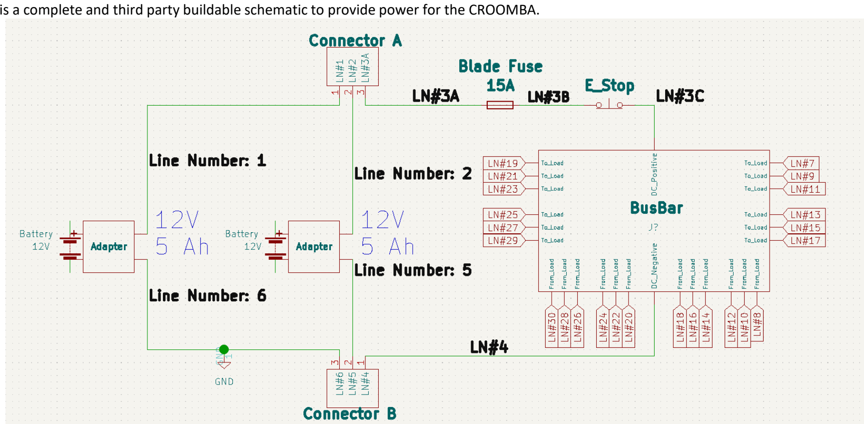
Signoff Request - 9/14

Saturday, September 3, 2022 11:00 AM

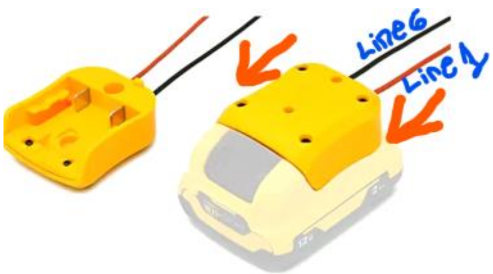
What it is Doing

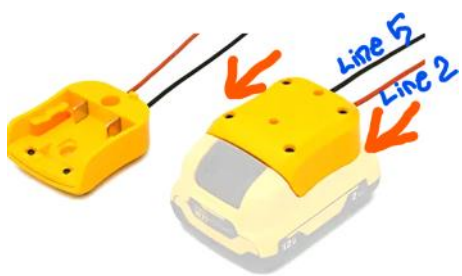
This is a complete and third party buildable schematic to provide power for the CROOMBA.



To assist with buildability, line numbers in the schematic will be marked on wires with colored tags :

The Batteries will be connected to the adapters as shown here:



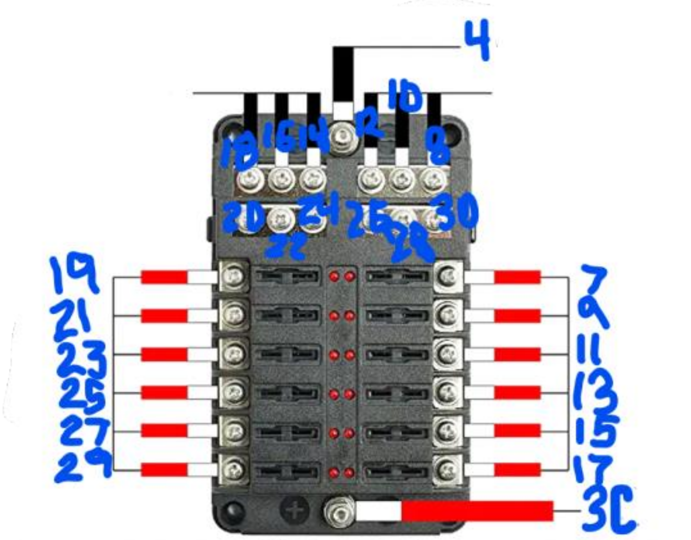


Connectors A & B will be made using terminal connectors and the line number labelled as follows :

The Blade Fuse will be connected between line numbers 3A and 3B as shown:

The on/off switch will be connected between line numbers 3B and 3C as shown here:

To complete the circuit, the busbar will be wired and labelled as follows:



[1] Batteries
[2] Adapters
[3]E-Stop
[4]Bus Bar
[5]Wires
[6]Terminal Connectors
[7]Blade Fuses
[8]Micro USB Breakout
[9]USB C Breakout

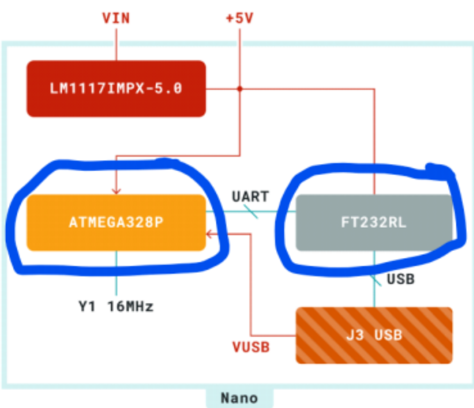
Constraints (FOR BUCK CONVERTER COMPONENT CONSTRAINTS SEE OTHER SIGNOFF REQUEST PLEASE)

Batteries- 12V Nominal output max of 5 amps in one hour before voltage begins to drop.
Wires- 14 gauge carry a maximum current of 15 Amps
Terminal Connectors- Rated for the gauge wire they are sized for.
Bus Bar- 100 Amp maximum current
E-Stop- 20 Amps at 12 Volts
Blade Fuses- 14 gauge 20 amp is listed as maximum current
Arduino Every- The USB port needs to kept open for serial communication between the Pi. It has an on board DC/DC converter input is 7-21V.

