Columbia and Atlantis – Two QB50 CubeSats Demonstrating Reliable Computing In Space With A Fast Track Project

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Small Satellite Reliability TIM
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Overview

- University of Michigan Space Physics Research Laboratory
- QB50 Project
- UM/SPRL Satellite Design
- C&DH Design
- Current Status
- Lessons Learned

Space Physics Research Laboratory (SPRL)

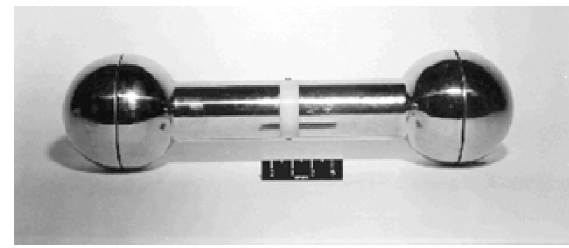
- Supported CLaSP/AOSS/SPRL PIs in the development of space research instruments since 1946

- Over 100 rocket, aircraft & balloon experiments developed to-date

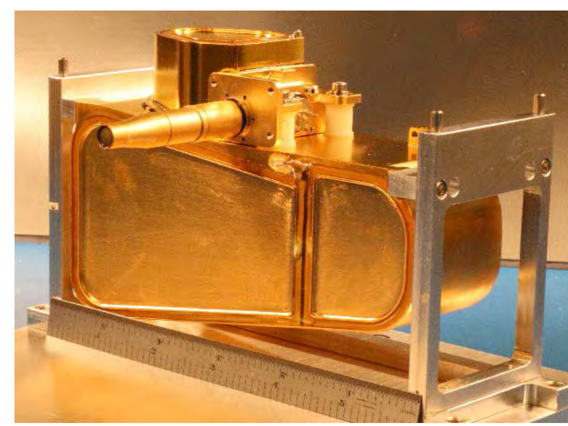
- Over 35 major space instruments developed to-date

- Engineering & technical services provided to UM and industry

Home of SPRL Today



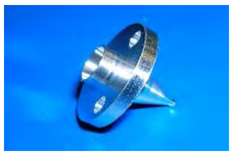
Early "Double Probes" flown on V2's

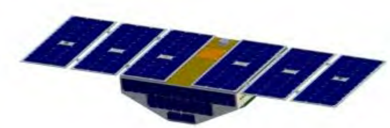


PIXL XRSA for Mars 2020 Mission

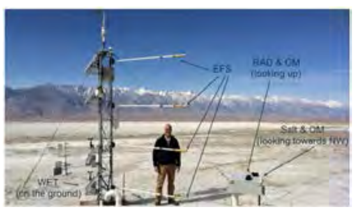
Some Dimensions of our Projects…

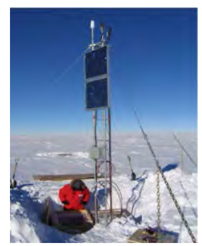
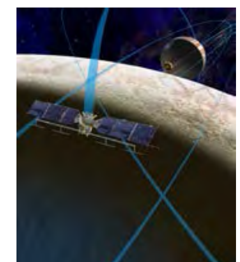
- ***Large Size Range:*** $3k precision parts to $100M projects



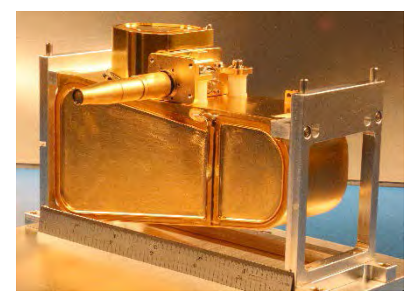
- ***Diverse Harsh Environments:***
  Very dry and dusty to very cold/very hot to very high radiation



- ***Responsive Management:*** Fast technology development to high reliability precision instrumentation





Our Challenge on QB50…

- Design and build 2 CubeSats from scratch in 5 months
- Take on system elements we had not done before
  - Radio link
  - Solar panels
  - Attitude control
  - Satellite integration
  - To name a few!
- Use new tools and processes

Your Speaker, Ryan Miller

- 1985 U of M, BS Computer Engineering, Summa Cum Laude
- 1987 U of M, MS Computer Engineering
- I've had the privilege of working in the Aerospace field for over 30 years
- Project History:

Infrared Calibrated Spatial Measurement System (IR CASMS): Aircraft-mounted infrared scanning system
Orbital Acceleration Research Experiment (OARE): Nano-g accelerometer flown on the Space Shuttle Columbia
Cassini Ion and Neutral Mass Spectrometer (INMS): Mass Spectrometer, Saturn
Huygens Gas Chromatograph Mass Spectrometer (GCMS): MS, Titan lander
TIMED Doppler Interferometer (TIDI): Optical Interferometer, Earth orbiter
Antarctic Magnetometer: Long duration research instrument
MSL Sample Analysis at Mars (SAM): Mass spectrometry suite, Mars Rover
LADEE Neutral Mass Spectrometer (NMS): Mass Spectrometer, Moon orbiter
MAVEN Neutral Gas and Ion Mass Spectrometer (NGIMS) : Mass Spectrometer, Mars orbiter
ExoMars Mars Organic Molecule Analyzer (MOMA): Ion Trap Mass Spectrometery Suite, Mars rover.
QB50, Atlantis & Columbia

Your Speaker in Action

What is QB50?

- QB50 is an international network of CubeSats for multi-point, in-situ measurements in the lower thermosphere and re-entry research.
- This EU project is managed by the von Karman Institute (Rhode-Saint-Genèse, Belgium).
- 36 CubeSats have been launched into orbit in 2017.

University of Michigan Involvement

- Development of two, 2U satellites,
  - 1 for UM,
  - 1 for Universidad del Turabo, Puerto Rico
- **The University came to SPRL with the request to deliver satellites in 5 months!**

How Could We Be Successful?

- Small, experienced team
- Streamline administrative burden.
- Rely on our engineering expertise, no time for reviews or time consuming analyses and reports.
- Engineers in primary role, supported by students.

