# THRUST STAND CONTROLLER

## Overview

The purpose of the thrust stand controller is to provide detailed measurements of motor performance which helps in motor selection for the aircraft. This controller can measure voltage, current, torque and thrust and can potentially take up to 33V and 55A. The schematic overview of the thrust stand controller is as follows:

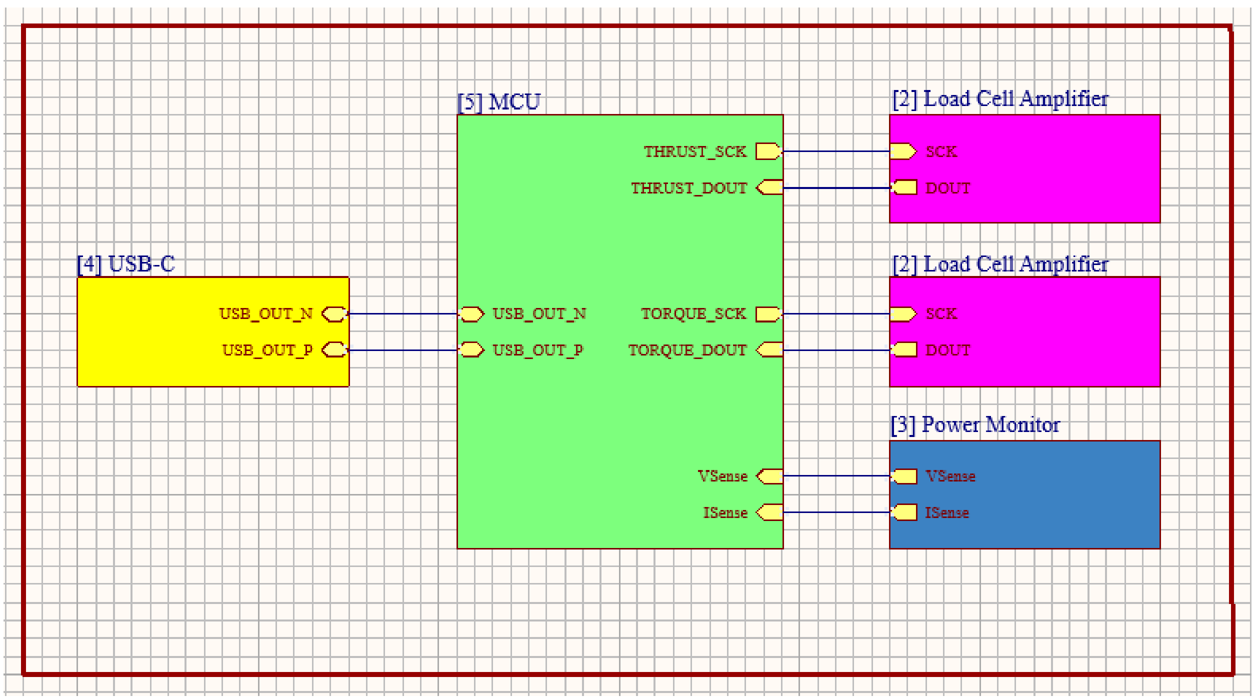


**Fig 1: Top Level Overview of the Schematic**

- **USB-C:** We will be using a USB-C connection for powering up the board and data logging.

- **HX711 Load Cell Amplifier:** There are two HX711 load cell amplifiers responsible for torque and thrust measurements. Each HX711 measures minute changes in resistance in the load cells, which are directly proportional to the force (thrust or torque). The digital output from the HX711 is fed into the microcontroller for further processing.

- **Power Monitor:** The power sensor uses a voltage divider circuit followed by an op-amp, which conditions the signal before sending it to the microcontroller's ADC for voltage measurement and a current sense amplifier, which senses the voltage drop across a shunt resistor and amplifies the differential signal to be sent to the microcontroller's ADC, for the current measurement.

- **ATMEGA32U4-AU MCU:** The ATMEGA32U4-AU microcontroller handles data acquisition from sensors and interfaces with the USB-C. It reads all the signals from the external circuits and processes them. The microcontroller also provides the necessary clock signals for the load cell ADCs (TORQUE_SCK and THRUST_SCK), ensuring synchronized data sampling for both torque and thrust measurements.

