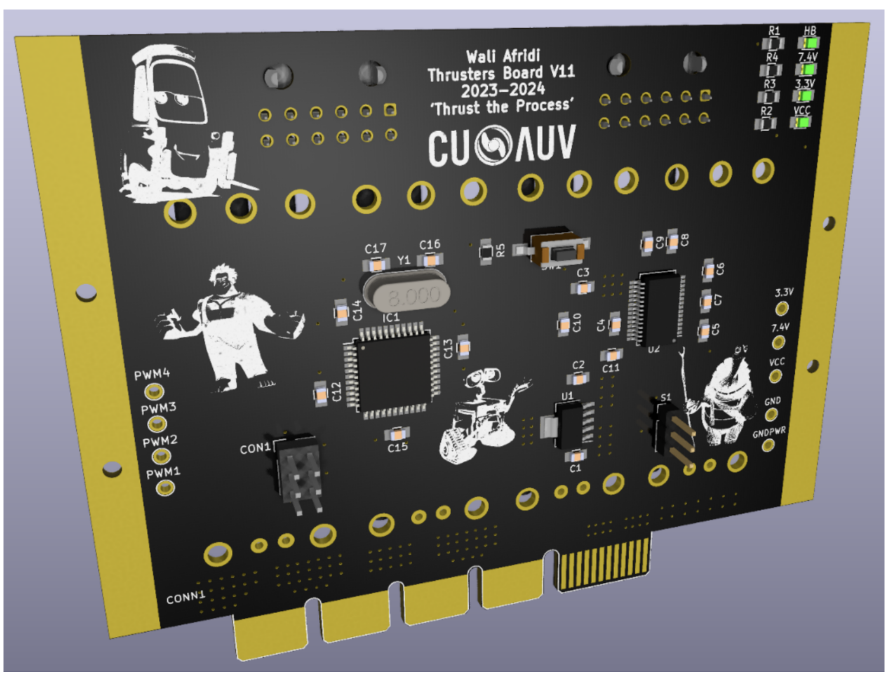
Cornell University Autonomous Underwater Vehicle Team

Spring 2024

Thrusters Board



Technical Report

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Contents

1 Abstract

Thrusters board utilizes 4 electronic speed converters (ESCs) to control each of the submarine's underwater thrusters. The job of the board is to provide each ESC with 16V and a PWM signal to control the speed of that thrusters. Two boards are used on the submarine to control a total of 8 thrusters.

2 Design Requirements

The requirements for thrusters board are as follows:

- Control 4 Blue Robotics T200 Brushless DC Thrusters using 4 Blue Robotics 30 A Basic ESCs
- Communicate with the 4 ESC modules via PWM from the ATXMega microcontroller
- Provide 16 V of unisolated power and unisolated ground for the ESCs and Thrusters
- Power an ATXMEGA microcontroller with a 3.3 V power line
- Communicate with the main computer of the vehicle over RS-232
- Provide test points for debugging purposes
- Be no taller 3.287", including the backplane connector
- Be no longer than 4.331", including the rails
- Be no thicker than 1.102", including all components
- Have a distance of 0.617" between the edge of the board and start of the backplane connector

3 Previous Designs

This is the eleventh iteration of the Thruster board and the sixth to utilize the Blue Robotics Basic R3 ESC modules. This design is a continuation of the successful Thrusters Board version 10. A priority for this board is to keep the ESCs at a cooler temperature. This year, with the addition of active cooling into our Upper Hull Pressurized Vessel (UHPV), the Thrusters board will be fitted with two rails so that all ESCs are directly in line with the active airflow path generated via 3 fans inside the UHPV.

