BROWN SPACE ENGINEERING

EQUiSat: Space for $3,776.61

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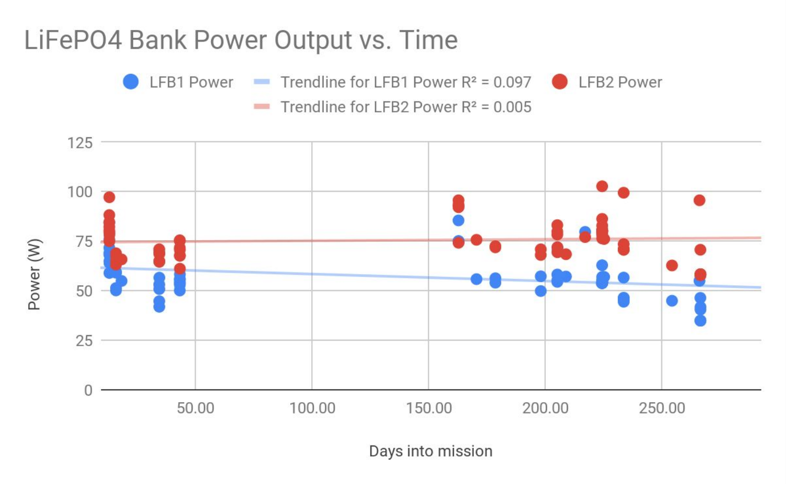
Mission

Accessibility

- Parts cost $3,776.61 in total
  - Cheaper than one subsystem in most commercially available CubeSat systems
- Fully open source hardware and software
  - Design documents: https://brownspace.org/equisat-resources
  - PCB schematics: https://github.com/BrownSpaceEngineering/EquiSat-EAGLE
  - Code: https://github.com/BrownSpaceEngineering/EQUiSatOS
- Public engagement

$LiFePO_4$

- Test Lithium Iron Phosphate batteries in space for the first time
    - Notable for their ability to supply high current on low notice
    - Required in EQUiSat to drive the high-powered LEDs, which have been observed to draw up to 15 A each
- The batteries performed as expected, but there will be more detailed analysis later in this presentation and in a paper to be released soon



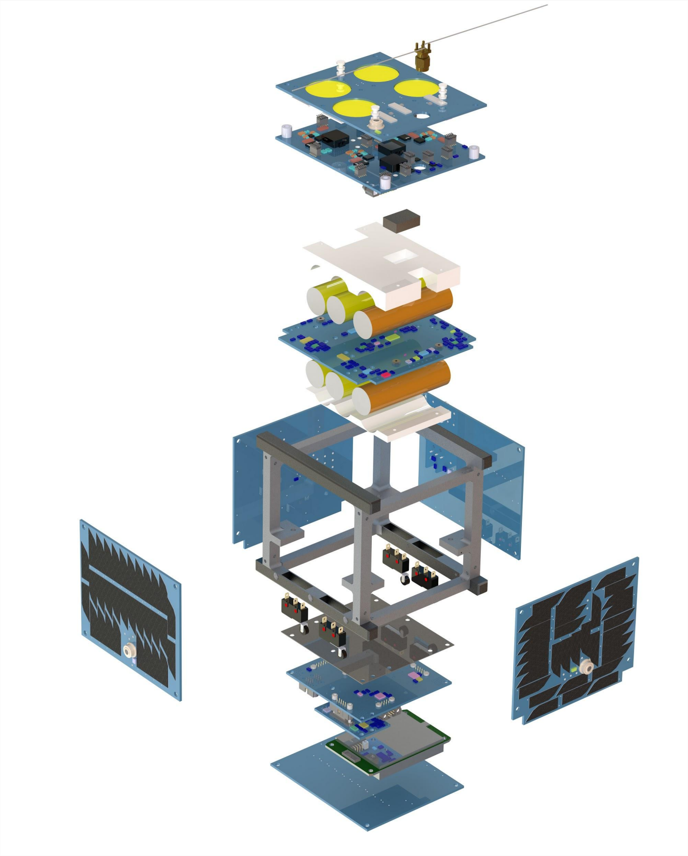
Work Organization

Five different subgroups of about five members each:

- Avionics hardware
- Avionics software
- Power (payload and EPS)
- CAD
- Manufacturing