1. The power system must be portable. No plugs because they would get tangled.
2. Prevent fire hazard with overcurrent protections.
3. Distribute voltage and current to all components.
4. The Arduino and Raspberry Pi require a low ripple input voltage. This constraint is referred to as a ripple rejection and will require simulation in the Analysis to fully quantify.
   4a. Arduino - The power for this system will enter through an onboard component called a Low Drop Out (LDO) Linear Voltage Regulator. The specific model used is LM1117IMPX-5.0. The Constraint for this comes from the maximum peak to peak voltage ripple this component can successfully filter out. The power then enters the ATMEGA328P and FT232RL. The voltage tolerance for these two components determine the allowable ripple.

3 Functional Overview

3.1 Block Diagram



ATmega48A/PA/88A/PA/168A/PA/328/P

29. Electrical Characteristics – (T_A = -40°C to 85°C)

29.1 Absolute Maximum Ratings*

Operating Temperature	-55°C to +125°C
Storage Temperature	-65°C to +150°C
Voltage on any Pin except RESET with respect to Ground	-0.5V to V_{CC}+0.5V
Voltage on RESET with respect to Ground	-0.5V to +13.0V
Maximum Operating Voltage	6.0V
DC Current per I/O Pin	40.0mA
DC Current V_{CC} and GND Pins	200.0mA

*NOTICE: Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or other conditions beyond those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

29.2 DC Characteristics

29.2.1 ATmega48A DC Characteristics

Table 29-1. ATmega48A DC characteristics - T_A = -40°C to 85°C, V_{CC} = 1.8V to 5.5V (unless otherwise noted)

Symbol	Parameter	Condition	Min.	Typ.[1]	Max.	Units
		Active 1MHz, V_{CC} = 2V		0.2	0.55	mA
		Active 4MHz, V_{CC} = 3V		1.2	3.5	mA

Table 3.4 UART Interface and CUSB Group (see note 3)

Notes:

1. The minimum operating voltage VCC must be +4.0V (could use VBUS=+5V) when using the internal clock generator. Operation [illegible] using an external crystal oscillator.
2. For details on how to use an external crystal, ceramic resonator, or oscillator with the FT232R, please refer Section 7.6
3. When used in Input Mode, the input pins are pulled to VCCIO via internal 200kΩ resistors. These pins can be programmed to gently pull low during USB suspend (PWREN# = "1") by setting an option in the internal EEPROM.

 8

FTDI Chip

FT232R USB UART IC Datasheet
Version 2.16

Document No.: FT_000053 Clearance No.: FTDI# 38

The maximum Ripple Allowed On the output of the LDO when both of these Components are considered is **1 V pk-pk**

The LDO Regulator has a ripple rejection of **75dB**:

Thermal Regulation	T_A = 25°C, 30-ms pulse			0.01	0.1	%/W
Ripple Regulation	f_{RIPPLE} = 1 20 Hz, $V_{IN} - V_{OUT}$ = 3 V V_{RIPPLE} = 1 V_{PP}	T_J = 25°C		75		dB
		over the junction temperature range 0°C to 125°C	60			
Adjust Pin Current	T_J = 25°C			60		µA
	over the junction temperature range 0°C to 125°C				120	
Adjust Pin Current Change	10 ≤ I_{OUT} ≤ 80 0mA, 1.4 V ≤ $V_{IN} - V_{OUT}$ ≤ 10 V	T_J = 25°C		0.2		µA
		over the junction temperature range 0°C to 125°C			5	
Temperature Stability				0.5%		
Long Term Stability	T_A = 125°C, 1000 Hrs			0.3%		
RMS Output Noise	(% of V_{OUT}), 10 Hz ≤ f ≤ 10 kHz			0.003%		

(4) The dropout voltage is the input/output differential at which the circuit ceases to regulate against further reduction in input voltage. It is measured when the output voltage has dropped 100 mV from the nominal value obtained at $V_{IN} = V_{OUT}$ + 1.5 V.
(5) The minimum output current required to maintain regulation.

Therefore the maximum allowable input ripple is:

$$75 = 20\log_{10}\left(\frac{\text{input Ripple}}{\text{output Ripple}}\right) \text{"1"}$$

$$10^{\frac{75}{20}} = \text{input Ripple}$$

$$\boxed{\text{Ripple} = 10^{\frac{75}{20}} \approx 5\ V_{pk\text{-}pk}}$$

5V pk-pk

The Logic line for the H bridge drivers is powered through an on board L78M05 LDO which has a ripple rejection of 62 dB. The datasheet for the MOSFET of the driver indicates an absolute maximum in the logic line of 7V which indicates an output on the LDO of at most 2V pk-pk. With the ripple rejection the LDO is capable of this indicates a maximum input ripple of **2.5 V pk-pk**

4b. Raspberry Pi - Here the power supply of the Raspberry Pi is used to determine the acceptable peak to peak voltage ripple.

Output	
Output voltage:	+5.1V DC
Minimum load current:	0.0A
Nominal load current:	3.0A
Maximum power:	15.0W
Load regulation:	±5%
Line regulation:	±2%
Ripple & noise:	120mVp-p
Rise time:	100ms maximum to regulation limits for DC outputs
Turn-on delay:	3000ms maximum at nominal input AC voltage and full load
Protection:	Short circuit protection Overcurrent protection Over temperture protection
Efficiency:	81% minimum (output current from 100%, 75%, 50%, 25%)
Output cable:	1.5m 18AWG
Output connector:	USB Type-C

