Project ELSA

Europa Lander for Science Acquisition

Spring Final Review

Team: Darren Combs, Gabe Frank, Sara Grandone, Colton Hall, Daniel Johnson, Trevor Luke, Scott Mende, Daniel Nowicki, Ben Stringer

Customer: Joe Hackel (Ball Aerospace)

Advisor: Dr. Robert Marshall

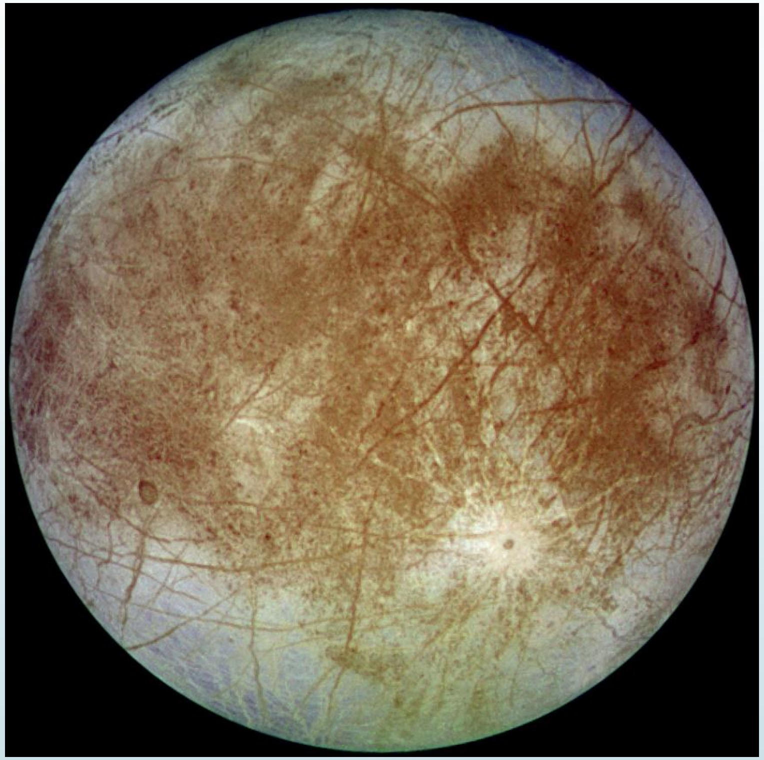
Agenda:

- Project Objectives
- Design Description
- Testing Overview and Results
- Systems Engineering
- Project Management

Project Purpose and Objectives

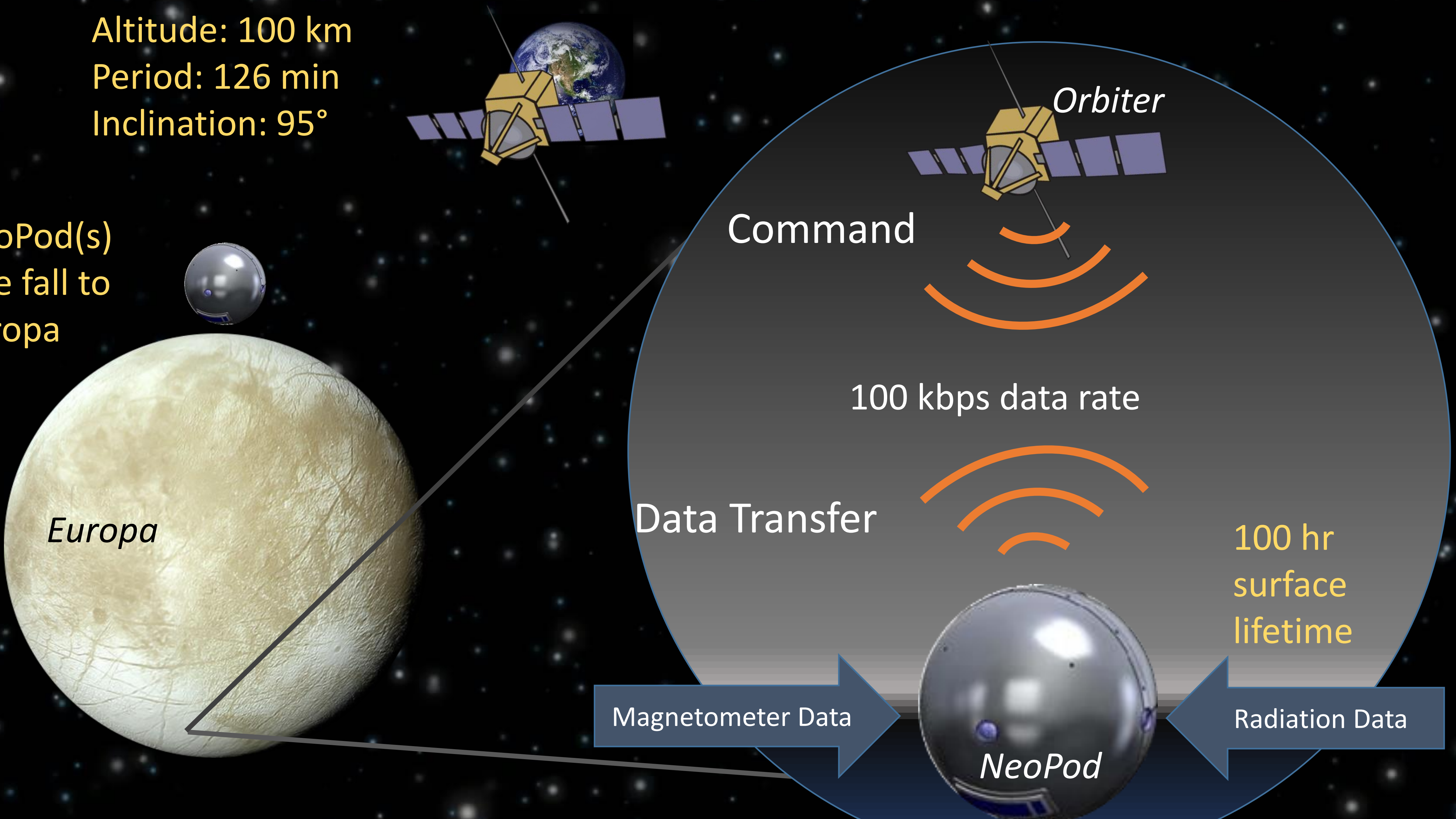
Motivation for Project: Europa Mission

- Moon of Jupiter **(85 hour orbit)**
- Icy surface with an active geology and scientific consensus of subsurface ocean
- Identified by NASA as a "High Priority Target" for its potential to support life
- **Ball Aerospace has developed a concept for a mission to Europa**
  - Polar orbiter (100 km, 95° inclination) deploys probe to surface
  - Probe collects data and then transmits it back during every pass



Altitude: 100 km
Period: 126 min
Inclination: 95°

NeoPod(s) free fall to Europa



Command

100 kbps data rate

Data Transfer

100 hr surface lifetime

Magnetometer Data

Radiation Data

Project Statement

The ELSA team will **design and build a prototype probe (the NeoPod) to collect, store, and transmit data via RF** to a Ground Station.

The NeoPod will operate in a stationary position for a **100 hour mission lifetime in a laboratory environment on Earth**, with a short distance between the NeoPod and the Ground Station.

