OreSat

A student team-based approach to an inexpensive, open, and modular (1-3U) CubeSat bus

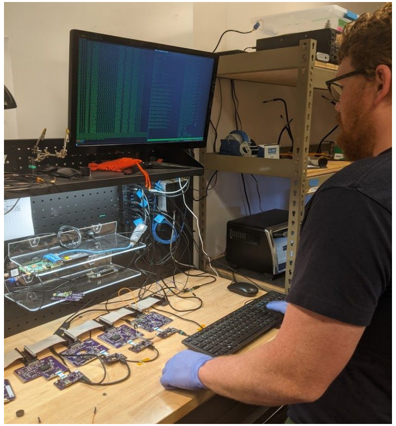
Andrew Greenberg, David Lay, Glenn LeBrasseur, Emma Levy,
Ryan Medick, Hayden Reinhold, Risto Rushford, and Miles Simpson

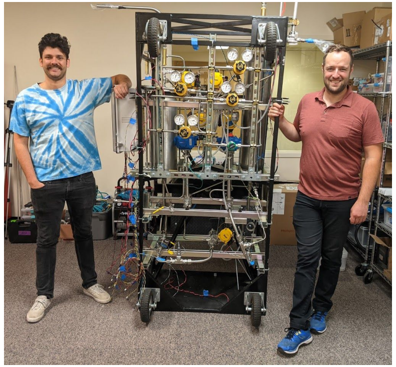
Portland State Aerospace Society at Portland State University
1930 SW 4th Avenue ste 160, Portland, OR 97201
503-708-7711 / adg4@pdx.edu

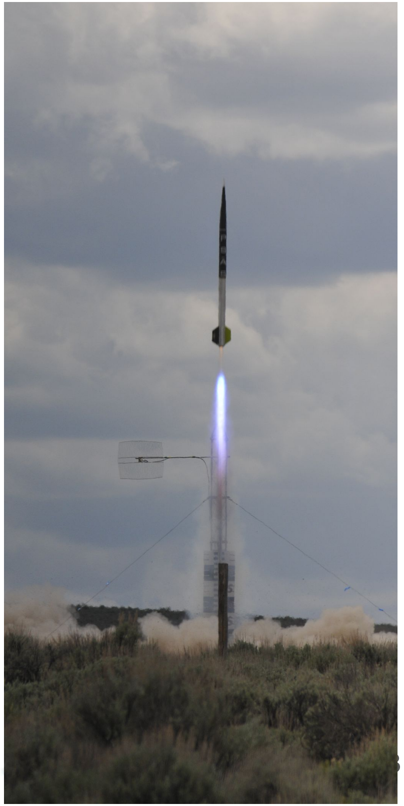
SSC21-WKI-09

Background

Portland State Aerospace Society







Open Source Space Hipsters from Portland

- Extracurricular interdisciplinary team-based hands-on student aerospace project
  - Sponsors Capstones (senior projects) and theses
- Militantly interdisciplinary
  - “Space Program” model, not a “satellite club” model
  - Not just ME/EE/CS; also business, math, physics, marketing
- Completely open source
- No formal funding source
  - Crowdfunding
  - Oregon Space Grant Consortium grants

- We have no idea what we’re doing (just delivered our first CubeSat)

Motivation

Educational CubeSat Dilema

- COTS CubeSat kits
  - Robust, flight proven, mostly plug and play components
  - Purchase what you can, build only what you need
  - Minimum development time (sophisticated beepsat in a month)
  - $35,000 (simple 1U beepsat) - $125,000 (3U with ADCS)
- DIY CubeSat
  - Absurdly risky
  - Build everything - you’ll need teams of MEs, EEs, and CS students
  - Absurdly expensive in time and effort
  - *Still* going to cost you ≥ $10,000 for a 1U *just for the development*

What we really really want

- 1 - 3U scalable design
- COTS subsystems
  - Solar, battery, OBC, deployables, ADCS
  - Capable subsystems, not just educational toys
- Open source to understand how these things work
- Scalable subsystem reference designs (microcontrollers to Linux boxes)
- Student team friendly
  - APIs everywhere - common interfaces for software, electrical and mechanical systems
  - Boards and systems are easily swappable
  - Uses common and obtainable development tools, with existing onboarding media
  - Documentation with explanation of *why* things are this way
- Based on standards
  - Duh

“An enthusiastically self-segmenting market”

- Onboarding boards and tools *students* can afford (~ $10s)
  - Let them onboard themselves!
  - *Everyone* gets a dev board!
- DIY subsystems (~ low $100s)
  - Students and teams build their own boards to minimize cost
  - Ubiquitous subsystem boards!
    - Each student should be able to have a CubeSat dev board
    - Each team should be able to have their own dev subsystem
- COTS Dev subsystems (~ high $100s)
  - Buy cheap untested dev boards for quick development
- COTS Flight subsystems (~ $1000s)
  - Verified flight boards

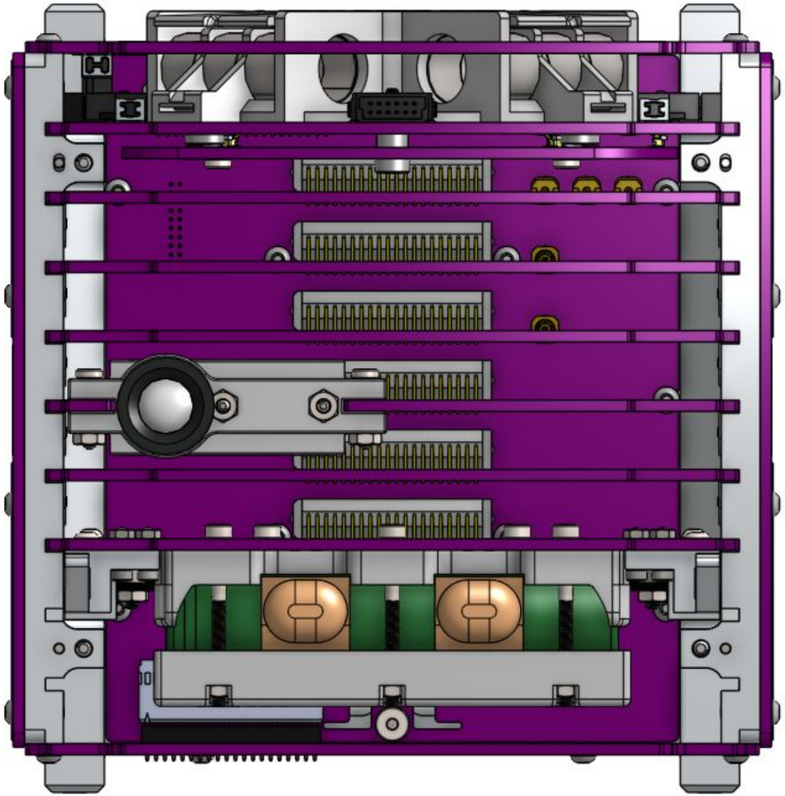
Challenge Accepted

This is a terrible idea

- Strongly don't recommend this
- Takes years (thank you CSLI for being patient)
- Hugely expensive
  - Spent ~ $75,000 on board revs and integration testing
- Hugely inefficient
  - "Generations" of student labor with hand-offs and ramp-ups and onboarding and ...
- Out of scope for most educational projects
  - Need *experienced* students in RF, thermal, mechanical, power, control, software, firmware, web infrastructure, not to mention management and fundraising

