



## Co-op End-Of-Block Presentation

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**Engineering Co-op I**

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# About Me

- Cornell University
  - Class of 2020
  - Rising Senior
- Major: Electrical and Computer Engineering
- Minor: Business
- Interested in embedded systems and board-level design
- Member of Cornell Rocketry Team
  - Radio Communications
  - Test and Validation
- Enjoy playing music
- Crew



# A&T Rotations

- Electronics
- F35
- V22
- Body Cell/EDM/Deburr
  - EDM = Electrical Discharge Machining
- Was not FAA trained
  - Couldn't touch anything



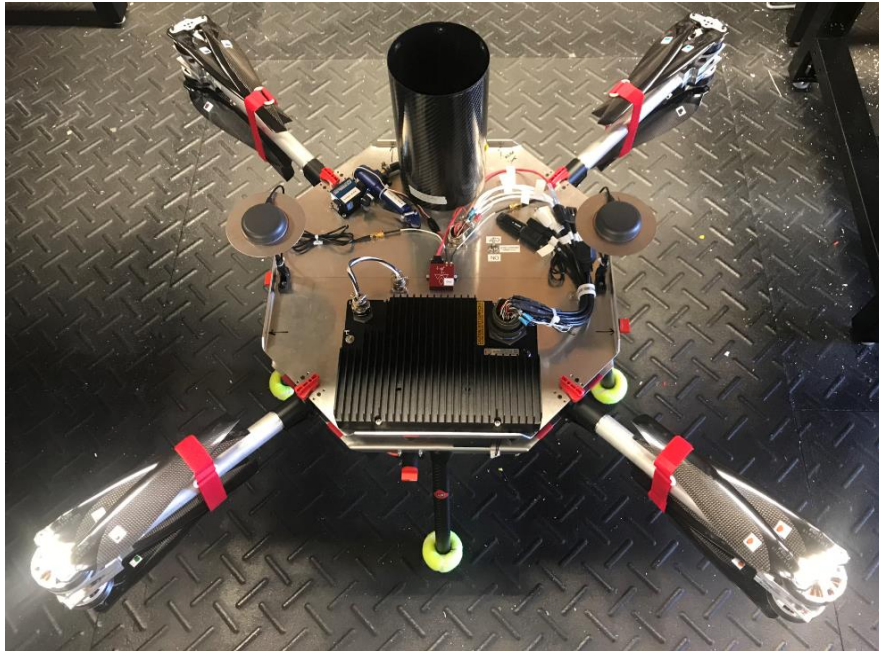
# V-22 Again





# AFSA Program

- Autonomous Flight Systems for Air Vehicles
- Part of Innovation Group



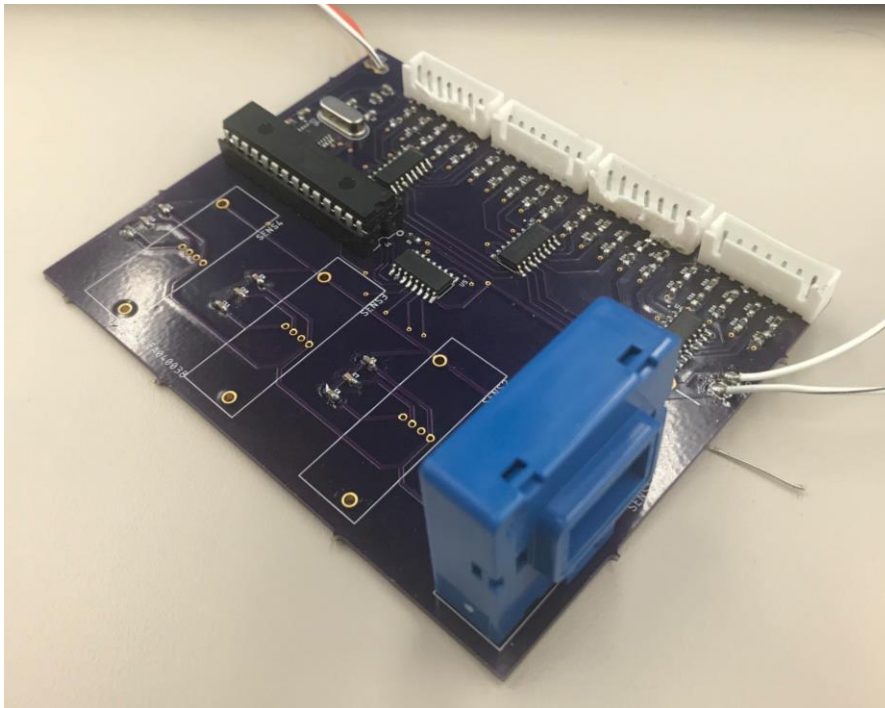
Electric Vertical Takeoff/Landing  
eVTOL



Optionally Piloted Vehicle  
OPV

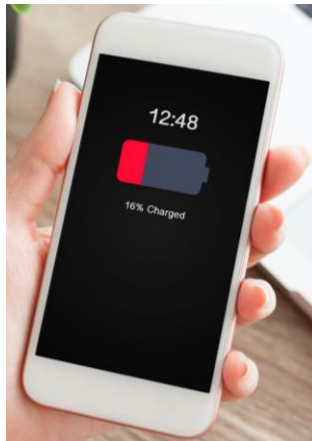
# Projects

- Taranis RC Controller Documentation
  - Comparing and logging different control configurations
- Current and Voltage Monitor
  - Tracking power information for quadrotor vehicles



