The Muon Data Acquisition system: the 4.7 Volt loss of power issue

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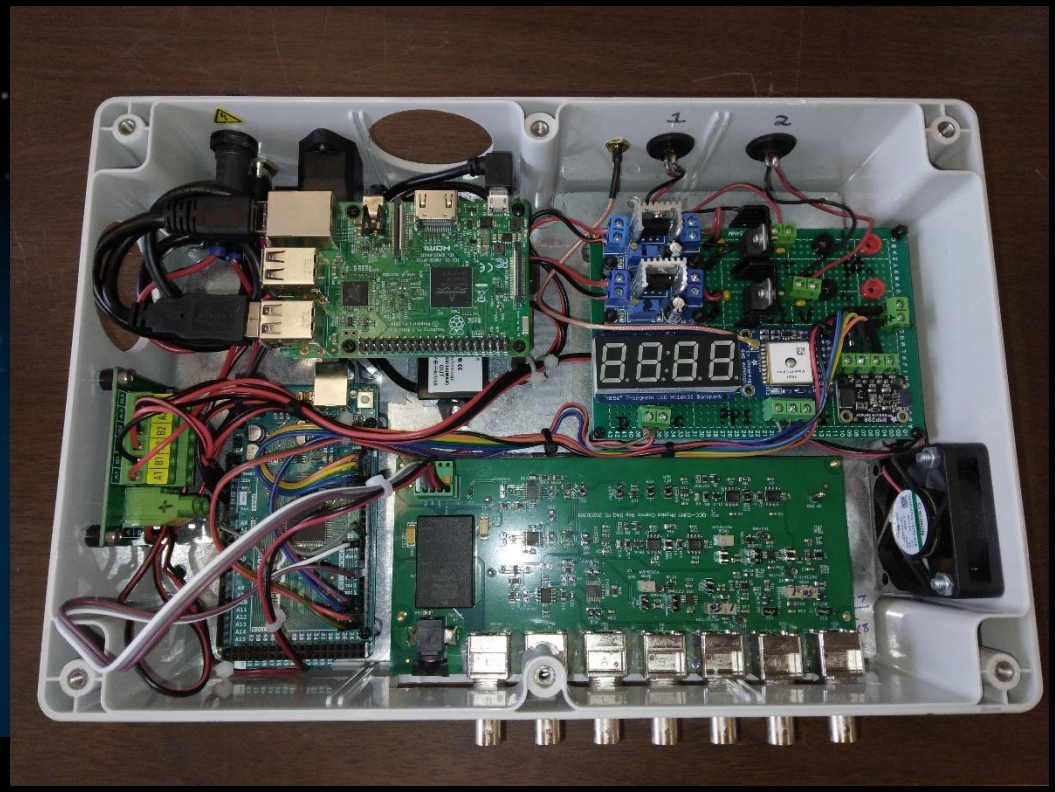


Abstract

Queensborough Community College, City University of New York, is constructing a cosmic ray muon detector array for undergraduate research. Each detector is composed of a plastic scintillator sheet that converts particle kinetic energy into a flash of light, a Photomultiplier Tube (PMT) that converts the light flash into an electrical pulse, and a Data Acquisition box (DAQ) that detects the electrical pulses and time stamps them with GPS. Each DAQ box houses voltage regulators to power PMTs, a DC-DC converter to step down the input voltage, a Raspberry Pi 3B+ computer with internet access, an Arduino Mega microcontroller which powers and communicates with a GPS receiver and other low voltage electronics.

The power in and out of all 20 DAQ boxes was measured. Tests showed that in several boxes their Arduino's 5V output terminal only put out around 4.7V, and in some cases even lower. This could lead to intermittent power to the Arduino and the components powered by the Arduino. To understand the issue and ensure the Arduino receives enough power from the Raspberry Pi, we conducted stress tests across multiple scenarios to duplicate the observed electrical inconsistencies and solve them.