The OreSat Bus

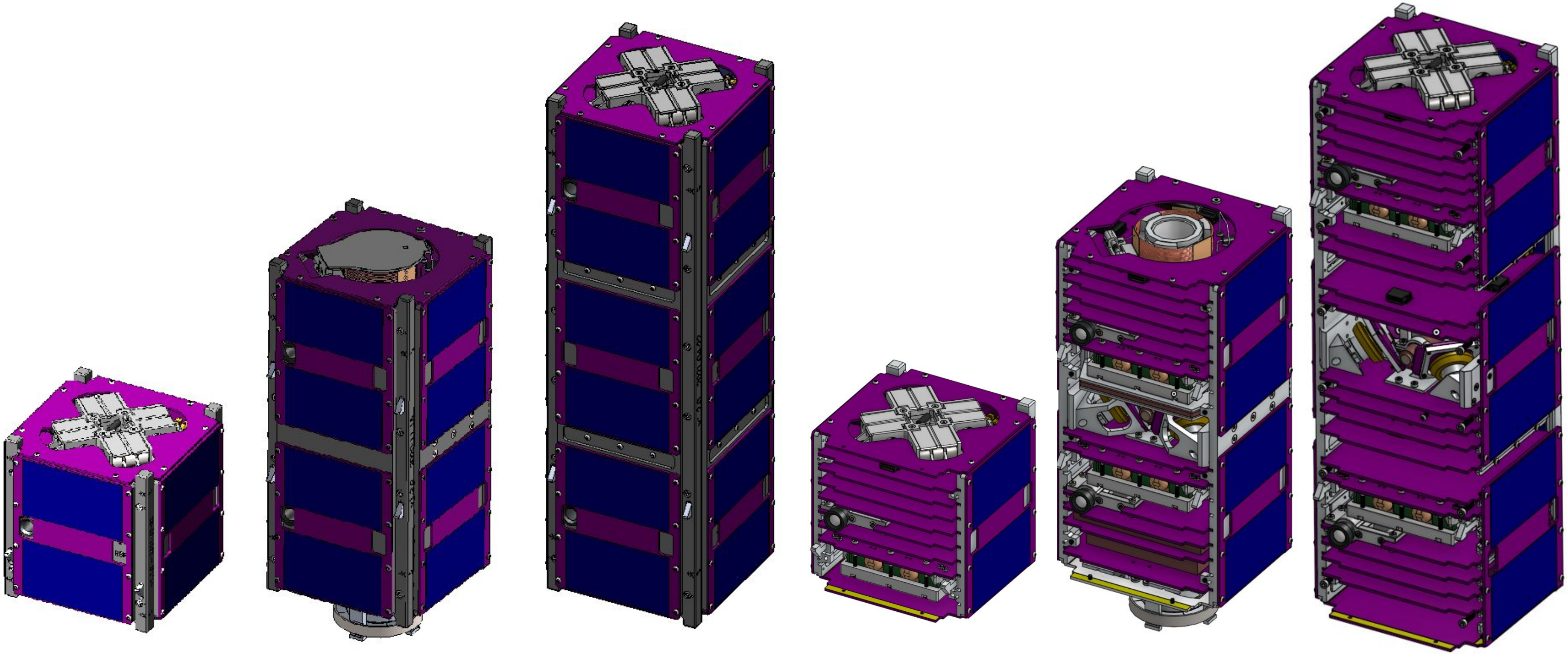
Card Cage



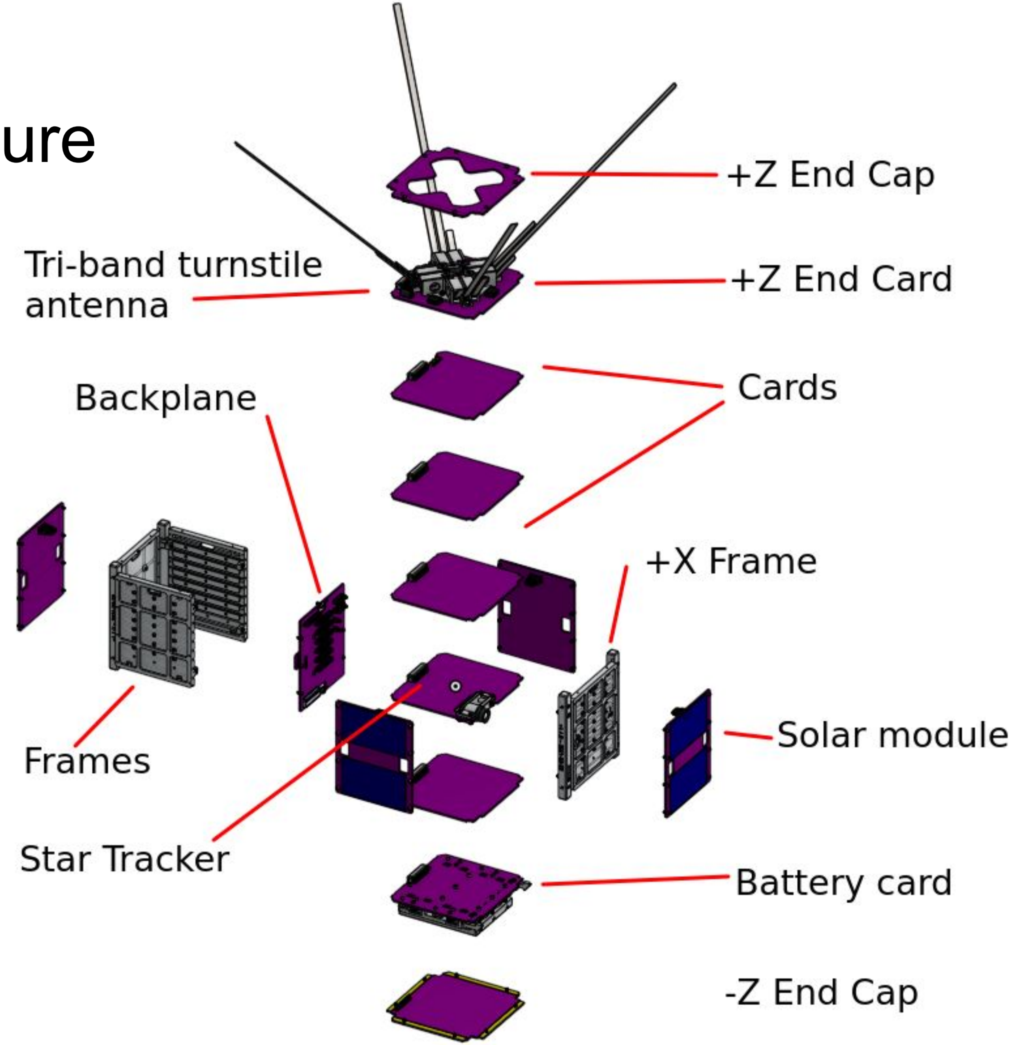
Not just for the 1970s

- Pros
  - Excellent for education teams: each subsystem is one or more cards
  - Common mechanical and electrical interfaces
  - Cards can be as simple (microcontroller) or as complex (Linux box) as necessary
  - Easily replaceable (hot swappable!)
  - ~ 40% available board area than a PC104 stack
  - Roughly 8 card slots per U
- Cons
  - Strongly discourages systems that cut through the Z axis
  - Still not terribly space efficient compared to custom stack ups