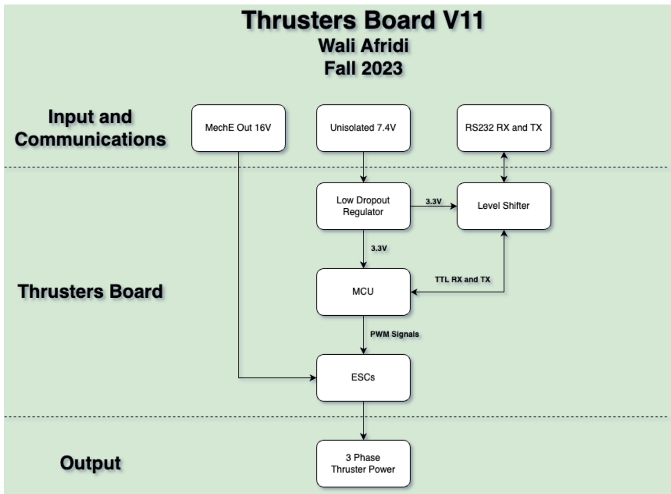


Figure 1: A high-level block diagram of the Thrusters Board

4 High Level Description

The Thrusters Board interacts with the rest of the submarine through the serial RX/TX lines via the backplane. The backplane also provides unisolated 7.4V and 16V power, as well as both unisolated and isolated ground connections. The 7.4V unisolated power is stepped down to 3.3V using a low dropout regulator (LDO) in order to power the microcontroller (MCU) and level shifter. The level shifter moves the RS232 Rx to TTL RX for the MCU. On the reverse, it turns the TTL TX from the MCU to the higher voltage RS232 to go back through the backplane. The data from serial tells the microcontroller the desired duty ratio for each thruster. Using this, the microcontroller generates pulse width modulated (PWM) signals which it sends to the ESCs. The ESCs are also provided with the 16V power line to power the thrusters.

The thrusters are controlled via a method known as Trapezoidal Control. Each thruster features three electromagnetic coils labeled A, B and C. At a given point in time, one of these coils will be high (receiving current), one coil will be low (current exits through the coil), and one coil will be off. The ESCs interpret the PWM signal from the microcontroller and sets coils A, B and C to high, low and off by controlling the current through each coil. Different PWM signals correspond to different thruster speeds, which changes the frequency at which the ESCs control A, B and C.

5 Implementation

5.1 Backplane Connector

The board receives 16V unisolated power to control the ESCs and thrusters, as well as 7.4V for the LDO. An RX and TX line are utilized in RS-232 protocol to communicate with the rest of the sub. An unisolated GNDPWR plane and an isolated GND plane are used to separate the noisy mechatronic signals and the more sensitive communication signals, such as the aforementioned RX and TX lines.

5.2 LDO

The TPS7A4533 LDO takes in the 7.4V unisolated power from the backplane and steps it down to 3.3V to be used to power the microcontroller and level shifter. This model is capable of generating 3.3V from a number of input voltages, which makes it a versatile choice for this board as the unisolated input power has changed twice in the last two iterations.

5.3 Level Shifter

The MAX3250 Level Shifter is utilized to convert the high voltage RS232 protocol serial data that is transferred between boards to the transistor-transistor logic (TTL) level that is used on the board. The level shifter shifts the serial data in reference to the isolated ground plane to ensure that noise does not interfere with our data lines. A serial header is used to read and write serial variables directly to the board.

5.4 Microcontroller

The ATXMega324U-A microcontroller accepts 3.3 V power as well as RX and TX signals from the level shifter to communicate with other boards via RS-232. The microcontroller is programmed in C to output four different PWM outputs, one to each ESC. These PWM signals correspond to different thruster speeds by controlling the frequency at which the ESCs adjust the A, B and C coils of each thruster. A reset switch, programming header and heartbeat LED are present to reset, program and monitor the status of the microcontroller respectively.

5.5 Electronic Speed Controller

Each Blue Robotics Thruster is controlled via a Blue Robotics Basic 30A Electronic Speed Controller (ESC). Each of the two thruster boards features four ESCs to control a total of eight thrusters on the sub. The ESC had three inputs, a 16 V power supply, an unisolated GNDPWR connection and a PWM signal from the microcontroller. The ESC has three different outputs corresponding to each of the thruster coils A, B, and C. These outputs are connected to the corresponding thruster via microfit connectors and external wires.