All undergraduates

CAD Exploded View



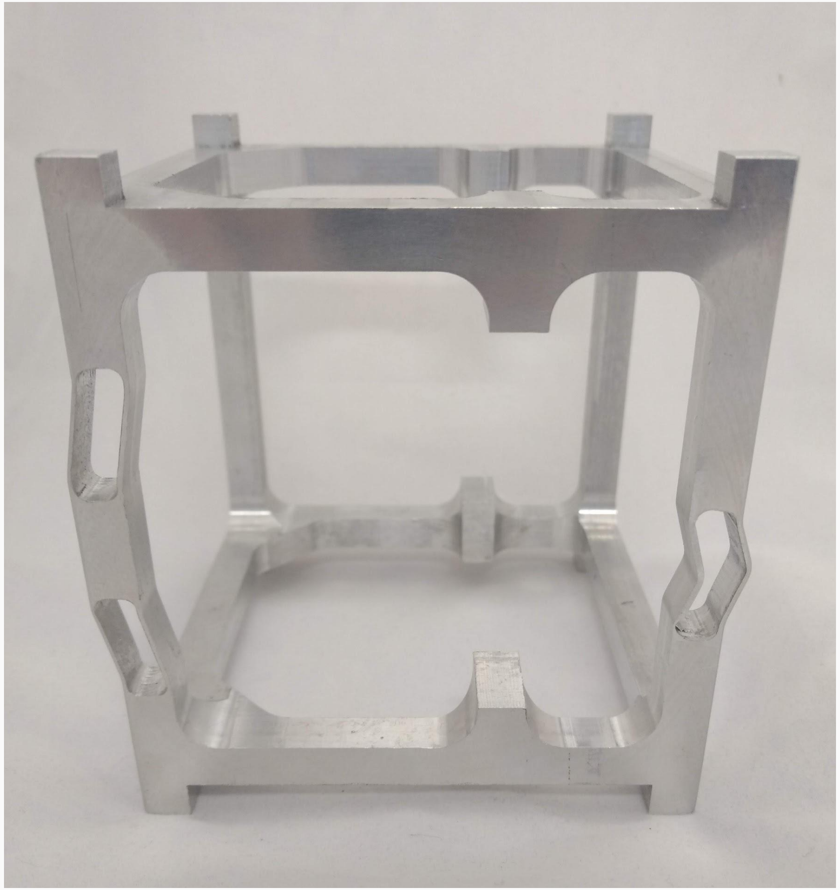
Subsystems

Chassis

- Mono-Block Aluminum
- CNC Mill
- 90 Hour machining time
- tabs/shelves
- Sturdy
- Steel attachment plate Thermal
- anodization

- Chassis was manufactured from a mono-block of aluminum alloy 6061
- Positives
  - It is cheap and soft enough to be milled
  - High strength made any trusses/skeleton structure unnecessary
- Drawbacks
  - Milling process took Mono-block took between 90 and 100 hours of machine time
  - Occasionally during the drilling process of deployment switches the mill head would be dislodged and damage the chassis, rendering it useless
- Another manufacturing concern was the buckling of the chassis due to pressure from holding plates during milling

Damaged Prototype



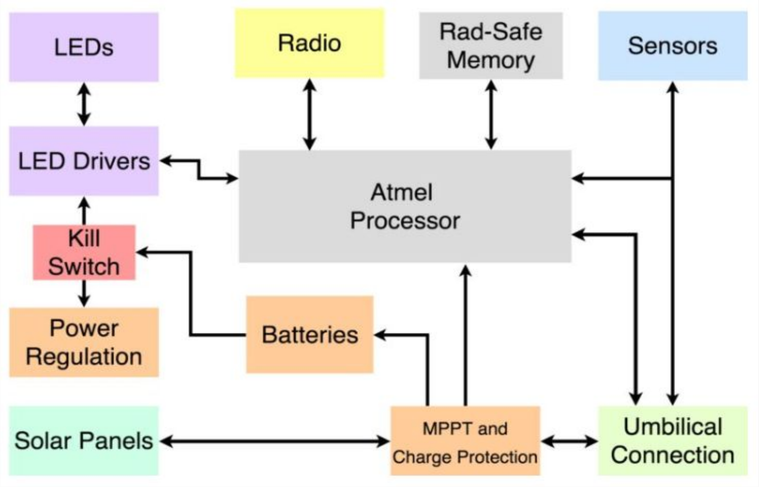
Structure

- 4 tabs as mechanical support for the battery bank and electronics
- Steel attachment plate supports battery block on top of tabs
- Chassis and attachment plate responsible for structural support, electrical grounding and thermal sinking
    - Rails are anodized to prevent cold welding
    - Internal faces of rails were not anodized for heat transfer
- Cho-Therm 1671 was used to transfer heat from source components to the sink
    - i.e. between radio and attachment plate