Scalable 1U - 3U

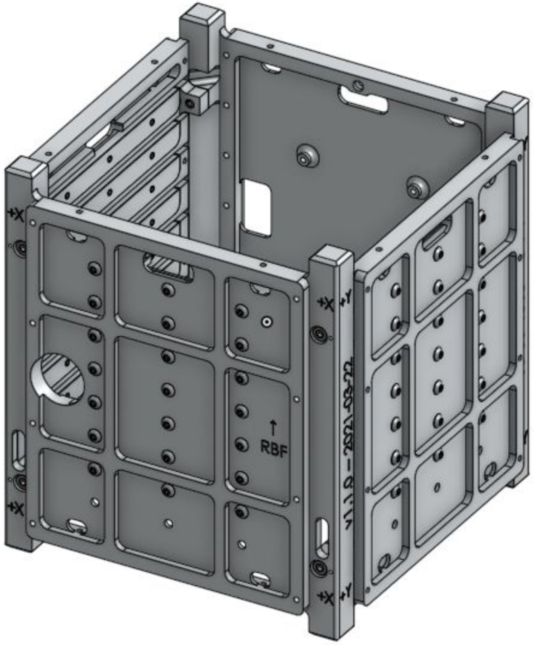


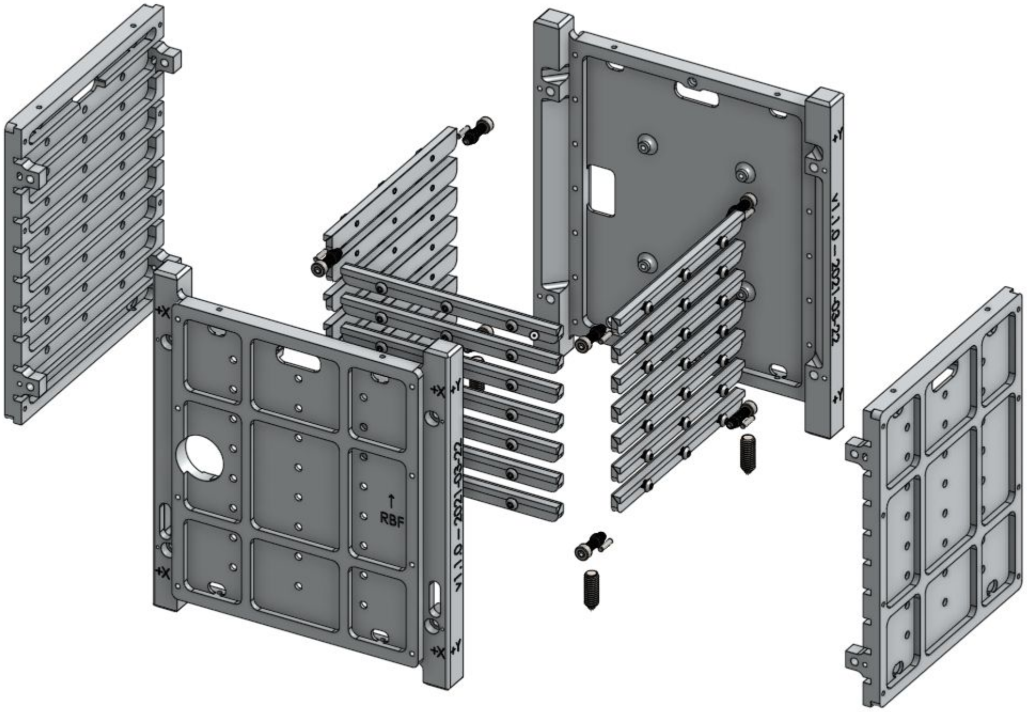
Nomenclature

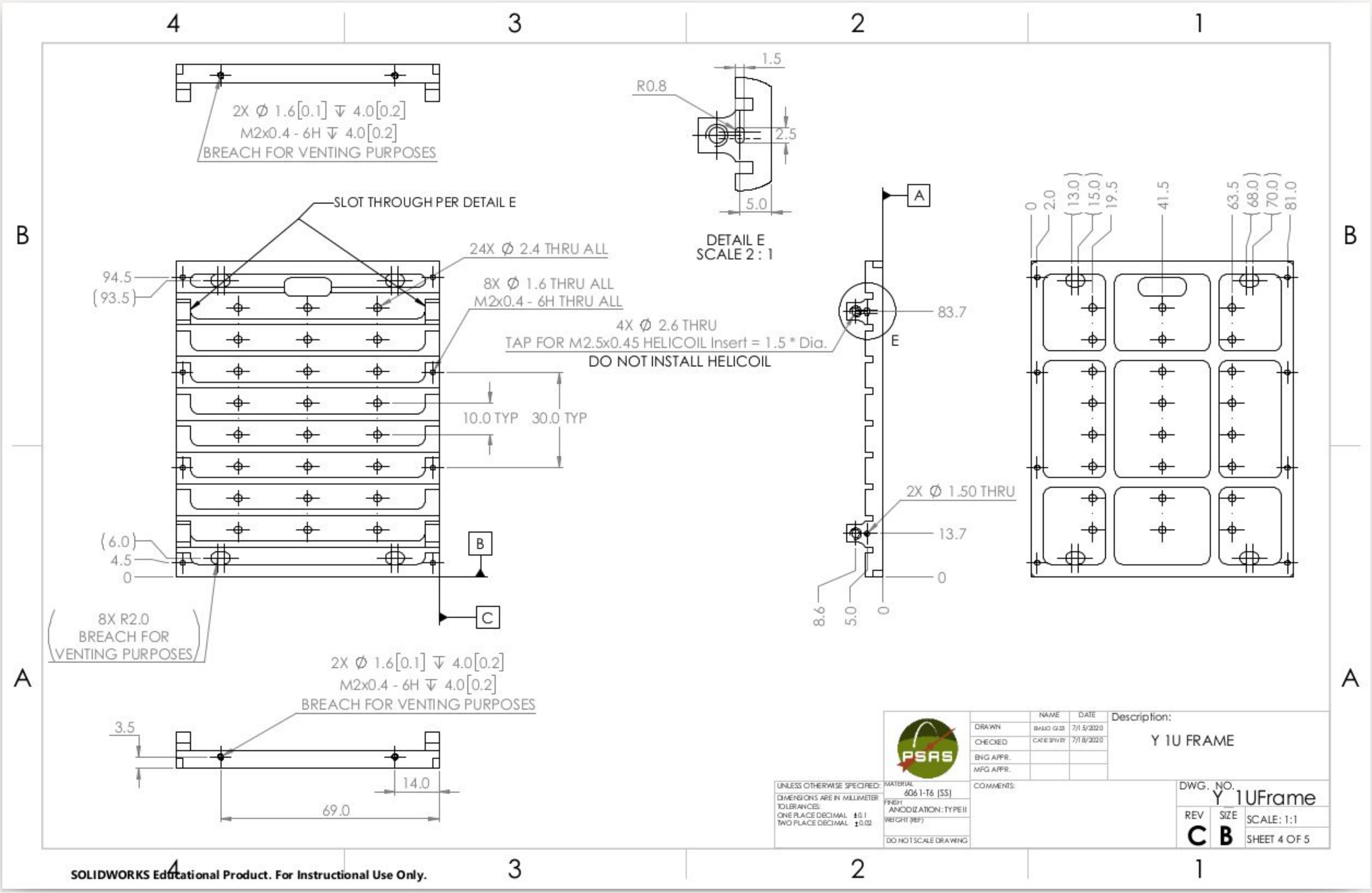


Structure

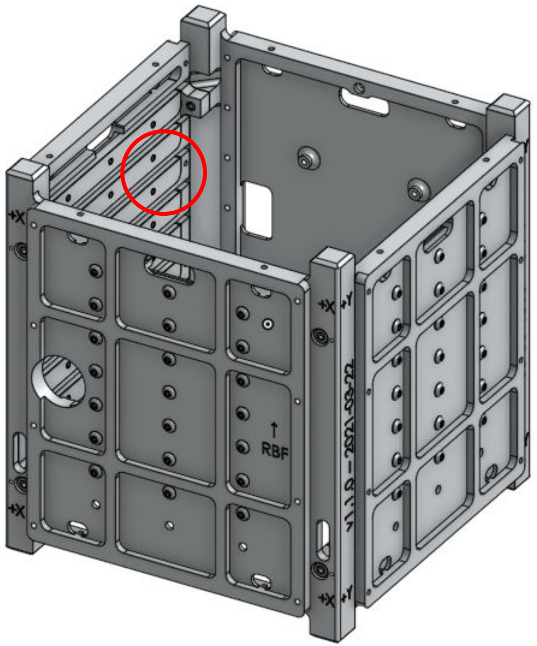
Structure (1U example)

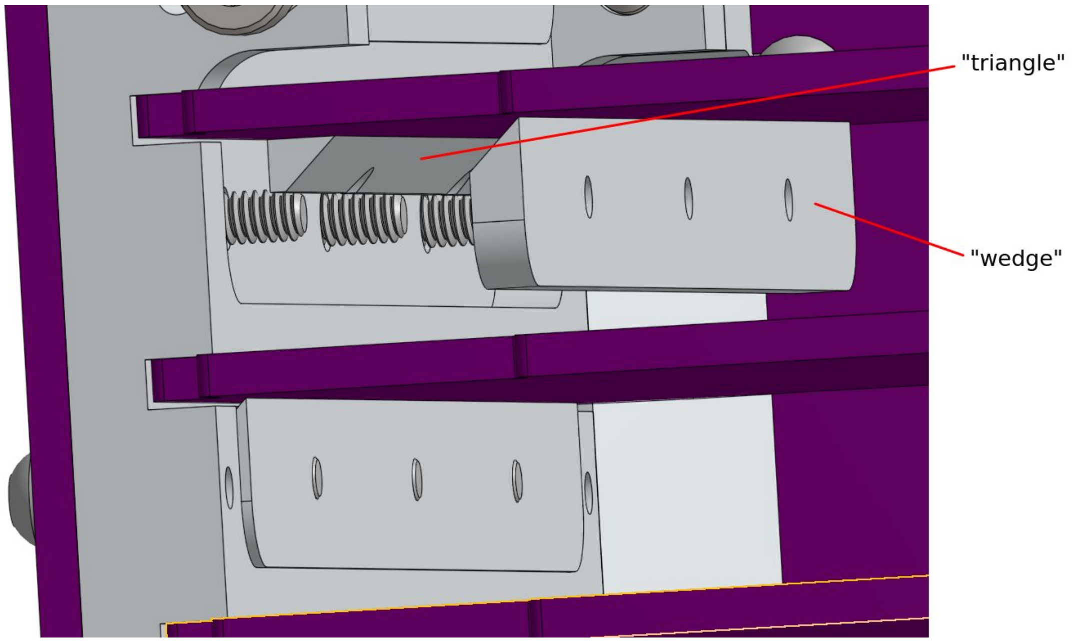





2X Ø 1.6[0.1] ↧ 4.0[0.2]
M2x0.4 - 6H ↧ 4.0[0.2]
BREACH FOR VENTING PURPOSES
SLOT THROUGH PER DETAIL E
24X Ø 2.4 THRU ALL
8X Ø 1.6 THRU ALL
M2x0.4 - 6H THRU ALL
4X Ø 2.6 THRU
TAP FOR M2.5x0.45 HELICOIL Insert = 1.5 * Dia.
DO NOT INSTALL HELICOIL
10.0 TYP
30.0 TYP
8X R2.0
BREACH FOR
VENTING PURPOSES
2X Ø 1.6[0.1] ↧ 4.0[0.2]
M2x0.4 - 6H ↧ 4.0[0.2]
BREACH FOR VENTING PURPOSES
DETAIL E
SCALE 2 : 1
2X Ø 1.50 THRU
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETER
TOLERANCES:
ONE PLACE DECIMAL ±0.1
TWO PLACE DECIMAL ±0.02
MATERIAL 6061-T6 (SS)
FINISH ANODIZATION: TYPE II
DO NOT SCALE DRAWING
DRAWN 7/15/2020
CHECKED 7/18/2020
ENG APPR.
MFG APPR.
COMMENTS:
Description:
Y 1U FRAME
DWG. NO. Y_1UFrame
REV C
SIZE B
SCALE: 1:1
SHEET 4 OF 5
SOLIDWORKS Educational Product. For Instructional Use Only.