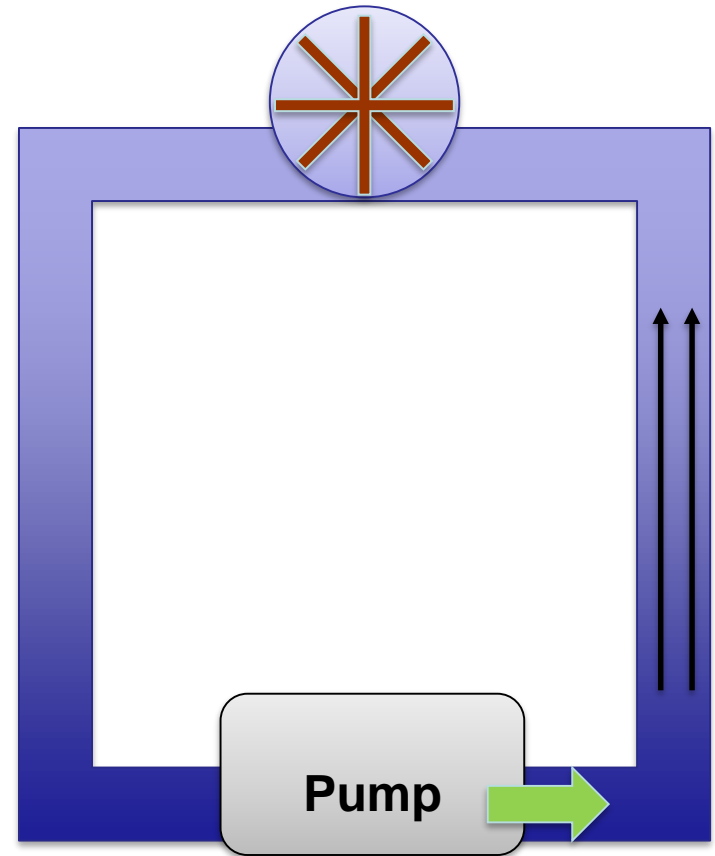
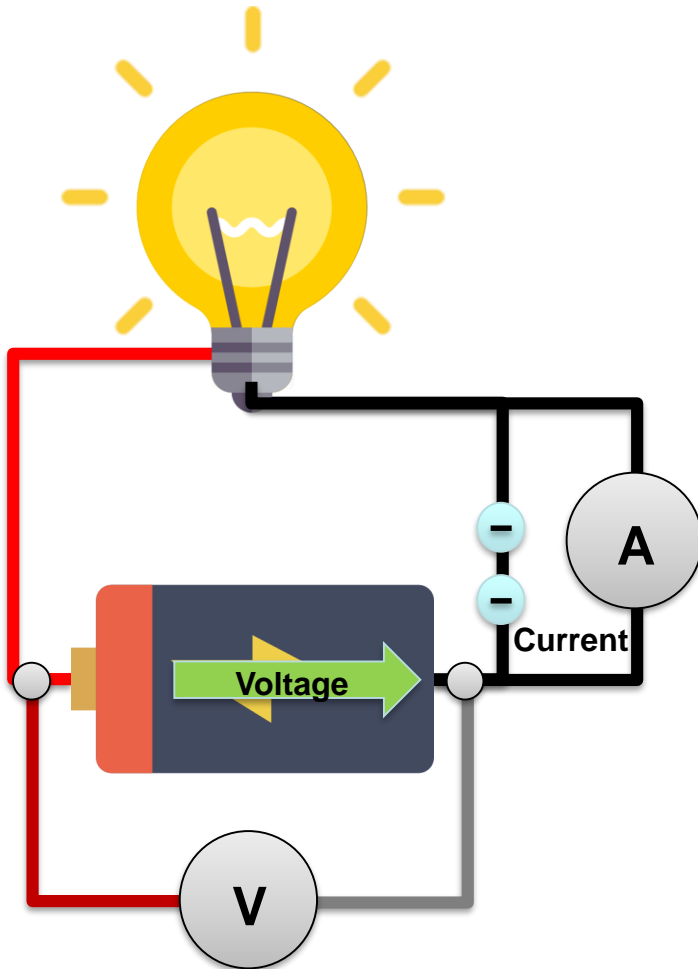
# In-Depth Look: Current & Voltage Monitor

- Battery powered quadrotors for testing
- Problem: Want to be able to track remaining battery charge
  - Prevent unexpected loss of power
  - Protect batteries by not draining them too low
- Should integrate with the existing flight computer
  - Use information to create an estimate of remaining flight time itself
  - Provide sufficient information for flight computer to make this prediction
- How do we estimate battery life remaining?



# In-Depth Look: Current & Voltage Monitor

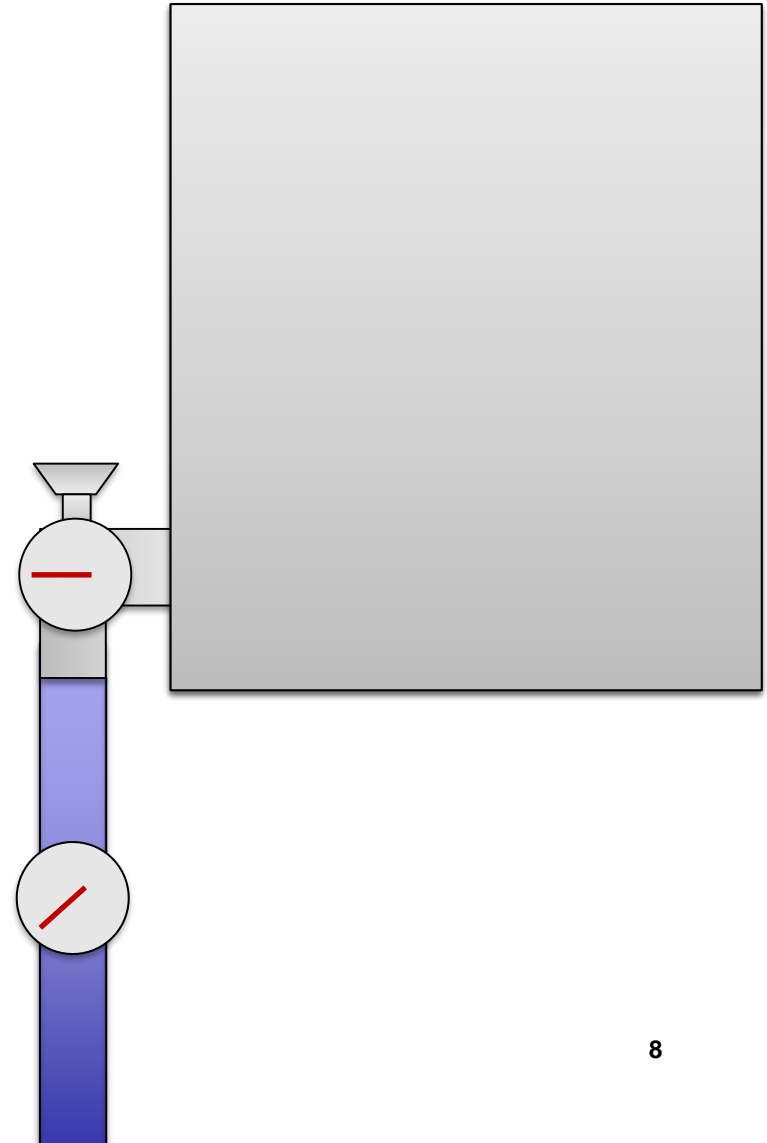
## Brief Explanation of Current and Voltage