- **Connections:** We have the following connections in the circuit:

    - There are 2x11P Male Header Pins on the board for accessing the GPIO pins of the microcontroller, providing flexibility for future expansion, testing or debugging.
    - There is a 2P Male Header Pin for sending PWM control directly from the microcontroller to the ESC. One of the pins will be connected to ground.
    - There are 2 pairs of solder pads to connect the Power Limiter and the ESC.

The diagram below shows how the thrust stand controller interfaces with external components of the plane’s power system for motor testing:

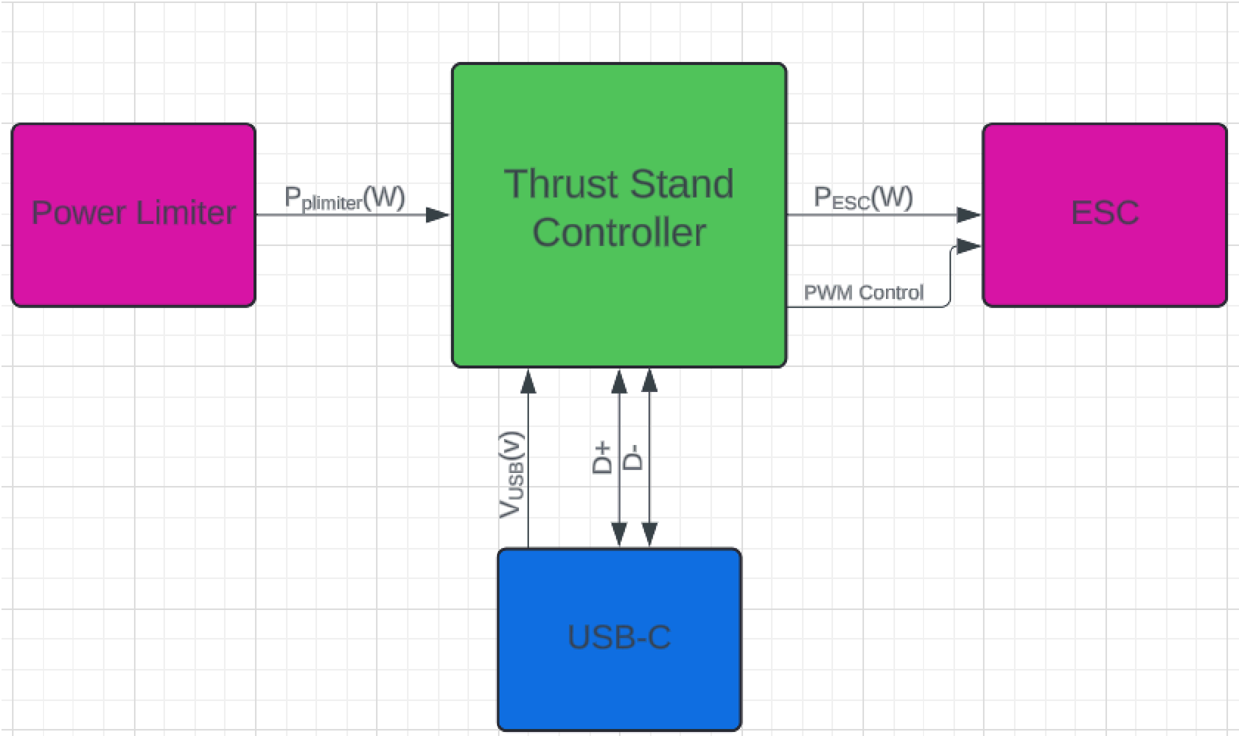

Fig 2: Thrust Stand Controller Connection Interface with External Hardware

# Sub Circuitry

In the following section, we will go over the main sub circuits of the thrust stand controller in detail and justify design decisions.