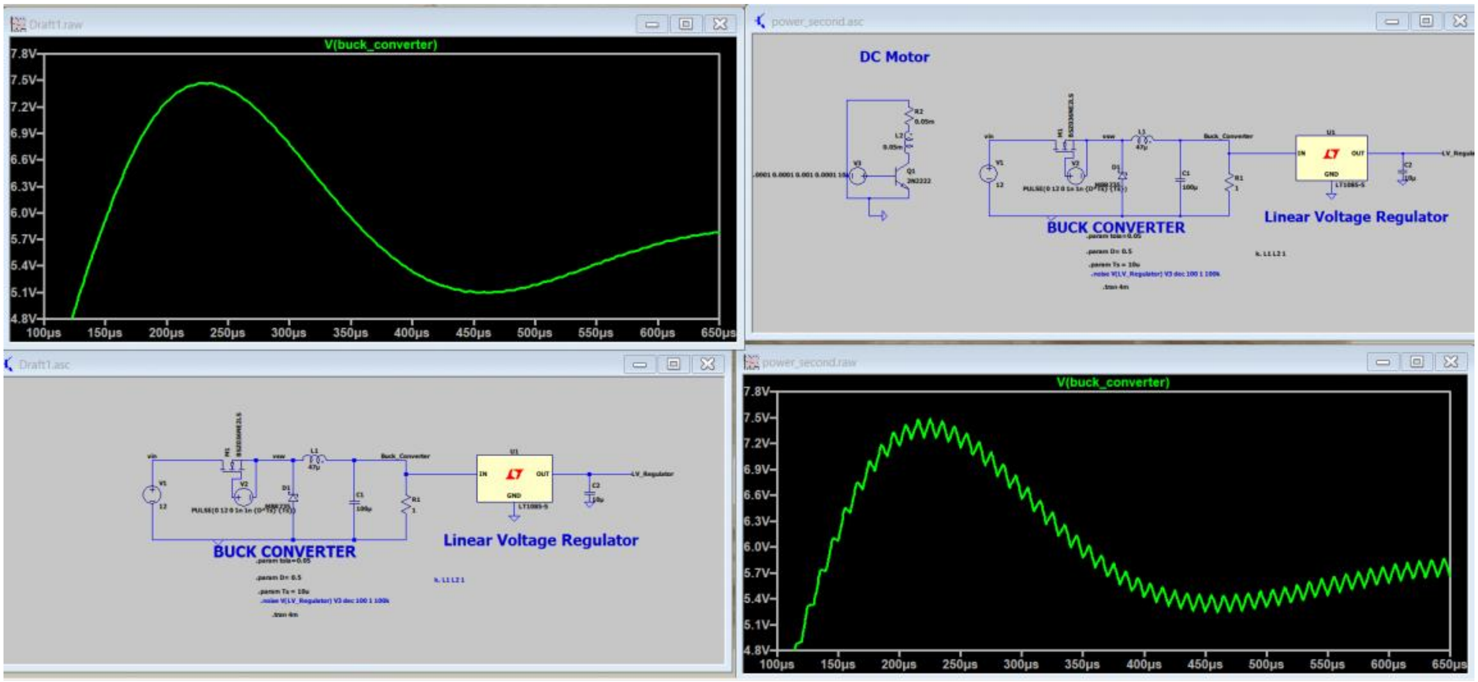
Input

0.12V pk-pk

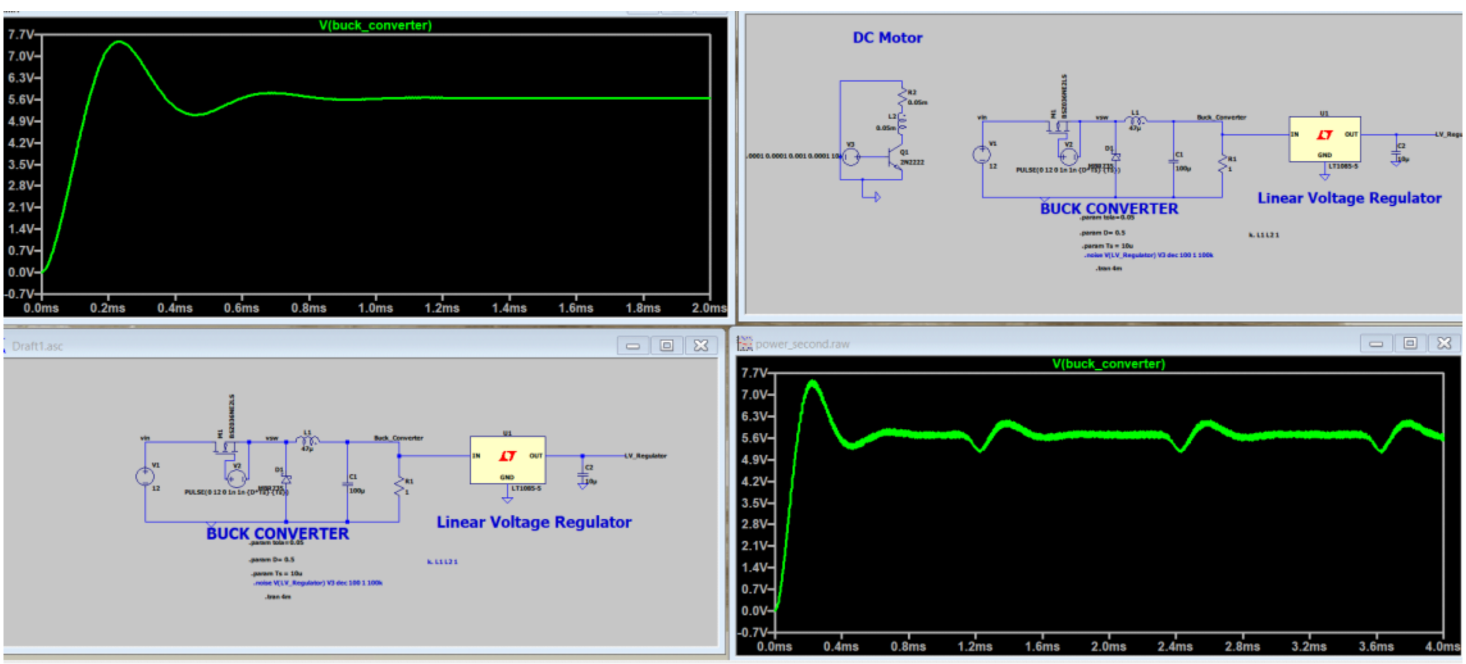
Analysis

Noise Simulation

In order to analyze the noise in the system we must simulate a ripple in a buck converter and come up with an implementable s olution for it. The Phenomenon of a ripple in the buck converter's voltage output is caused from a time varying magnetic flux density (when the inductor of the motor's field collapses from starting and stopp ing) coupling into some part of an adjacent system. The circuit component that is doing the coupling is an inductance. Whether it is a discrete inductor component or an inductance that is present in all real world wires is irrelevant. This is described in Maxwell's third equation: $\nabla X E = -\frac{\delta B}{\delta t}$
