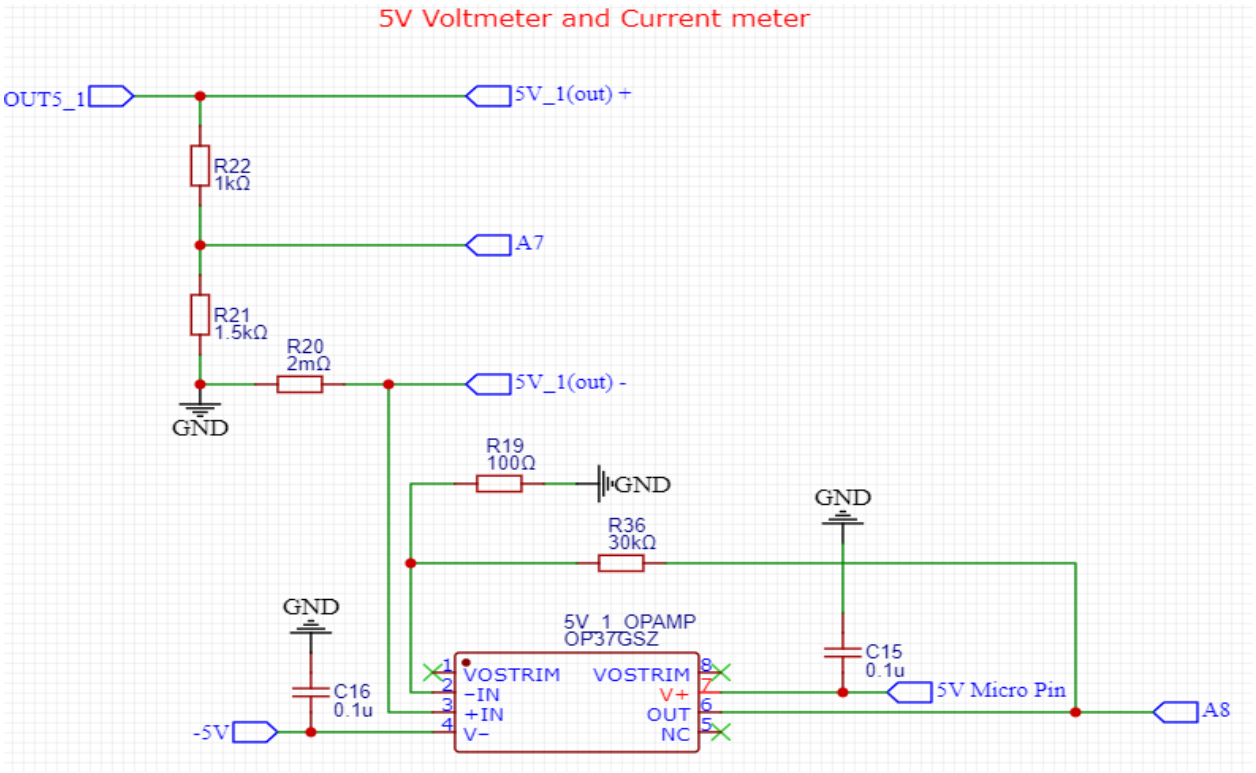

Figure 11: 5V Voltage and Current Monitoring Hardware

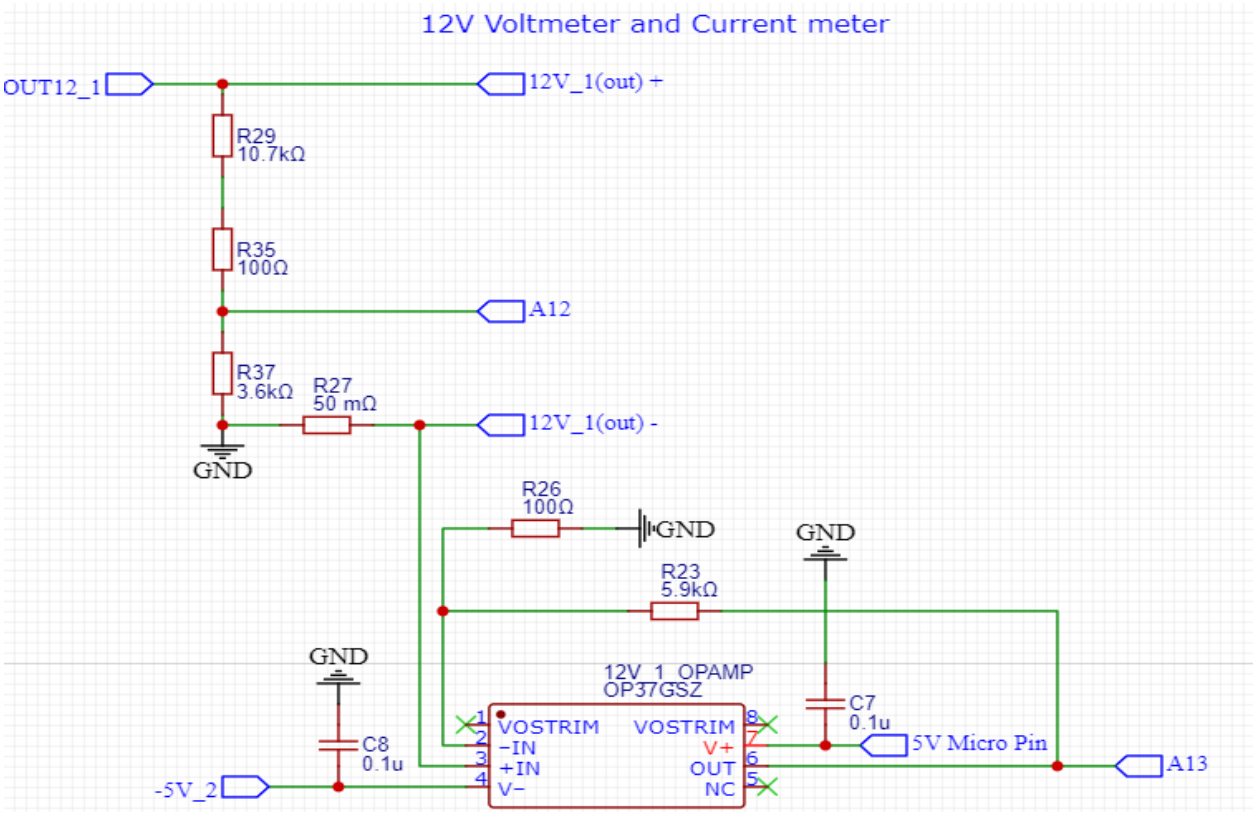

Figure 12: 1.25-12V Voltage and Current Monitoring Hardware

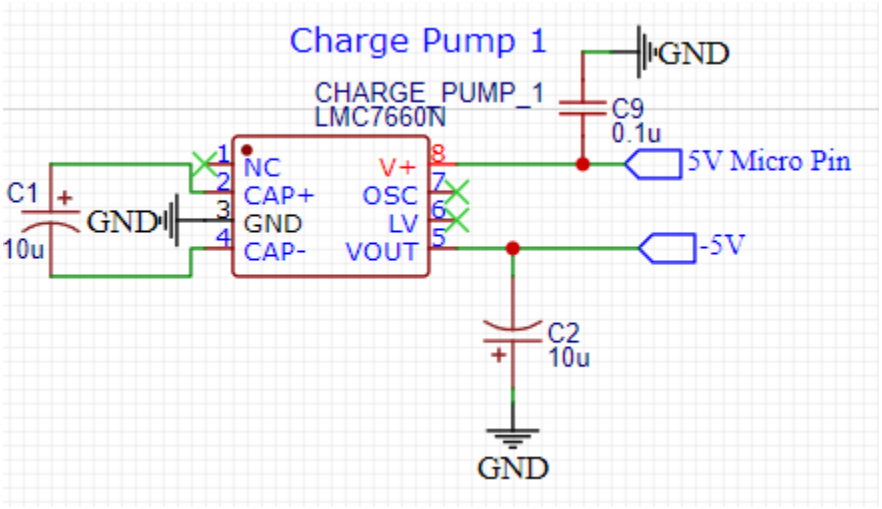

Figure 13: Charge Pump Schematic