## 1. Load Cell Amplifier

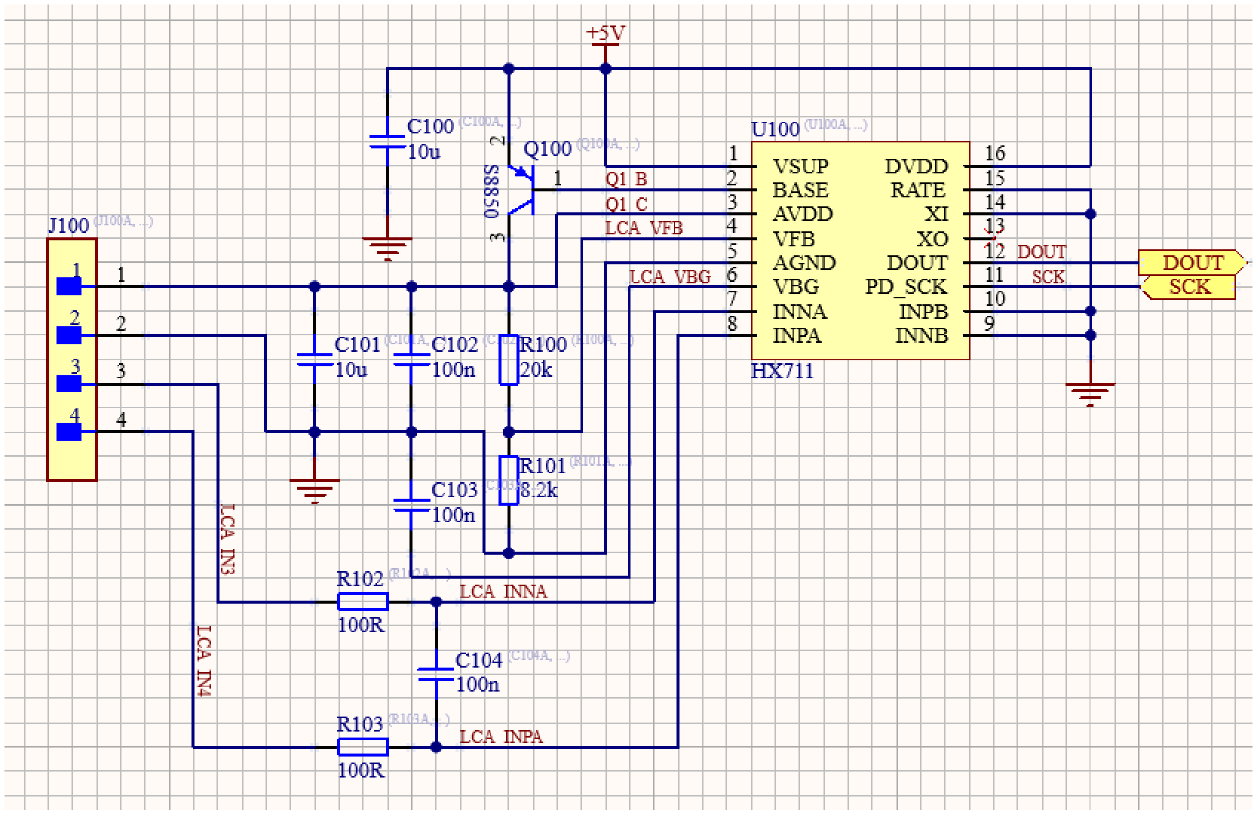


**Fig 3: Load Cell Amplifier Schematic**

The load cell amplifier is inspired by the circuitry suggested for the HX711 ADC in the datasheet (Fig.1 and Fig.4 in [1]).

The recommended component values for most of the components in the load cell amplifier is given in the datasheet as well. The only thing needed to be identified is the values of the voltage divider network (R100 and R101 in this diagram). The voltage divider network is crucial for setting the AVDD voltage of the HX711 and the formula is given by:

$$V_{AVDD} = V_{BG} * \frac{(R_{100}+R_{101})}{R_{101}}$$

VBG is 1.25V [1]. With the resistor network chosen, we get AVDD voltage as 4.3V, which is suitable for powering the analog portion of the HX711 since it must be slightly lower than VSUP (by at least 100mV) for proper operation [1]. Also note, the formula given for AVDD is incorrect and has

R101 and R100 swapped [2]. The clock for the HX711 will be fed by a GPIO pin of the microcontroller.

