MOOG
AIRCRAFT GROUP

Co-op End-Of-Block Presentation

Alex Hatzis

Engineering Co-op I

August 1, 2019

ahatzis@moog.com

(End Date: August 16, 2019)

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

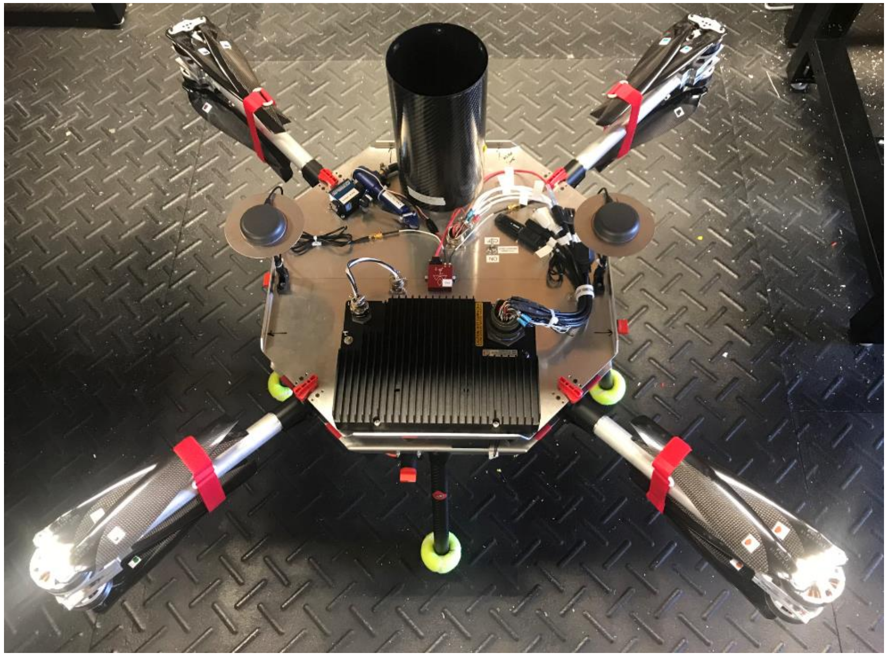
V-22 Again

MOOG AIRCRAFT GROUP

AFSA Program

MOOG AIRCRAFT GROUP

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

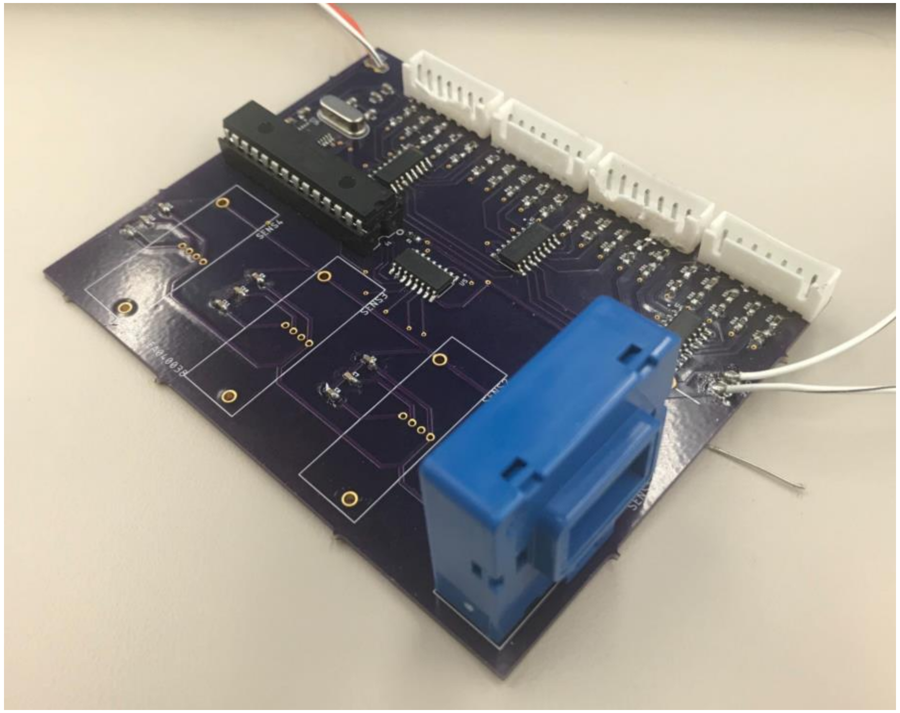


Electric Vertical Takeoff/Landing
eVTOL

Optionally Piloted Vehicle
OPV

Projects

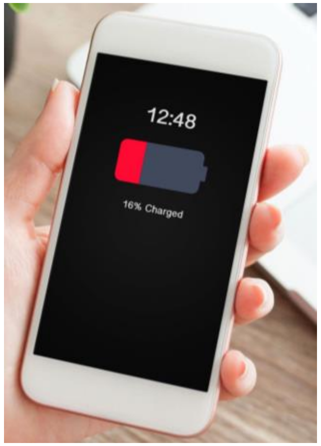
- Taranis RC Controller Documentation
  - Comparing and logging different control configurations
- Current and Voltage Monitor
  - Tracking power information for quadrotor vehicles