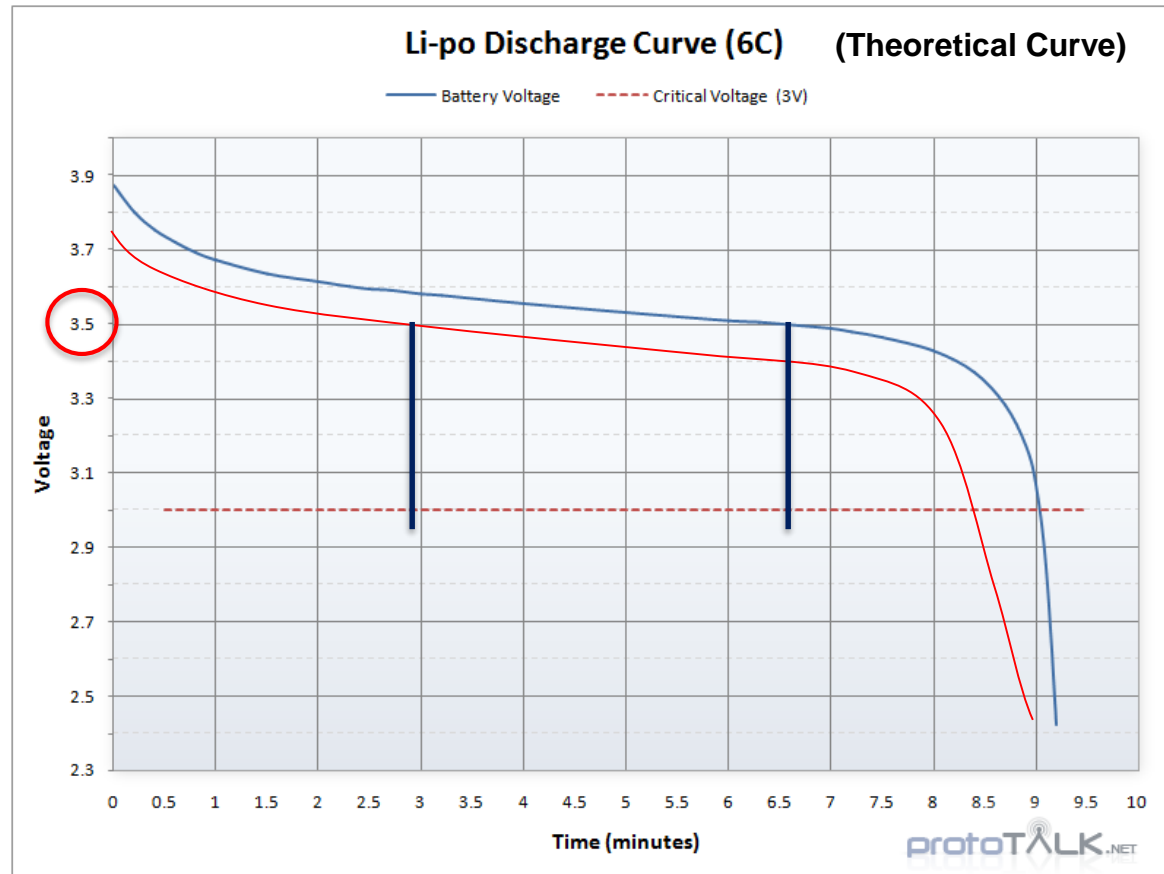
# Estimating State-of-Charge

- State-of-Charge (SoC) is the amount of energy currently stored in the battery relative to its full capacity
- There is no known way to directly measure SoC
- What are ways to estimate the amount of water in the tank?
- Measure pressure at opening
- Keep track of how much water flows out



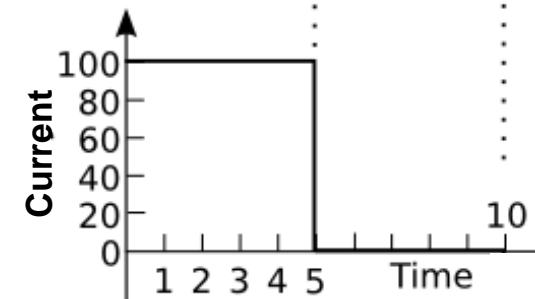
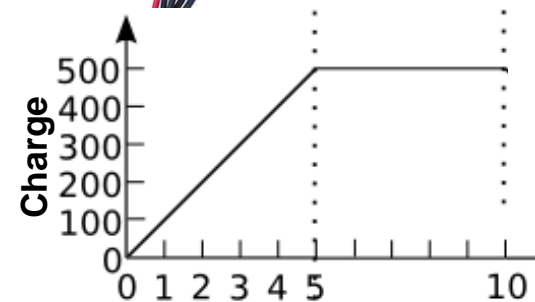
# Estimating SoC using Voltage

- Can use battery voltage to estimate SoC
- Voltage is relatively flat for most of the discharge curve
  - Can make this measurement prone to inaccuracies
- Temperature, battery age, and discharge rate change the curve
- Batteries experience voltage hysteresis
  - Recommendation: batteries should settle for 1-2 hours before voltage is accurate indication of SoC
- A minimum voltage threshold can be used to combat shortcomings of just using battery life