The power distribution

A power supply adapter brick converts 120VAC to +15V DC, 3.34A 50W max, which powers a DC-DC converter (7 – 20 VDC input) with 5V DC output (3A,15W max). The DC-DC converter powers a Raspberry Pi 3B+, which powers an Arduino Mega. We measured that when lower than 4.7 V is applied the Pi operated intermittently and its red LED light turns off. Power supply adapters typically purchased with the Pi 3B+ are rated to output 5.25V, 2.5A max. Arduino Mega's are often powered from a computer USB, and USB 2.0 output is specified at 5V +/- 0.25V.

https://www.digikey.com/en/products/detail/cui-inc/SDI50-15-U-P5/102-3797-ND/5297446

https://www.amazon.com/gp/product/B09TFLZMC2/ref=ox_sc_act_title_1?smid=A1VTL661FOEJB1&th=1

Voltage drops across different components

The DC-DC converter powers the Raspberry Pi 3B+ through its micro-USB input. The power cable loss between the DC-DC converter and the Pi is specified at 70 –150mV typical, but the total drop depends on the load and temperature. The Pi 3B+ power specifications recommend 5.1V - 5.2V through its micro-USB power input, a range of 4.75V- 5.25V, and above 4.63V is required to operate. The Pi 3B+ has a fuse after its micro-USB input, which can cause a drop of 0.04V to 0.225V depending on current draw and component temperature. The Pi also has an over-voltage protection Zener diode which under normal operating voltage does not drop any voltage. The Pi is connected to a monitor via HDMI, a mouse and a keyboard via USBs, and powers the Arduino Mega.

The Pi powers the Arduino Mega through a short (~12 inch long) USB-A to USB-B cable. The Arduino Mega specifications state the voltage required through its USB power input is 5V and that it typically provides 5V output. The Arduino Mega has a polyfuse which the USB-input power passes through to protect a computer's USB port from over-currents. This fuse can cause a voltage drop of about 0.1 - 0.2V. After the fuse is a MOSFET to switch between USB power and external wall power, with a small voltage drop 0.1 – 0.3V. The Arduino runs code and powers small electronics including a GPS receiver/antenna, LCD counter, atmospheric pressure & temperature sensors. Neither the Pi micro-USB power input nor the Arduino USB power input have a 5V regulator.

The total voltage drop from DC-DC converter to the Arduino Mega 5V-terminal output can be 310 mV – 875 mV:

Pi power cable: ~ 70 –150mV

Pi protection fuse: ~ 40 – 225 mV (using R_{fuse} 0.1 - 0.15 Ohm, and for I = 0.4A to 1.5 amp we get a V_{drop} = IR = 0.04V to 0.225V)

Arduino Mega polyfuse: ~ 100 – 200 mV

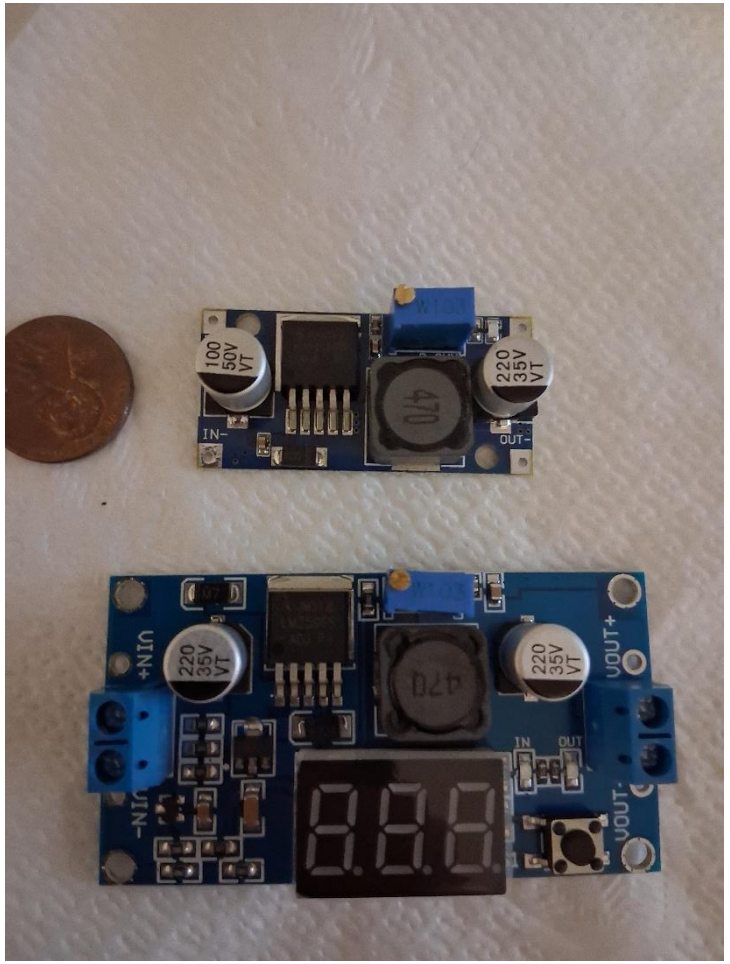
Arduino Mega MOSFET: ~100 – 300 mV

If the DAQ electronics draws high current the voltage drop could be too high causing power interruption. To ensure the Raspberry Pi is powered with sufficient voltage (5.2 – 5.3V) we can consider replacing the 5V output DC-DC converter with this variable DC-DC buck converter:

LM2596: 3.0 - 40V input to 1.5 - 35V output: https://www.amazon.com/dp/B0DBVYP91F?ref=ppx_yo2ov_dt_b_fed_asin_title&th=1

or

LM2596S: 4.0 - 40V input to 1.25 - 37V output, 2A, with LED Voltmeter Display:
https://www.amazon.com/dp/B0D2TRVBYQ?ref=ppx_yo2ov_dt_b_fed_asin_title&th=1



Arduino Mega 2560

5V output is 400mA max when powered by USB.

5V output is 900 mA when powered through power jack with 7V. The jack can take 7-12V. The higher the voltage, the lower the current.

The 3.3V output is 50 – 100 mA max when powered through USB or through the power jack. The 3.3V output draws power from the 5V through a second voltage regulator which has a max output of 150 mA.

https://docs.arduino.cc/resources/datasheets/A000067-datasheet.pdf -Page 8

LM317T 1.5A output current
https://www.digikey.com/en/products/detail/texas-instruments/LM317T/3701346?gclsrc=aw.ds&gad_source=1&gad_campaignid=17922795960&gclid=EAIaIQobChMI3MDzoJa2kAMV3mBHAR1DRyTlEAAYASAAEgJymPD_BwE

Adafruit BMP280 2.7 µA @ 1HZ sampling rate
https://cdn-shop.adafruit.com/datasheets/BST-BMP280-DS001-11.pdf

Adafruit LED HT16K33 Backpack
https://cdn-shop.adafruit.com/datasheets/ht16K33v110.pdf

Adafruit Ultimate GPS Breakout V3 (MTK3339) 25mA @ 3.3V, 1Hz sampling rate
https://cdn-shop.adafruit.com/datasheets/865datasheet.pdf

GPS External Antenna 4mA-20mA @ 3.3V
https://cdn-shop.adafruit.com/datasheets/GlobalTop-FGPMMOPA6H-Datasheet-V0A.pdf

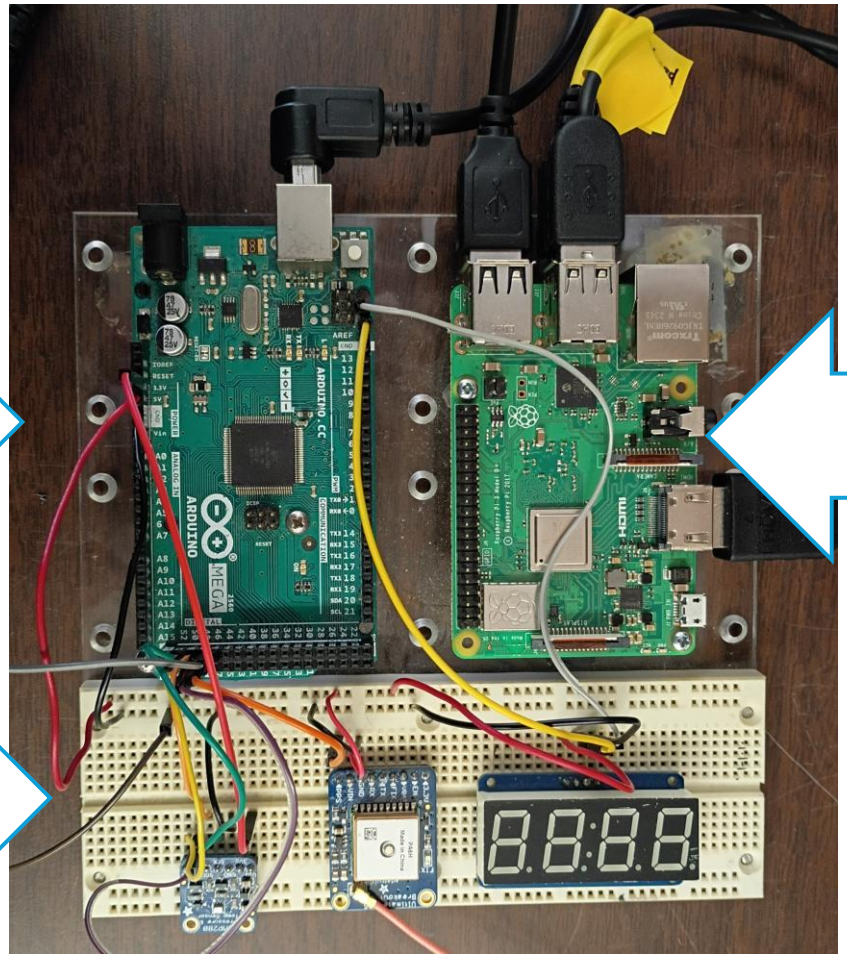
XBEE3 XB3-24Z8PT (Receiving / Transmitting) 15mA/135mA
https://docs.digi.com/resources/documentation/digidocs/pdfs/90001543.pdf