In-Depth Look: Current & Voltage Monitor

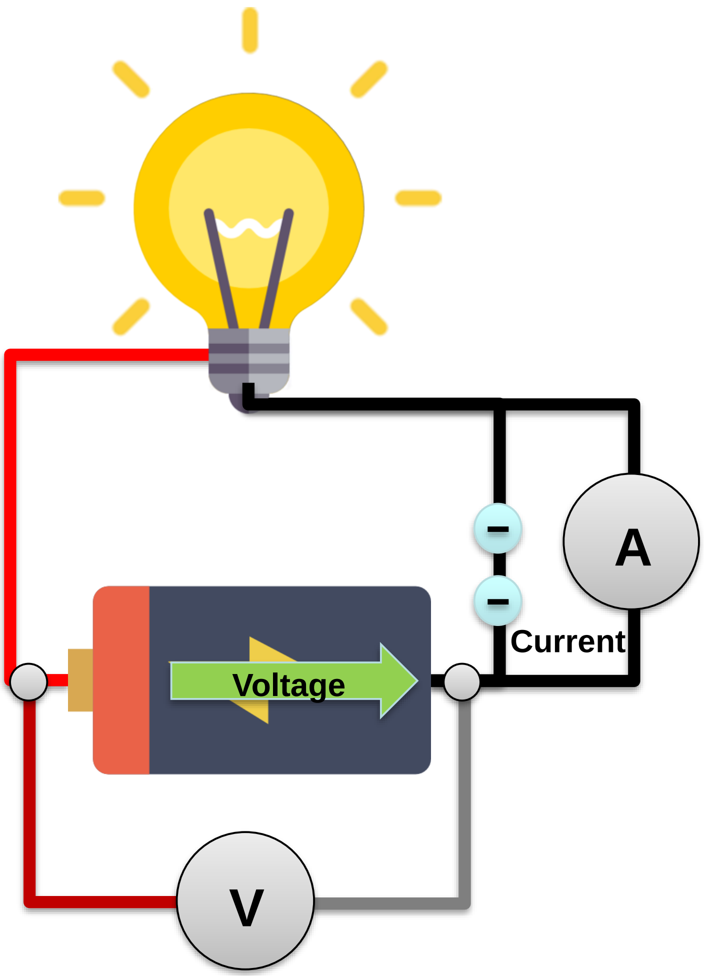
MOOG AIRCRAFT GROUP

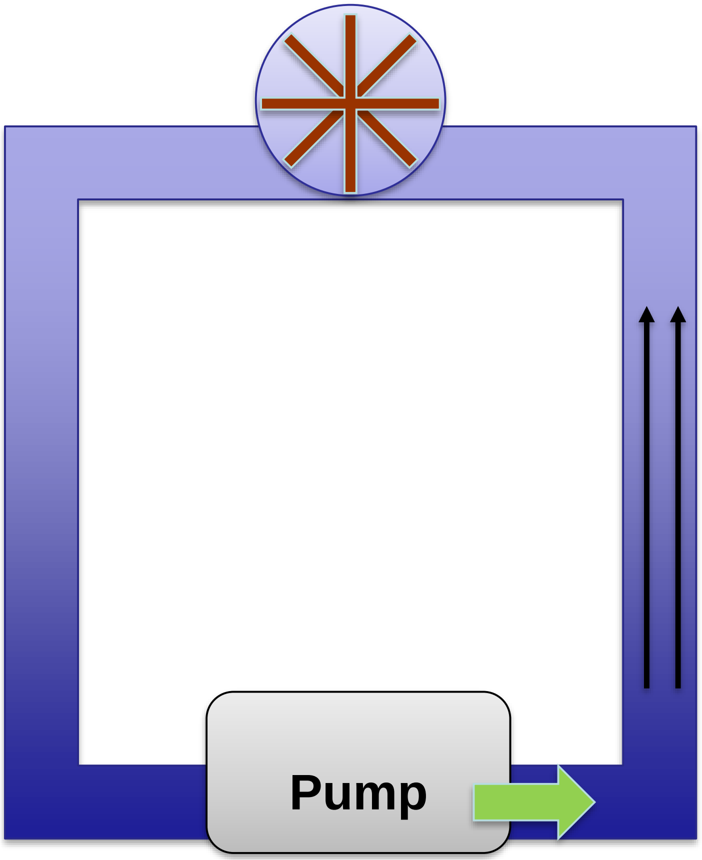
- Battery powered quadrotors for testing
- Problem: Want to be able to track remaining battery charge
  - Prevent unexpected loss of power
  - Protect batteries by not draining them too low
- Should integrate with the existing flight computer
  - Use information to create an estimate of remaining flight 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