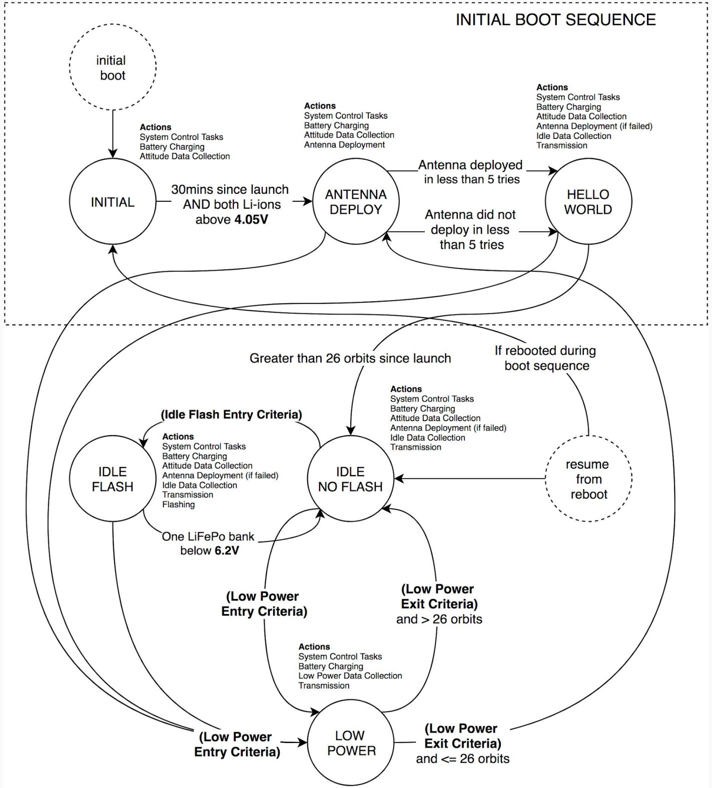
Control Board & Sensors

- ATMEL SAMD21J18A processor
- 6 subgroups
- Double redundancy of OS
- Triple redundant ADS

- Central control board with processor
- 6 different schematics based on function
  - Microcontroller, LED driver board, solar panels, radio, power regulation and the sensor multiplexor
- OS stored in two radiation safe MRAM chips
- Suite of triple redundant ADS sensors



State Diagram



Idle Flash Entry Criteria:
At least one non-decommissioned LiFePO4 bank is above **6.75V or**
a single battery in a bank is above **3.9V or** the charger reads a bank as full.
Additionally, the other bank must be above **6.2V**.

Low Power Entry Criteria:
Both Li-ion **below 3.9V**
or both Li-ions are decommissioned
or one Li-ion is decommissioned and other is **above 3.9V**
(this is a software bug; the intention was "*below 3.9V*")

Low Power Exit Criteria (complement):
Both Li-ions **above 3.9V**
or one Li-ion is decommissioned and other is **below 3.9V**
(the intention was *"above 3.9V"*)

Electrical Power System (EPS)

Batteries:

- 2 3.7V Li-ion
- 4 3.3V $LiFePO_4$ (Lithium-Iron-Phosphate)

Solar cells:

- 160 TrisolX Solar Wings

Solar panel coating:

- NuSil CV 2500

- Solar panel details
  - Cells arranged in 8 rows of 4 cells on 5 panels
  - Generate 1.08 W minimum, 1.46 W maximum
  - Power routed to MPPT (Maximum Power Point Tracking) chip which optimizes distribution to the charging circuit
  - Wings were tedious to solder, coating is expensive
- Battery board details
  - Batteries soldered directly to the board
    - Bad! Hard to maneuver, solder
  - Software determines which bank of batteries to charge
  - Connected to control with thick bundle of wires
    - We would recommend using connectors instead whenever possible
  - Has performed thousands of charge-discharge cycles so far on-orbit

Flash

LEDs:

- Luminus CHM-27-50 LED
- Each draws 108 W at 36 V and 3 A

- Estimated apparent magnitude of 3
- $LiFePO_4$s required to provide high current
  - Up to 60 A per flash
- Flashed approximately 1,500 times in the year since deployment
- Not yet seen
  - Likely due to ACDS issues
  - We used passive attitude control - two hysteresis rods and a small magnet
  - We have observed consistent rotation at a very low rate on all axes
  - Makes observation of a flash significantly less likely

Radio

- XDL Micro from Pacific Crest
- Transmits in 4FSK at 435.55 GHz

- Uses proprietary encoding
- This fact escaped early designers, became a big issue when building the ground stations
- Ground stations had to have their own XDL Micros
- After deployment, we were able to reverse engineer the decoding process
- Results published on GitHub https://github.com/BrownSpaceEngineering/gr-equisat_decoder
- Online decoder at https://decoder.brownspace.org/
- Now, a significant portion of our data can come from SatNOGS

Antenna Deployment

- 20 cm nitinol antenna
- 10x10 cm face of satellite

- Tied antenna into a circle using nylon
- Nylon wrapped through nichrome loops connected to a MOSFET
- PWM signal to MOSFET cause nichrome to heat up, burning the nylon and releasing the antenna
- Triple redundant
  - One loop powered by each bank of batteries
- Tested extensively in vacuum chamber
- Nylon tying had to be triple checked
  - If it was tied at all incorrectly the antenna would stick
- Redundancy was essential
  - Early data indicates that the antenna may have not deployed right away

What’s next: PVDX

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