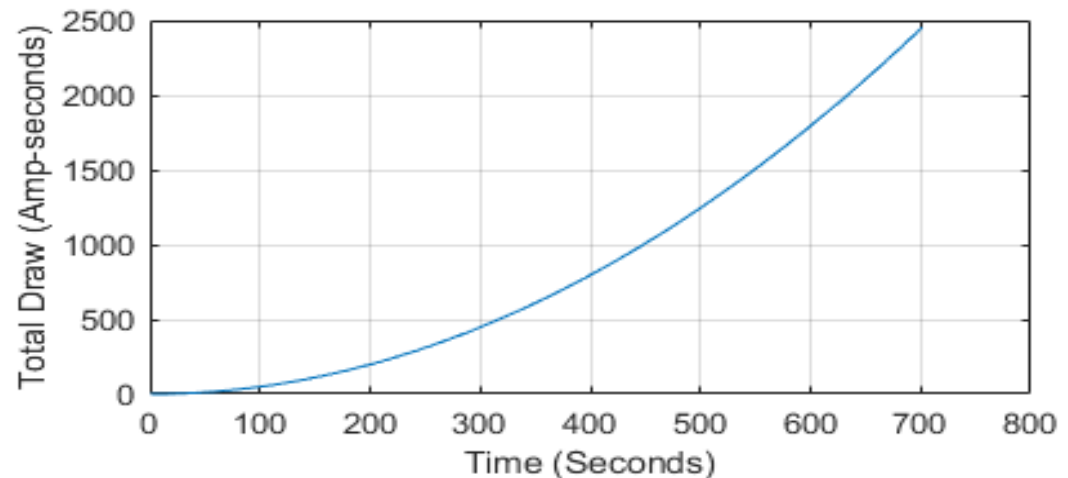
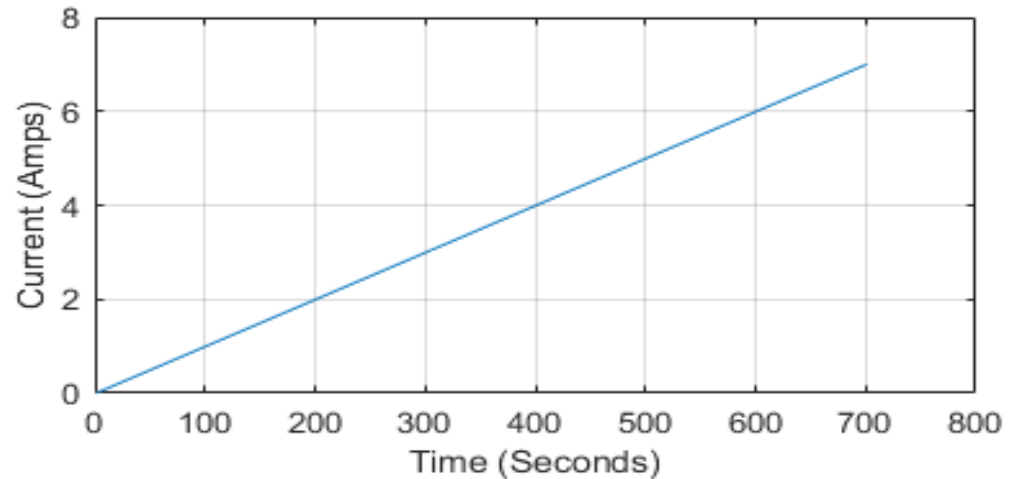
# Estimating SoC using Current

- Coulomb Counting
- Battery capacity is measured in amp-hours
- 12 Amp-Hours:
  - 1 amp for 12 hours
  - 2 amps for 6 hours
  - 12 amps for 1 hour
  - 60 amps for 12 minutes
- Current is the rate at which charge is drawn from the battery
- Taking time integral of current will give the total charge drawn in amp-hours
- Example: Start at full charge, draw 6A for one hour, 50% charge remains
- Shortcomings:
  - Requires knowing the initial amount of charge in the battery



# SoC Estimation Summary

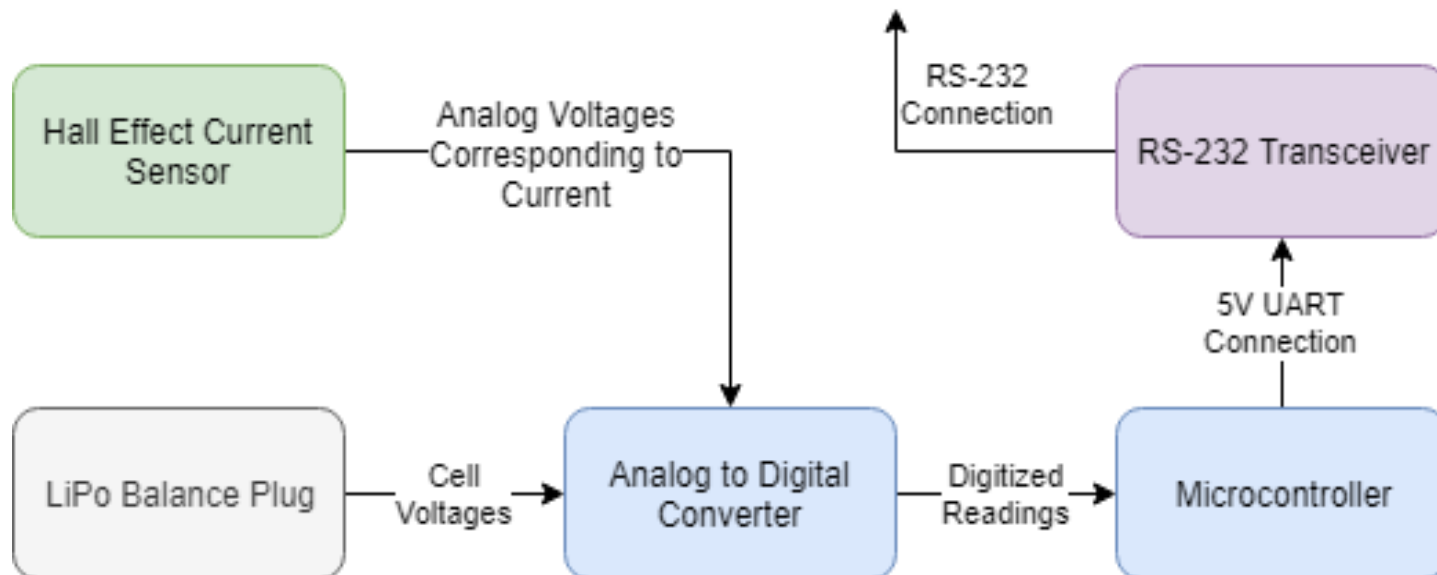
- Use voltage to estimate initial SoC of settled battery
- Use coulomb counting to calculate total charge drawn
- Take difference of total charge drawn and initial charge to determine remaining charge
- These steps should result in a reasonably accurate prediction of SoC





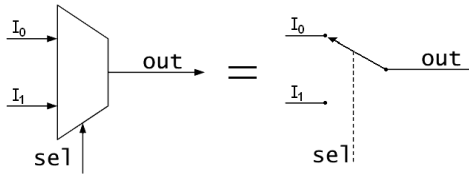
# Current & Voltage Monitor Design

- Requirements:
- Measure Current
  - Hall-effect sensors
- Measure Voltage
  - Voltage dividers and analog to digital converter
- Log and Process Values
- Forward data over RS-232 Serial Interface
  - Microcontroller