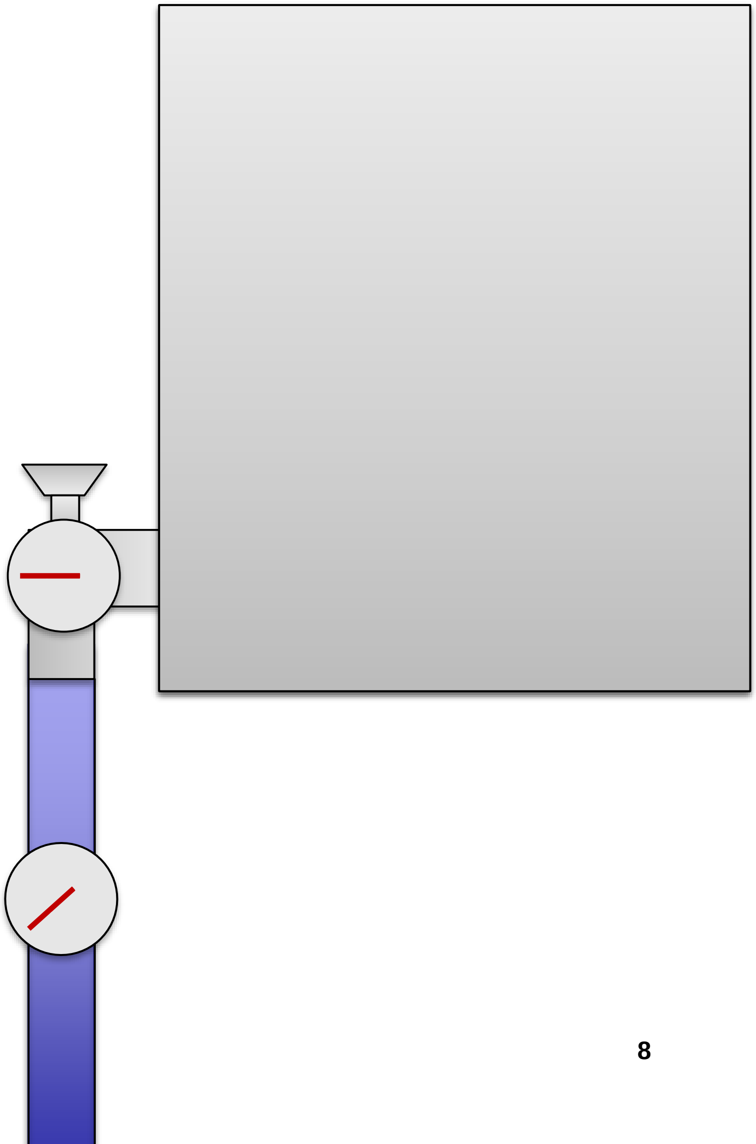




Estimating State-of-Charge

MOOG AIRCRAFT GROUP

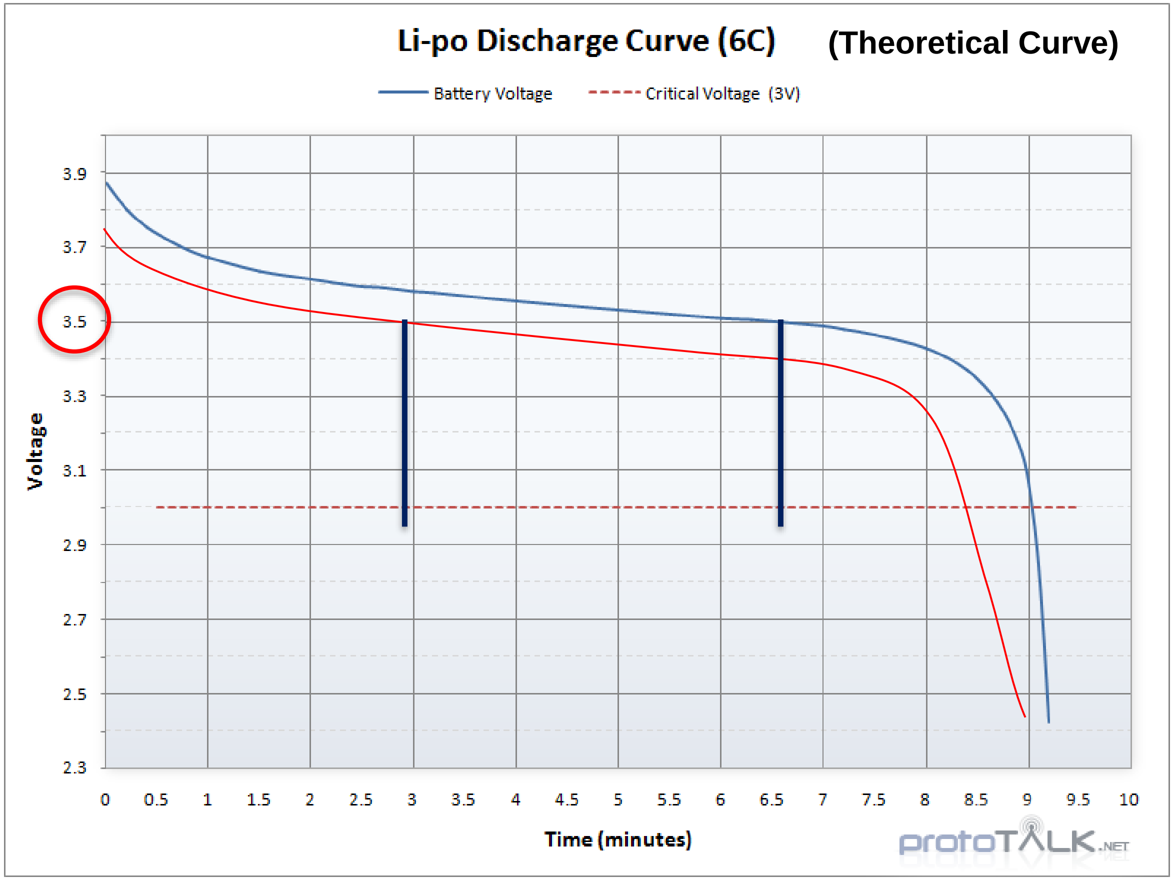
- State-of-Charge (SoC) is the amount of energy currently stored in the battery relative to its full capacity
- There is no known way to directly measure SoC



- What are ways to estimate the amount of water in the tank?
- Measure pressure at opening
- Keep track of how much water flows out