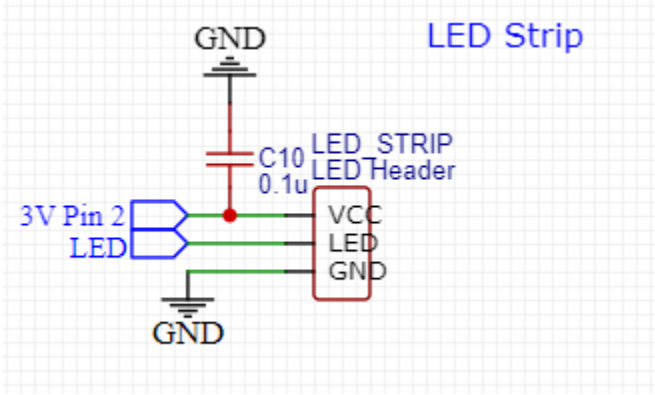

Figure 14: LED Strip Schematic

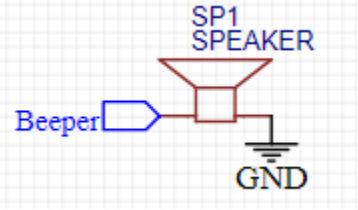

Figure 15: Beeper Schematic

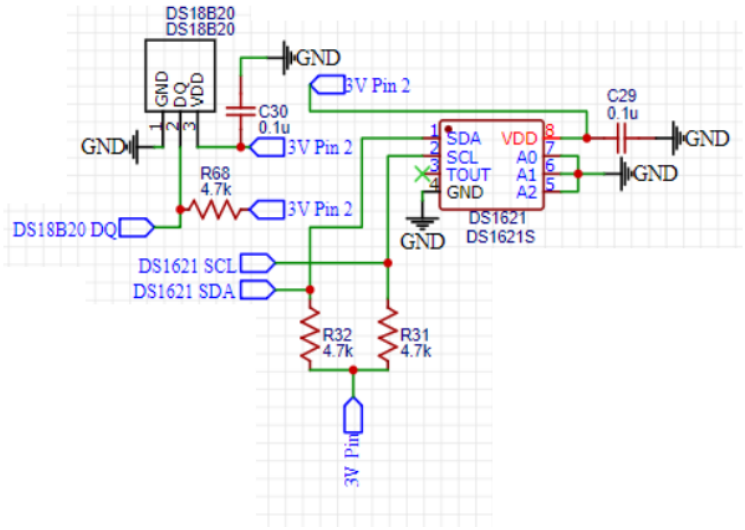

Figure 16: Ambient and Onboard Temperature Sensor Schematic