5.6 Layout

To ensure that the ESCs could be easily soldered and de-soldered from their through-hole pads, the pads were selected for thermal relief, allowing enough copper connection to provide the necessary current, but also preventing all the heat from a soldering iron dissipating in the large GNDPWR and +16V copper planes.

In order to fully utilize Sirius' new active cooling in the UHPV, it was desirable to have all of the ESCs in the airflow path to keep their heatsinks cool. Given the fitment constraints from the racks, this required fitting Thruster board with rails on both sides. This also required careful modifications to the backplane and backplane shield.

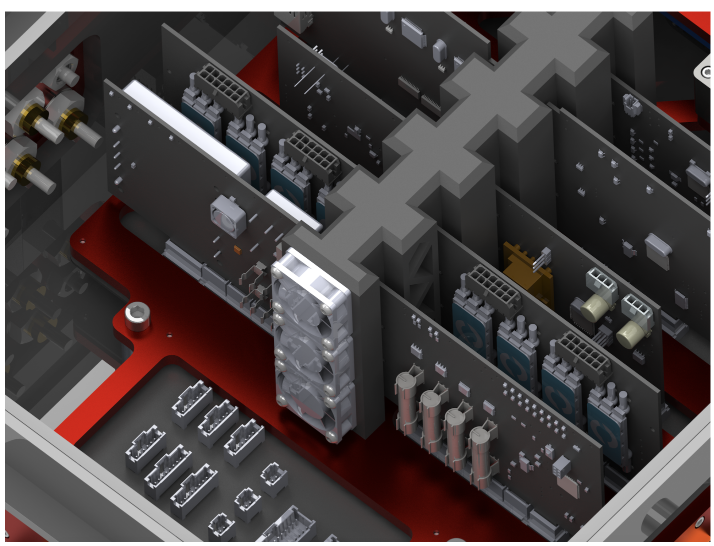


Figure 2: Sirius Board Racks with ESCs (blue) in airflow path

6 Software Walk-Through

Similar to other electrical boards in the vehicle, the Thruster Board utilizes standard serial communication and heartbeat functionality. The Thruster Board is responsible for regulating the thrusters, maintaining the desired duty cycles specified by the main computer via serial communication. All four pins responsible for ESC communication are configured as output pins. To establish communication with the ESCs, the microcontroller's Timer/Counter module specific for wave generation gener- ates a PWM signal. Initially, the PWM signal starts in a high state at the beginning of each cycle.

For each ESC, four compare channels are utilized to update the PWM signal. A counter, incrementing from the BOTTOM value to the TOP value, is continuously updated every two milliseconds using a timer-triggered interrupt. Each compare channel constantly compares the counter value with the period stored in the register. If they are equal, an interrupt is generated, indicating the end of the duty cycle and causing the PWM signal to transition to a low state.

7 Current Status

3 Thruster Boards have been fully populated and tested to the standards in the Sirius Thruster Board User Manual.

7.1 Future Improvements and Known Issues

Currently, there are no known issues or specific directions for future iterations, but testing throughout the summer will likely shed light on any problems with the current Thruster Board.

A Appendix

A.1 Pinouts

1, 2, 3, 4	GNDPWR
5, 6	RX Thruster
8, 9, 10, 11	Ground
13, 14, 15, 16	+7.4V
27, 28	TX Thruster
29, 30, 31, 32	+16V