Built-in Card Clamps

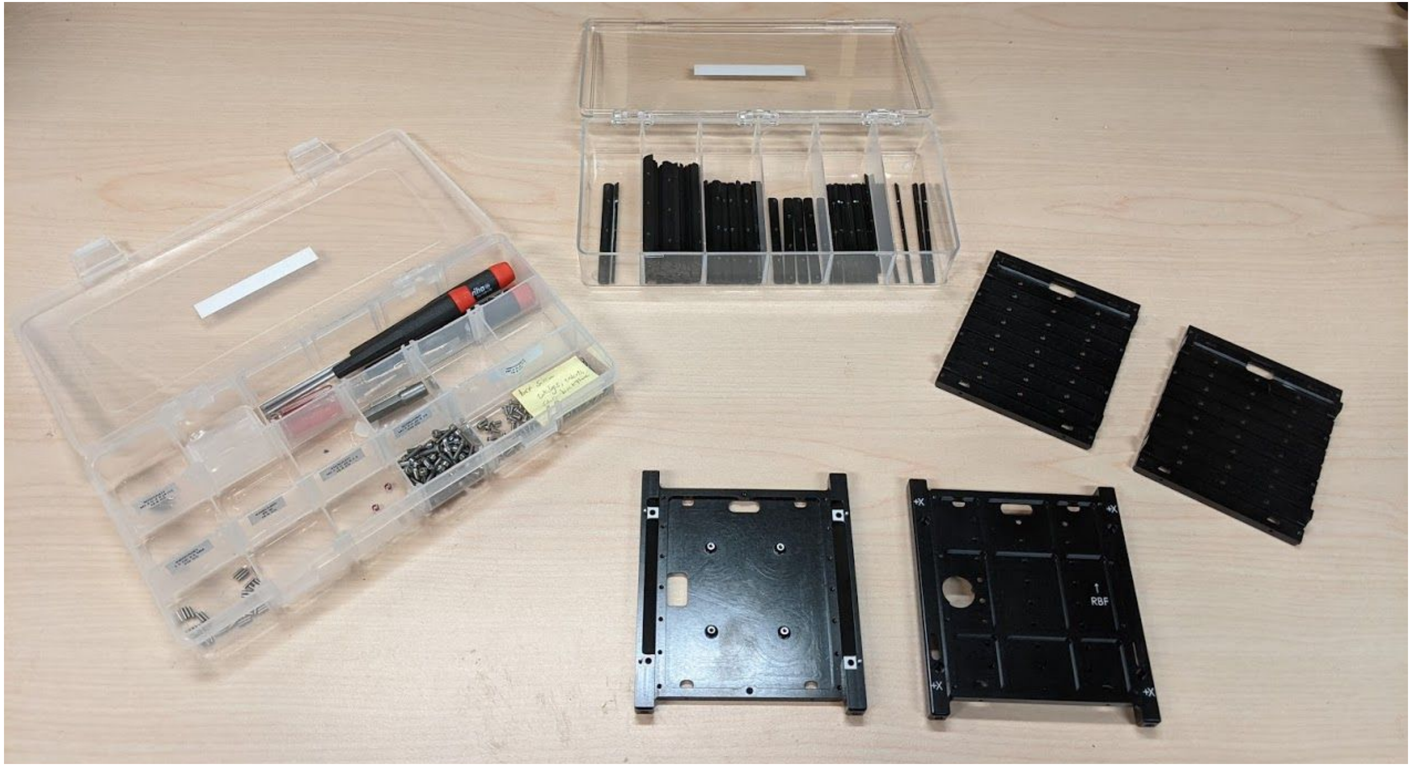




Frames

- 6061-T6 Aluminum, Type II anodized (black)
- Machinable by students on a 3 axis mill from 15 mm (½ inch) plate stock
- Decent cost if made commercially
    - 1U: $2,700/ea @ 2 down to $1,100/ea @ 10
- Standardized on Torx button head SS 18-8 M2 and M2.5 fasteners
- Thermal tuning
    - Type II anodization allows thermal *but not electrical contact* between cards / structure
    - Thermal properties tuned by copper ground plane under clamps
- Electrical grounding
    - Structure is grounded at backplane and frame elements are grounded together
    - Antenna cards are RF grounded to frame using anodization mask + Alodine 1201 coating at card clamp features

1u Structure "Kit"



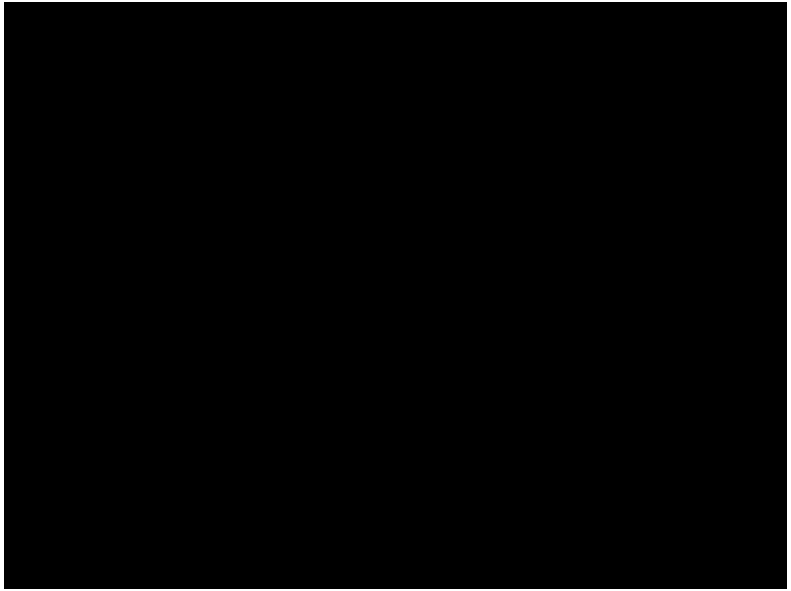
Environmental Verification

Vibration, Shock, and Weight

- Random vibration tests
    - 4 tests to SpaceX Falcon-9 Maximum Predicted Environment in all three axes
    - No failures, no debris, no visible change
    - No excessive movements or vibrations
- Shock tests not conducted
    - Except by undergraduate students. Several times. On the floor.
    - No failure. Except possibly the undergraduate students...
- Weight
    - 1U frame alone: 343 g
    - 1U with all card slots filled: ~ 1.28 kg
    - With more analysis (FEA), more weight can be taken out of frames (25%?)

Thermal Simulations

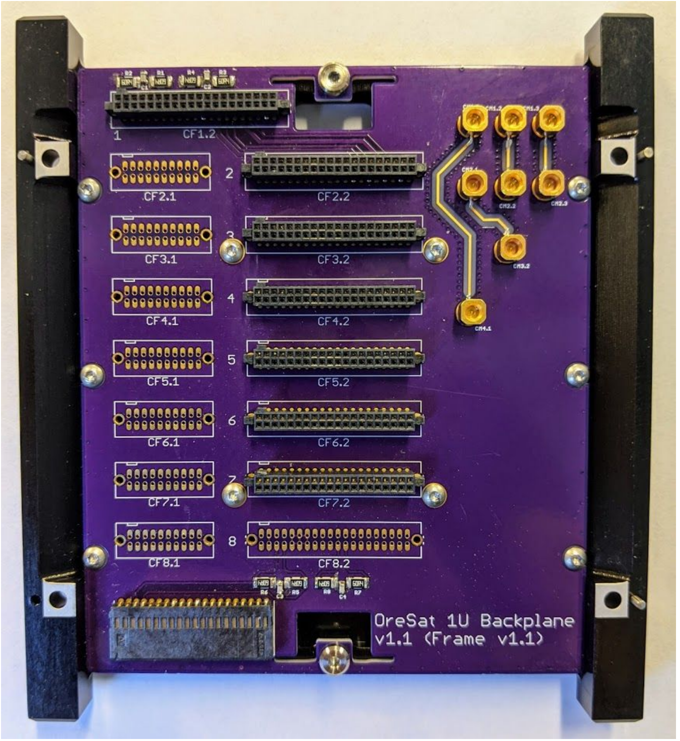
- Thermal desktop simulation of SSO
- Can’t charge batteries < 0 °C
- Simulated ± 6 °C for batteries
- Battery thermal management
  - Thermally disconnected battery from frame (no ground plane contact)
  - Kapton heater strip on cells
  - MLI around batteries