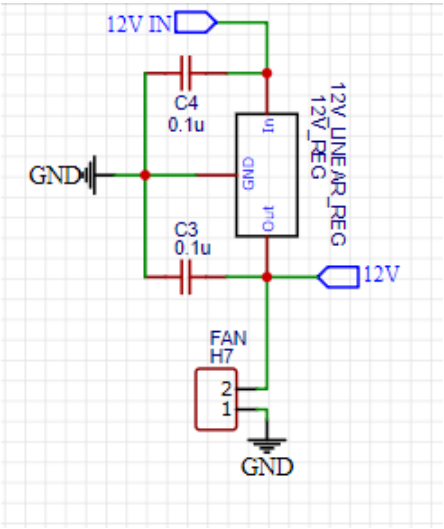

Figure 17: Internal 12V Regulator and Fan Schematic

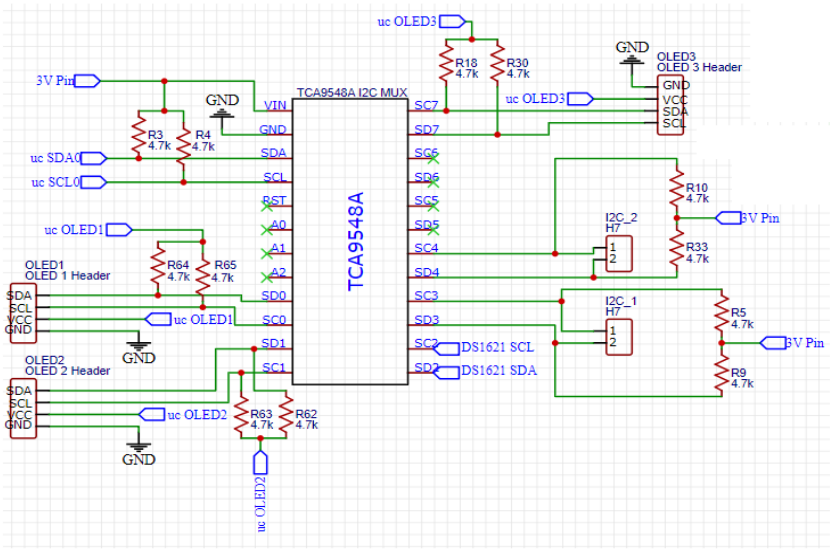

Figure 18: I2C Multiplexor Schematic

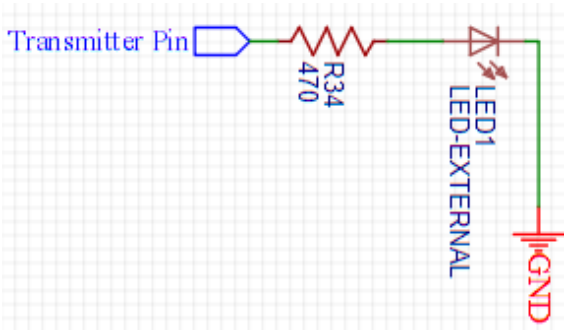

Figure 19: Wireless Receiver LED (On Main PCB)