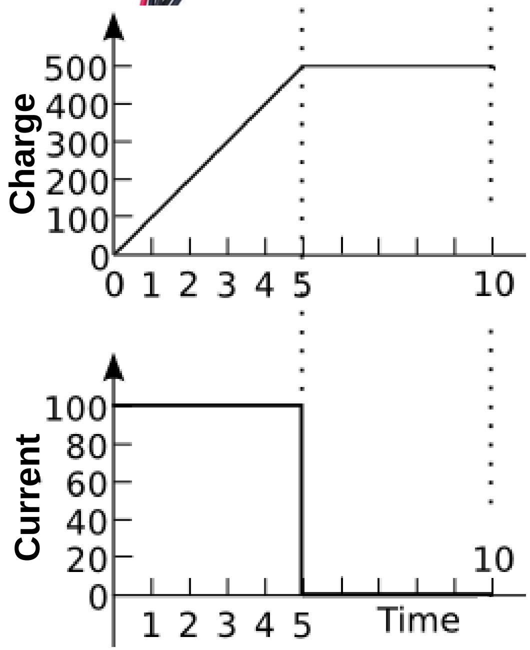
Estimating SoC using Voltage

- 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

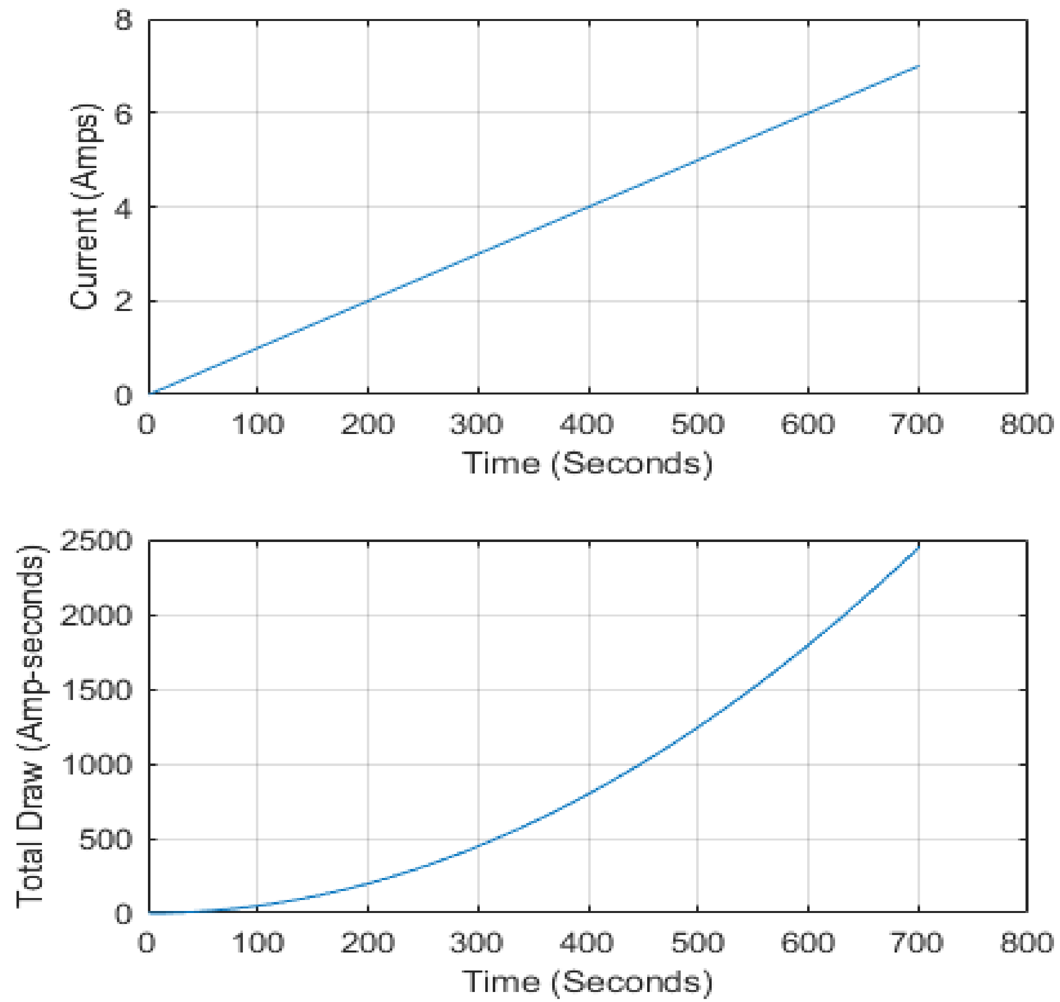
- Coulomb Counting
- Battery capacity is measured in amp-hours
- 12 Amp-Hours:
  - 1 amp for 12 hours
  - 2 amps for 6 hours
  - 12 amps for 1 hour
  - 60 amps for 12 minutes
- Current is the rate at which charge is drawn from the battery
- Taking time integral of current will give the total charge drawn 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

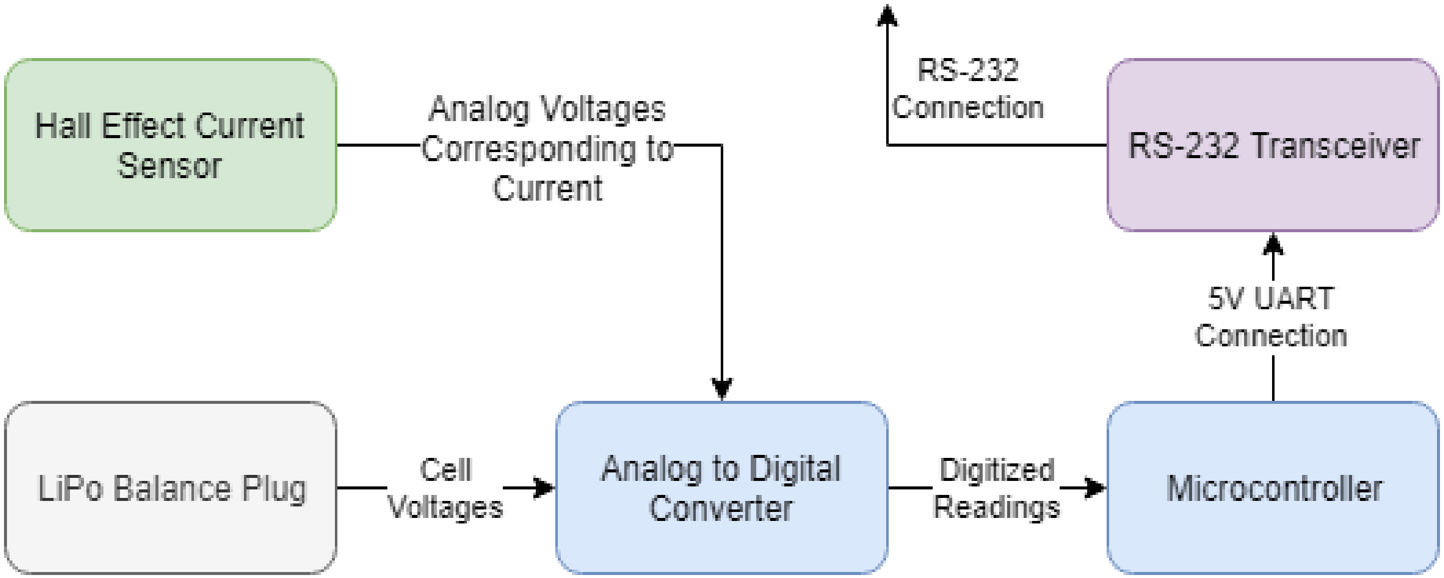
- These steps should result in a reasonably accurate prediction of SoC