DAQ Box: Software Systems

- The Data Acquisition Box Software Systems is composed of different components whose goal is to collect data from the cosmic rays.

Arduino Mega 2560

BMP 280
GPS
LED Backpack



Raspberry Pi 3B+

DAQ Box: Software Issue

- As of now, the DAQ box is far from being ready. The current issue of power distribution to the fragile software components, alongside the lack of precise reading.
- The DC-DC converter is in charge of alimenting the Raspberry Pi -> Arduino-> Perfboard. If the DC-DC converter provide not enough voltage, the systems set up is put in jeopardy for it very susceptible to damage.
- The issue is some DC-DC converter provide 4.7 volts to the Raspberry Pi-> Arduino->Perfboard systems and we are concerning whether the systems can operate under such low voltage especially since the components specification ask for a stable 5V for use
- Therefore, we need to determine how much current the power supply need to provide? How much current does the software systems draw? (knowing this will help us determine whether the current provided by the power adapter is enough 3.4A) At what voltage the systems stops working?(knowing this help with the DC-DC converter issue) At what low voltage can the systems run (is it safe at 4.7 V)?

Initial Test

- Voltage of DC-DC
- Voltage of Arduino
- Voltage of Perfboard

Voltage of DC-DC converter

DC-DC converter	Value Written	Value Measured
1	4.77V	4.97V
2	4.7V	5.01V
3	4.7V	5.22V
4	4.7V	5.17V
5	4.4V	5.78V
6	4.77V	5.04V

Voltage DC-DC to Arduino

DC-DC converter	Value Written	Value Measured
1	4.77V	4.81V
2	4.7V	4.82V
3	4.7V	5.09V
4	4.7V	5.02V
5	4.4V	4.78V
6	4.77V	4.88V

Voltage of Perfboard

DC-DC converter	Pressure Temp	GPS	7-Segment LLED
1	4.81V	4.81V	4.81V
2	4.82V	4.82V	4.82V
3	5.09V	5.09V	5.09V
4	5.2V	5.2V	5.2V
5	4.78V	4.78V	4.78V
6	4.88V	4.88V	4.88V

Test Under Load

- Through this experiment we were able to determine the cause of the 4.7V issue is an unexpected voltage drop through the Raspberry Pi and Arduino Mega.