A.2 Part References

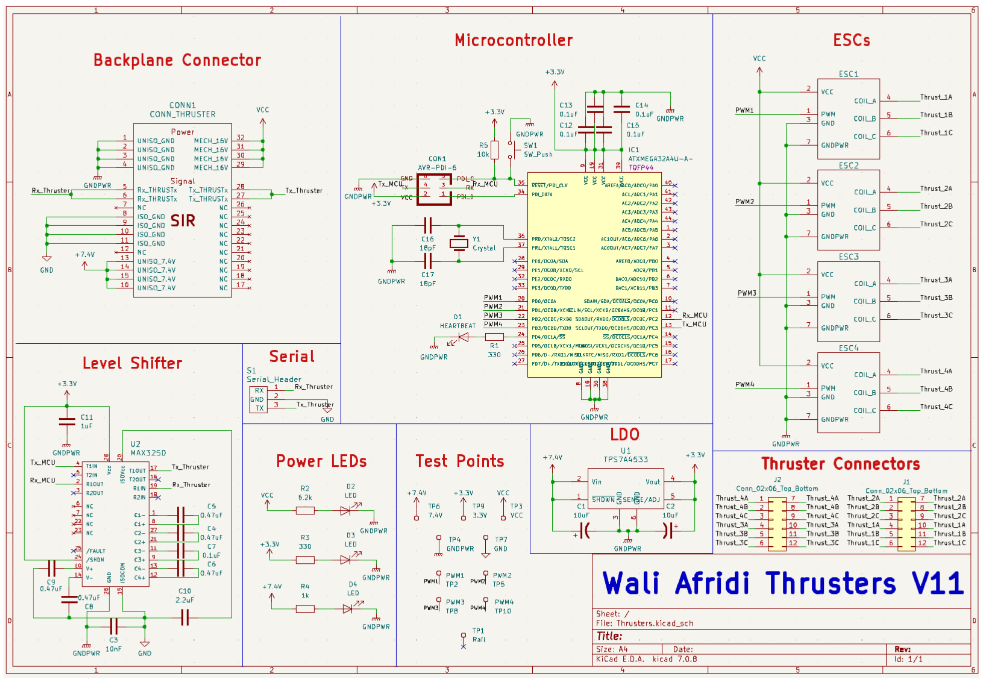
A.2.1 Analog

ATxmega32A4U MCU	ATxmega32A4U MCU Datasheet
MAX3250 Level Shifter	MAX3250 Datasheet
Blue Robotics Basic 30A ESCs	ESC Datasheet
Blue Robotics T200 Thrusters	Thrusters Datasheet
TPS7A4533 LDO	TPS7A4533 Datasheet

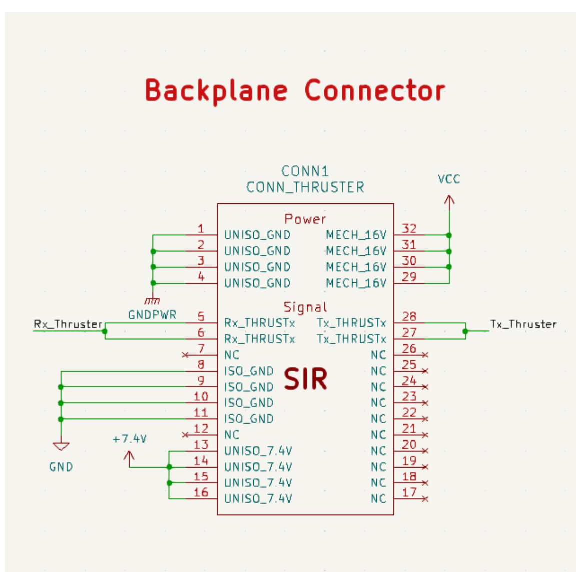
A.3 Schematics

Here are some schematics.