Current & Voltage Monitor Design

MOOG AIRCRAFT GROUP

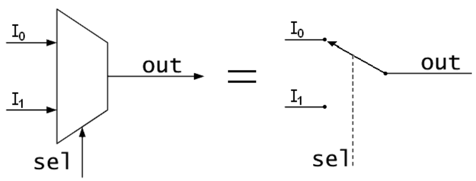
- Requirements:
- Measure Current
  - Hall-effect sensors
- Measure Voltage
  - Voltage dividers and analog to digital converter
- Log and Process Values
- Forward data over RS-232 Serial Interface
  - Microcontroller



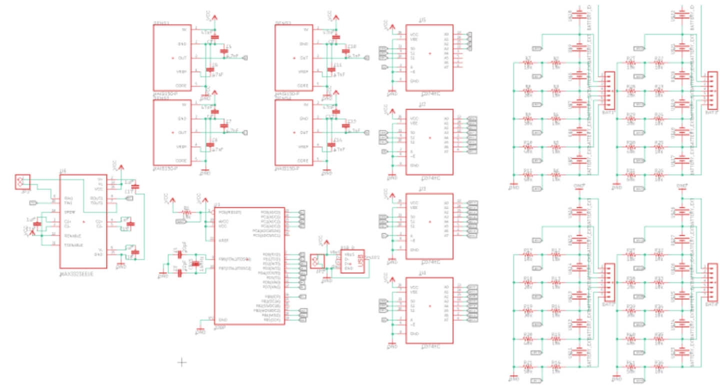
Hardware Design

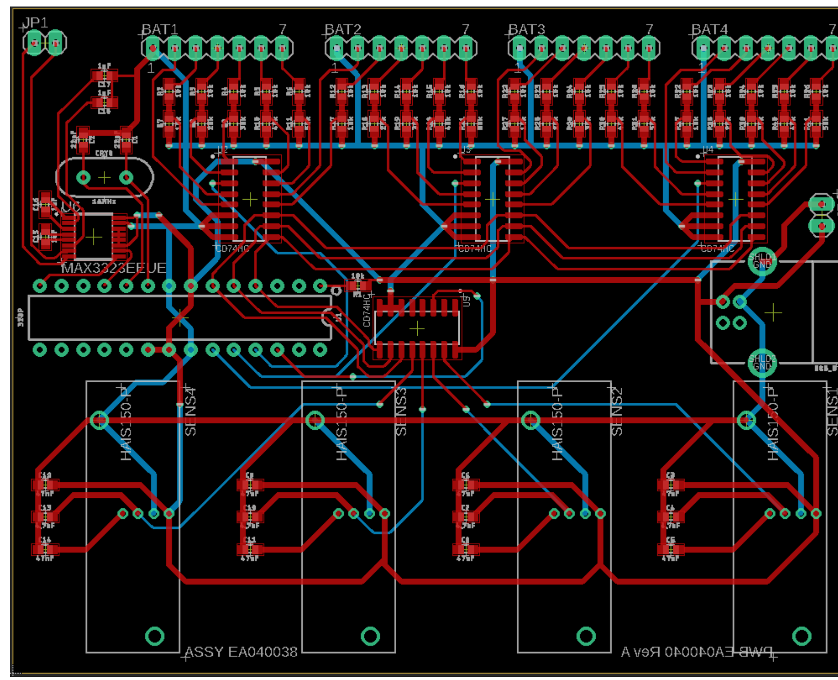
MOOG AIRCRAFT GROUP

- 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



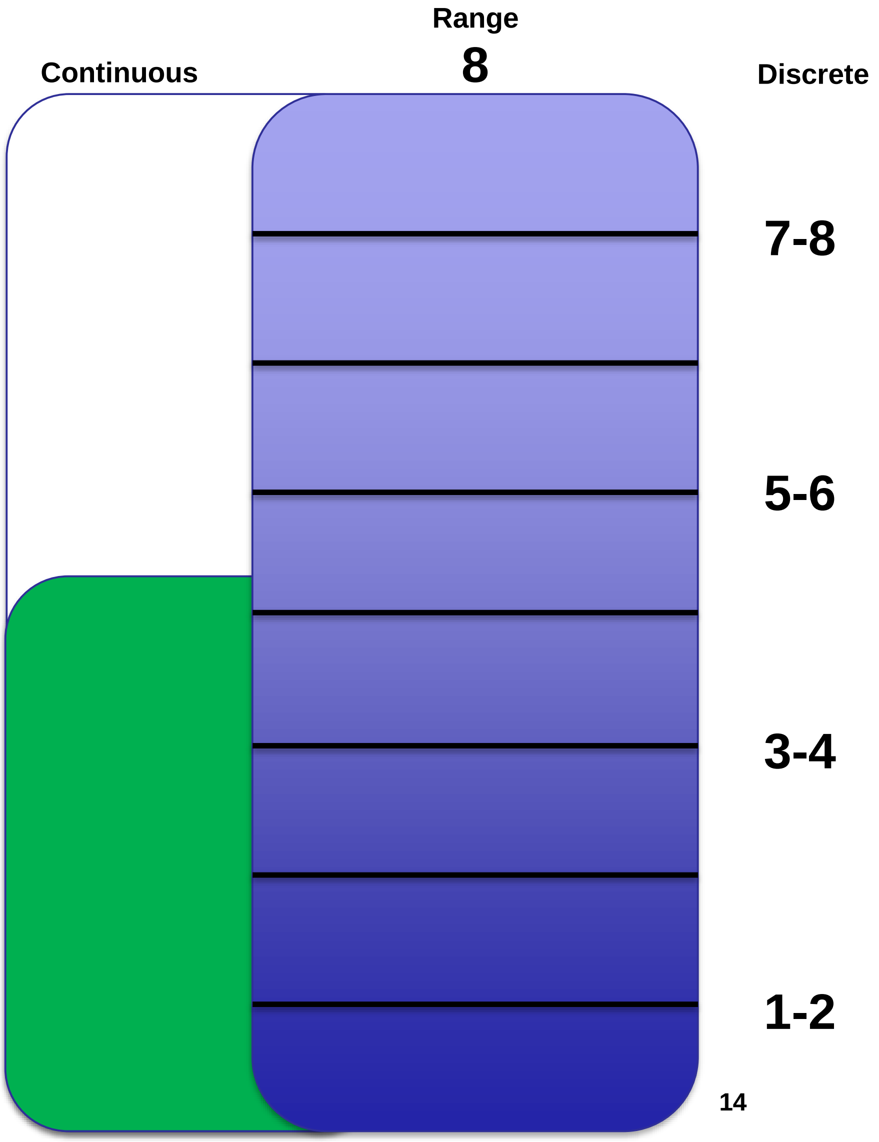


6S

Challenges

MOOG AIRCRAFT GROUP

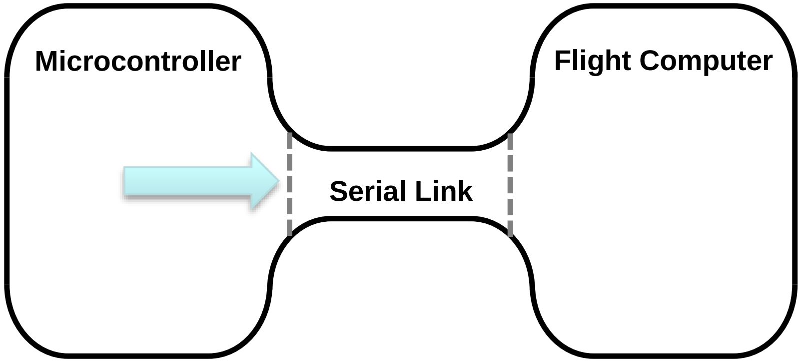
- Need to measure a large current range with good accuracy
  - Trade-off between range and resolution
- Trying to measure up to 130A with high accuracy