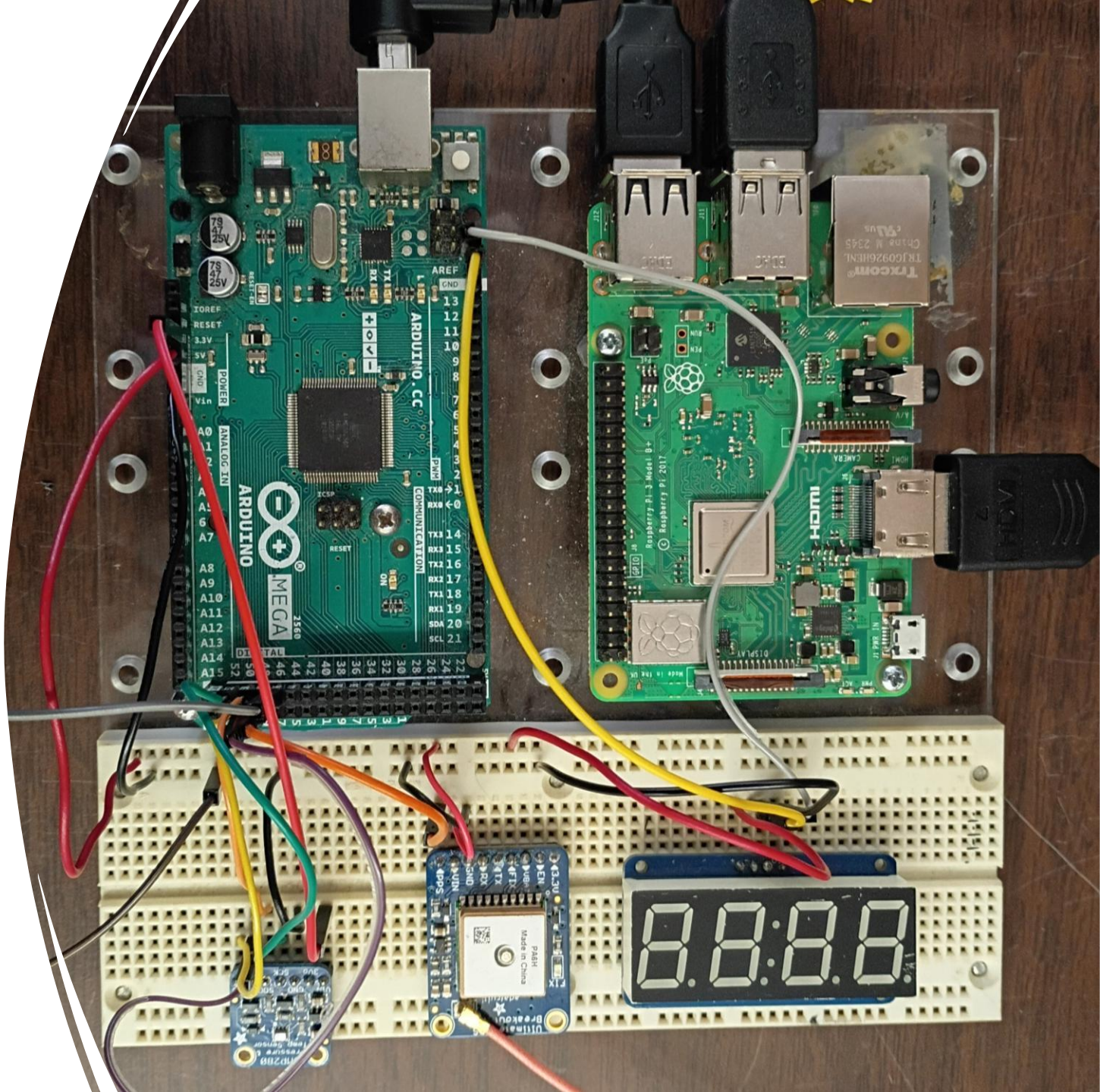
Results

DC-DC #	Value Written	I_AC adapter	V_ DC-DC	V_ R Pi	V_ Rail
0	5V/3A(max)	200mA	5.21V	5.14V	5V
1	4.7V	0.01A	dead	dead	dead
2	4.7V	0.018A	5.01V	dead	dead
3	4.7V	0.198A	5.22V	5.04V	4.88V
4	4.7V	0.192A	5.17V	5.08V	4.96V
6	4.77V	0.19A	5.09V	4.97V	4.805(±0.035)

Note: V_Rail is the voltage of Raspberry Pi.

Testing the limit of the DAQ Box software systems

- Baseline Test
- Variable Raspberry Pi
- Variable DC-DC converter
- Variable Power Supply



Experiment 1: Baseline

- This experiment goal is to determine the voltage and current in the perfboard (BMP280, LED counter, GPS) under a load.
- It was performed in three individual set, in which each components (Adafruit BMP280 Temperature & Pressure sensor, Adafruit LED Backpack Counter, Adafruit Ultimate GPS Breakout V3) was powered up by the Arduino and was receiving order from it.
- The load is applied through the Arduino which is connected to a computer. The Arduino is running an operational test on individual components to assure correct functionality.
- The result obtained during the operational test is used as guideline for future experiment. Under ample working condition the components should receive and consume set amount of voltage.

Results

	BMP 280	LED	GPS
Voltage	4.98V	4.97 V (+- 0.1)	4.97(+-0.1)
Current	0.88mA (+-0.1)	41.35mA (+-0.1)	23.4mA

Experiment 2: Variable Raspberry Pi

- This experiment goal is to determine the voltage and current of the components when the software systems is working under load and powered up by power adapter.
- Materials: Raspberry Pi, HP ZR2440W monitor, HP keyboard, HP mouse, Arduino Mega 2560, BMP 280, LED Backpack, Ultimate GPS, power adapter.
- Under different conditions (open monitor, close, run operational test, add mouse and remove) record the voltage and current values. This will determine the amount of voltage and current the components is receiving. And the amount of power consumed with each added components.