Design Approach

- Start from scratch
  - Ultimate control
  - Avoid working around/fixing someone else's designs
- Simplify everything
  - Mechanical
  - Electrical
  - Cabling
  - Software
- Design for ease of assembly and testing
- Utilize our space expertise to build in reliability from the start

Design Constraints

- No ball-grid-array packages for components
- No ribbon cables, minimize cabling overall
- Follow normal derating guidelines
- Follow normal signal integrity practices
- Stake heavy components and fasteners
- No space qualified components – all parts had to be in-stock at Digikey
- Minimize use of busses (I2C, SPI, etc.)
- Utilize non-bussed backplane for board-board connects
- Add redundant components where possible
- Provide power control for all components

My Design Responsibilities

- Command & Data Handling (CDH)
  - Electrical Design of CDH board
  - FPGA Design
  - Boot Software
  - Flight Software
  - Radio Interface
  - Science Unit Interface (FIPEX)
  - Ground Station
  - Ground Software
  - Testing off all of these

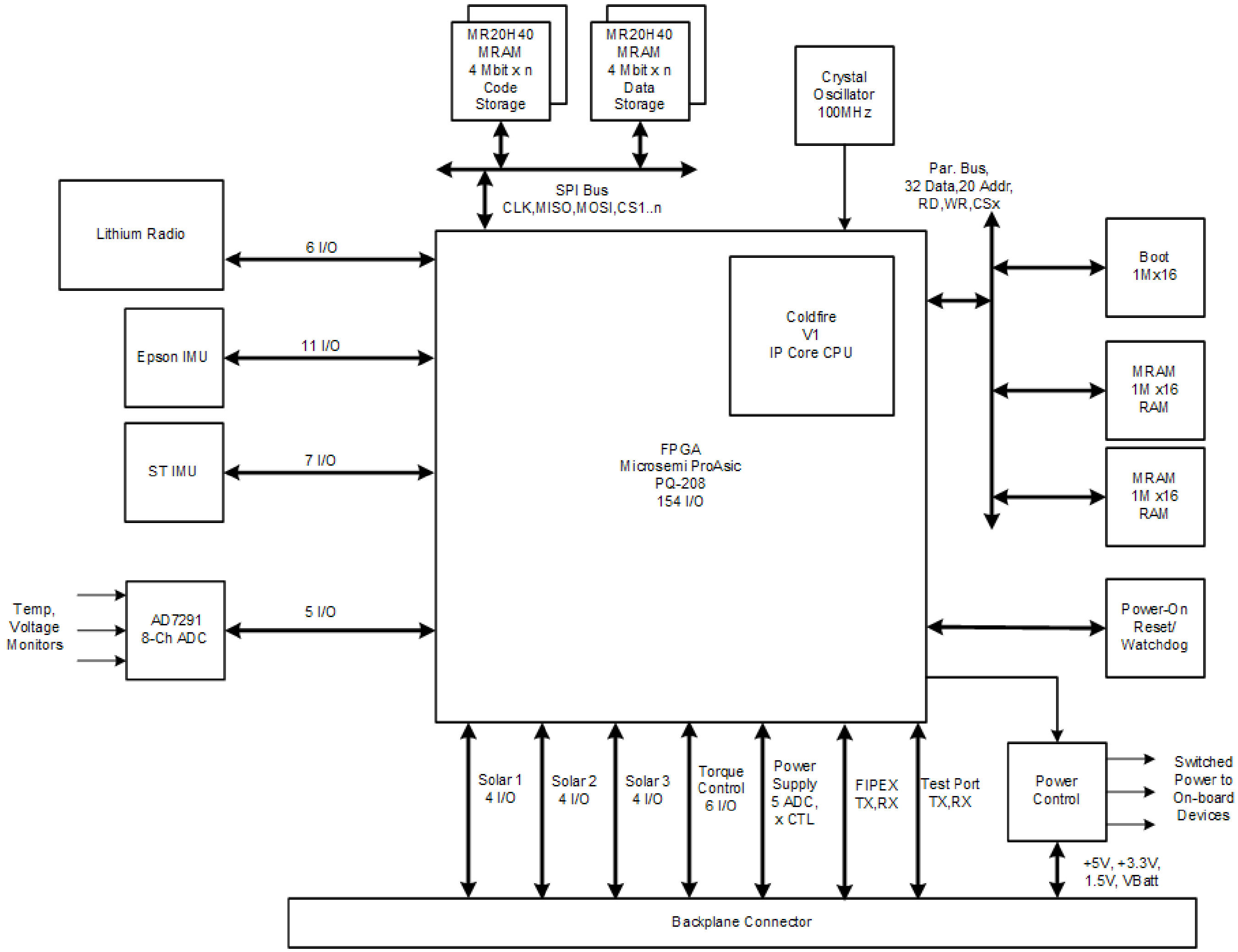
Command & Data Handling (C&DH)

- Short hardware design cycle to maximize software development
- Utilize a CPU with which we have experience
- Utilize components with some sort of established heritage (but commercial grade)
- Provide a high degree of functional integration to minimize off-board I/O (also less design cycles)
- Utilize point-to-point communication interfaces to minimize cascade failures due to multiple components on a bus

Major Components of C&DH

- CPU
- SRAM Memory (software working RAM)
- Non-Volatile Memory (code/data storage)
- PROM (boot loader, non-changeable in flight)
- FPGA (programmable logic)
- Clock Oscillator
- Other Devices
  - Radio
  - IMU
  - Analog to digital and digital to analog converters