The *Actual* Bus

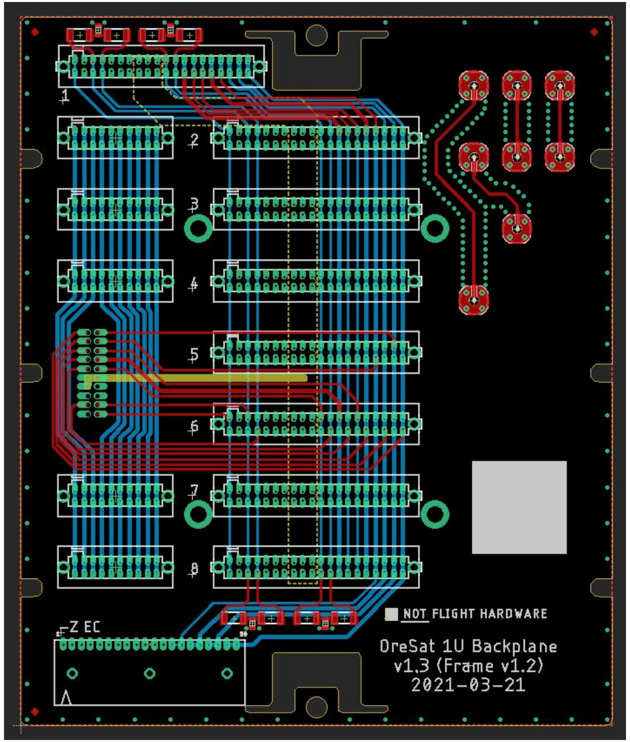
Backplane

- Power + Data
  - 40 pin 1.27 mm Samtec “TigerEye” connectors
  - Raw battery pack distribution: 6.0 V - 7.2 V_{NOM} - 8.4 V
  - CAN 1: critical systems / CAN 2: mission systems
- RF
  - Standard SMPM connectors
  - Microstrips for all RF
- Satellite control
  - Satellite shutdown
  - OreSat Power Domain (OPD) control lines
  - 5 spare lines
- Auxiliary connector
  - Because everyone wants something different
  - Ethernet between cards, maybe
- Bespoke backplane for each mission!
  - Why not, it’s cheap!



Two kinds of Simple PCBs

- Two layer boards
  - Because: cheap
  - 6/6 mil (0.152 mm) trace/space
  - End caps, solar modules
- Four layer boards
  - Because: density and RF friendly (Isola FR408-HR)
  - 5/5 mil (0.127 mm) trace/space
  - All cards, Backplane
- Why Purple?!
  - OSH Park PCBs (an OreSat sponsor) uses a purple solder mask!



3 Levels of Computing

- Distributed simple computing
  - Solar modules, battery pack
  - Cortex M0 (STMicro STM32F091) running ChibiOS RTOS + CANOpen Node
  - Mostly asleep, or running simple state machines, or sending telemetry
- Command and control: STM32F439
  - C3 OBC
  - Cortex M4F (STMicro STM32F439) running ChibiOS RTOS + CANOpen Node
  - High reliability, dual bank memory, watchdogs, saves state
- Mission processors
  - Star tracker, SDR GPS, mission boards
  - Cortex A8 (Octavo OSD335x-SM) running Debian Linux
  - Image processing, mission data processing, Python scripts

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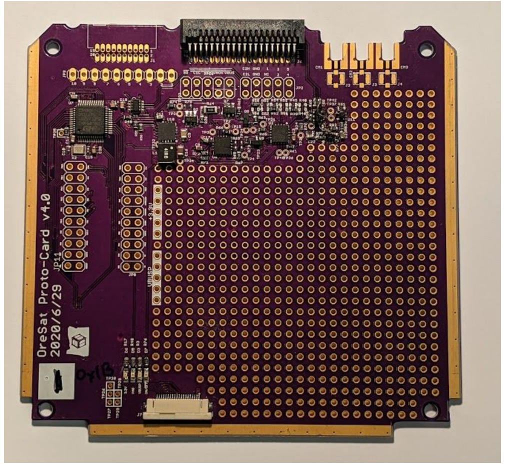
3 Levels of Firmware Development Tools

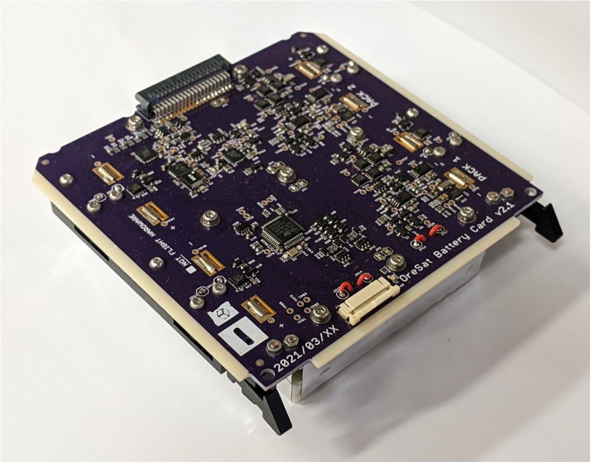
$11 COTS development board

Purchased online, used for firmware onboarding, breadboarding, tool bringup



~$75 OreSat “Protocard”