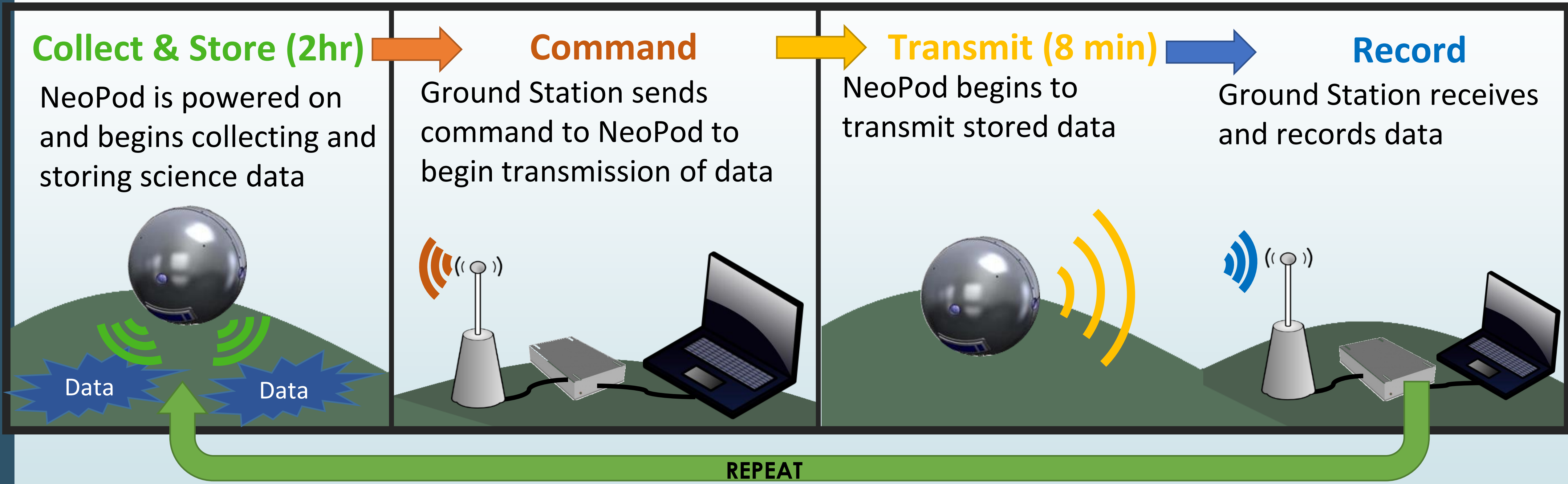
NeoPod

ELSA Mission Objectives

“Do science, get it back.”

- **SCI 0:** *NeoPod shall collect scientific data relevant to the study of Europa*
- **COM 0:** *NeoPod shall communicate with the Ground Station*
- **INT 0:** *NeoPod shall integrate with existing mission architecture*

ELSA CONOPS



Collect & Store (2hr)

NeoPod is powered on and begins collecting and storing science data

Command

Ground Station sends command to NeoPod to begin transmission of data

Transmit (8 min)

NeoPod begins to transmit stored data

Record

Ground Station receives and records data

Total: 100 hour mission timeline

Levels of Success: Systems

- Level 1 Success defined as component level functional test

Level of Success	Level 2 Success	Level 3 Success	Level 4 Success
Test	Avionics Integration Testing	Flat-Sat Test Demonstration of Full Integration	Fully Integrated Test
Testing Time	Limited Continuous Testing	8 hours of Testing	100 hours of Testing
Requirements	Meets **48/48** Requirements	Meets **0/1** Requirement	Demonstrates Full Success of Mission Design and Concept
Models	-	Limited Battery and Thermal Model Validation	Full Battery and Thermal Model Validation (Meets **9/9** Requirements)

Met 57/58 Requirements

Non-validated requirement related to functional longevity

Design Overview

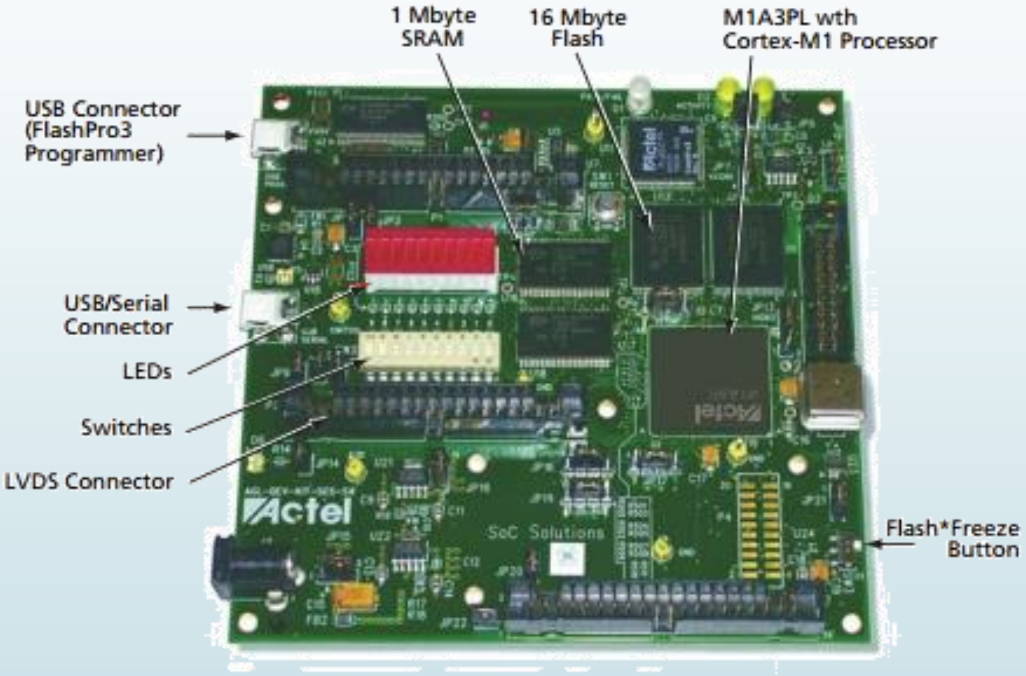
Executive Summary

- **Design Changes from TRR**
  - Off-ramp taken to include Microsemi Dev Kit instead of Ball Aerospace FPGA

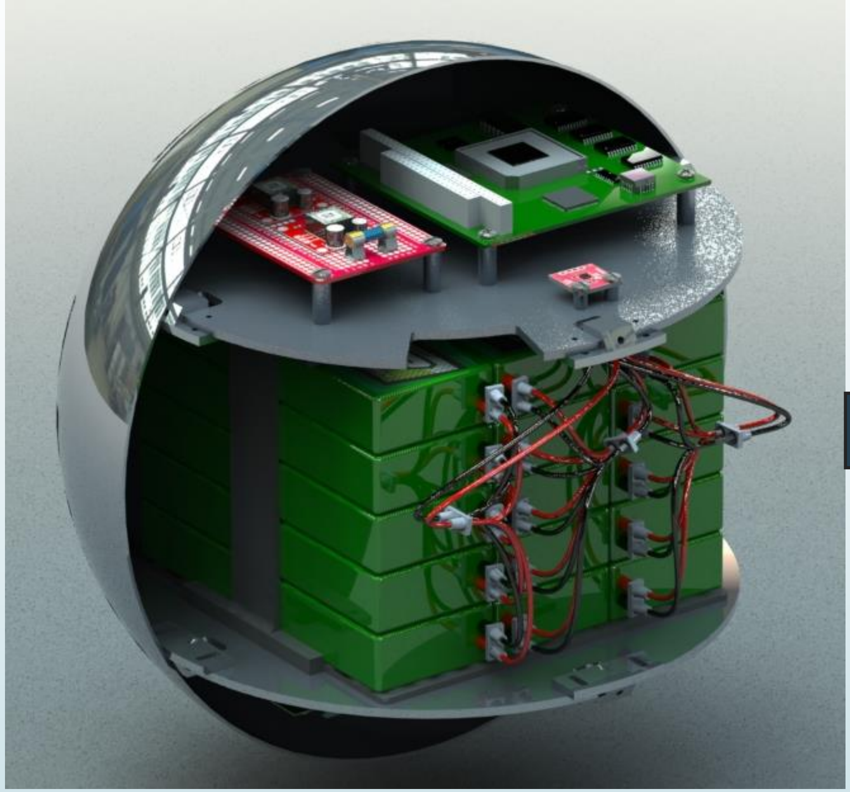
- **Requirements and Models**
  - Validated all models (Thermal, Power, and RF)
  - 57 out of 58 requirements verified