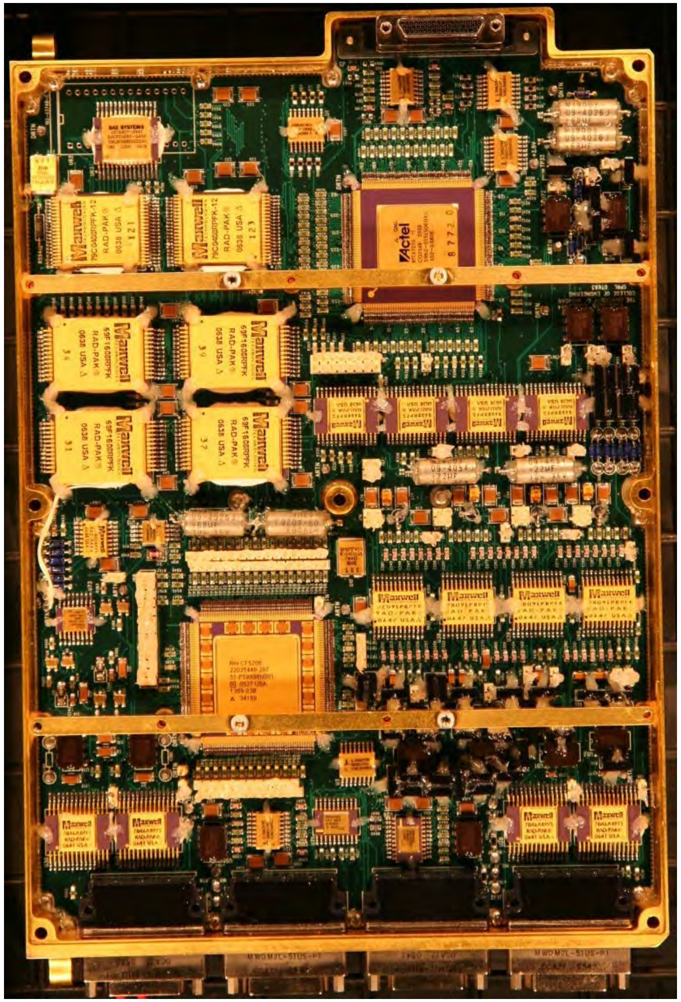
C&DH Block Diagram

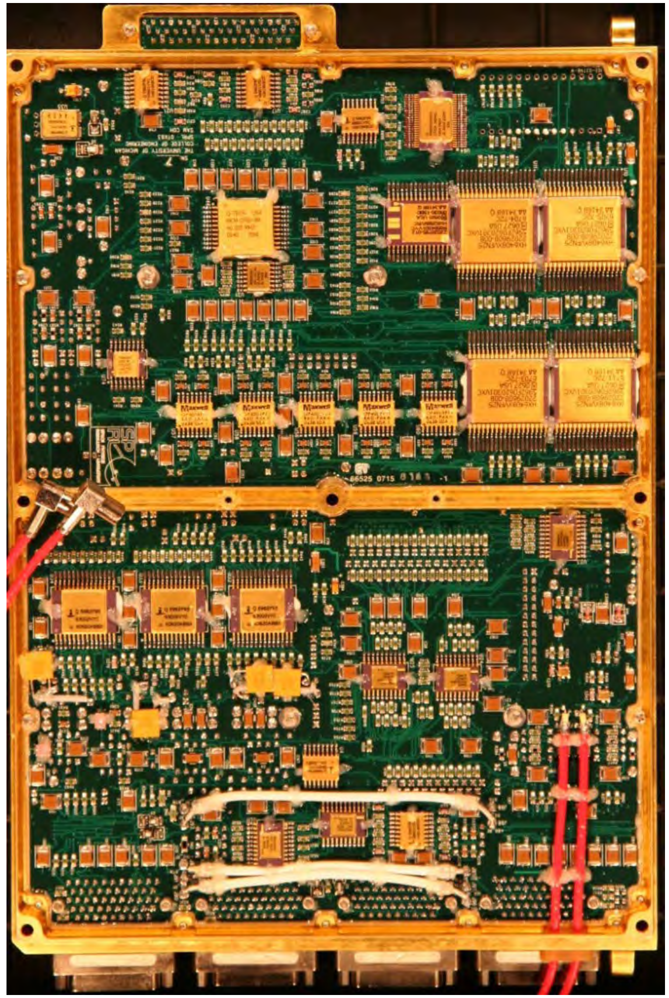


Component Selection

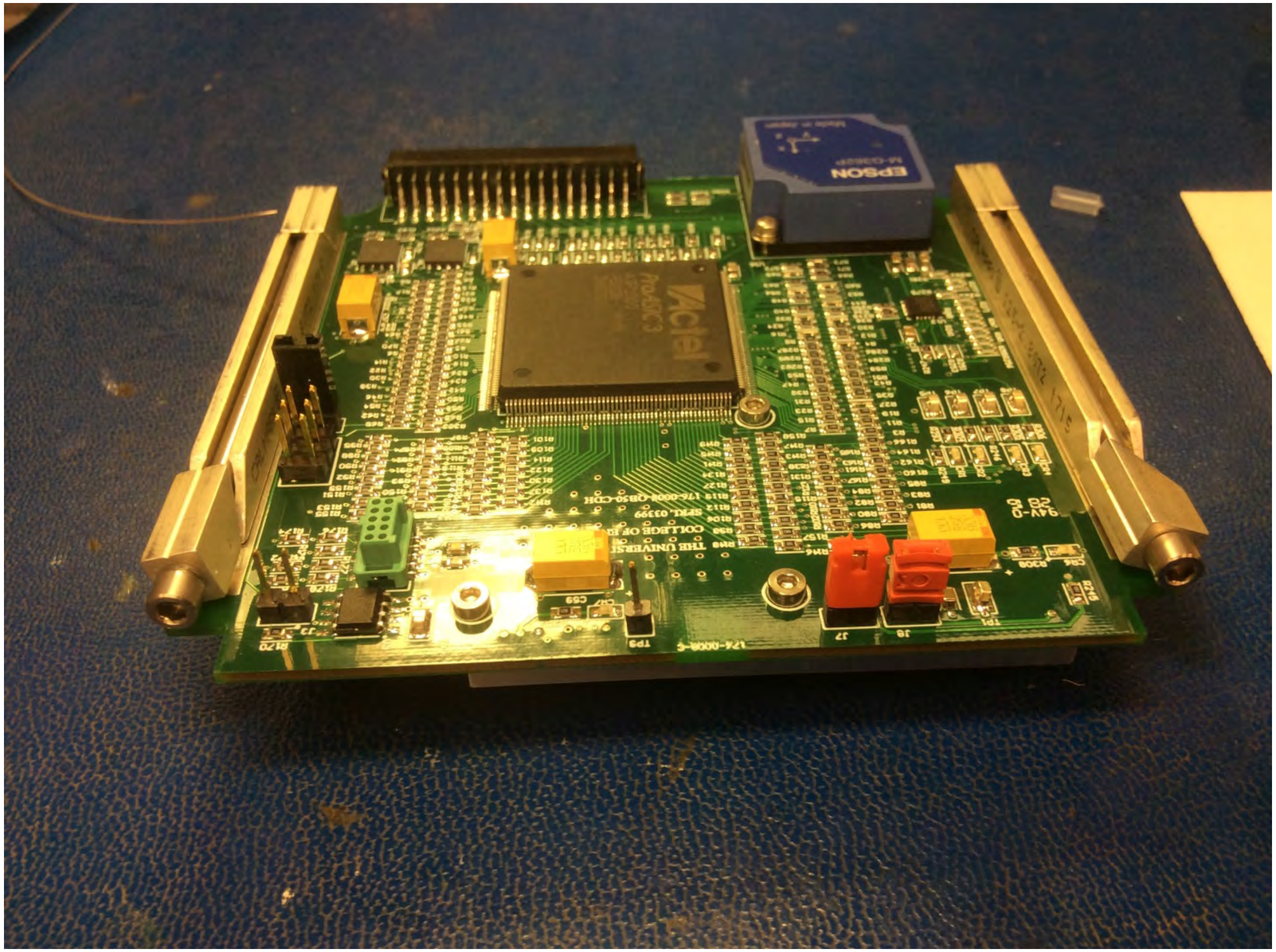
- FPGA
  - Microsemi ProAsic
    - previous use, JPL radiation test(s)
- CPU
  - Coldfire IP Core Processor
    - CPU gains benefits of FPGA reliability
    - Could use TMR/EDAC to improve reliability
    - Software can be executed with FPGA timing simulation
    - Can customize I/O to support point-to-point comm
    - SPRL has used discrete ColdFire CPUs on last several space projects
- Memory
  - Everspin Magneto-Resistive MRAMs
    - Naturally radiation tolerant, JPL radiation test(s)
    - Non-Volatile, fast, no write cycle limits
    - Can be used as PROM, EEPROM, Flash, SRAM