Challenges

MOOG AIRCRAFT GROUP

- 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

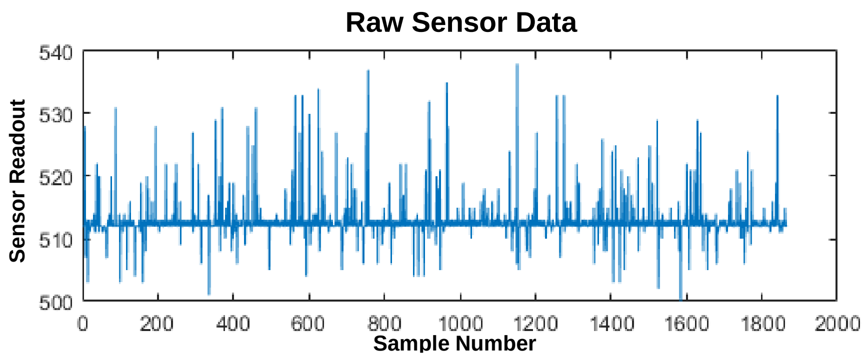


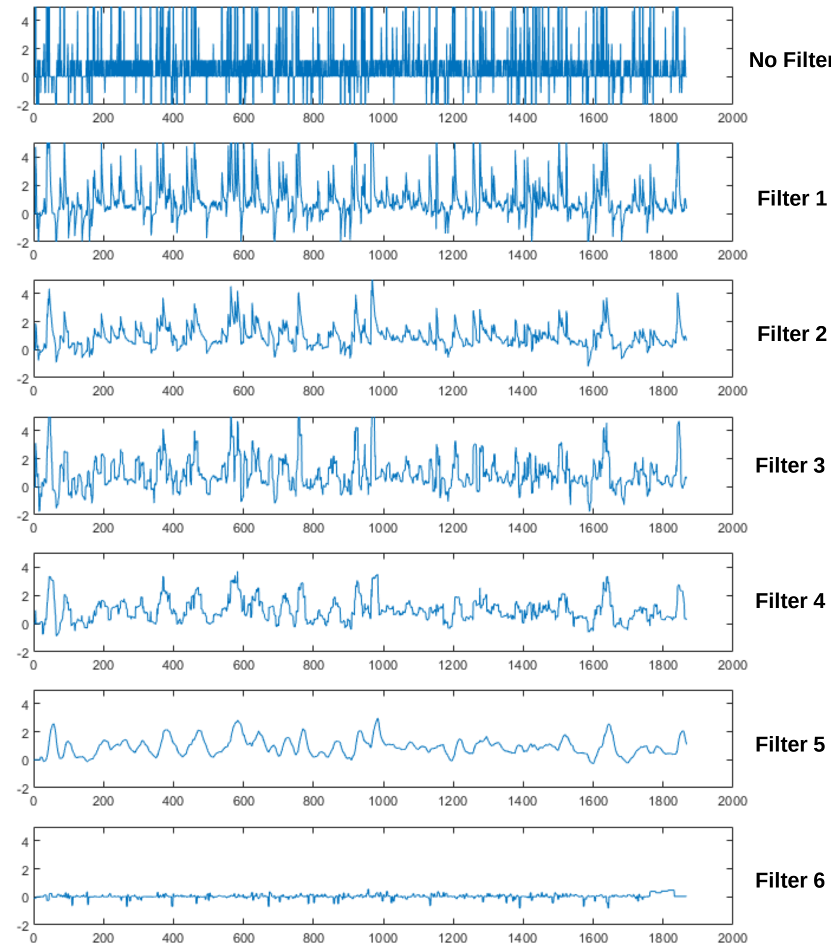

```
/* ===================== Payload Structure (tentative) =====================
 * bits:     15  14  13  12  11  10  9   8   7   6   5   4   3   2   1   0
 * content:  {----------------DATA---------------} {--CELL#--} {V} {BAT #}
 *                                         V/I reading toggle ^
 *           |                              ||                              |