## 2. Power Monitor

The power monitor circuitry consists of a voltage sensor and a current sensor which sends data signals to the microcontroller for power measurement. We use solder pads to interface the power limiter and ESC with the microcontroller. The voltage and current from the power limiter is fed into the power monitor and the ESC in this scenario is treated as a load.

### a. Voltage Sensor

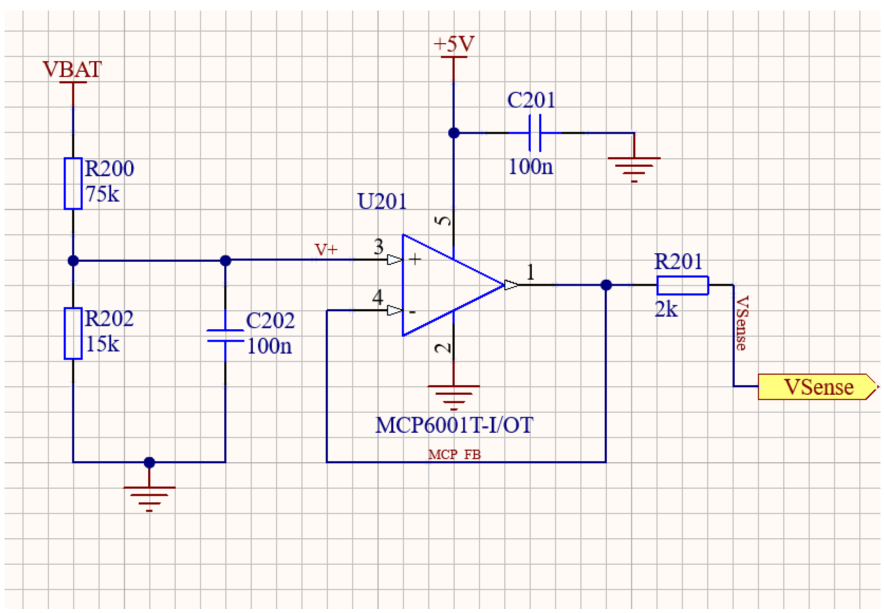


Fig 4: Voltage Sensor Schematic

The schematic of the voltage sensor consists of a simple voltage divider network followed by a voltage follower circuit and an additional resistor. The values of the voltage divider network was chosen in such a way that the high and low voltage levels of the input (which corresponds to a 6S LiPo) was easily detected by the microcontroller. In other words, we need to scale down a full charge and low charge 6S to a voltage level in the range of 2.7-5.5V (operating voltage range of the microcontroller (Page 2 of [3])). The voltage divider network gives us a scaling ratio of ⅙. This means:

$$V_{VSENSE} = V_{BAT} * \frac{R_{202}}{R_{200}+R_{202}} = \frac{V_{BAT}}{6}$$

A 6S LiPo at full charge is 25.2V and at low charge is 19.2V. When passed through this circuit, we get estimated values for VSense to be 4.2V and 3.2V respectively. With these calculations, we can expect the circuit to take up to 33V maximum (since the microcontroller supports up to 5.5V) This can be backed up by the spice simulations conducted:

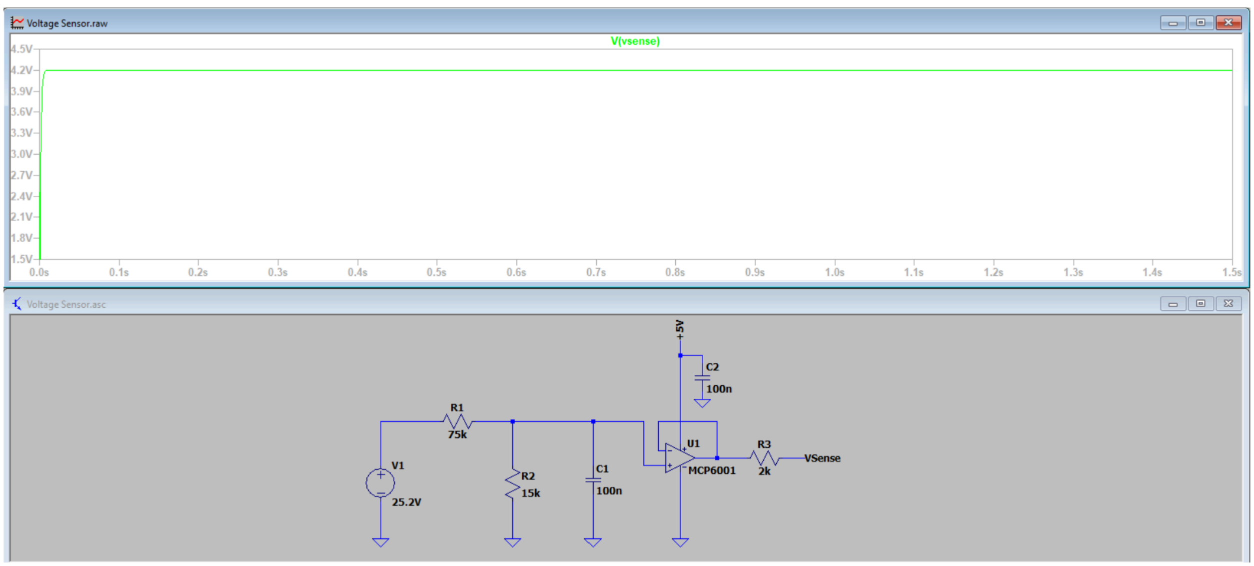


Fig 5: LTSpice Simulation for Voltage Sensor at 25.2V

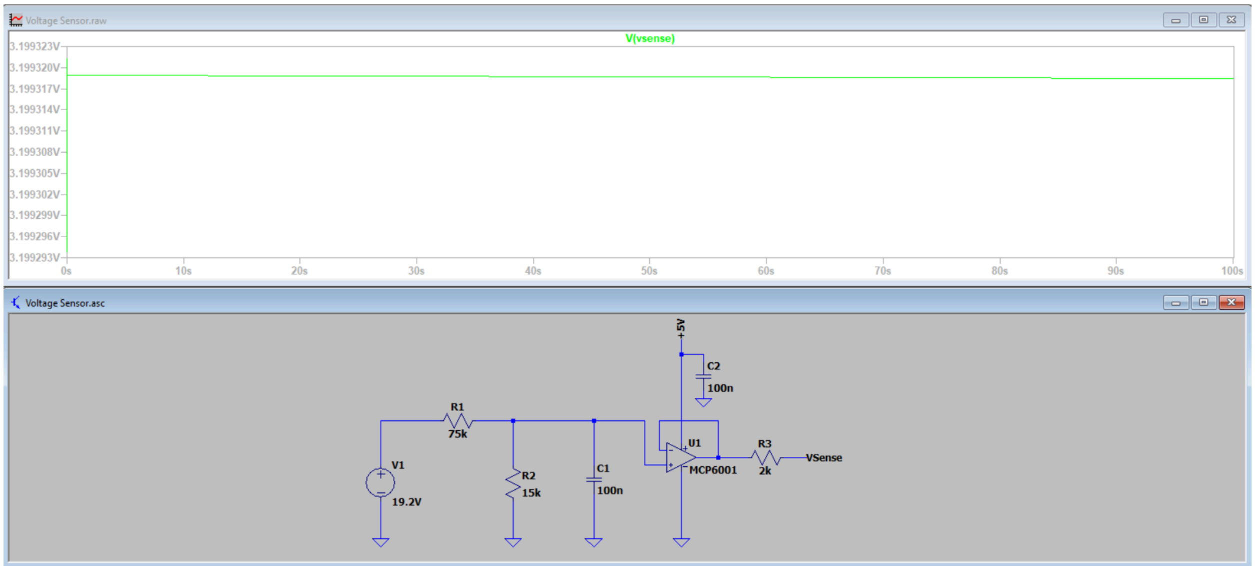


**Fig 6: LTSpice Simulation for Voltage Sensor at 19.2V**

The purpose of the capacitor is for decoupling purposes at the input of the opamp. The purpose of the voltage follower and the 2kOhm resistor is to transmit the scaled voltage to the microcontroller with as minimal current as possible since the microcontroller pins can take up to a few milliamps. The voltage follower helps in achieving this and the resistor just serves as extra protection. While we can expect some voltage drop across the resistor as a consequence, this voltage drop is minimal since we can expect the output of the voltage follower to be the transmitted voltage with minimal current. This additional circuitry allows us to detect the voltage coming in from the power limiter without damaging the microcontroller.

## b. Current Sensor

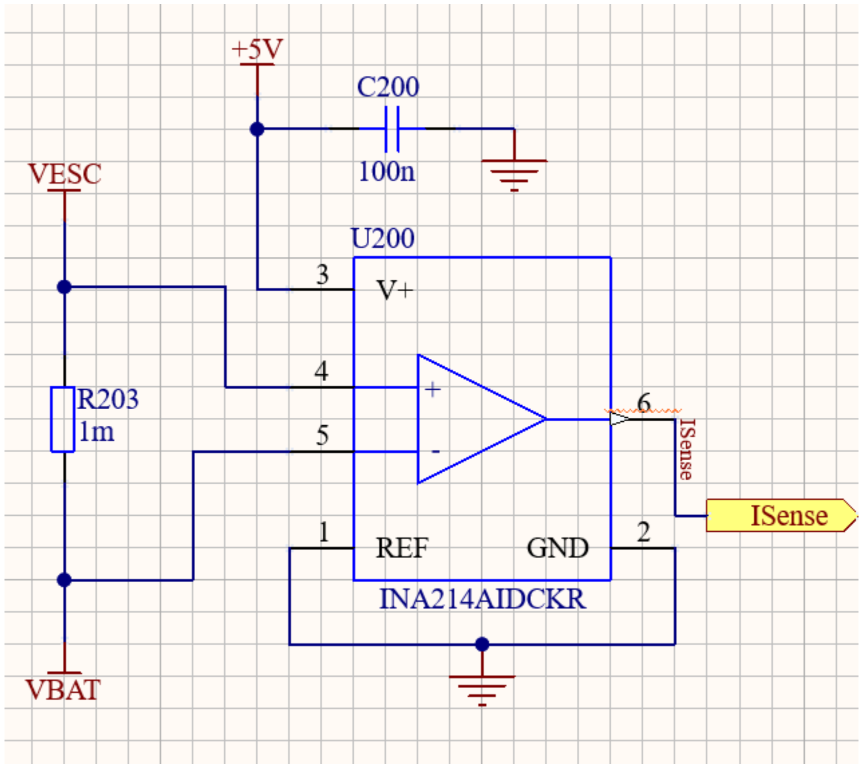


Fig 7: Current Sensor Schematic

The schematic of the current sensor consists of a shunt resistor followed by a current sensing amplifier (INA214AIDCKR). This current sensing amplifier has a gain of 100 V/V (Pg.1 of [4]) and follows the following formula for the output voltage:

$$V_{ISENSE} = (I_{BAT} * R_{203} * Gain) + V_{REF} = 0.1 * I_{BAT}$$

R203 is chosen as 1mOhm as it provides a good balance between maximizing current input that is readable for the microcontroller and ease of calculation. With the formula given for voltage of Isense, we can conclude that the maximum amount of current that can be detected by the microcontroller would be 55A. Furthermore, the shunt chosen is rated for 6W and on performing power calculations for maximum current flowing into the shunt, we see:

$$P_{SHUNT} = (I_{BAT}^{2} * R_{203}) = 55^{2} * 0.001 = 3.025W$$

The power consumed is well within the range of the shunt's power rating, making it an appropriate choice for this design. Lastly, since we are only concerned with the unidirectional current coming in from the power limiter to the current sense amplifier, we connect the REF pin to ground (Pg. 20 [4]).