# Hardware Design

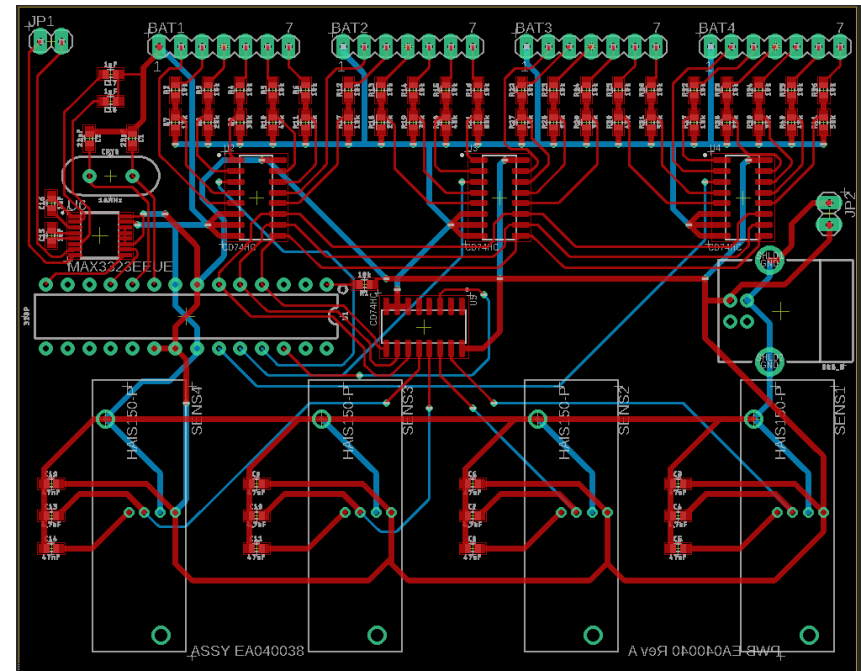
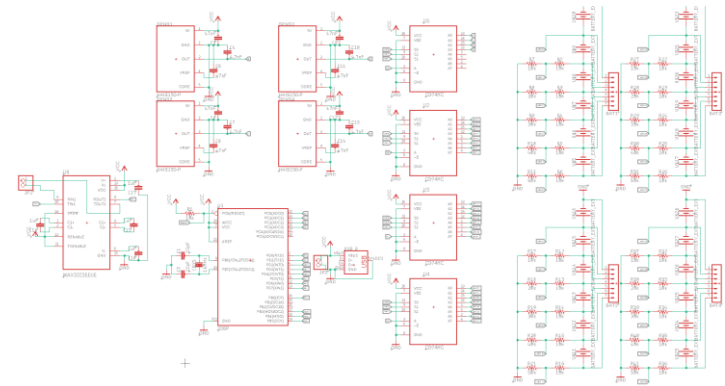
- Designed a printed circuit board (PCB)
- Included balance connector plugs to monitor individual cell voltages
- Voltages are multiplexed to ADC



- RS-232 transceiver chosen to handle voltage difference between microcontroller and flight computer