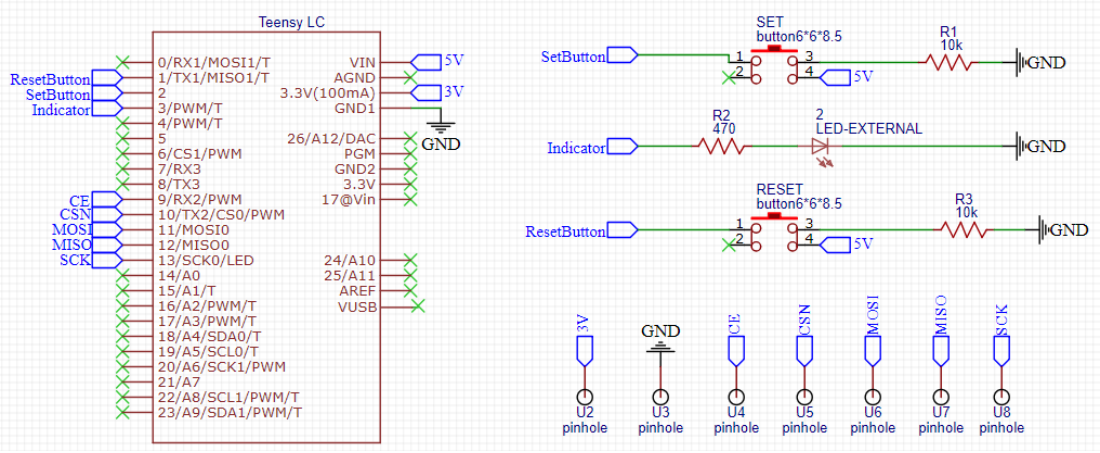

Figure 20: Wireless Transmitter Schematic (Off Main PCB)

12. Part List and Data Sheets

Given below is a list of all the components used for making one PCB along with their digikey website page which includes the datasheet for that component, or their datasheet if they were ordered from amazon.

Charge Pump IC LMC7660 x2-
https://www.digikey.com/en/products/detail/texas-instruments/LMC7660IN-NOPB/32523
12V Linear Regulator x1-
https://www.digikey.com/en/products/detail/texas-instruments/UA7812CKCSE3/1494016
3.3V Step down converter x2-
https://www.pololu.com/product/2842
5V Buck Regulator x4-
https://www.pololu.com/product/2851
0-12 [V] regulator x1-
https://www.amazon.com/Adjustable-Converter-1-25-36v-Efficiency-Regulator/dp/B079N9BFZC/ref=sr_1_27?crid=5L8N2QEJEKQU&dchild=1&keywords=XL4015&qid=1635951772&sprefix=xl4015%2Caps%2C97&sr=8-27
10 µF Electrolytic Capacitor x4-
https://www.digikey.com/en/products/detail/rubycon/50YXF10MEFC5X11/3562878
1N4001 Diode x3-
https://www.digikey.com/en/products/detail/diodes-incorporated/1N4001-T/45351
OP37 Op-amp x7-
https://www.digikey.com/en/products/detail/analog-devices-inc/OP37GSZ-REEL7/699336
LED strip x1-
https://www.digikey.com/htmldatasheets/production/2371852/0/0/1/ws2812b-led.html?utm_adgroup=General&utm_source=google&utm_medium=cpc&utm_campaign=Dynamic%20Search_EN_RLSA_Buyers&utm_term=&utm_content=General&gclid=Cj0KCQiA15yNBhDTARIsAGnwe0XovEQhiD8lm3w5i_8VOdOumnmovbgbfbsfzNQyYoK71a73jhozrtUaApQkEALw_wcB
2 mΩ shunt x3-
https://www.digikey.com/en/products/detail/vishay-dale/WSL12062L000FEA18/9758433
40 mΩ shunt x2-
https://www.digikey.com/en/products/detail/vishay-dale/WSL1206R0400FEA/712493
50 mΩ shunt x2-
https://www.digikey.com/en/products/detail/vishay-dale/WSL1206R0500FEA/712495
DS1621V+ (Temp Sensor) x1-
https://www.digikey.com/en/products/detail/maxim-integrated/DS1621V/119705
Bypass capacitors x29-
https://www.digikey.com/en/products/detail/kemet/C0805C105K3RACTU/2211765
Teensy 4.1 x1-
https://www.digikey.com/en/products/detail/sparkfun-electronics/DEV-16996/13158152
Fan x1-
https://support.arctic.de/en/f8-pwm-pst