## 3. USB-C Connection

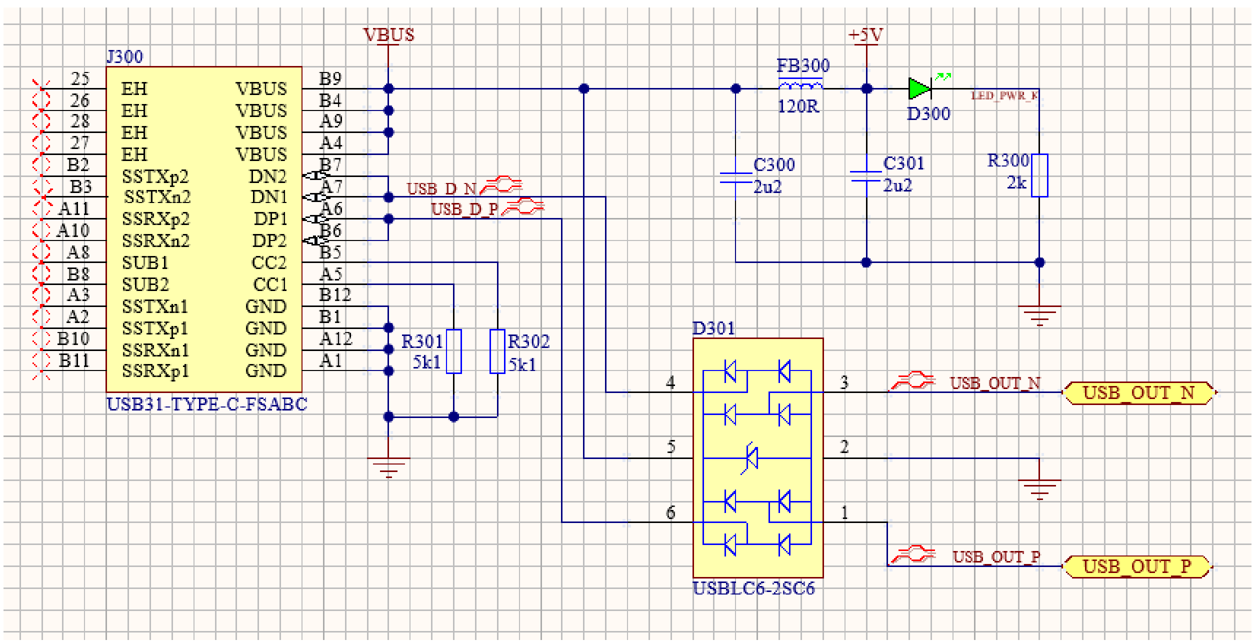


**Fig 7: USB-C Connector Schematic**

The USB-C Connector schematic consists of our USB-C connector paired with an ESD protection device at the differential pair lines. The power pin of the USB-C is connected to a pi filter, which serves to reduce noise at the power supply and improve the quality of power delivered to the circuit. Furthermore, an LED circuit is added at the end of the pi filter to indicate whether the circuit is being powered by the 5V coming out of the USB-C. Lastly, the USB-C is configured for USB 2.0 communication.