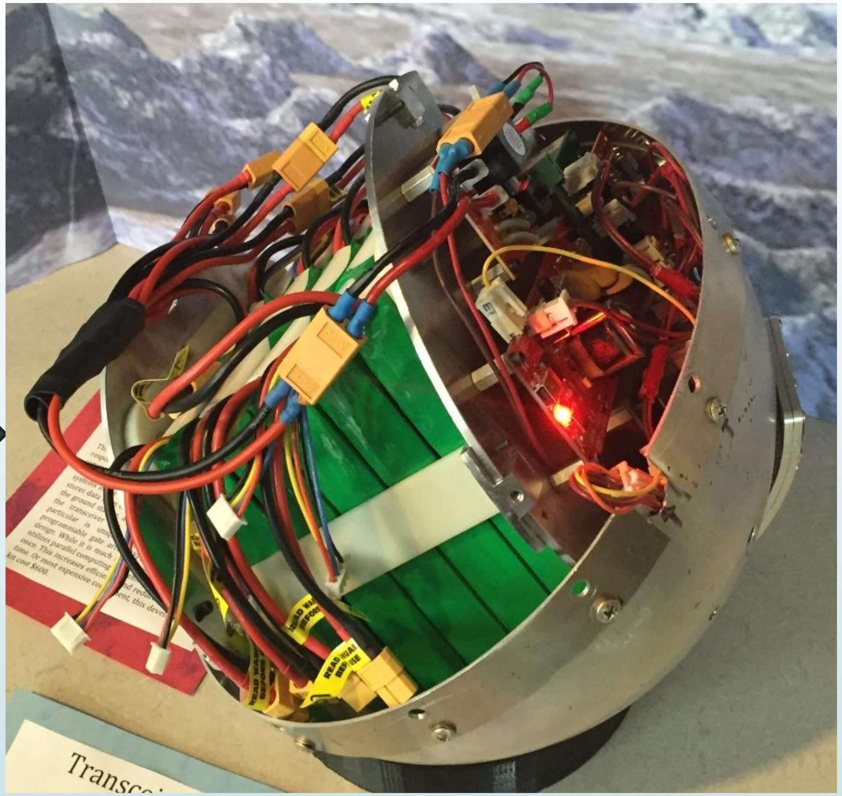
- **Testing Plan Changes**
  - Test Plan modified due to late Spring schedule slip

- **Budget Review**
  - Redundant components purchased to reduce risk
  - Spent ~$3500



NeoPod Final Design:

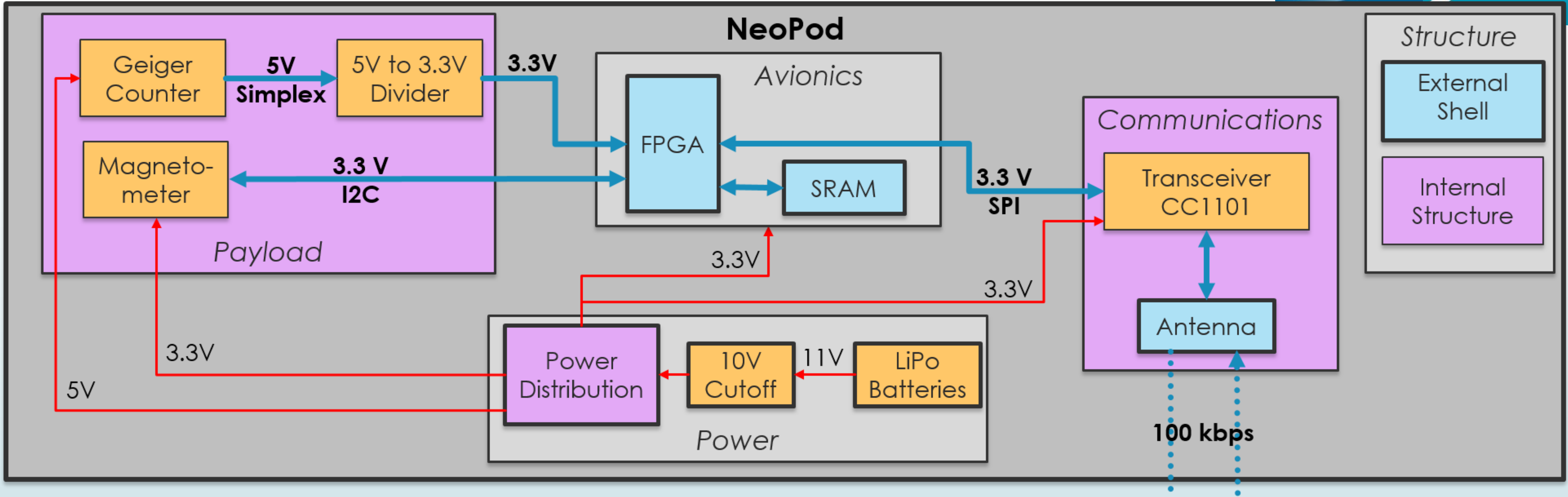




Key Parameter	Value
Mass	7.51 kg
Diameter	25 cm
Power Capacity	736 Wh
Maximum Data Rate	100 kbps

All Components Integrated

FBD of ELSA System



NeoPod

Payload

Geiger Counter

5V Simplex

5V to 3.3V Divider

3.3V

Magneto-meter

3.3 V I2C

Avionics

FPGA

SRAM

3.3 V SPI

Communications

Transceiver CC1101

Antenna

Structure

External Shell

Internal Structure

3.3V

3.3V

3.3V

5V

Power

Power Distribution

10V Cutoff

11V

LiPo Batteries

100 kbps

Key

Purchased

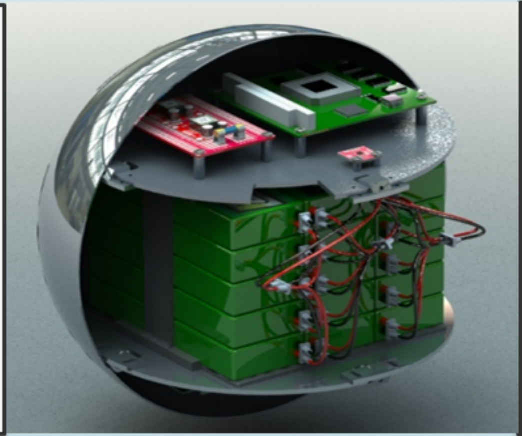
Manufactured

Provided

Data/Command

Power

Wireless



Ground Station

Transceiver CC1101

CC1101 Dev Kit

Laptop w/ COSMOS

Critical Project Elements

Designation	CPE	Description
CPE-1	Avionics Hardware Integration and FPGA Software	Avionics Board must **interface** with all components and structures. Lack of previous team **FPGA** experience.
CPE-2	Communications System Design	**Two-way communication** between NeoPod and Ground Station. Multiple data types.
CPE-3	Power System Design	Accurate models to ensure power is supplied for **100 hour mission** lifetime. Custom PCB and circuit design necessary.
CPE-4	Mechanical Integration	All components must **satisfy mass and volume requirements**. Internal components must not exceed thermal tolerances.