The ripple will therefore be modelled by coupling an inductor that is being switched on and off into a buck converter simulat ion:

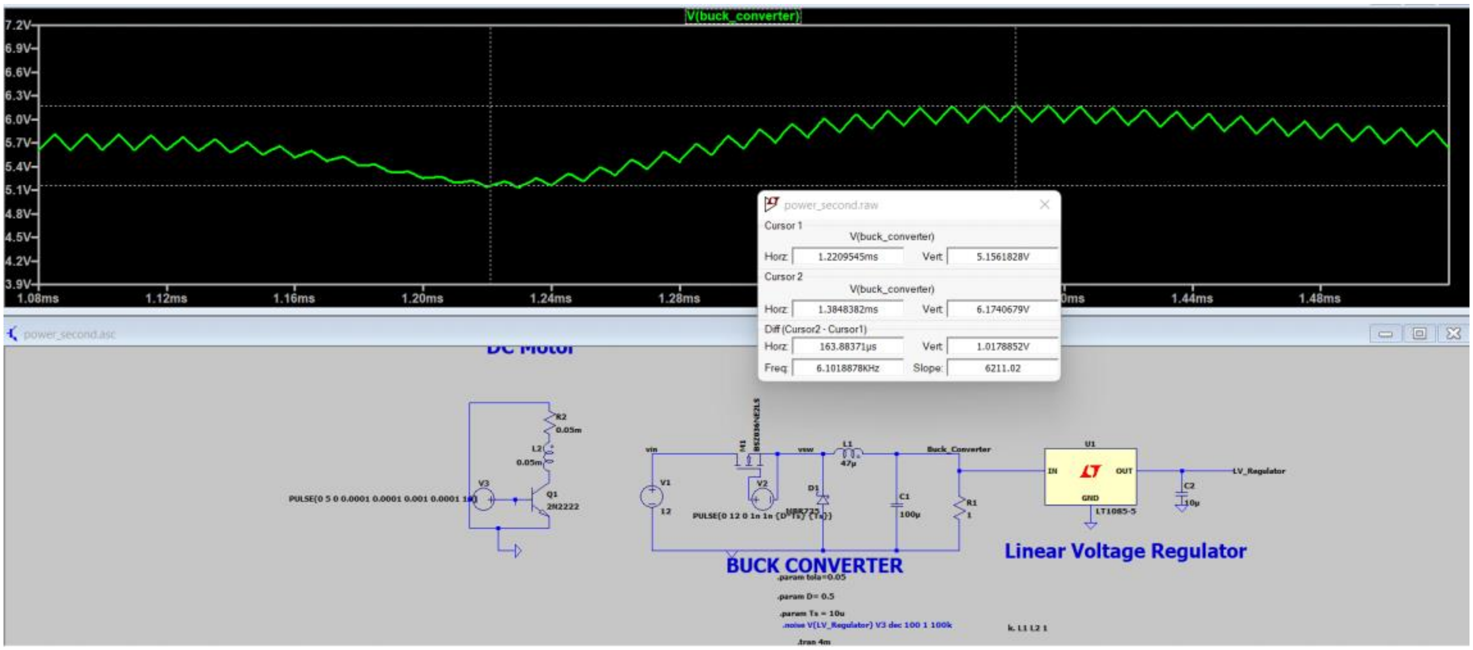


It can be seen from this figure that the ripple is seen on the output of the simulated buck converter. This figure shows the overall response in Comparison:



In the simulation, it is seen that while the initial overshoot stays more or less the same the steady state output has much l arger ripples that may cause what is known as a "Brown out" in sensitive Croomba systems if it is not controlled.

It will be demonstrated that a capacitor in parallel alleviates this problem and the response is then compared to maximum peak to peak voltage limits:

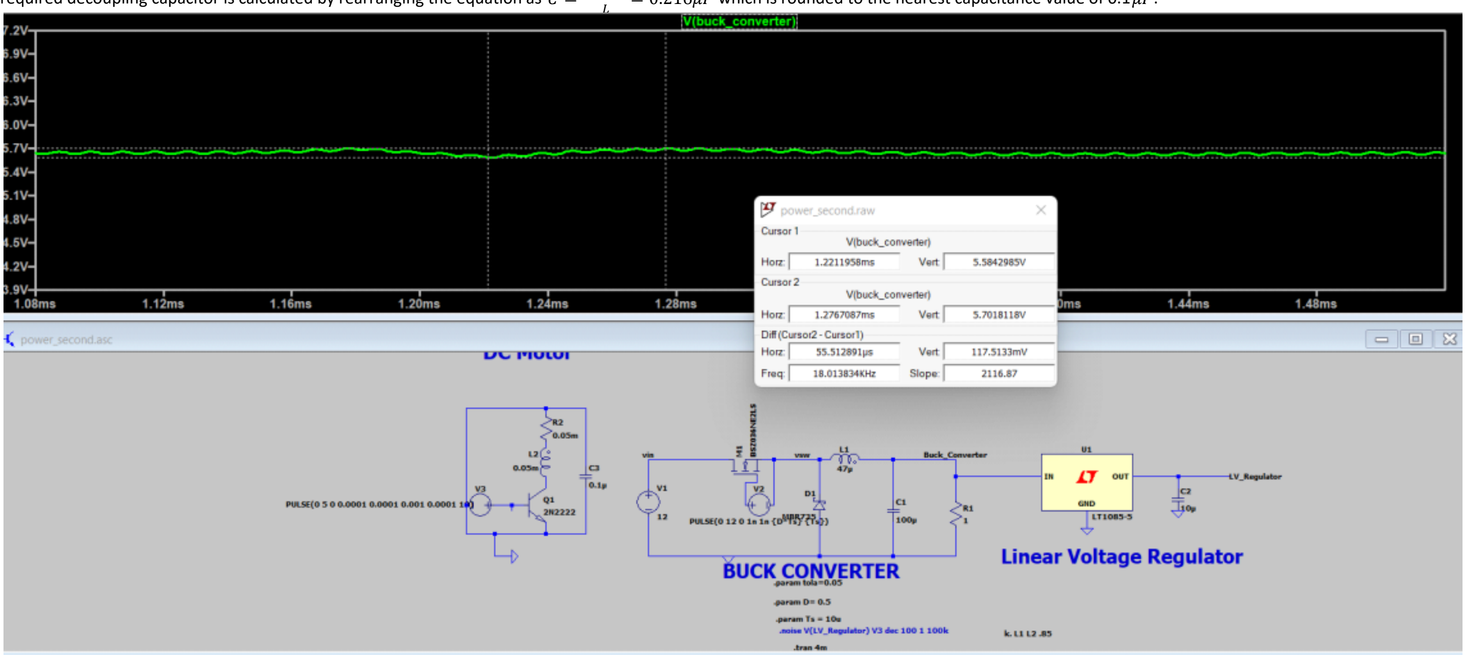


Here it can be seen that the voltage ripple is about 1.00V peak to peak. This puts the Design out of Specifications for the following components:

Arduino: 5V pk-pk
Raspberry Pi: 0.12V pk-pk
LM298N: 1V pk-pk

A capacitor is used to decrease coupling by using the frequency of the buck converter(100kHz) and the inductance of the inductor(47μH) with the following formula: $f = \frac{1}{2\pi\sqrt{LC}}$

The required decoupling capacitor is calculated by rearranging the equation as $C = \frac{(\frac{1}{2\pi f})^2}{L} = 0.216\mu F$ which is rounded to the nearest capacitance value of $0.1\mu F$.



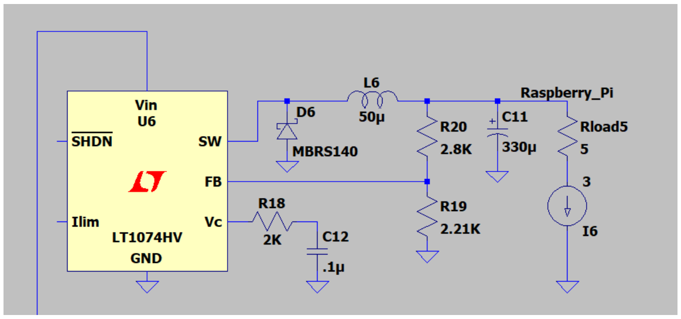
Here it can be seen that the voltage ripple is 0.117V peak to peak. This affects the Specifications for the following components:

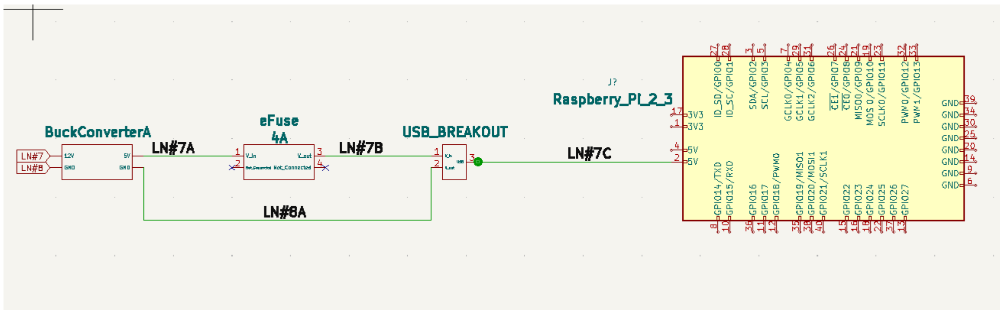
Arduino: 5V pk-pk
Raspberry Pi: 0.12V pk-pk
LM298N: 1V pk-pk

Here various Worst Case currents and voltages will be analyzed. In order to analyze the voltages and currents for the circuit, the loads across the bus bar must be estimated based and a noise analysis performed where possible. The analysis will proceed with a line by line estimation of the loads. Then conclude with the total load across the bus bar line numbers 3D & 4

Line 7A & 8A:

Buck Converter A >> eFuse >>Raspberry Pi





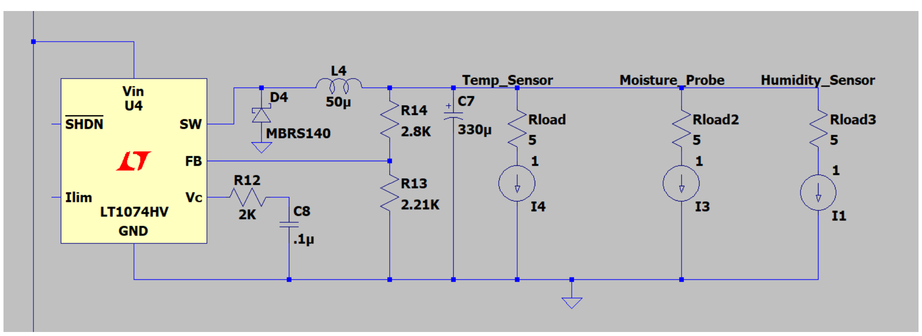
Worst Case Analysis

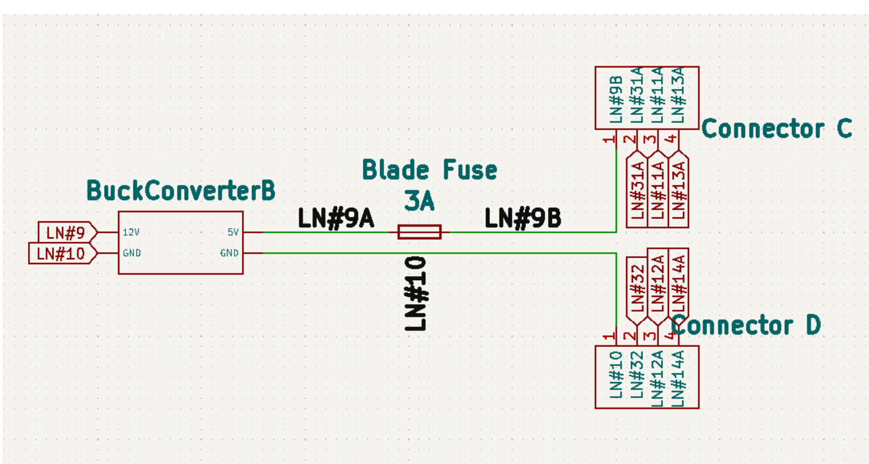
The base operating system has been installed on the Pi. It has been measured to consume 0.5 A at 5V during normal operation and **1A at 5V** during start up. There will be four ultrasonic sensors that each consume 0.02A at 5V for a total of **0.08A at 5V** provided through the Pi. There will be a LIDAR unit that requires **0.1A** of current at **5V** provided through the Pi. An HD camera will be used that consumes **0.15A at 5V** provided through the Pi. A light that consumes **0.6A at 5V** will be provided through the Pi. There will be an ESP32 connected that uses a maximum of **0.08A at 3.3V** provided by the Pi. The input to the buck converter to provide this will have to be 5.1 * 2.01 / 12 = **.854A at 12V.** The buck converter efficiency at this current is about 84%, so to account for this: 0.854 * (1- 0.84 + 1) = 0.9906 **A at 12V**

The Worst Case current and voltage of this line is **0.996 at 12V**

Line 9A & 10

This line will have the current and Voltage Requirements of the three environmental sensors for the CROOMBA. The change was made from previous signoffs to improve efficiency and reduce noise. The noise reduction happens from decreasing the total number of buck converters, which are a source of electrical noise. The buck converters operate at an efficiency of about 75% at a load of about 0.5 Amps, but operate at an efficiency of about 83% at a load of 1.5 Amps.



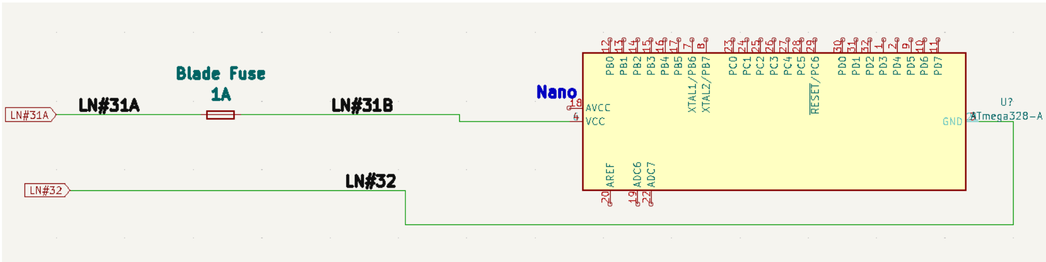


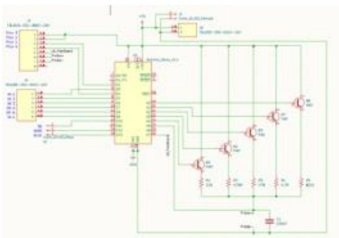
The input to the buck converter to provide this will have to be 5.1 * (0.785+0.785+0.3) / 12 = **0.7948A at 12V.** The buck converter efficiency at this current is about 83%, so to account for this: 0.7948*(1-0.83 + 1) = **0.9299A at 12V**

The Worst Case current and voltage of this line is **0.929A at 12V** (Please see Lines 31A & 32, 11A & 12A, 13A & 14A for Calulations as a reminder this line is the sum of those three lines)

Line 31A & 32:

Buck Converter >> blade fuse >>Arduino Nano





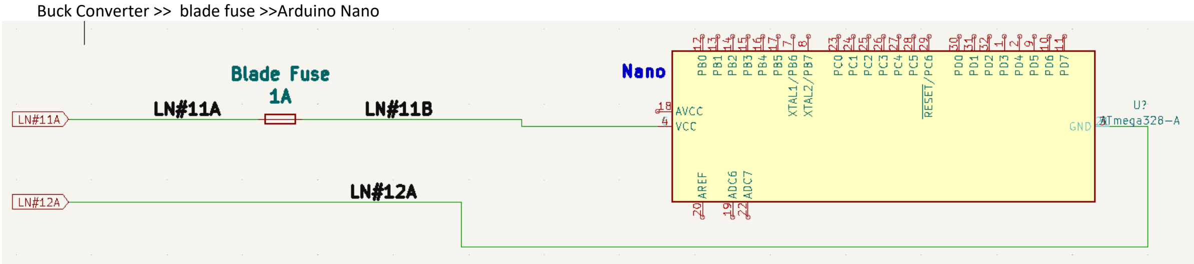
Worst Case Analysis

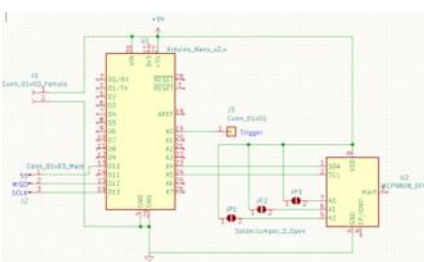
The Moisture content probe being operated by this Nano will require a maximum of 0.785 A at 5V. The calculations for this can be found in the environmental sensing signoff requests. "As shown in the schematic, this circuit is using 18 I/O pins, 14 of which will be set for output. Furthermore, only one of the auto-ranging ohmmeter pins will be outputting at a time. Along with the MCU, the auto-ranger is able to pull 0.206962 Amps through whichever transistor is active (based on LTSpice simulation created for that signoff). Adding the max board current, max pin current for each I/O pin, and the separate auto-ranger current, the maximum current pulled by this module at any point is 0.785 Amps. This measurement is a maximum however, all I/O pins will not be on at the same time or pulling max current under normal operation."

The Worst Case current and voltage of this line is **0.785A at 5V**

Line 11A & 12A:

Buck Converter >> blade fuse >>Arduino Nano





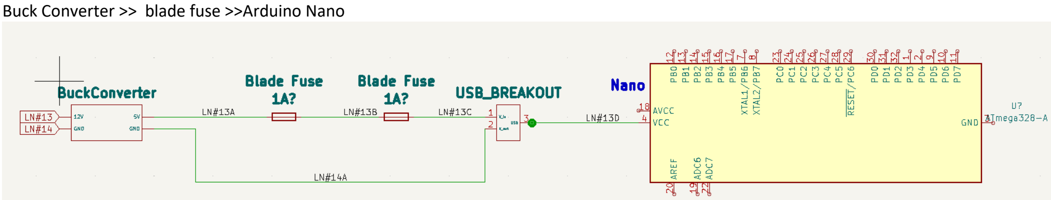
Worst Case Analysis

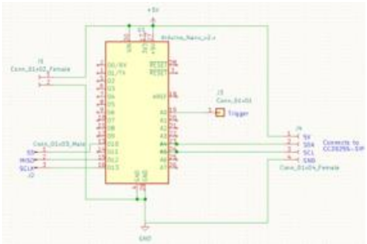
The Temperature probe being operated by this Nano will require a maximum of 0.785 A at 5V. The calculations for this can be found in the environmental sensing signoff requests. "This subsystem has 6 I/O pins being used as outputs from the Nano. The temperature sensor chip that is on its own power will pull 200 µA for its operating current based on its [datasheet](). Adding these values along with the inherent 19 mA board current shows 259.2 mA as the max current."

The Worst Case current and voltage of this line is **0.785A at 5V**

Line 13A & 14A:

Buck Converter >> blade fuse >>Arduino Nano





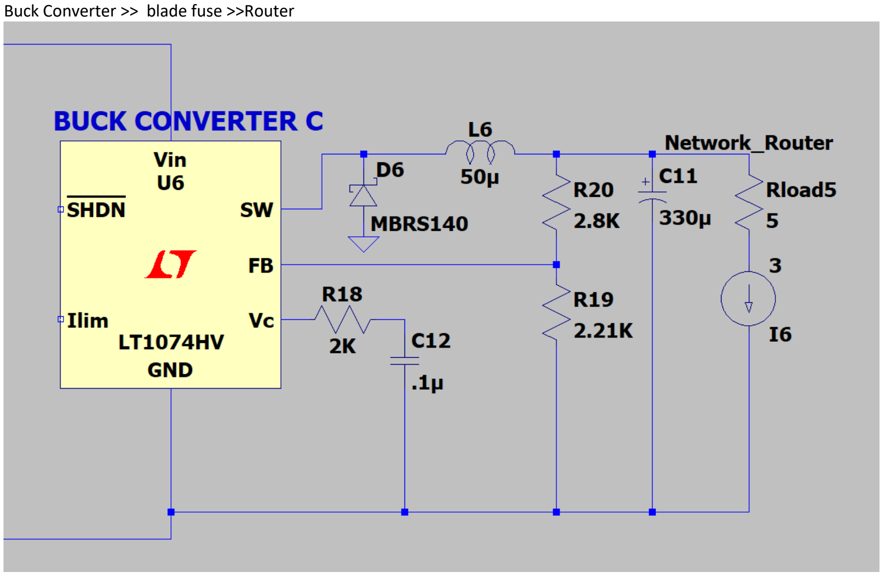
Worst Case Analysis

The Humidity Sensor being operated by this Nano will require a maximum of 0.3 A at 5V. The calculations for this can be found in the environmental sensing signoff requests. "This system also has 6 I/O pins in use and a separate sensor chip which, based on the datasheet, will pull a supply current of 750 mA." Adding all current values gives a total of 259.75 mA.