 *           |------------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

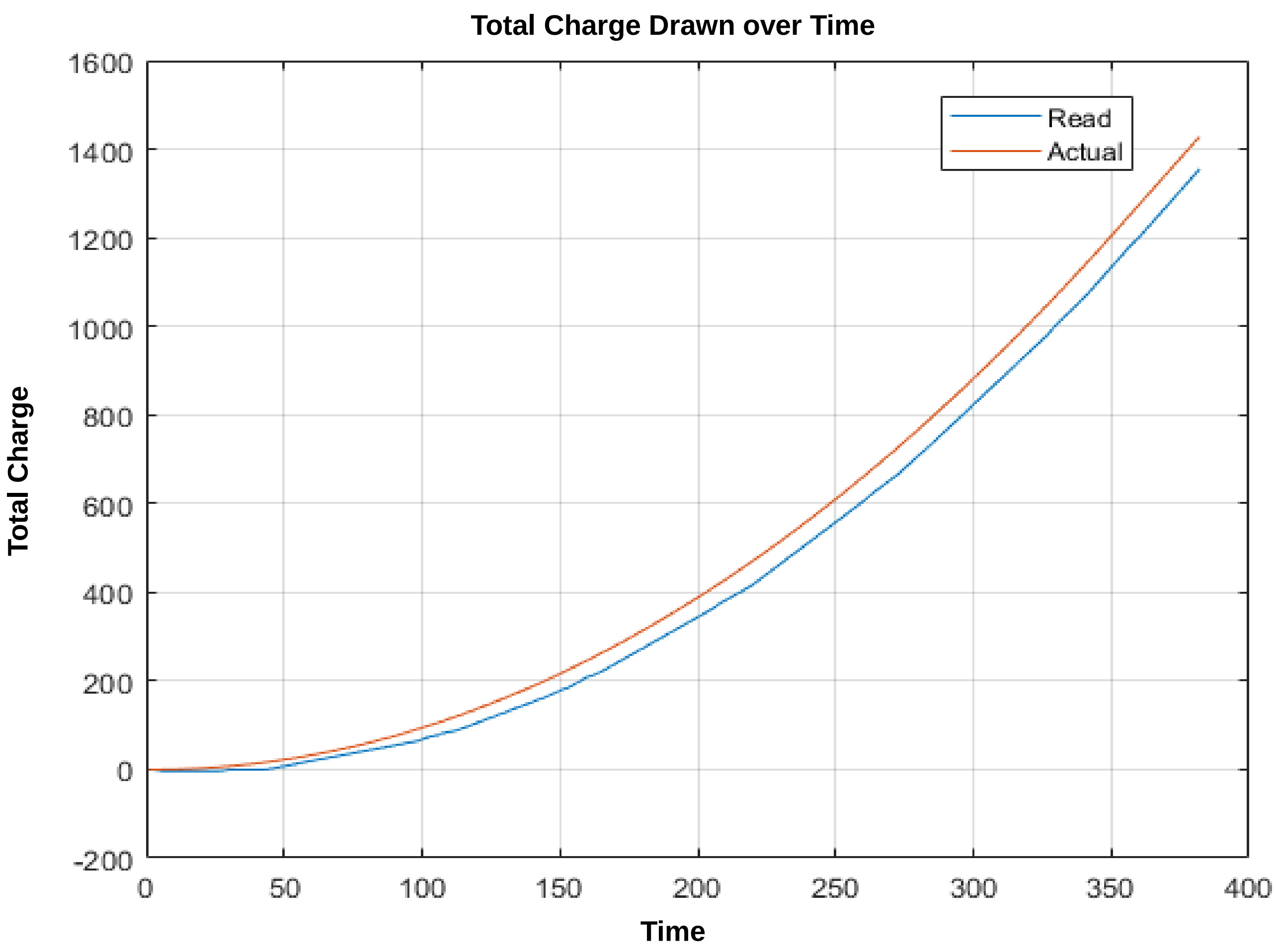
MOOG AIRCRAFT GROUP

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



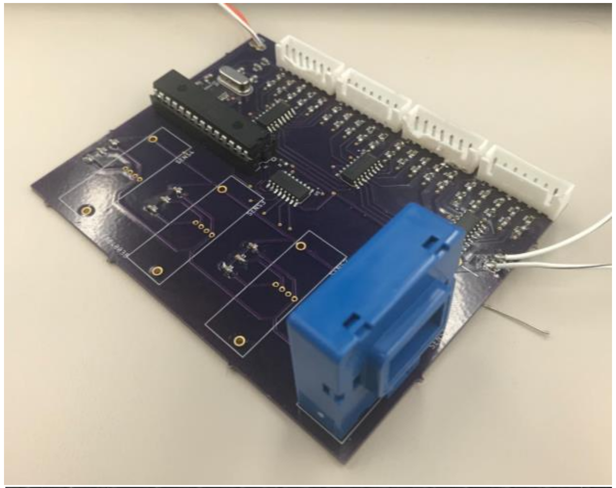


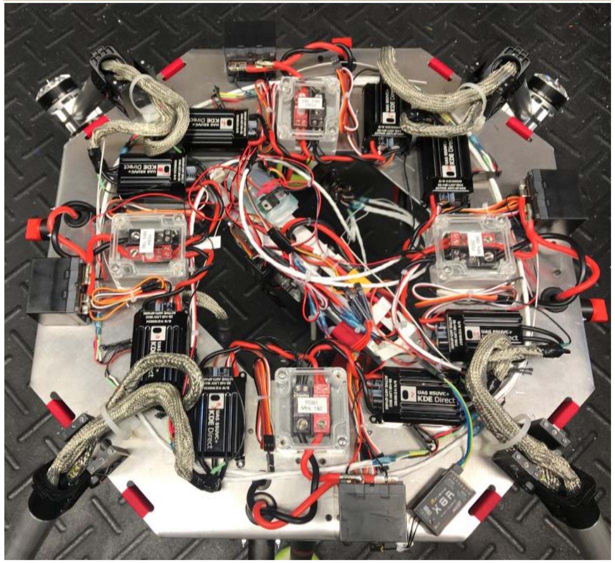
Challenges


Total Charge Drawn over Time
Total Charge
Time
Read
Actual
1600
1400
1200
1000
800
600
400
200
0
-200
0
50
100
150
200
250
300
350
400

Going Forward

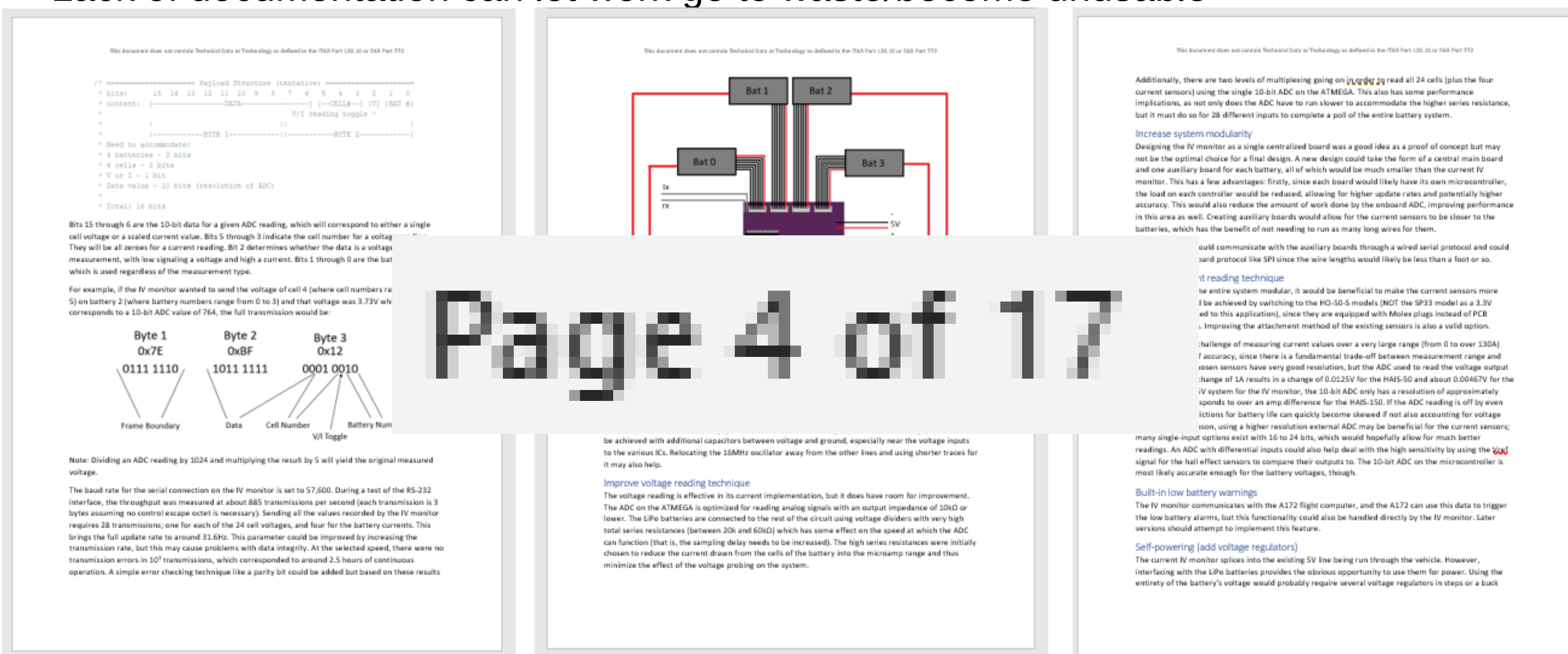
- Vehicle Integration