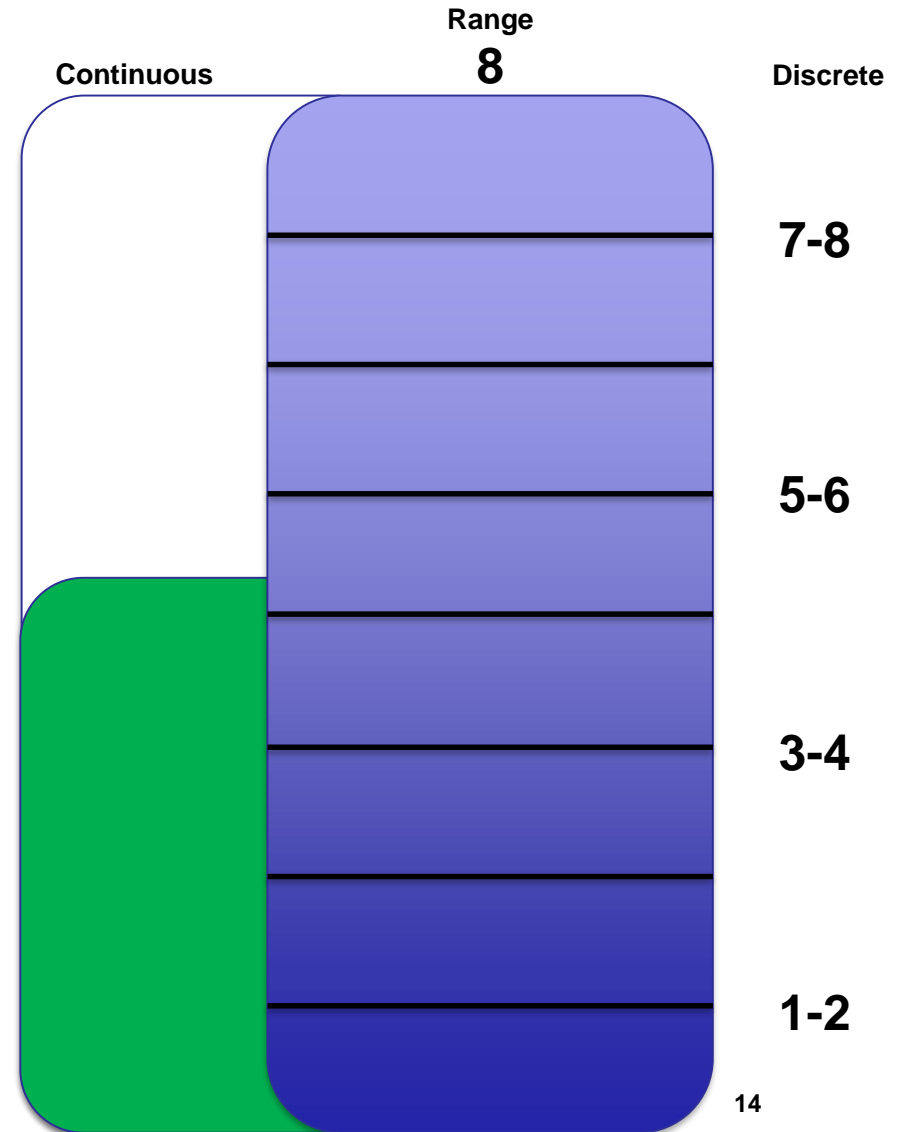


6S



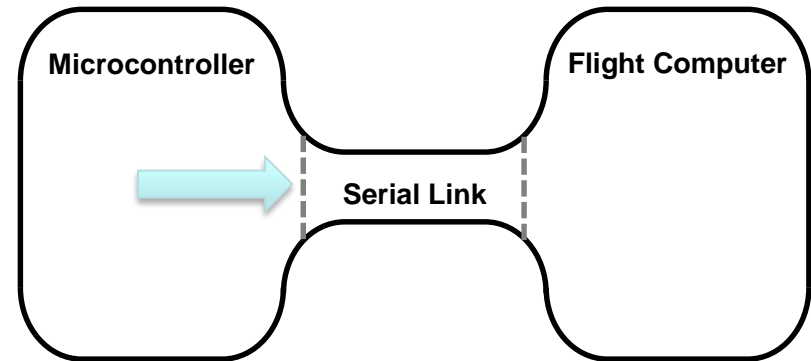
# Challenges

- Need to measure a large current range with good accuracy
  - Trade-off between range and resolution
- Trying to measure up to 130A with high accuracy



# Challenges

- Packaging data efficiently to increase effective transfer speed over serial link
  - Using minimum number of bytes to encode information
- Send and identify data:
  - Four batteries
    - Immediate Current draw
    - Cumulative current draw
    - Estimated %
  - 6 cells/battery
    - Voltage level
    - Low voltage warning



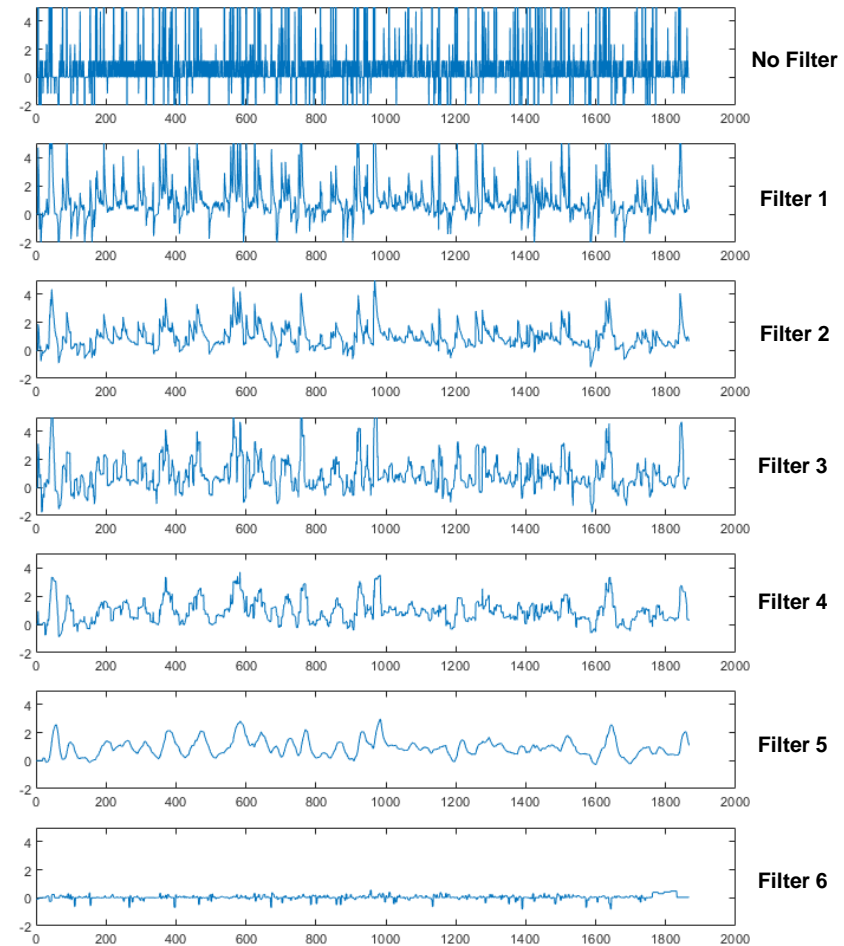
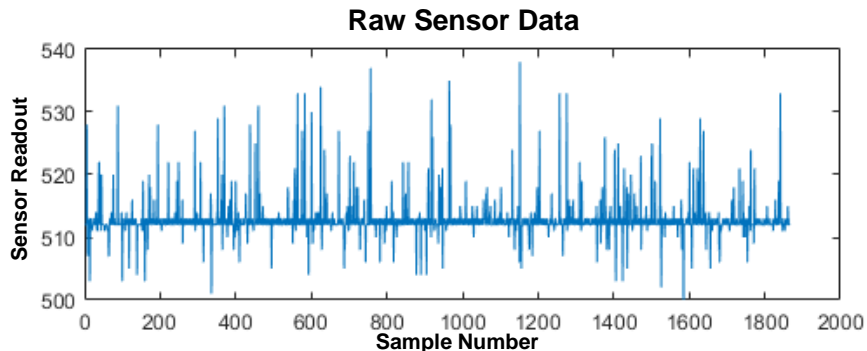
```

/* ===== Payload Structure (tentative) =====
* bits:      15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
* content: {-----DATA-----} {--CELL#--} {V} {BAT #}
*
*                                     V/I reading toggle ^
*           |                               ||                               |
*           |-----BYTE 1-----| |-----BYTE 2-----|
*
* Need to accommodate:
* 4 batteries - 2 bits
* 6 cells - 3 bits
* V or I - 1 bit
* Data value - 10 bits (resolution of ADC)
*
* Total: 16 bits
  