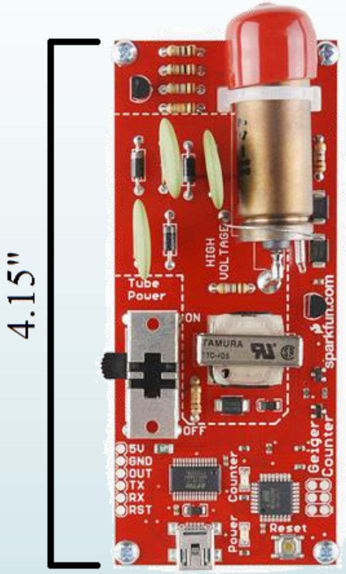
Sensor Payloads

- Performed **trade study** on 10 sensors
- Evaluation Criteria
  - Science Value
  - Weight
  - Cost
  - Size
  - Complexity

Triaxial Magnetometer:

Key Specifications
Model: SparkFun Triple Axis Magnetometer HMC5883L
Interface: I2C
Sampling Rate: 0.75 – 75 Hz
Power and Logic: 3.3VDC and 3.3V Logic
Range: ± 8e5 nT
Resolution: 500 nT

Geiger Counter:



Key Specifications
Model: SparkFun Geiger Counter
Interface: Serial
Sampling Rate: Maximum of 100 Hz
Power and Logic: 5VDC and 5V Logic

Radiation & Magnetic Field measurements would support further missions to Europa

Avionics Board Change

- Issues with Ball Aerospace Avionics Board
  - Installed Jumpers: Power connected to GND, disabled programming circuit
  - SDRAM data line missing
  - Programming pins arranged differently than programmer
  - **Could not make contact with board**
- Switch to Microsemi Dev Kit off-ramp in late February

Software Change Required

Ball Avionics	Microsemi Dev Kit	Impact on Project
32 MB SDRAM	*1 MB SRAM*	2 Week Setback
6 Available PLL	1 Available PLL	Minimal
Team Selected Power Header 3.3V	Pre-determined Power Connector 5V	Minimal
Smaller Footprint	Larger Footprint	Layout Reorganization

Avionics Hardware Off-ramp

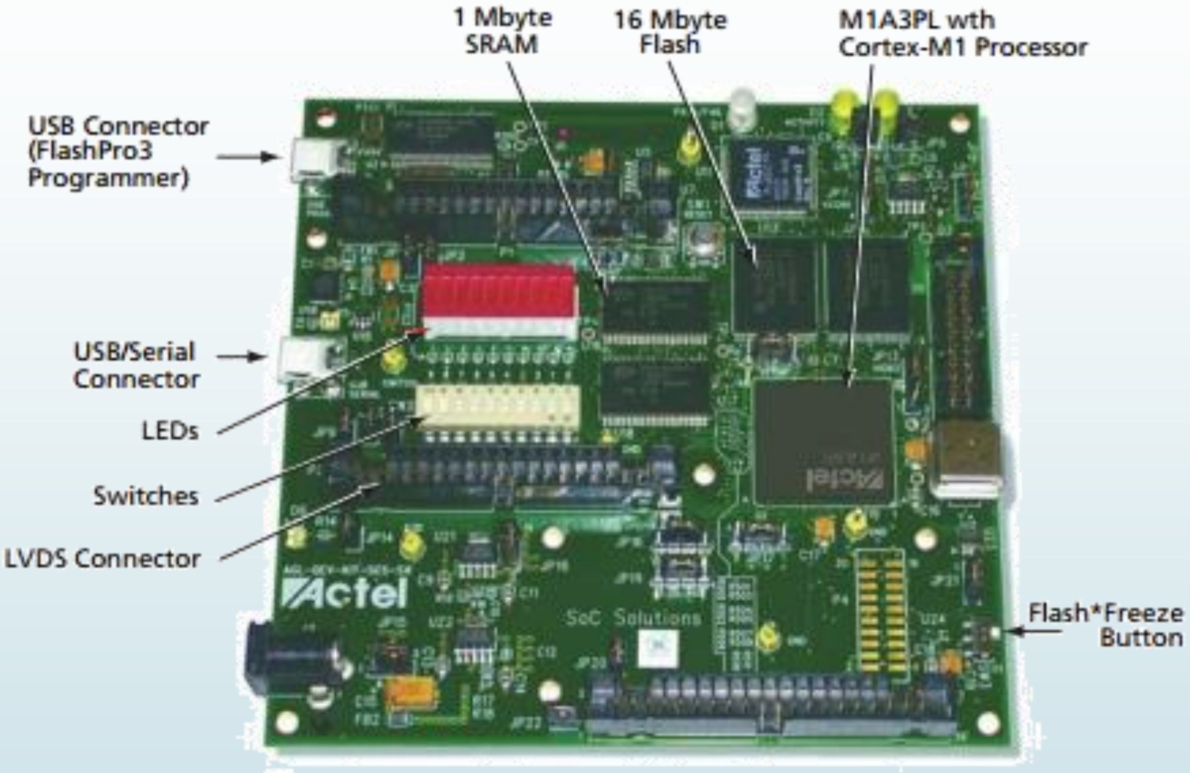
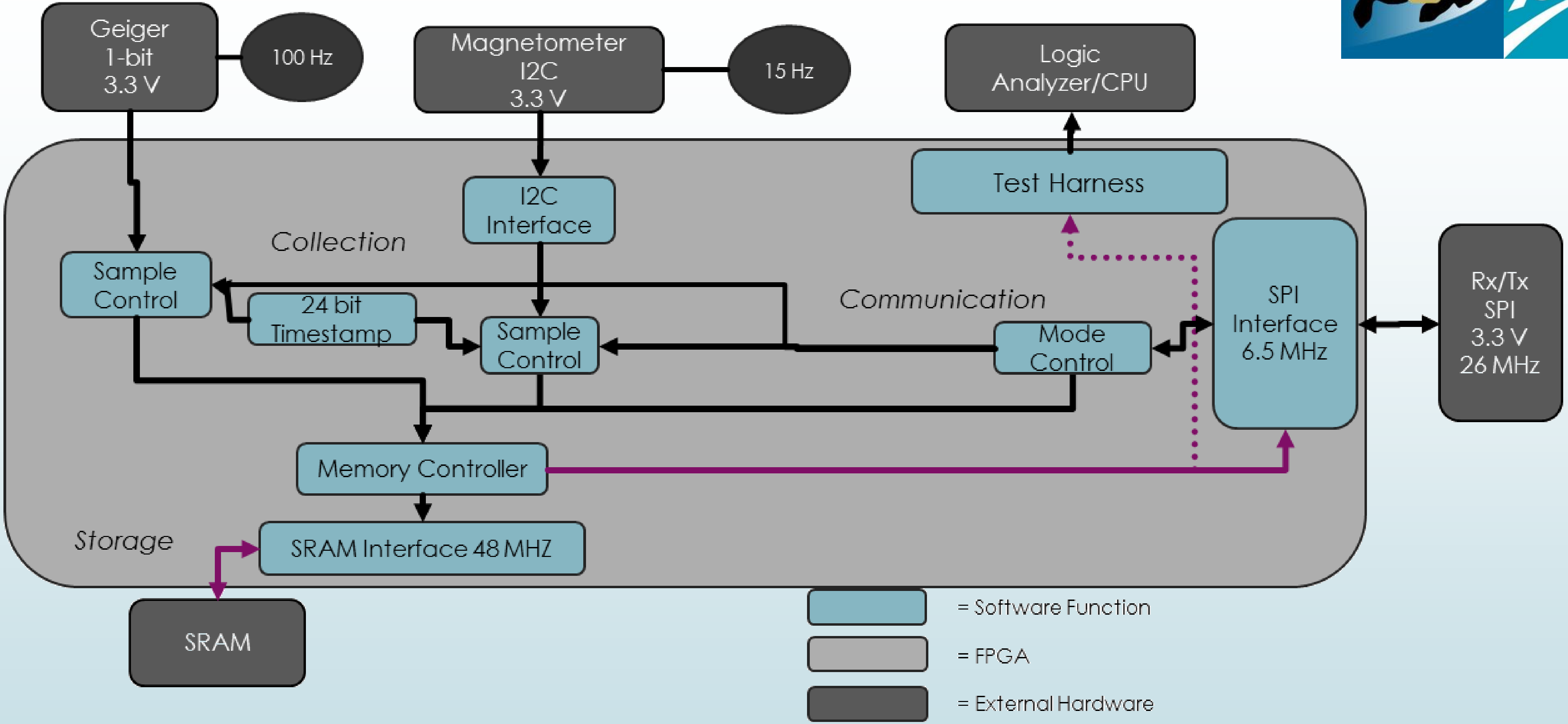