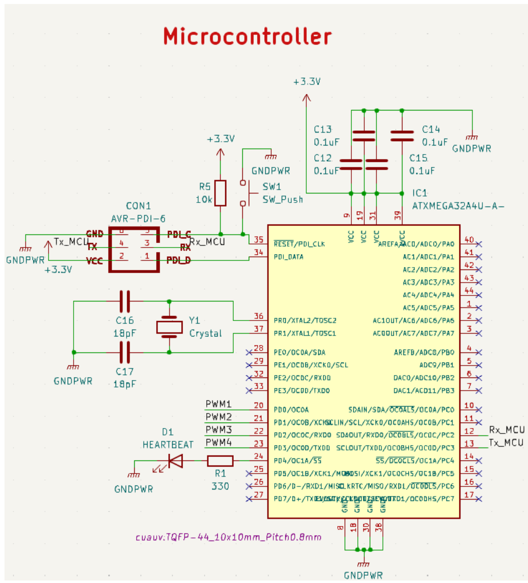
A.3.1 Full Schematic



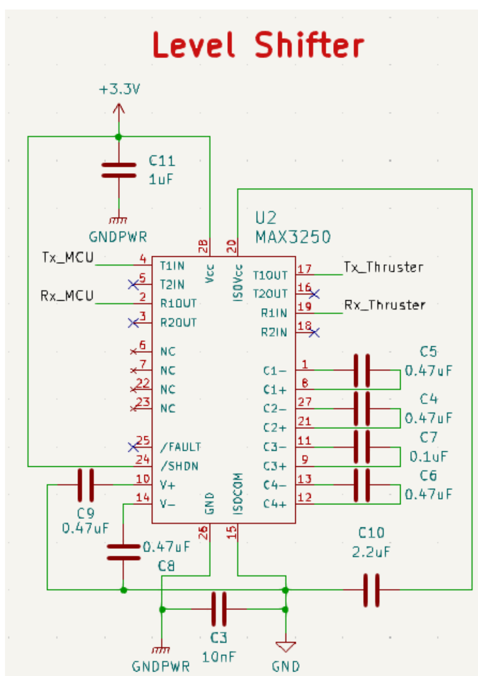
A.3.2 Backplane Connector



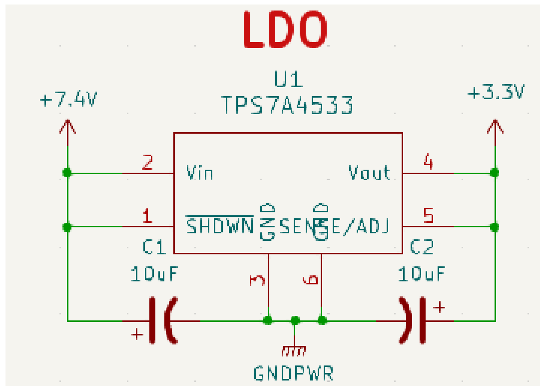