SAM CDH vs. QB50 CDH





Completed CDH



QB50 CDH vs. SAM CDH

SAM

- ColdFire CPU, 32-bit, 20MHz
- 2 MBytes SRAM
- 1 MBytes EEPROM
- 32K PROM
- Watchdog Timer
- 4 ADCs
- 16 DACs
- Serial Interfaces
- 64 MBytes Flash
- Redundant Rover Interface

QB50

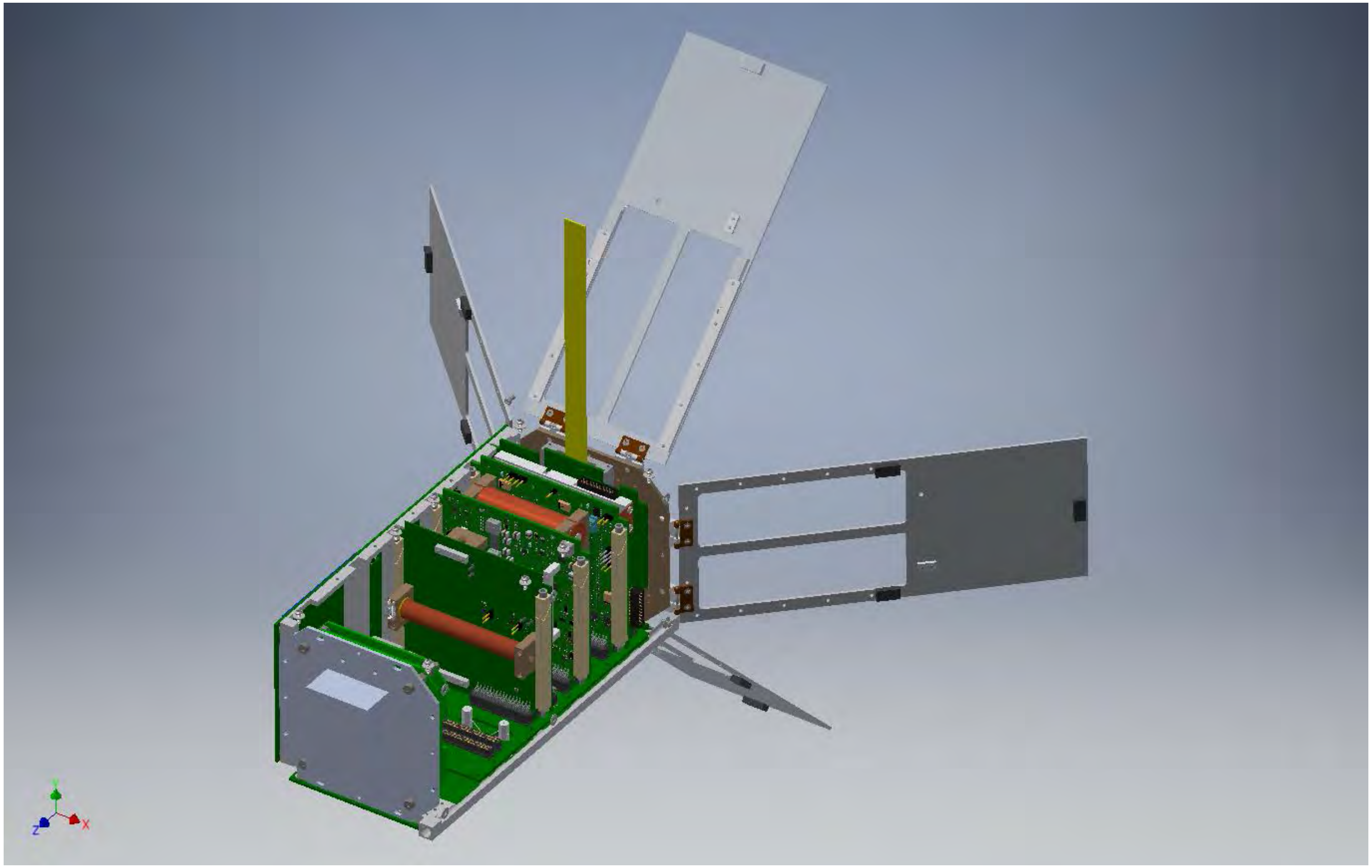
- ColdFire CPU, 32-bit 25MHz
- 4 MBytes SRAM
- 2 MBytes EEPROM/Flash
- 2 MBytes PROM
- Watchdog Timer
- 1 ADC
- 1 DAC
- Serial Interfaces
- 2 IMUs
- 1 Lithium UHF Radio

CDH Operational Results

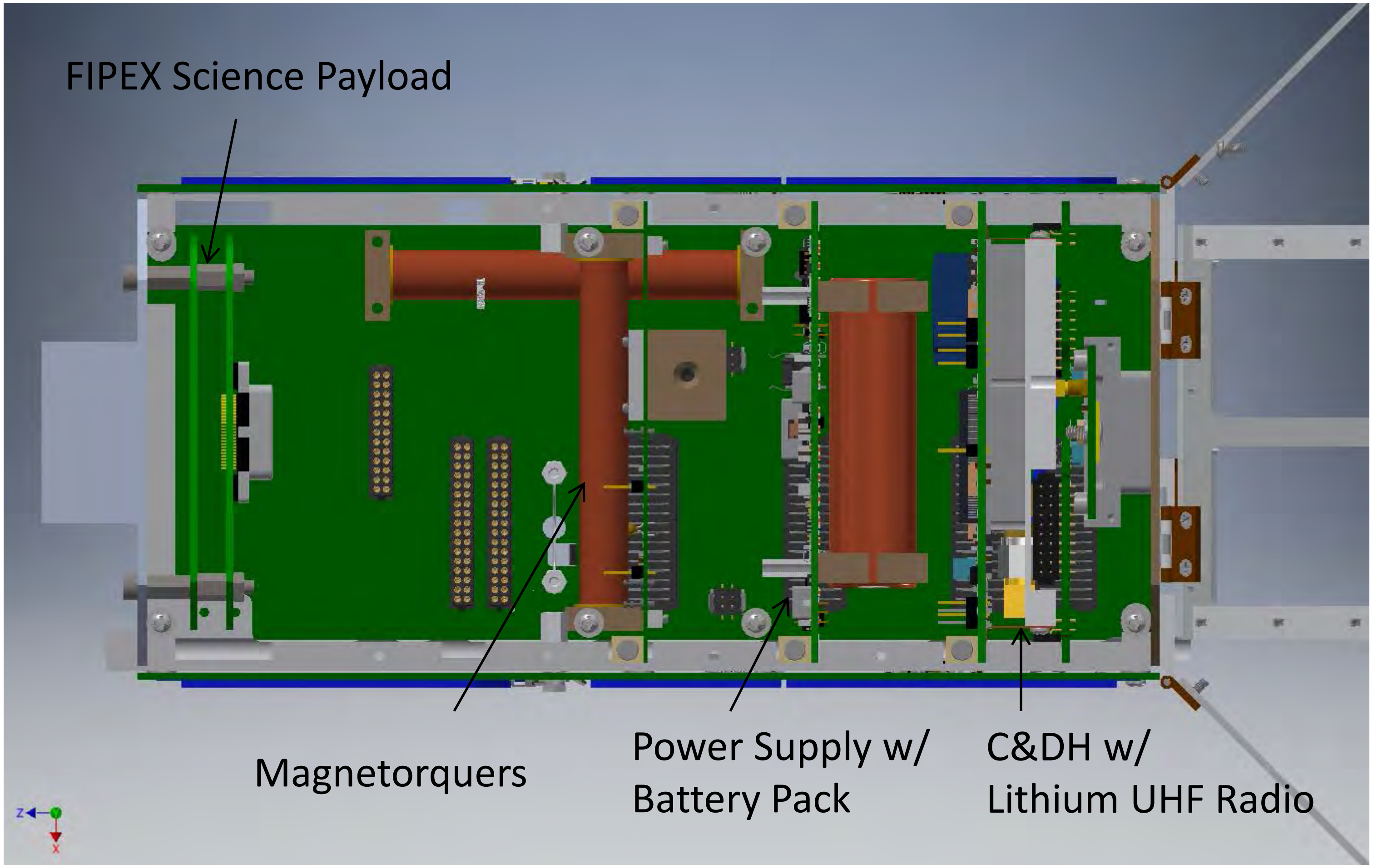
- Integrating the V1 Coldfire core into FPGA proved straightforward
- Ability to simulate software within FPGA was extremely helpful.
- Developed bootloader and flight software (~18,000 lines of code) without a debugger.
- Very little on-satellite debugging required
- Chose to ignore 'failed' magnetometer due to redundancy and point-to-point design