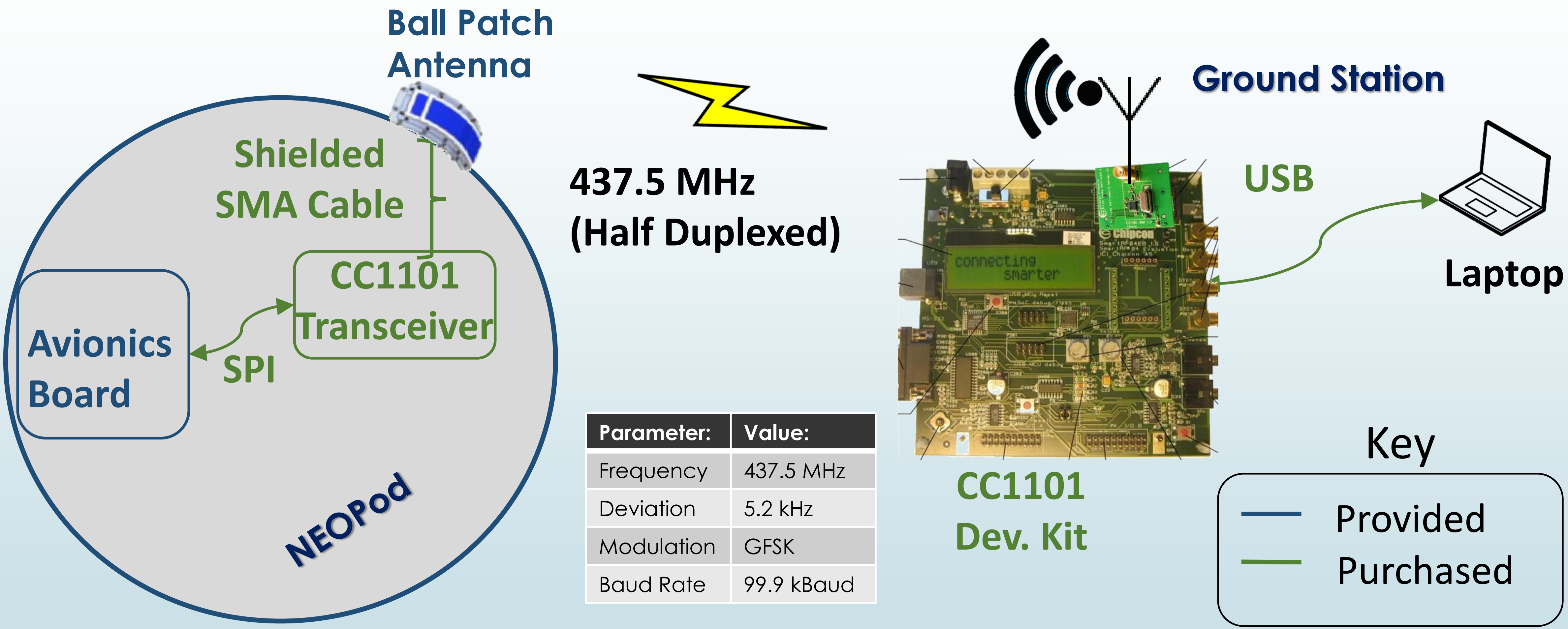
Photo Credit: http://www.microsemi.com/products

- **Microsemi M1A3PL-DEV-Kit**
  - FPGA: M1A3PL-1000
- 120 GPIO Pins
- **SRAM Data Storage**
- **SPI and I2C Hardware Interfacing**
  - Magnetometer: I2C
  - Geiger Counter: Simplex
  - Transceiver: SPI
- **Custom Verilog Design**