```

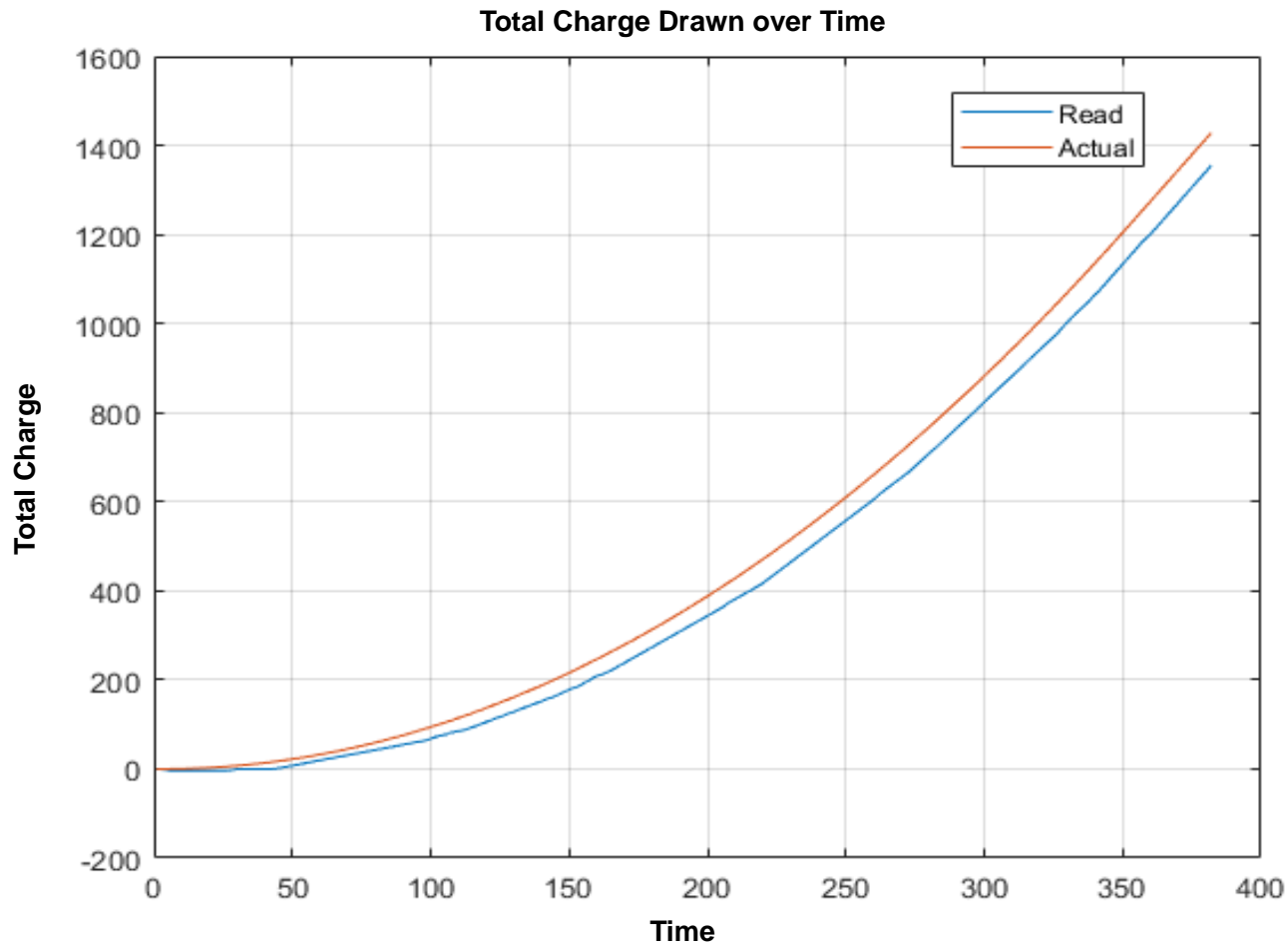


# Challenges

- Low-pass HW filters were added but noise was still present
- Processing current sensor output to obtain cleaner readout

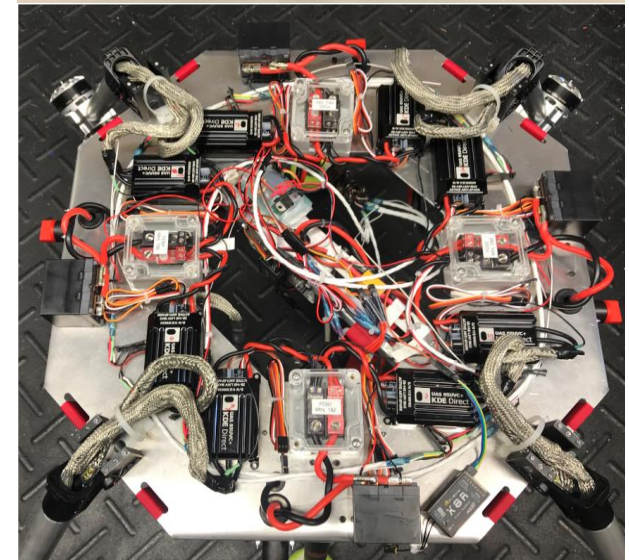
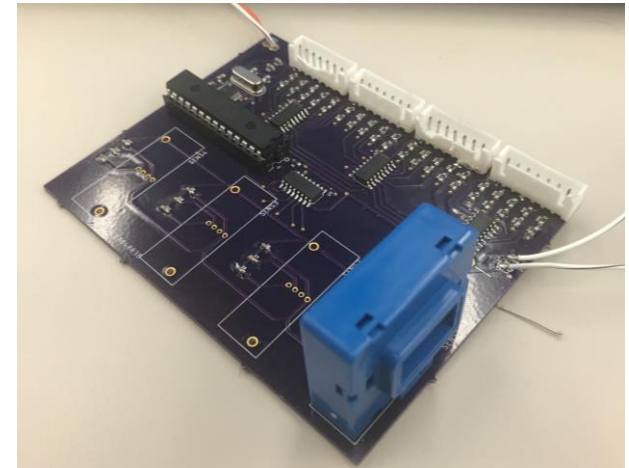


# Challenges



# Going Forward

- Vehicle Integration
  - Packaging Specifications/Schematic Updates
- Battery Testing
  - Obtaining characteristic voltage curves
- Ground/Flight Performance Testing
- Flight Time Prediction



# Takeaways

- It is important to always keep the high-level function of a system in mind
  - Easy to get caught up in implementation
- Documentation is important
  - Lack of documentation can let work go to waste/become unusable

This document does not contain Technical Data as defined in the ITAR Part 120.10 or EAR Part 772

```

/* This document does not contain Technical Data as defined in the ITAR Part 120.10 or EAR Part 772
 *
 * Byte 1: 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
 * content: [-----DATA-----] [---CELL#---] (V) (BAT #)
 *
 * 1: [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----]
 * 2: [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----]
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 * 15: [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----] [-----]
 *
 * Send to accumulator
 * 4 batteries = 2 byte
 * 6 cells = 3 byte
 * 7 bit 2 = 1 bit
 * Data value = 10 bits (precision of ADC)
 *
 * Total: 14 bits

```

Bits 15 through 6 are the 10-bit data for a given ADC reading, which will correspond to either a single cell voltage or a scaled current value. Bits 5 through 3 indicate the cell number for a voltage. They will be all zeroes for a current reading. Bit 2 determines whether the data is a voltage measurement, with low signaling a voltage and high a current. Bits 1 through 0 are the bit which is used regardless of the measurement type.