A.3.3 Microcontroller



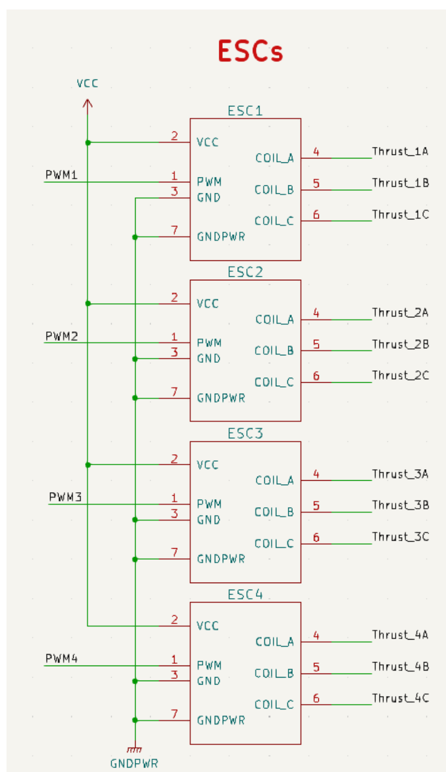
A.3.4 Level Shifter



A.3.5 LDO

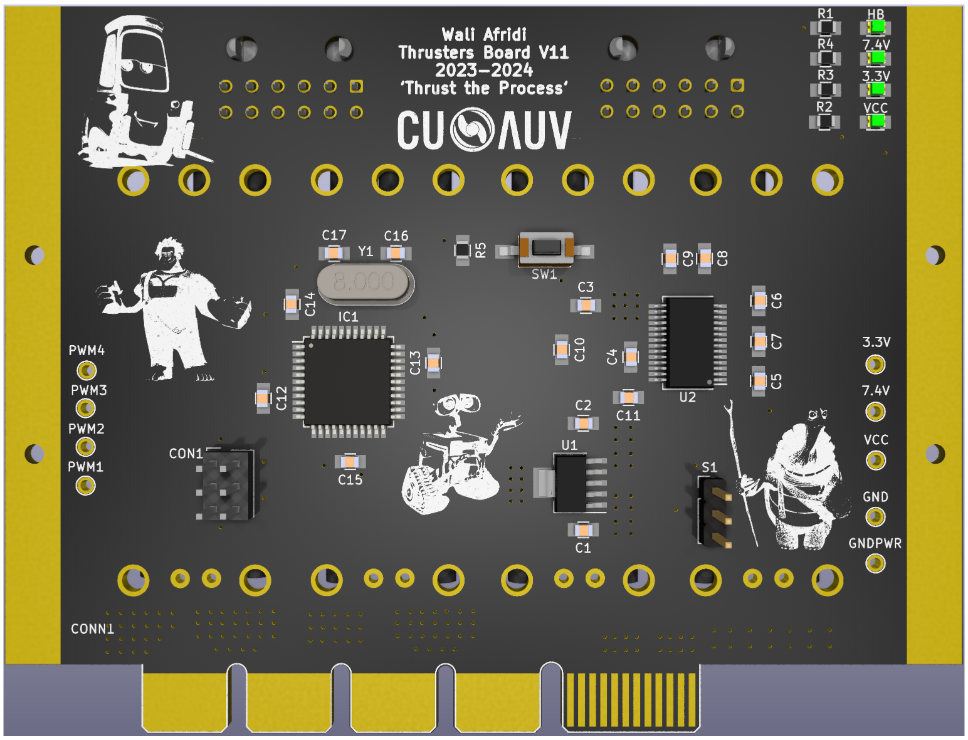


A.3.6 ESCs