Avionics Software



Communications Layout

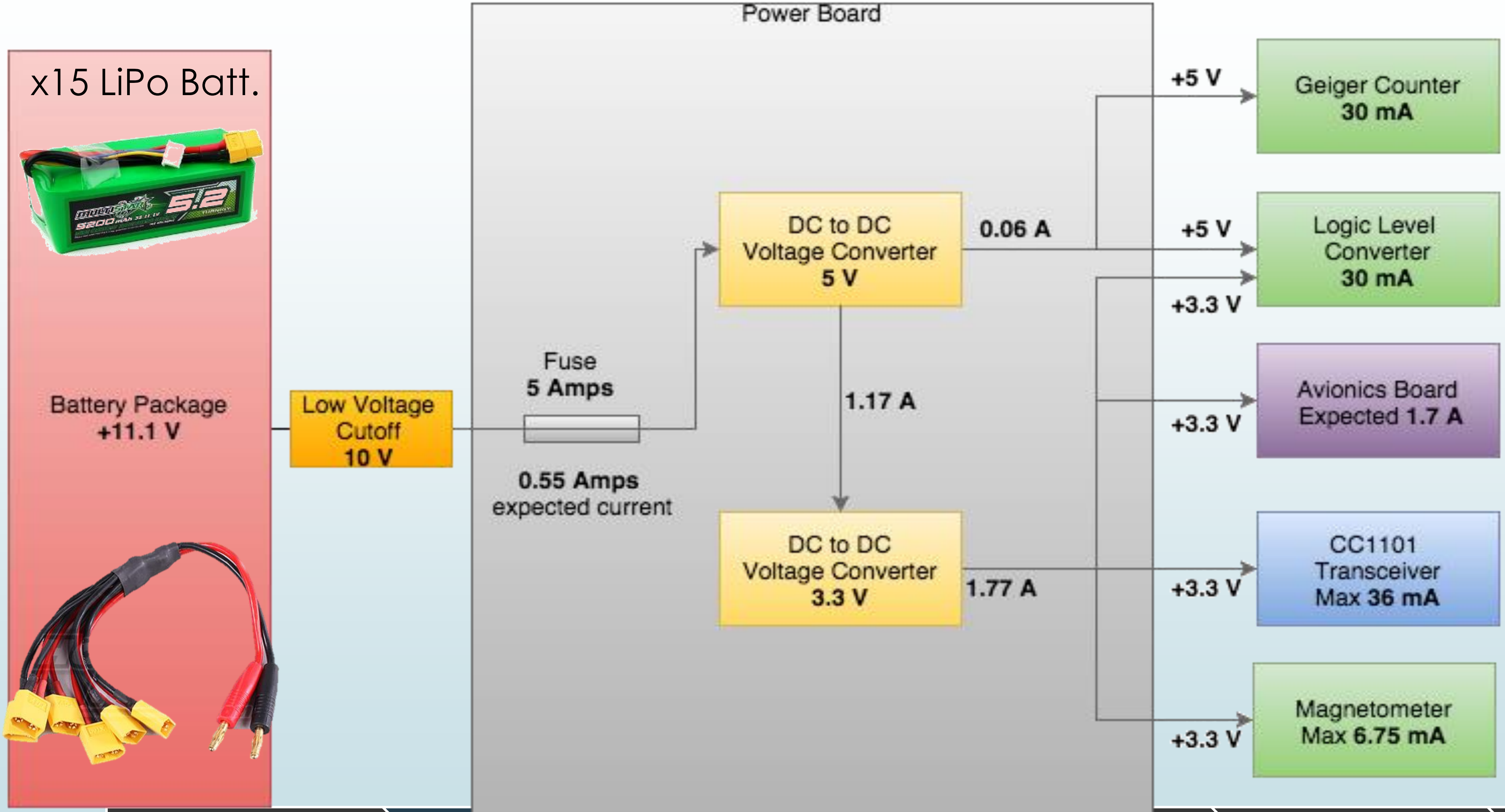


Parameter:	Value:
Frequency	437.5 MHz
Deviation	5.2 kHz
Modulation	GFSK
Baud Rate	99.9 kBaud

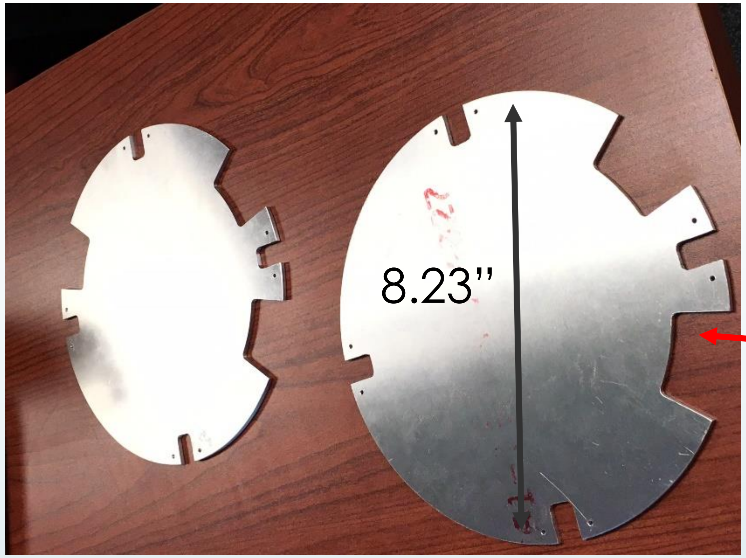
Key

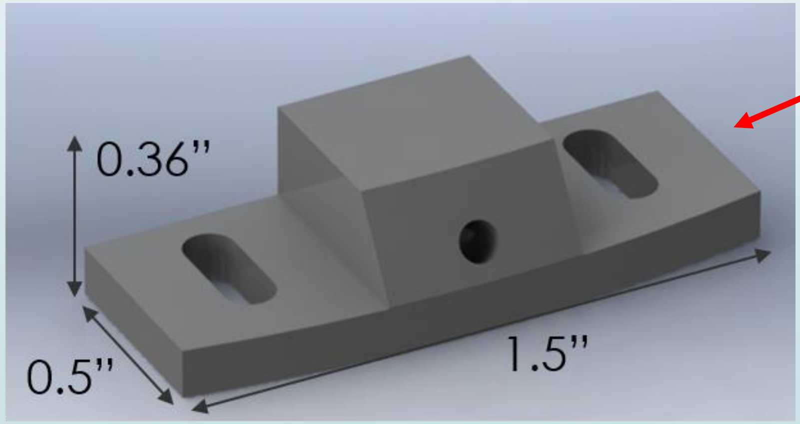
—	Provided
—	Purchased

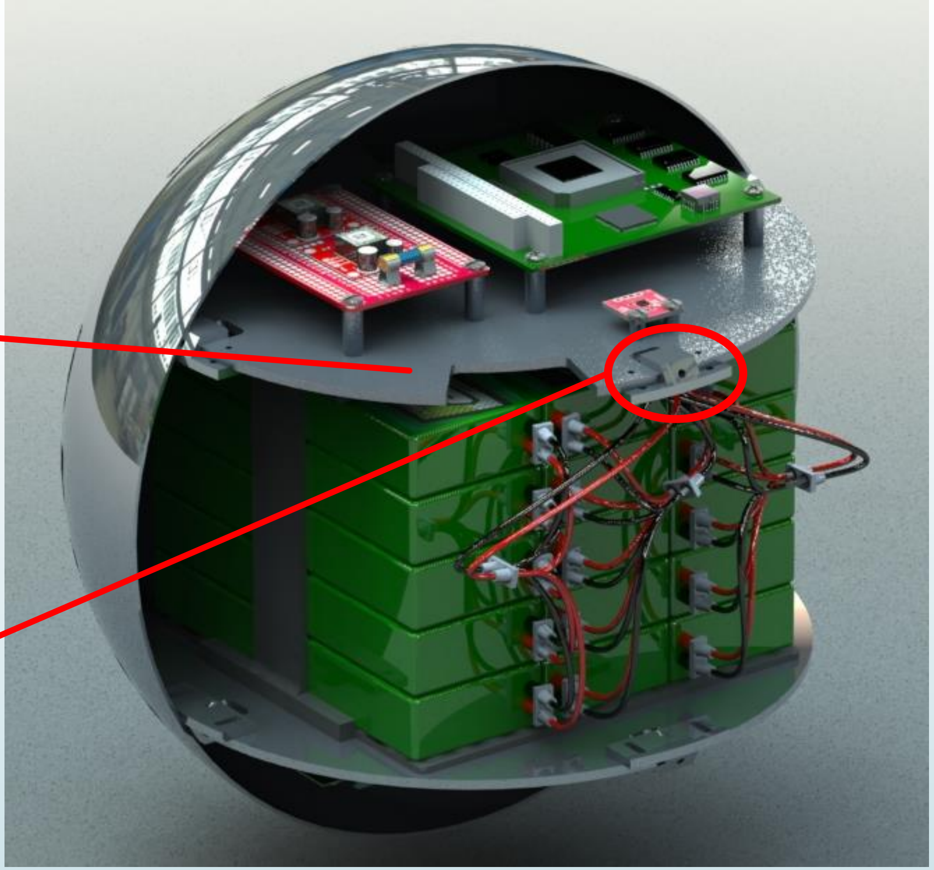
Power System Overview



Structural Design







Key Specifications:

Subsystems will be mounted to **two circular shelves** using **standoffs.**

Batteries secured with **3D printed structure**

Internal shelves will **be mounted to external shell using brackets** shown

Testing Overview

Project Objectives

Design Description

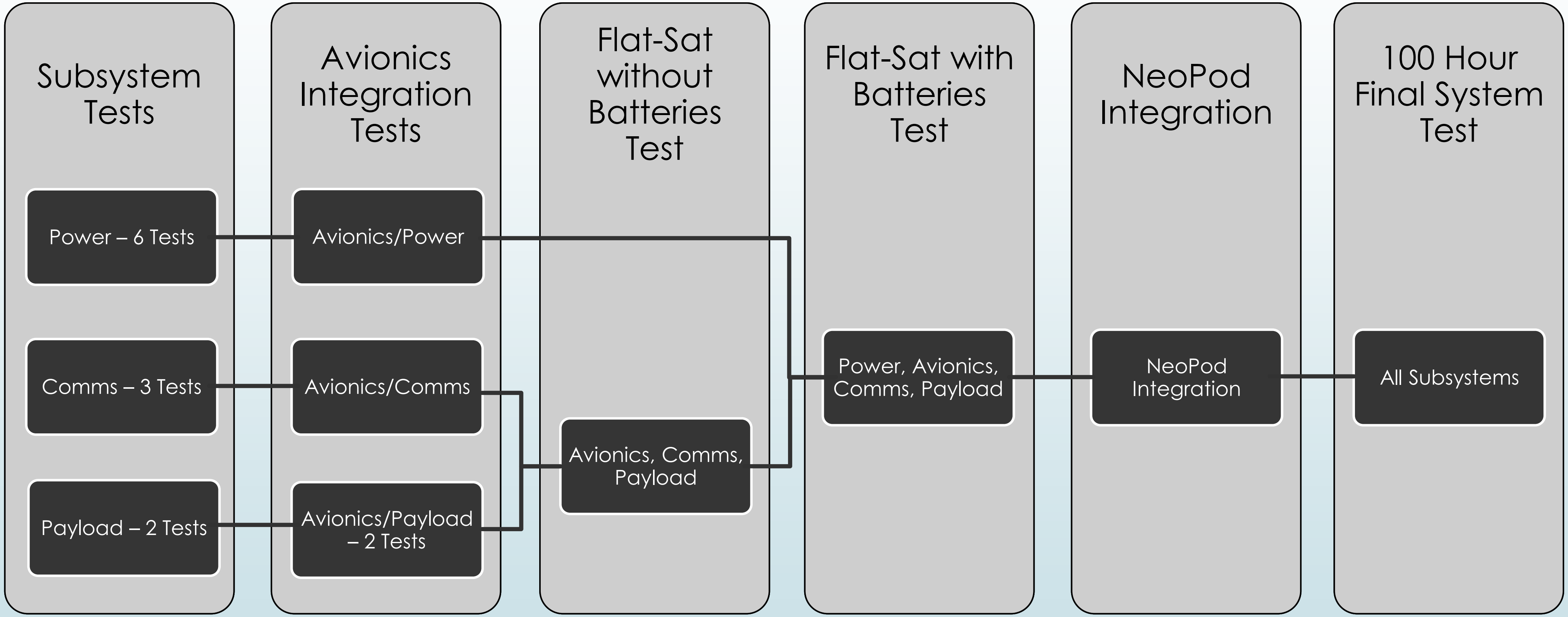
Test Overview

Test Results

Systems Engineering

Project Management

Test Plan



Subsystem Tests

- Power – 6 Tests
- Comms – 3 Tests
- Payload – 2 Tests

Avionics Integration Tests

- Avionics/Power
- Avionics/Comms
- Avionics/Payload – 2 Tests

Flat-Sat without Batteries Test

- Avionics, Comms, Payload

Flat-Sat with Batteries Test

- Power, Avionics, Comms, Payload

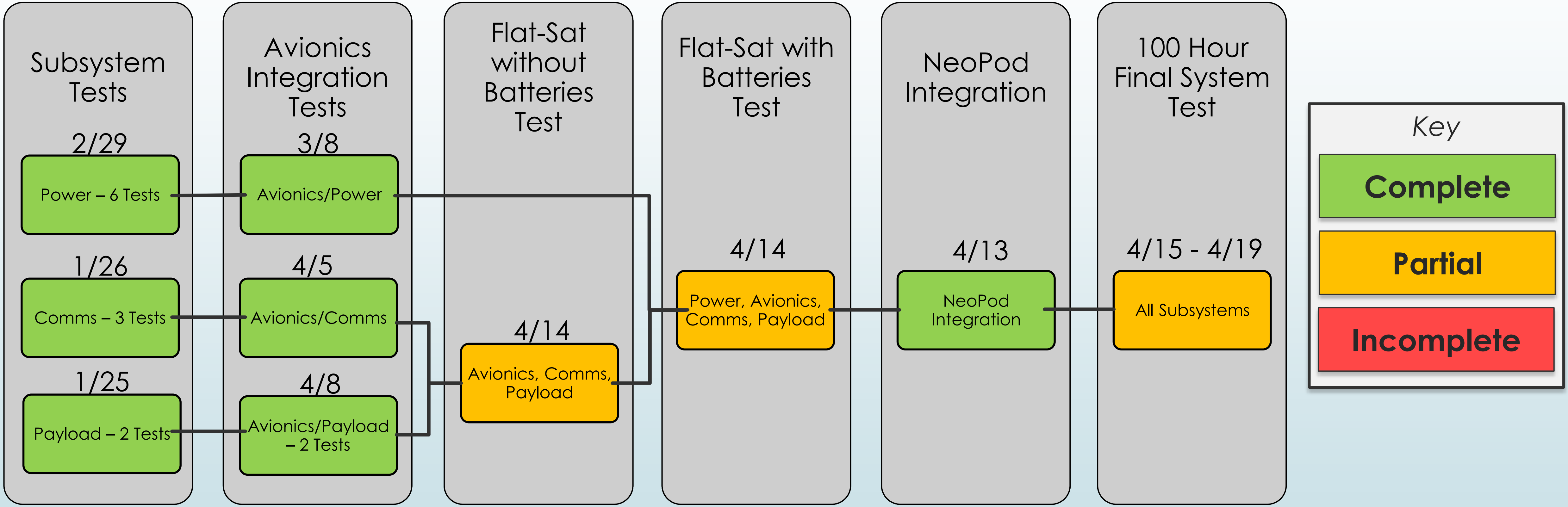
NeoPod Integration

- NeoPod Integration

100 Hour Final System Test

- All Subsystems

Test Plan



Subsystem Tests

2/29
Power – 6 Tests

1/26
Comms – 3 Tests

1/25
Payload – 2 Tests

Avionics Integration Tests

3/8
Avionics/Power

4/5
Avionics/Comms

4/8
Avionics/Payload – 2 Tests

Flat-Sat without Batteries Test

4/14
Avionics, Comms, Payload

Flat-Sat with Batteries Test

4/14
Power, Avionics, Comms, Payload

NeoPod Integration

4/13
NeoPod Integration

100 Hour Final System Test

4/15 - 4/19
All Subsystems

Key

🟩 **Complete**

🟧 **Partial**

🟥 **Incomplete**

Requirement Mapping

Subsystem Tests	Avionics Integration Tests	Flat Sat Test	NeoPod Integration	100 Hour Final System Test
Payload L1 – L2	Payload L3		Structure L3 – L4	Power L1 – L4
Communication L1 – L4	Avionics L2 – L4		–	–
System L1	System L2		–	–
Ground Station L1 – L4	–		–	–
INT 3, 5.2 – 5.3	–		INT 1 – 2, 4, 5.1, 8	INT 6, 7, 9,10
COM 1.1 – 1.2, 2.1 – 2.2, 2.4, 3.1 – 3.2, 4.2 – 4.3	COM 1.3, 5	COM 2.3, 3.3, 4.1	–	
SCI 1	SCI 3		–	SCI 2
RF Link	–		–	Thermal
–	–		–	Power