Hand-built in-house, used for firmware bringup, CAN communication, FlatSat



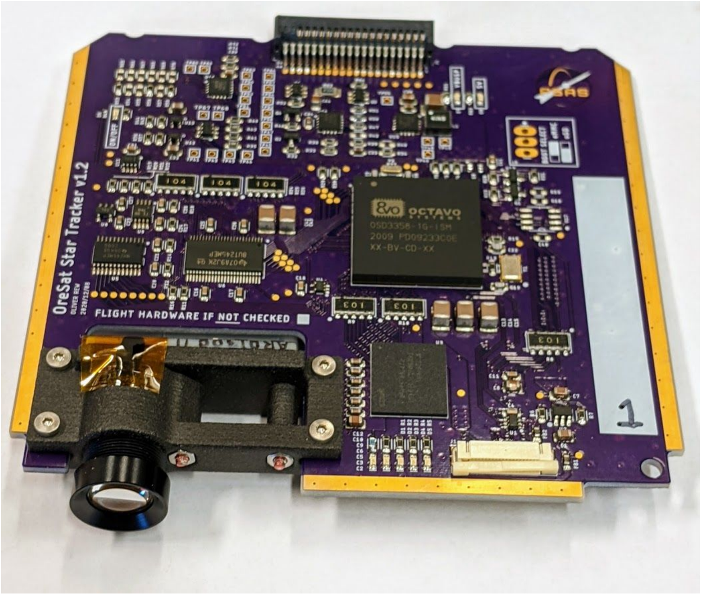
~$350 OreSat Battery Card

Built professionally, used for final development and integration testing

2 Levels of Software Development Tools

$35 COTS development board

Purchased online, used for software onboarding, breadboarding, tool bringup

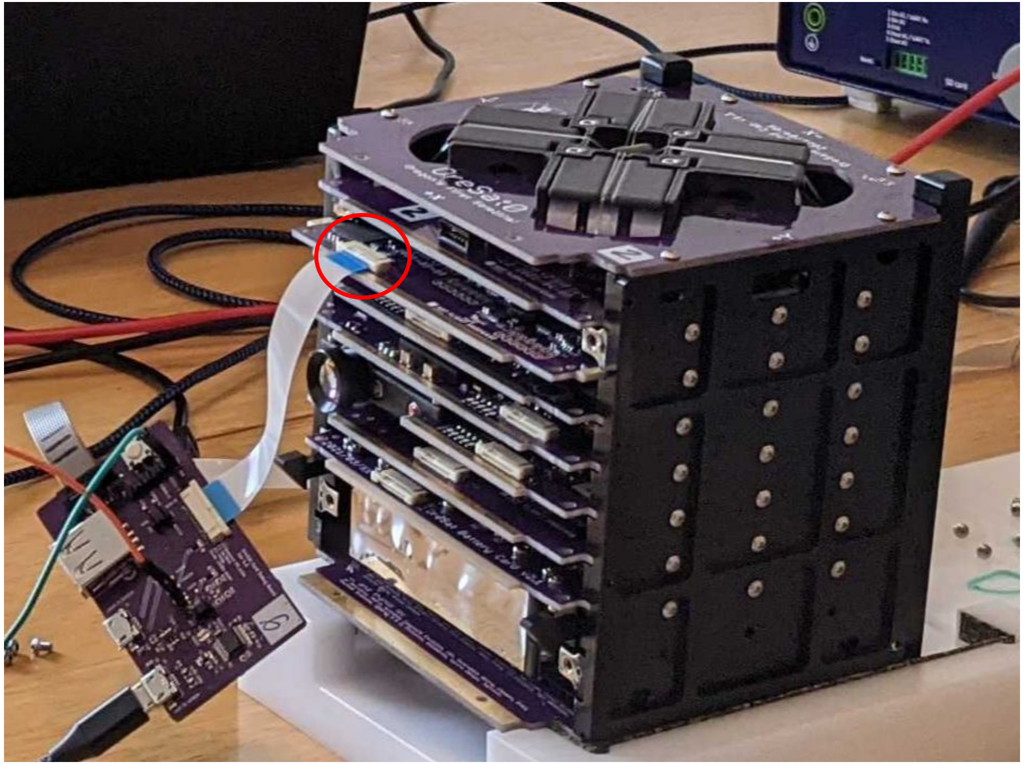


~ $600 OreSat Star Tracker

Built professionally, used for final development and integration testing

Common debugging tools for all processors

- Common FFC debug port
  - JTAG / SWD for programming
  - Serial port
  - Host/Device USB (Octavo only)
- Common debug board
  - Onboard USB to serial adapter
  - USB connectors
- Shared between all cards



1U FlatSat

Battery IMU Star tracker Mission SDR GPS OBC

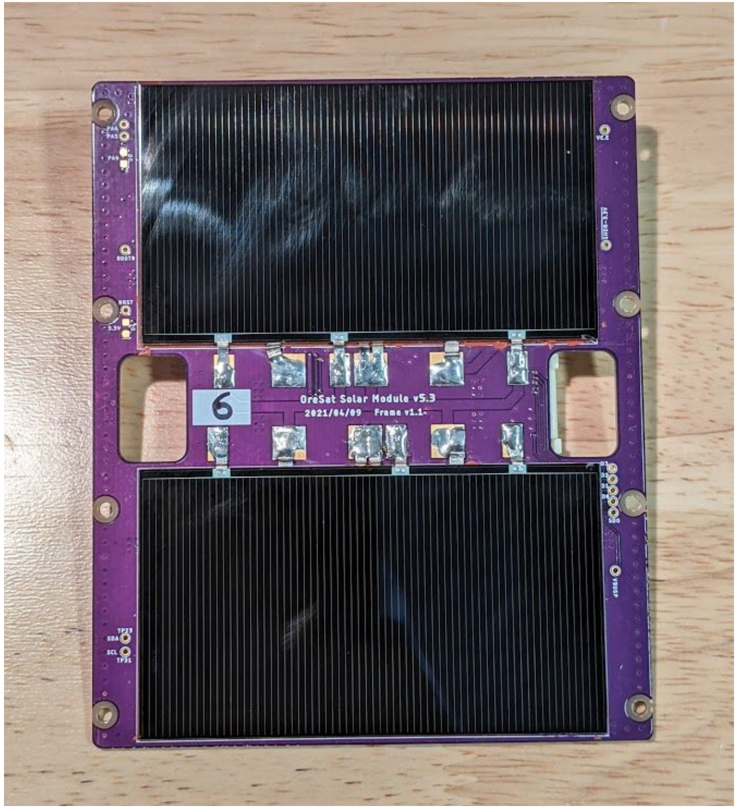
CANopen-based communication

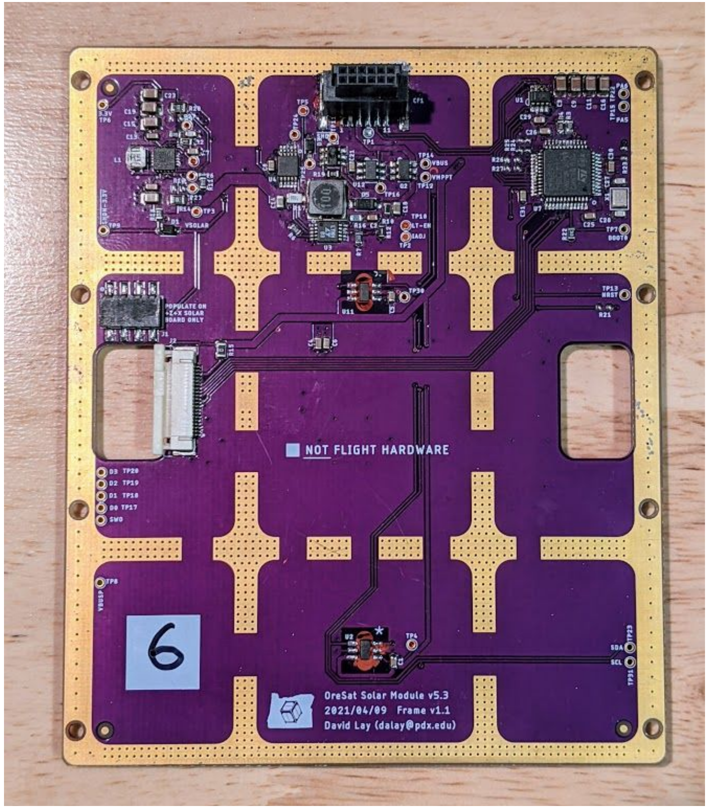
- CANopen implementation of CCSDS recommended Spacecraft onboard interface services (SOIS)
- Each card has CANopenNode + data object descriptions
- Each card subscribes to the data objects it's interested in

Solar modules

- 1 per X,Y side (4 per U)
- 2 Spectrolab XTE-SF cells = 4.2 W_{pk} / module
- True independent MPPT on each module
  - *Not* an MPPC
  - Software controlled MPPT: P&O, INCCOND, or DIY
  - Directly charges the battery via Vbus
- Directly thermally connected to the frame
  - Like the cards: ground plane to anodized Aluminum
- Also contains
  - Look-through for star tracker
  - Remove Before Flight (RBF) interface to satellite shutdown