# 4. ATMEGA32U-AU Microcontroller

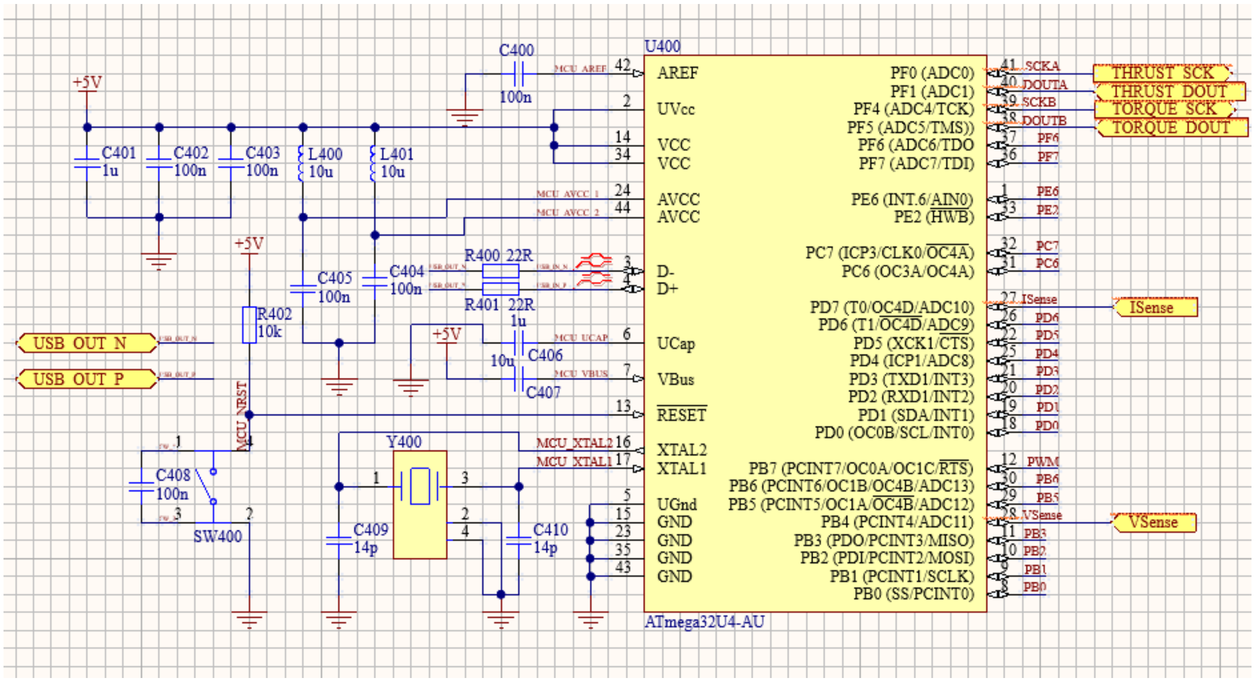

Fig 8: ATMEGA32U4-AU Schematic

The ATMEGA32U4-AU schematic consists of the microcontroller with its peripheral connections. The justifications for all the peripheral connections with reference to the datasheet is given below:

- 2 x 100nF capacitors at the VCC pins as standard practice
- 2 x LC Filters consisting of a 10uH inductor and 100nF capacitor connecting to each AVCC pin to eliminate noise (Section 24.7.2 of [3])
- 2 x 22 Ohm resistors connected in series with the differential pair pins (Section 21.5 of [3])
- 1 x 1uF capacitor connected to ground at UVCC (Section 21.5 of [3])
- 1 x 1uF capacitor connected to ground at UCAP (Section 21.5 of [3])
- 1 x 10uF capacitor connected to 5V at VBus (Section 21.5 of [3]). It is necessary to have a VBUS connection because it can help detect USB connection in the microcontroller (Section 21.11 of [3])
- A 5V active low logic connection for the RESET pin (Section 26.6.2 of [3])

- A 16MHz crystal oscillator with 14pF capacitors. The load capacitance of the crystal is 10pF and the shunt capacitance is 3pF [5]. We can assume the stray capacitance to be anywhere from 2pF to 5pF, so for the sake of convenience, we will stick to the stray capacitance being equal to the shunt capacitance (i.e. 3pF) [6]. This gives us the external load capacitance as [6]:

$$C_{EXT} = 2 * (C_{LOAD} - C_{STRAY}) = 2 * (10 - 3) = 14pF$$

# References


[1] HX711 Datasheet: 24-Bit Analog-to-Digital Converter (ADC) for Weigh Scales
[2] Modifying the HX711 Breakout Board for 3.3V operation
[3] ATMEGA16U4/ATMEGA32U4: 8-bit Microcontroller with 16/32K bytes of ISP Flash and USB Controller
[4] INA21x Voltage Output, Low- or High-Side Measurement, Bidirectional, Zero-Drift Series, Current-Shunt Monitors
[5] TXC 7M Series SMD Crystal Datasheet
[6] How to calculate the value of crystal load capacitors?