Speaker x1-
https://www.digikey.com/en/products/detail/db-unlimited/SM151708-1/9990588?s=N4IgTCBcDa4IwAYAsBaAygWTgVjgdgQA4U4UA5AERAF0BfIA
Ambient temp sensor x1-
https://www.digikey.com/en/products/detail/maxim-integrated/DS18B20-PAR/1197285
Oled displays x1-
https://www.amazon.com/SSD1306-Self-Luminous-Display-Compatible-Raspberry/dp/B08LYL7QFQ/ref=sr_1_4?dchild=1&keywords=Frieda+SSD1306&qid=1632796410&sr=8-4
RF antennas x1-
https://www.amazon.com/MakerFocus-NRF24L01-Transceiver-Antistatic-Compatible/dp/B01IK78PQA/ref=sr_1_1?dchild=1&keywords=4328612760&qid=1632796896&sr=8-1
2N3904 BJT x3-
https://www.digikey.com/en/products/detail/diotec-semiconductor/2N3904/13575042
I2C multiplexer x1-
https://www.digikey.com/en/products/detail/adafruit-industries-llc/2717/5604376?s=N4IgTCBcDaIIwFYwA4C0cDMA2DqByAIiALoC%2BQA
Screw Terminals x8-
https://www.digikey.com/en/products/detail/cui-devices/TB002-500-02BE/10064069?s=N4IgTCBcDaICoCEAMSwFoCsK2oQURAF0BfIA
100 Ω resistor x15-
https://www.digikey.com/en/products/detail/vishay-dale/CRCW1206100RJNEAC/7921979?s=N4IgTCBcDaIMICU4HUCMYAMA2VGMICkA5AUQEE4QBdAXyA
1 kΩ resistor x10-
https://www.digikey.com/en/products/detail/vishay-dale/CRCW12061K00JNEAC/7928625?s=N4IgTCBcDaIMICU4HUCMYAMA2VBpDGAUgHICiAgnCALoC%2BQA
1.5 kΩ resistor x3-
https://www.digikey.com/en/products/detail/vishay-dale/CRCW12061K50JNEAC/7928631?s=N4IgTCBcDaIMICU4HUCMYAMA2VBpArBgFIByAogIJwgC6AvkA
1.5 kΩ through hole x8-
https://www.digikey.com/en/products/detail/ohmite/RC07GF152J/13915093
10.7 kΩ resistor x2-
https://www.digikey.com/en/products/detail/vishay-dale/CRCW120610K7FKEA/1176761
3.6 kΩ resistor x2-
https://www.digikey.com/en/products/detail/vishay-dale/RCS06033K60FKEA/5868545?s=N4IgTCBcDaIEoGEDKAGAbCgzJg0hgYjgKICCIAugL5A
14.7 kΩ resistor x2-
https://www.digikey.com/en/products/detail/vishay-dale/CRCW120614K7FKEA/1176775
30 kΩ resistor x3-
https://www.digikey.com/en/products/detail/vishay-dale/RCS060330K0FKEA/5868642?s=N4IgTCBcDaIEoGEDKAGAbCgzJlBpFAYrgKICCIAugL5A
5.9 kΩ resistor x2-
https://www.digikey.com/en/products/detail/vishay-dale/CRCW12065K90FKEA/1176732
4.7 kΩ resistor x15-
https://www.digikey.com/en/products/detail/yageo/RC1206FR-074K7L/728887

Barrel jack x1-
https://www.digikey.com/en/products/detail/cui-devices/PJ-037AH/1644547
50 kΩ Potentiometer x2 (Found in this box)-
https://www.amazon.com/dp/B07Z8ZT6RD?psc=1&ref=ppx_yo2_dt_b_product_details
Momentary push buttons x2 (Found in this box)-
https://www.amazon.com/dp/B07BD1MS18?psc=1&ref=ppx_yo2_dt_b_product_details
12V Relays x3-
https://www.amazon.com/dp/B07PMW33V6?psc=1&ref=ppx_yo2_dt_b_product_details