  - Packaging Specifications/Schematic Updates
- Battery Testing
  - Obtaining characteristic voltage curves
- Ground/Flight Performance Testing
- Flight Time Prediction





Takeaways

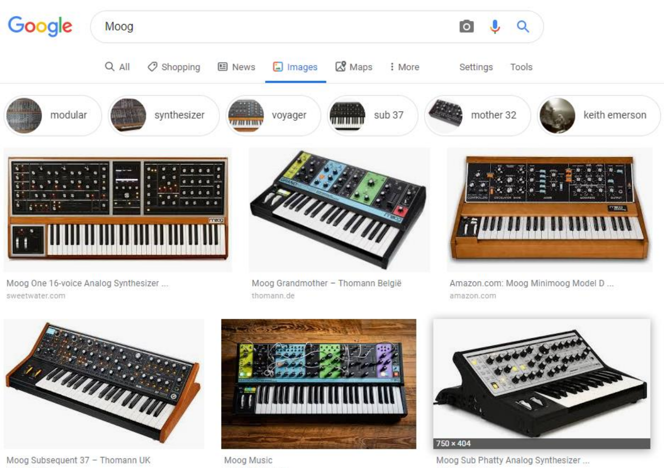
- It is important to always keep the high-level function of a system in mind
  - Easy to get caught up in implementation
- Documentation is important
  - Lack of documentation can let work go to waste/become unusable



- 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

Thank you for coming!

ahatzis@moog.com