Mission Accomplished

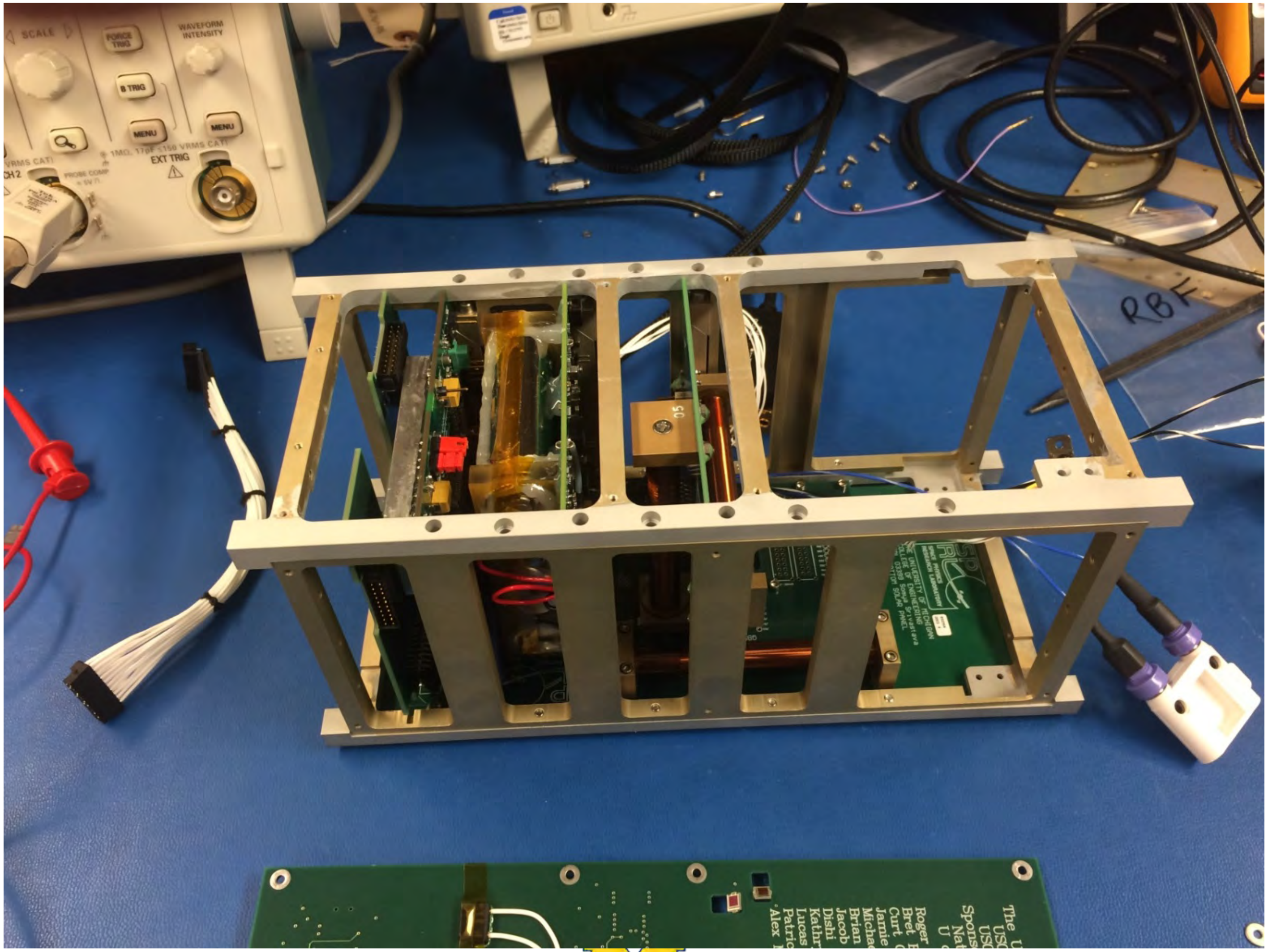
Overall Design Features



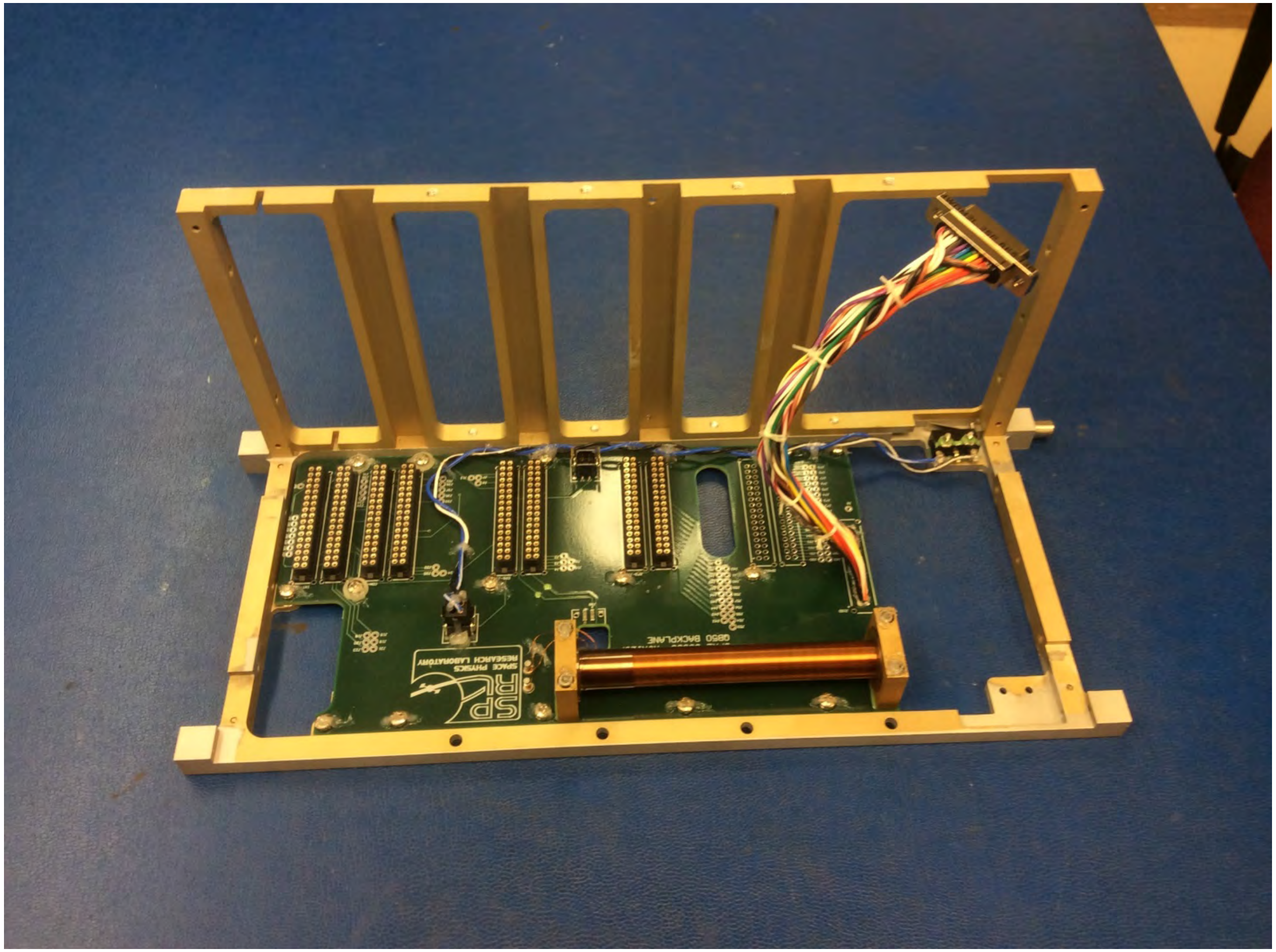
Design, Top View



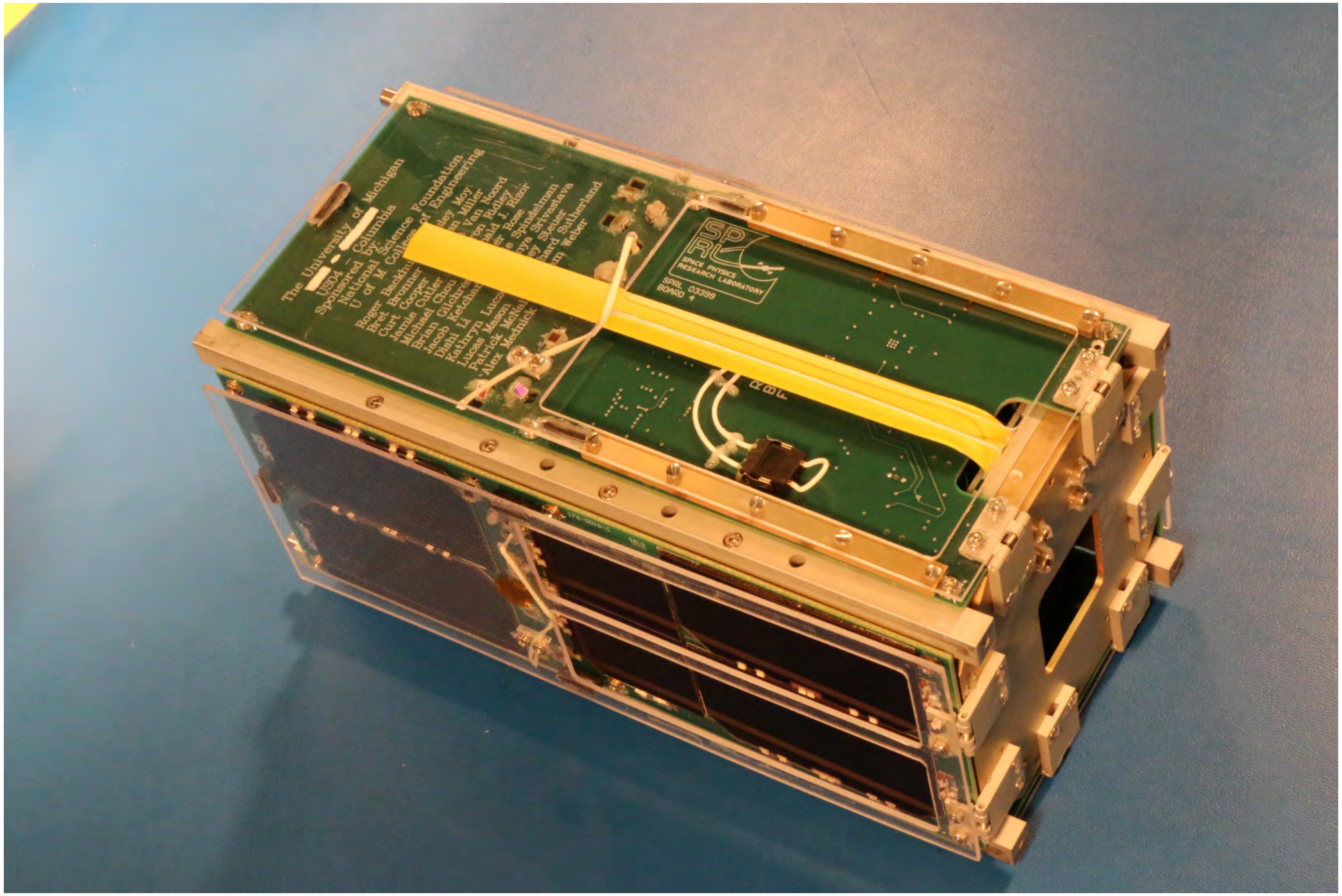
Internal Structure



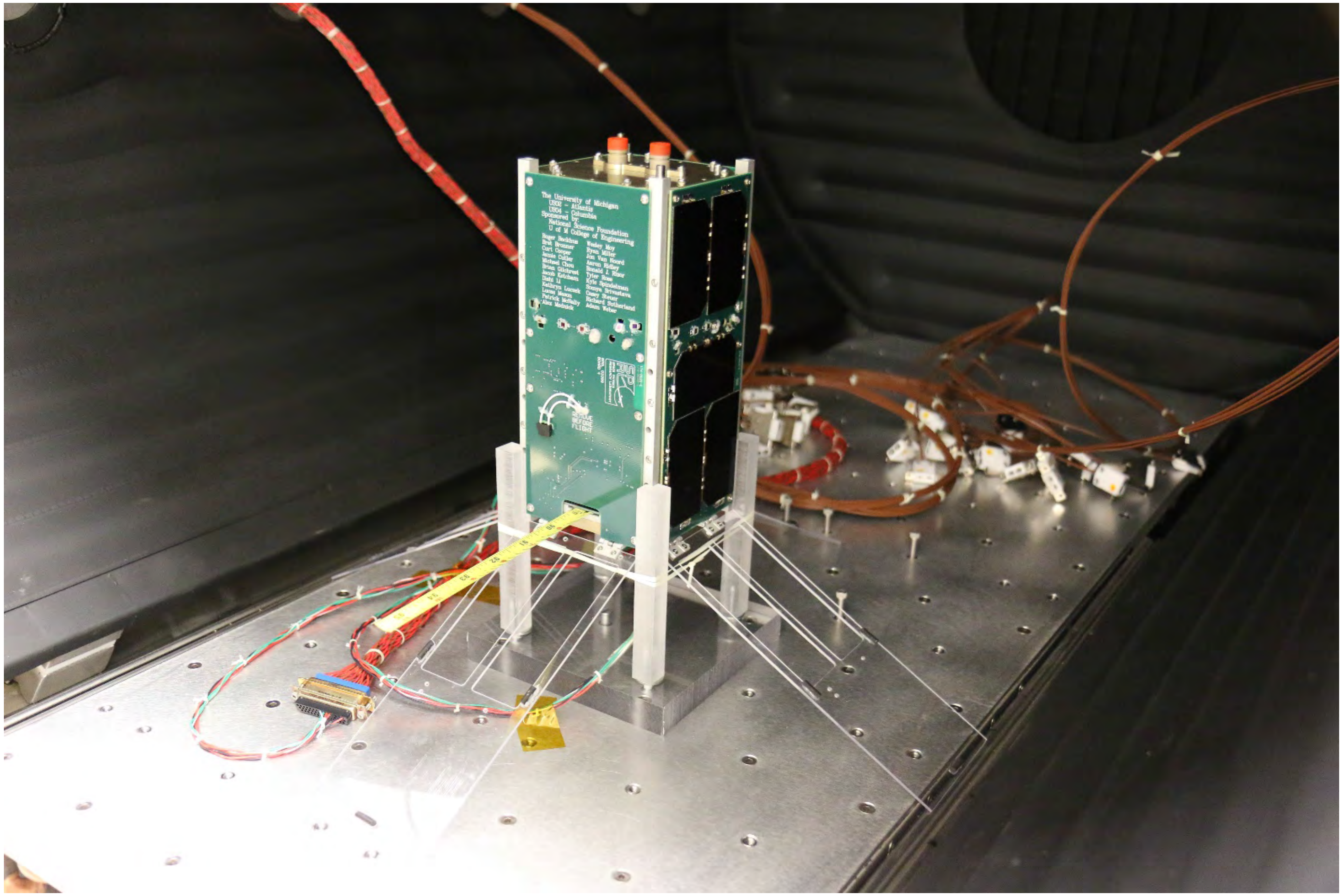
Partial Assembly



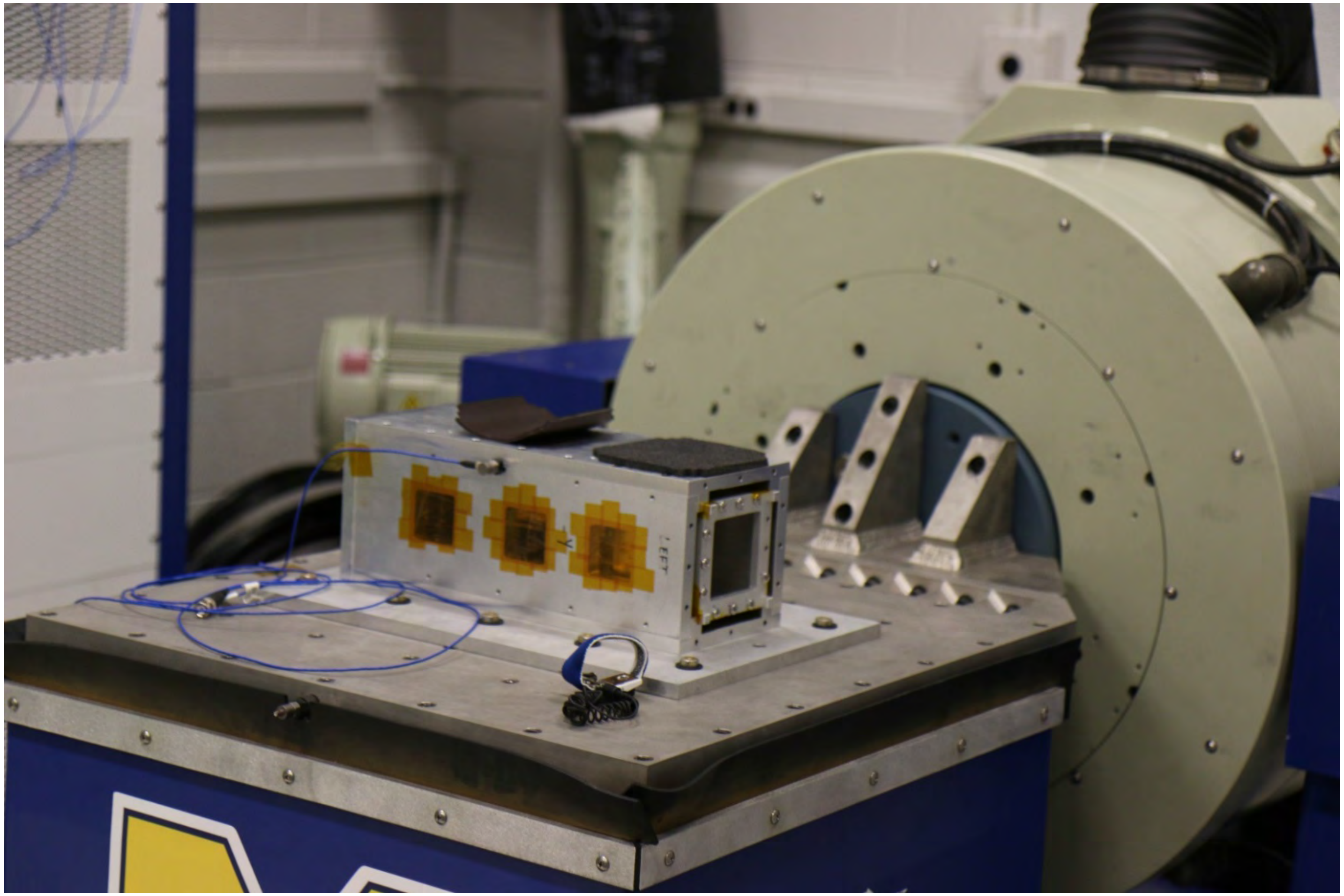
Completed Satellite – Glamour Shot



Testing – Thermal-Vacuum



Testing - Vibration



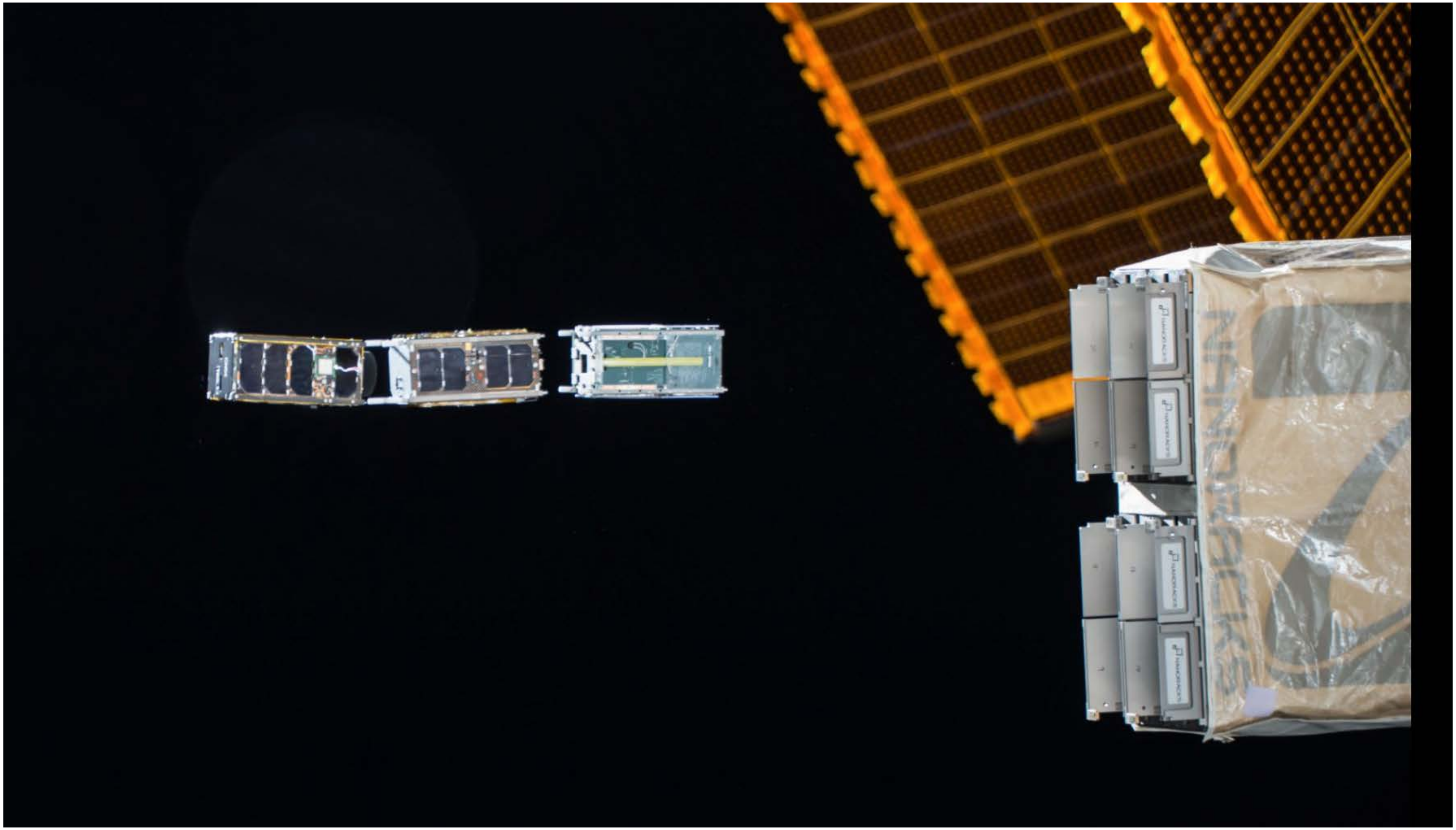
Current Status

- 2 CubeSats delivered and integrated into Nano-Racks, October 2016 (all work completed in Sept.)
- Launched to ISS, April 2017
- Deployed from ISS, May/June 2017