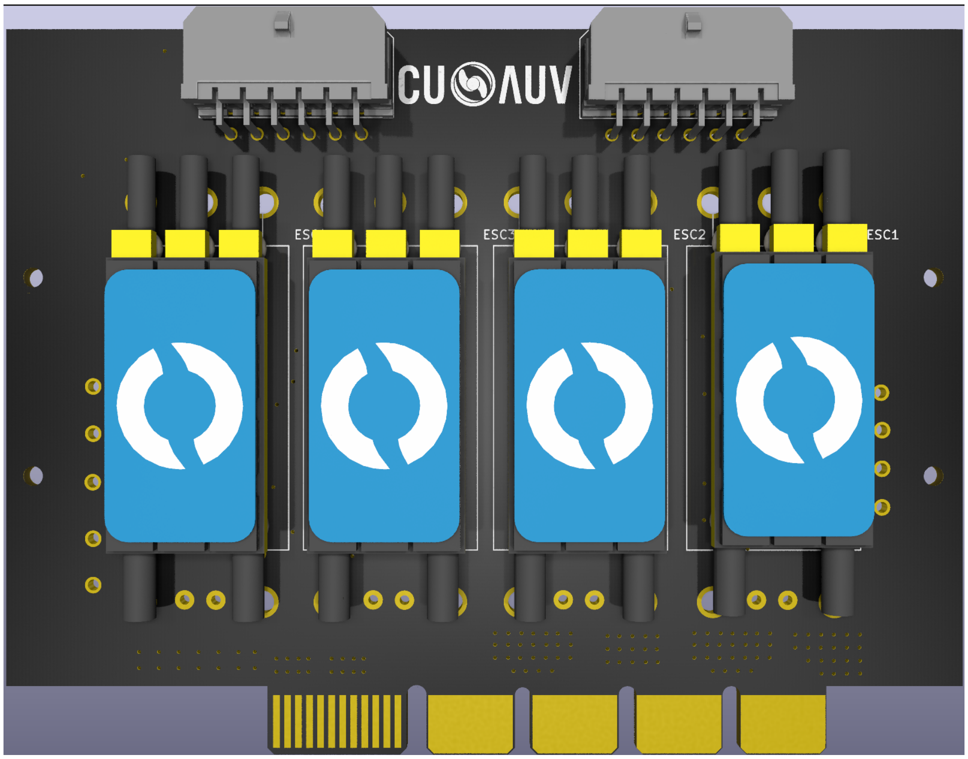


A.4 Layout

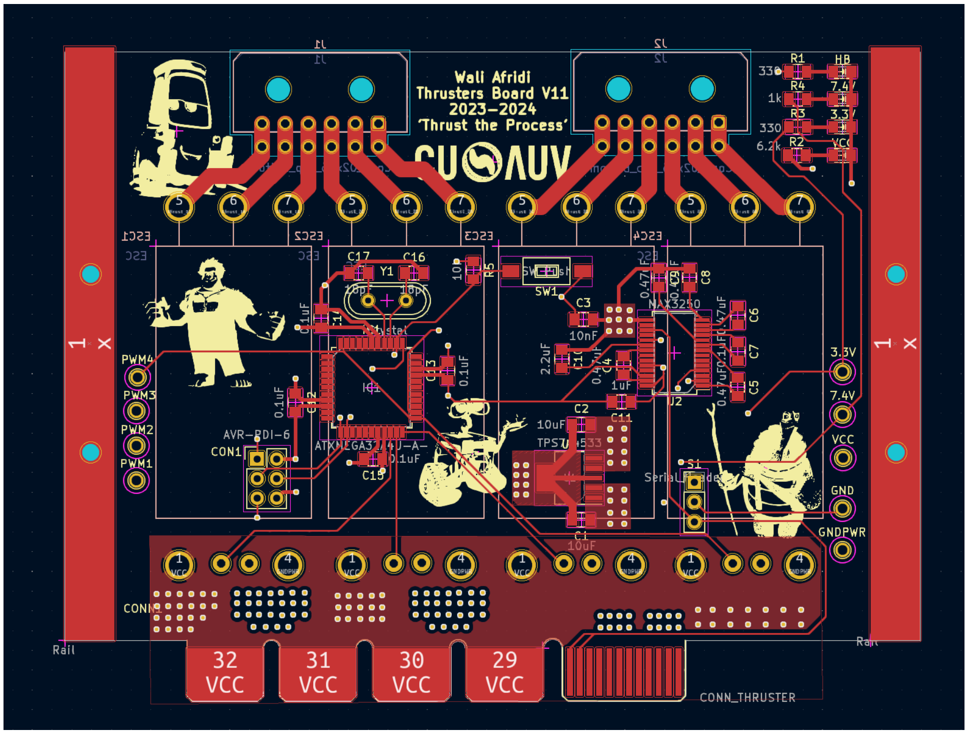
A.4.1 Front Side Render



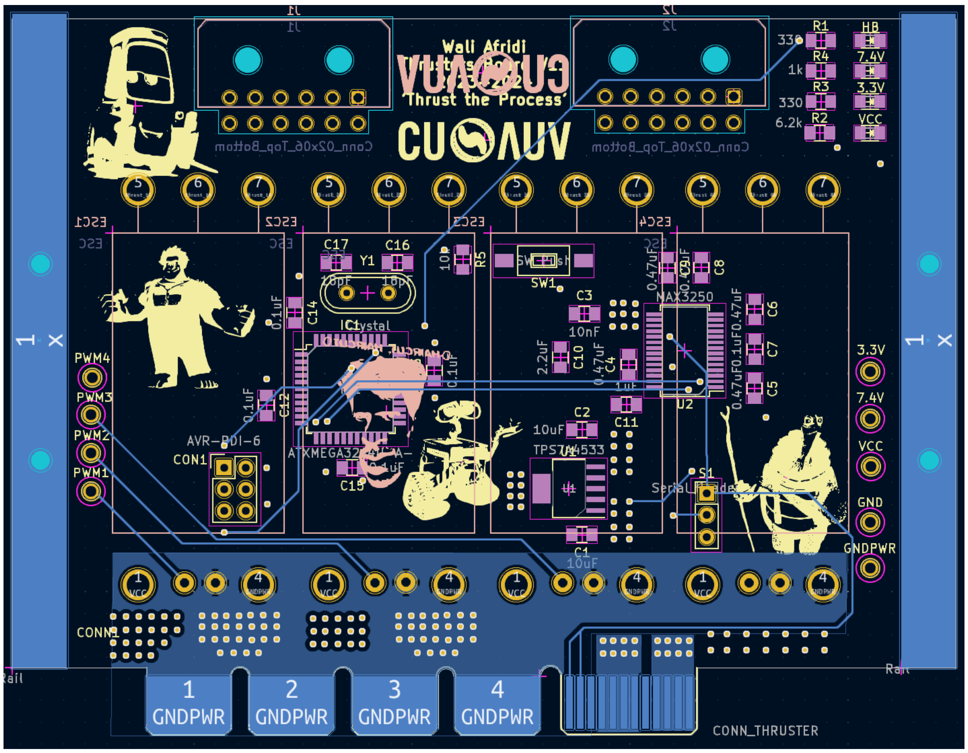