Solar modules



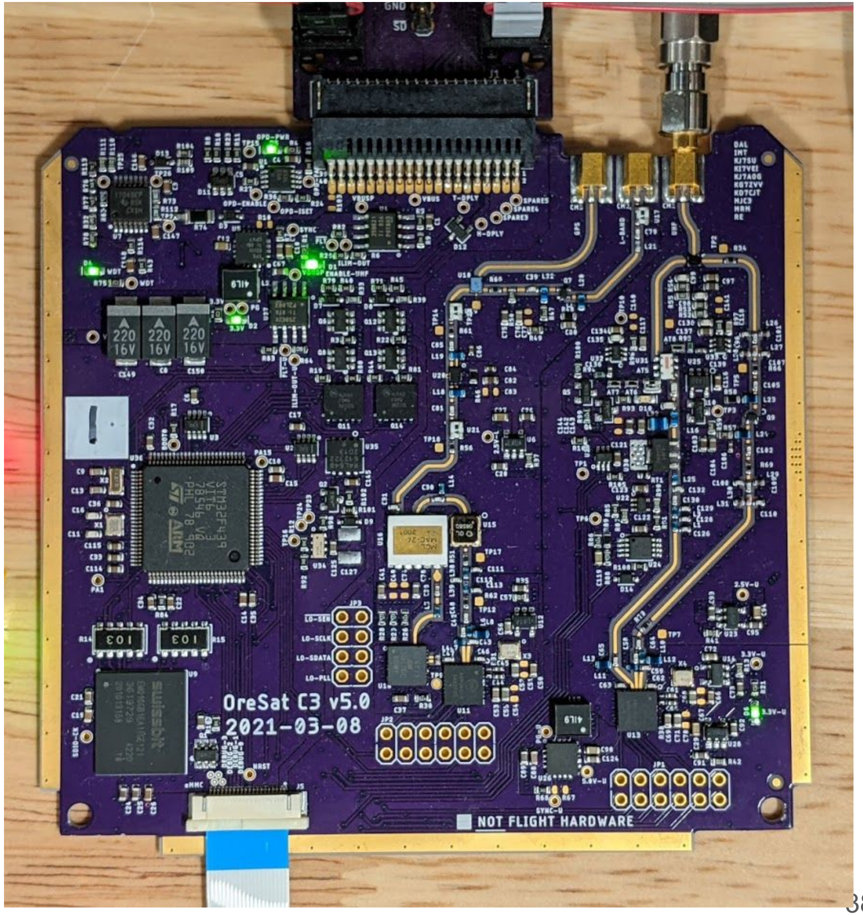


Battery Pack

- Two 2S1P Li ion 18650 cell packs on one card (7.2 V @ 5.2 Ah)
- Hardware overcharge, overdischarge, and overcurrent circuits
- Fuel-gage with cell balancing
- Firmware charge / discharge controls
- Inhibit switches (in +X axis rail face)
    - Positive terminal battery disconnect switch
    - Inhibit switch asserts Satellite Shutdown, which disables solar and all batteries

"C3" Onboard Computer

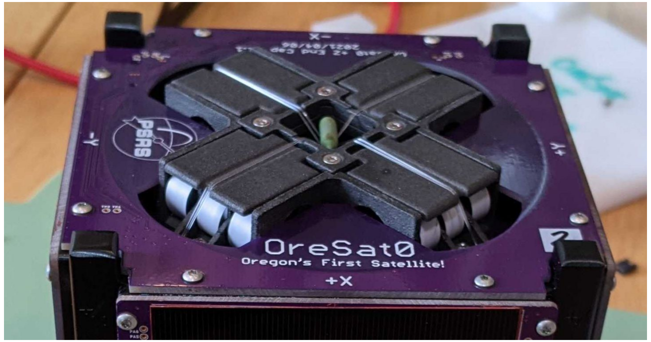
- L band receiver (1.26 GHz)
- UHF transceiver (436 MHz)
- Radiation tolerant watchdog circuit
  Tied to satellite shutdown
- FRAM + RTC state storage
- 16 GB of onboard data storage

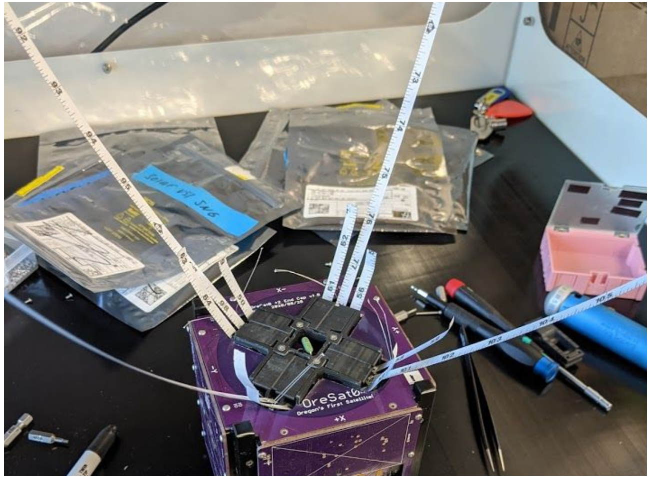


Deployables

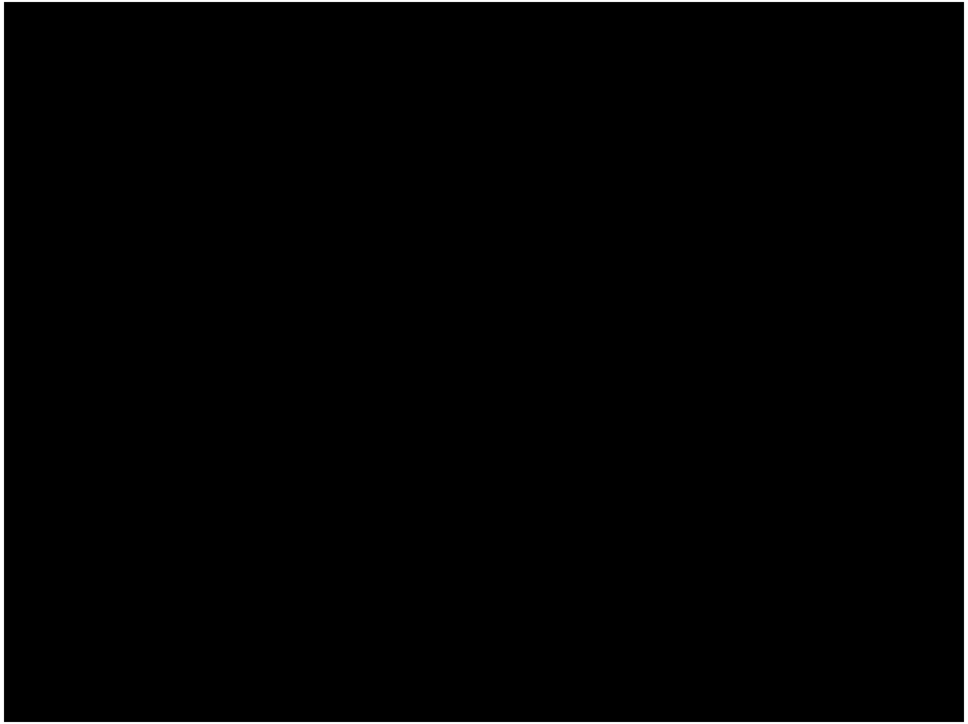
Deployable Tri-band 4 Element Turnstile Antenna

- UHF (436 MHz)
- L band (1.2 GHz)
- S band (2.4 GHz)
- Omnidirectional
    - Polar scan TBD
- Standard monofilament
  Nylon meltwire + resistor





Live Action Video



More Information

Current Status

- Ongoing subsystem development
    - ADCS (Reaction wheels and Magnetorquers)
    - S band 1 Mbps telemetry system
    - 6 m/px Earth observation camera in ¼U (2-3 cards)
    - SWIR camera
- OreSat0 1U tech demonstration mission
    - Handed off April 2021; waiting for flight!
- OreSat1 2U CSLI mission
    - Handoff NET Oct 1 2022
    - Deployment Winter 2023

More Information

- A good place to start: https://www.oresat.org/
- Full source at: https://github.com/oresat
- More open source aerospace: https://www.pdxaerospace.org/
- Contact us at oresat@pdx.edu

Thank you!