- Drag panels deployed and they de-tumbled the satellites within about 2 weeks.
- **We successfully track both satellites and receive data every day!**
- **Zero issues with electronics and software. No upsets, reboots, lock-ups, etc.**

There are some issues…

- FIPEX, the scientific payload
  - Atomic oxygen sensor supplied by University of Dresden
  - Sensitivity to one of the supply voltages preventing science operations
- Radio Communications
  - Downlink is very reliable
  - Uplink is unreliable, even with amplifier

Deployment from the ISS



Lessons Learned

- Satellite Reliability is Achievable
  - Requires careful component selection
  - Fault handling procedures
  - Well thought-out designs
  - Testing
- Backplane Design
  - Very successful for assembly and test
  - Allowed individual board testing with extender card
  - Eliminated cabling
- Card Wedge-locks
  - Convenient for testing
  - Increases rigidity of chassis due to integral guides

Lessons Learned

- Burn mechanism for deployment
  - Developed thermal knife nichrome wire heating elements which doubled as hold-downs
  - Improvement over fishing line/resistor method
- Solar Panel Production
  - Utilized multi-layer double-sided adhesive tapes for bonding with vacuum pressure
  - Developed tab cutting and recycling methods
- CDH Design
  - IP core processor was critical and very successful
  - Point-to-point interfaces very successful
  - High level of integration saved additional board designs
  - Boot PROM write disable needed to be accessible

Lessons Learned

- Radio Testing
  - Need to simulate full link
  - Error detection and correction
  - More fully developed protocol (ACK/NAK, etc.)
- Third Party Modules
  - Insist on full integration test
- Batteries
  - Careful selection
  - Testing is very time consuming