A.4.2 Back Side Render



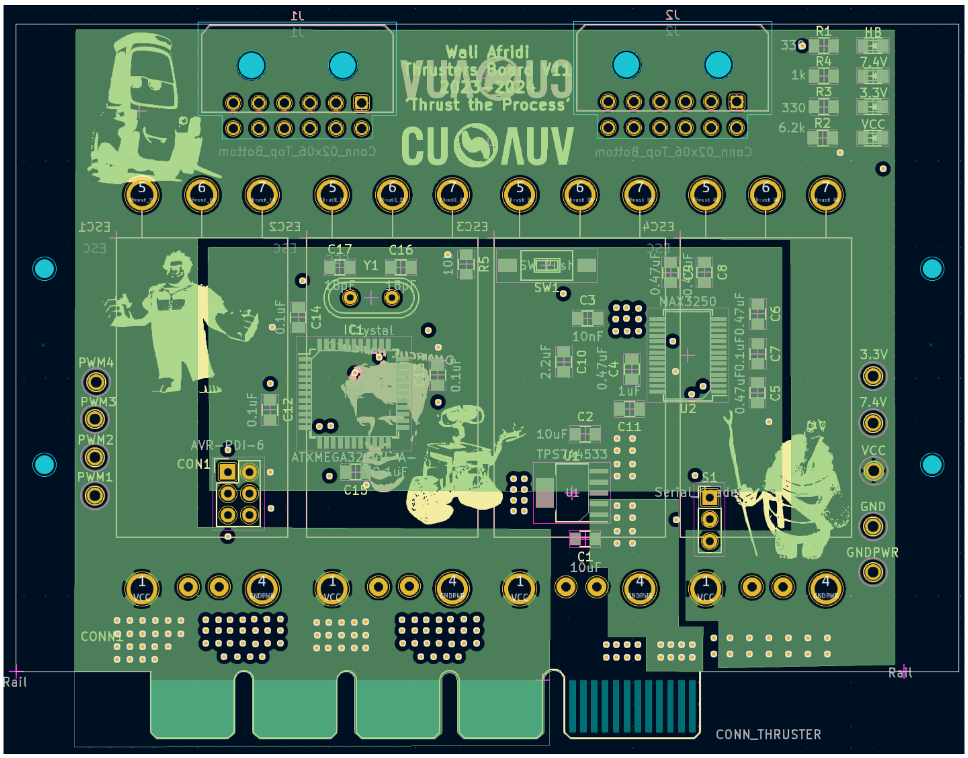
A.4.3 Front Side Copper



A.4.4 Back Side Copper



A.4.5 Power Plane



A.4.6 Ground Plane