For example, if the IV monitor wanted to send the voltage of cell 4 (where cell numbers 1-5 are batteries 2 (where battery numbers range from 0 to 3) and that voltage was 3.73V it corresponds to a 10-bit ADC value of 764. The full transmission would be:

Byte 1  
0x7E  
0111 1110

Frame Boundary

Byte 2  
0x8F  
1011 1111

Data

Byte 3  
0x12  
0001 0010

Cell Number  
V/I Toggle  
Battery Num

Note: Dividing an ADC reading by 1024 and multiplying the result by 5 will yield the original measured voltage.

The baud rate for the serial connection on the IV monitor is set to 57,600. During a test of the RS-232 interface, the throughput was measured at about 885 transmissions per second (each transmission is 3 bytes assuming no control escape octet is necessary). Sending all the values recorded by the IV monitor requires 28 transmissions; one for each of the 24 cell voltages, and four for the battery currents. This brings the full update rate to around 33.6Hz. This parameter could be improved by increasing the transmission rate, but this may cause problems with data integrity. At the selected speed, there were no transmission errors in 10<sup>7</sup> transmissions, which corresponded to around 2.5 hours of continuous operation. A simple error checking technique like a parity bit could be added but based on these results

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Additionally, there are two levels of multiplexing going on [unclear] 20 read all 24 cells (plus the four current sensors) using the single 10-bit ADC on the ATMEGA. This also has some performance implications, as not only does the ADC have to run slower to accommodate the higher series resistance, but it must do so for 28 different inputs to complete a pot of the entire battery system.

**Increase system modularity**

Designing the IV monitor as a single centralized board was a good idea as a proof of concept but may not be the optimal choice for a final design. A new design could take the form of a central main board and one auxiliary board for each battery, all of which would be much smaller than the current IV monitor. This has a few advantages: firstly, since each board would likely have its own microcontroller, the load on each controller would be reduced, allowing for higher update rates and potentially higher accuracy. This would also reduce the amount of work done by the onboard ADC, improving performance in this area as well. Creating auxiliary boards would allow for the current sensors to be closer to the batteries, which has the benefit of not needing to run as many long wires for them.

Just communicate with the auxiliary boards through a wired serial protocol and could send protocol like SPI since the wire lengths would likely be less than a foot or so.

**it reading technique**

he entire system modular, it would be beneficial to make the current sensors more (as achieved by switching to the KO-10-5 model (NOT the SP3 model as a 3.3V ed to this application), since they are equipped with Molex plugs instead of PCB . Improving the attachment method of the existing sensors is also a valid option.

challenge of measuring current values over a very large range (from 0 to over 130A) 'accuracy, since there is a fundamental trade-off between measurement range and even sensors have very good resolution, but the ADC used to read the voltage output range of 1A results in a change of 0.0225V for the HAIS-50 and about 0.00467V for the V system for the IV monitor, the 10-bit ADC only has a resolution of approximately 100µV. This means that for a 10A current, the ADC reading is off by even 100µV. For battery life can quickly become skewed if not also accounting for voltage son, using a higher resolution external ADC may be beneficial for the current sensors;

many single input options exist with 16 to 24 bits, which would hopefully allow for much better readings. An ADC with differential inputs could also help deal with the high sensitivity by using the **Woo** signal for the hall effect sensors to compare their outputs to. The 10-bit ADC on the microcontroller is most likely accurate enough for the battery voltages, though.

**Built-in low battery warnings**

The IV monitor communicates with the A372 flight computer, and the A372 can use this data to trigger the low battery alarms, but this functionality could also be handled directly by the IV monitor. Later versions should attempt to implement this feature.

**Self-powering (add voltage regulators)**

The current IV monitor splices into the existing 5V line being run through the vehicle. However, interfacing with the LiPo batteries provides the obvious opportunity to use them for power. Using the entirety of the battery's voltage would probably require several voltage regulators in steps or a buck

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be achieved with additional capacitors between voltage and ground, especially near the voltage inputs to the various ICs. Relocating the 16MHz oscillator away from the other lines and using shorter traces for it may also help.

**Improve voltage reading technique**

The voltage reading is effective in its current implementation, but it does have room for improvement. The ADC on the ATMEGA is optimized for reading analog signals with an output impedance of 50Ω or lower. The LiPo batteries are connected to the rest of the circuit using voltage dividers with very high total series resistances (between 20k and 60kΩ) which has some effect on the speed at which the ADC can function (that is, the sampling delay needs to be increased). The high series resistances were initially chosen to reduce the current drawn from the cells of the battery into the microamp range and thus minimize the effect of the voltage probing on the system.

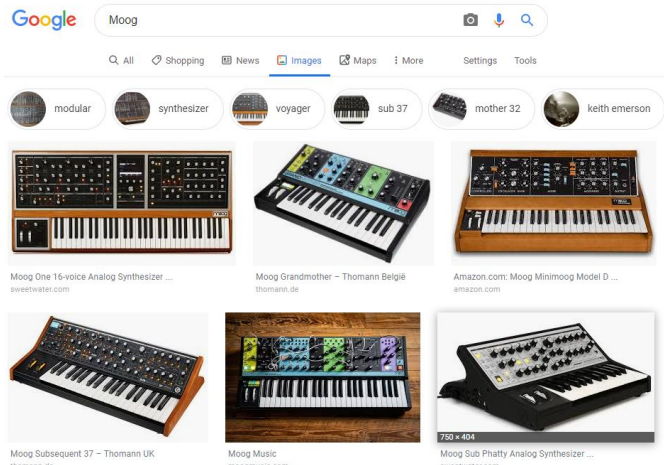
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- Acronyms are confusing
  - Does this make me a failure as an engineer?



# Summary

- Wish Moog did more to facilitate meeting other co-ops
- Got to fully own a project
- Moog is cool



# Questions

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Thank you for coming!

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