Results

Test #	Supply (V or A)	Measured Voltage	Measured Current	Conditions
1	5.25V---2.5A	5.13V	0.4205A (+- 0.01)	Bare
2	5.25V---2.5A	5.10V	0.44 A (+- 0.01)	+ monitor
3	5.25V---2.5A	5.10V	0.44 A (+-0.01)	+ keyboard
4	5.25V---2.5A	5.10V	0.44 A (+-0.01)	+mouse
5	5.25V---2.5A	5.05 (+0.03)	0.51 A (+- 0.01)	+code BMP
6	5.25V---2.5A	5.03 (+0.03)	0.51 A (+- 0.01)	+code LED
7	5.25V---2.5A	5.00 (+0.03)	0.55 A (+- 0.05)	+code GPS

Experiment 3: Variable DC-DC

- This experiment goal is to determine the voltage and current of the components when the software systems is working under load and powered up by a DC-DC converter.
- Materials: Raspberry Pi, HP ZR2440W monitor, HP keyboard, HP mouse, Arduino Mega 2560, BMP 280, LED Backpack, Ultimate GPS, power adapter, DC-DC converter.
- Under different conditions (open monitor, close, run operational test, add mouse and remove) record the voltage and current values. This will determine the amount of voltage and current the components is receiving. And the amount of power consumed with each added components.

Results

Test #	Supply (V/A)	Measured Voltage	Measured Current	Actual Current	Conditions
1	15V---3.34A	4.98	0.164(+-0.001)	=	bare
2	15V---3.34A	5.01	0.170(+-0.001)		+monitor
3	15V---3.34A	5.00	0.173(+-0.001)		+keyboard
4	15V---3.34A	5.00	0.177(+-0.002)		+mouse
5	15V---3.34A	5.00(+-0.01)	0.195(+-0.005)		+code BMP
6	15V---3.34A	4.97(+-0.01)	0.189(+-0.001)		+code LED
7	15V-3.34A	4.97	0.195(+-0.005)		+code GPS

Experiment 4: Variable Power Supply

- This experiment goal is to determine the voltage and current of the components when the software systems is working under load and powered up by a power supply.
- Materials: Raspberry Pi, HP ZR2440W monitor, HP keyboard, HP mouse, Arduino Mega 2560, BMP 280, LED Backpack, Ultimate GPS, power supply.
- Under different voltage from 5V and below record the voltage and current values. This will determine the amount of voltage and current the components is receiving.

Results

Test#	Supply (V/A)	V_ Output	V_ PI	V_ Rail	I_ Output
1	5.4V	5.40V	5.34V	5.16V	0.5A(±0.01)
2	5.2V	5.21V	5.15V	4.995V(±0.015)	0.49A(±0.01)
3	5V	5.00V	4.93V	4.78V	0.49A(±0.01)
4	4.9V	4.93V	4.86V	4.73V	0.47A(±0.01)
5	4.8V	4.80V	4.73V	4.595(±0.015)	0.50A(±0.01)
6	4.7V	4.78V	4.72V	4.51V	0.49A(±0.01)
7	4.6V	4.66V	4.59V	4.415(±0.015)	0.51A(±0.01)
8	4.5V	4.55V	4.48V	4.27V	0.52A(±0.01)
9	4.2V	4.26V	4.19V	3.97V	0.51A(±0.01)

Conclusion

In conclusion, the recommended input voltage for the Raspberry Pi needs to be higher than 5V. Based on my observation, some of the DC-DC converters were damaged as they demonstrated fluctuating voltage values and current. Others showed that the output value is partially dependent on the power supply and DC-DC converter. If the power supply is not providing high enough voltage, then due to the voltage drop across the Raspberry Pi, the Arduino might receive less than 5V input resulting in a less than 5V output in the Perfboard.

Works Cited

- https://www.adafruit.com/product/746?srsltid=AfmBOor9dI8FBX_N0nBcIza_M_qpDuTm0c-vx4EAro_rR6RT0jlWSl5V
- https://pip-assets.raspberrypi.com/categories/532-raspberry-pi-3-model-b/documents/RP-008338-DS-2-raspberry-pi-3-b-plus-product-brief.pdf?disposition=inline
- https://learn.adafruit.com/adafruit-led-backpack/1-2-inch-7-segment-backpack-arduino-wiring-and-setup