The current and voltage of this line is **0.3A at 5V**

Line 15 & 16:

Buck Converter >> blade fuse >>Router



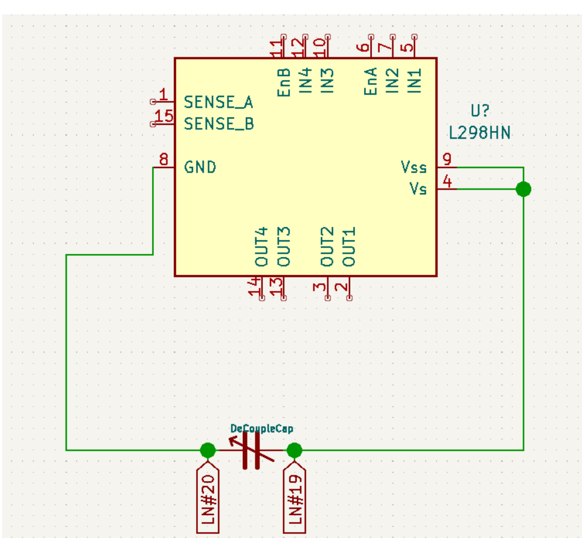
Worst Case Analysis

The power calculations found in the Navigation Signoff request indicate the router will use **1A at 5V**."The nano router requires a constant voltage of 5 Volts and a constant current of 1 Amp for operation [3]. Over one hour, the N300 router would use approximately 1 Amp Hours (AH) and 5 Watt Hours (WH)." The input to the buck converter to provide this will have to be 5.1 * 1 / 12 = **0.425A at 12V.** The buck converter efficiency at this current is about 83%, so to account for this: 0.425* (1- 0.83 + 1)=**0.4973A at 12V**

The current and voltage of this line is **0.4973A at 12V**

Line 19 & 20:

Blade Fuse>>Blade Fuse>>L298N



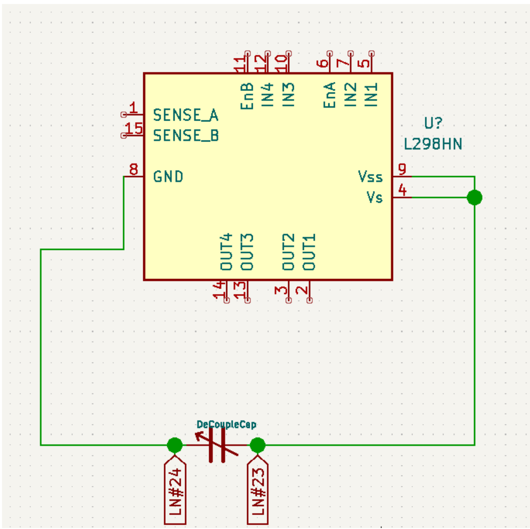
Worst Case Analysis

This line will provide the power used by the two DC motors that will move the CROOMBA and the logic line for the L298N. According to the datasheet for the H-bridge driver the logic supply voltage is typically **5V** and the current is at a maximum (**worst case**) of **0.036A** . The locked rotor current for the motors selected have been told to me to be : 1.8 amps * 2 motors = 3.6 A

The worst case current and voltage of this line is **3.64A at 12V**

Line 23 & 24:

Blade Fuse>>Blade Fuse>>L298N



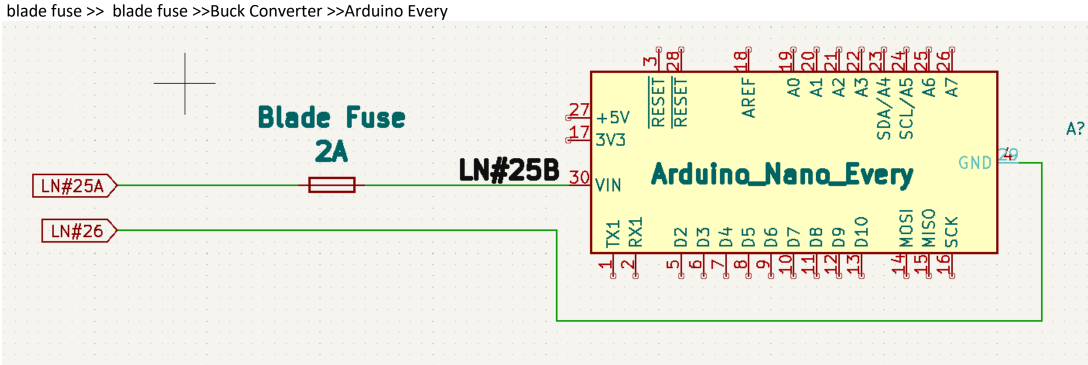
Worst Case Analysis

This Line will provide power to a rotational motor, a much smaller linear actuator, and the logic level of the MOSFET. According to the datasheet for the H-bridge driver the logic supply voltage is typically **5V** and the current is at a maximum (**worst case**) of **0.036A** . The motors will be powered off a separate source than the Arduinos will because they need higher voltage and will steal more current. The linear actuator has a stall current of 650 mA based on the product page while the rotational motors stall current is 1.6 Amps based on its website. The motor driver running these two can pull up to 36 mA internally when it is operating the motors based on the datasheet. This means that the total current the motors in this system will pull comes out to 2.246 Amps.

The worst case current and voltage of this line is **2.27A at 12V**

Line 25B & 26:

blade fuse >> blade fuse >>Buck Converter >>Arduino Every



Worst Case Analysis

This line will provide the power for the Arduino Every. The arduino every has an on board MPM3610 DC to DC converter that, according to the manufacturer operates at 86% efficiency at 12V input. The maximum current the DC/DC converter can handle according to the datasheet is **1.2A at 12V.** At 86% efficiency the board will require 1.2*(1-0.86+1) = **1.368 A at 12** .

The current and voltage of this line is **1.368A at 12V**

Line 27 & 28:

Not Connected

Line 29 & 30:

Not Connected

Line 3D & 4:

The total power required will be 1.368+2.27+3.64+0.929+0.996=**9.203A at 12V**

The two 5 Ah batteries in parallel should be able to provide 9.203 A for 10/9.203 = **1.0866 Hours**