Key
Levels of Success
Functional Requirements
Models

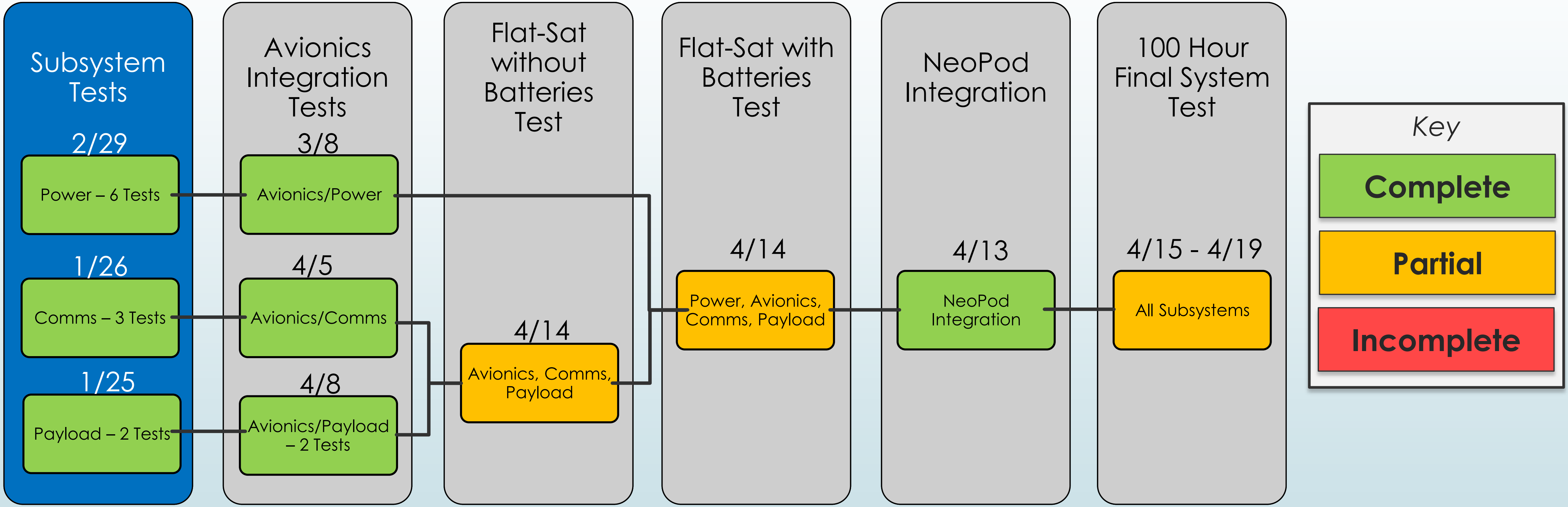
All Requirements mapped to Verification Method

Highest subsystem levels of success met

Project Objectives | Design Description | **Test Overview** | Test Results | Systems Engineering | Project Management

Test Results

Subsystem Test Results



Subsystem Tests

2/29

Power – 6 Tests

1/26

Comms – 3 Tests

1/25

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3/8

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4/14

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NeoPod Integration

4/13

NeoPod Integration

100 Hour Final System Test

4/15 - 4/19

All Subsystems

Key

🟩 **Complete**

🟨 **Partial**

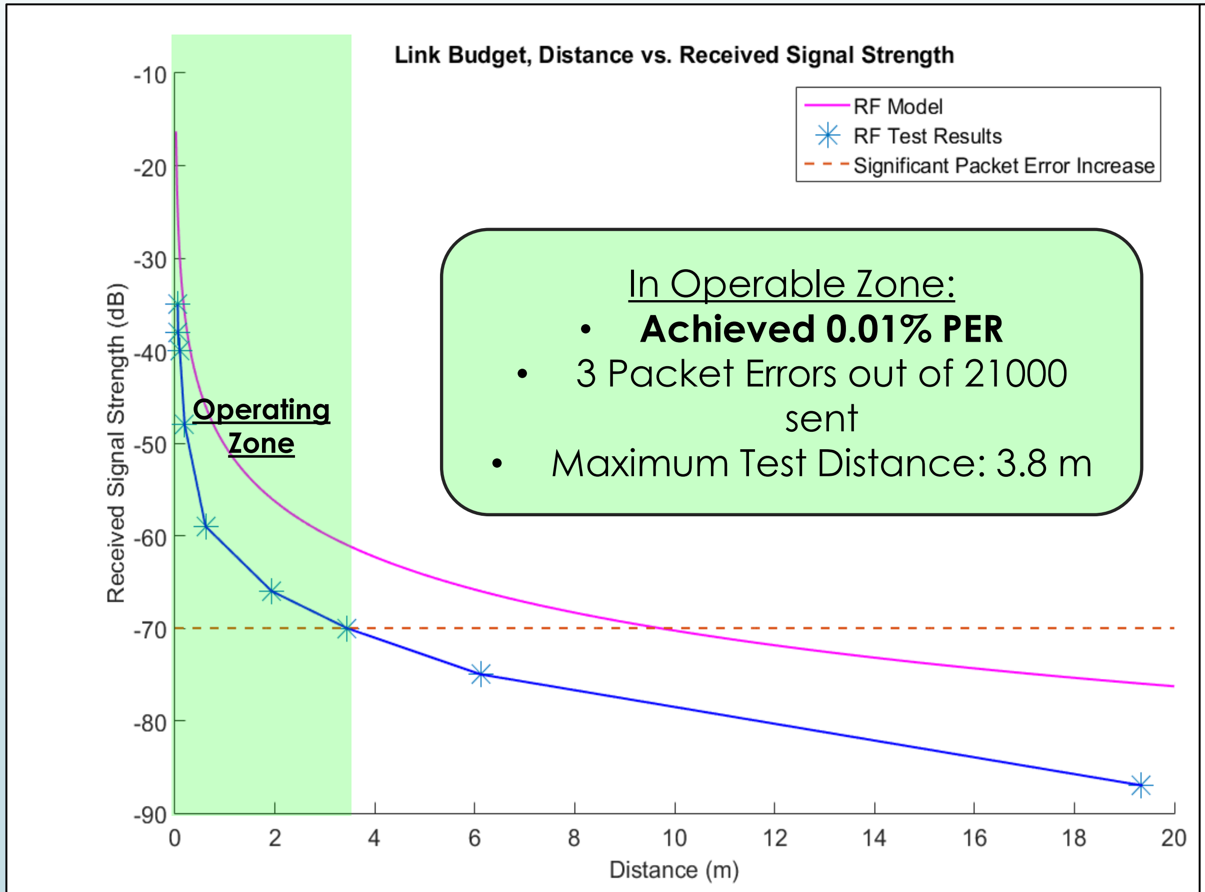
🟥 **Incomplete**

Communications Test Requirements

Communications System Design – CPE 2

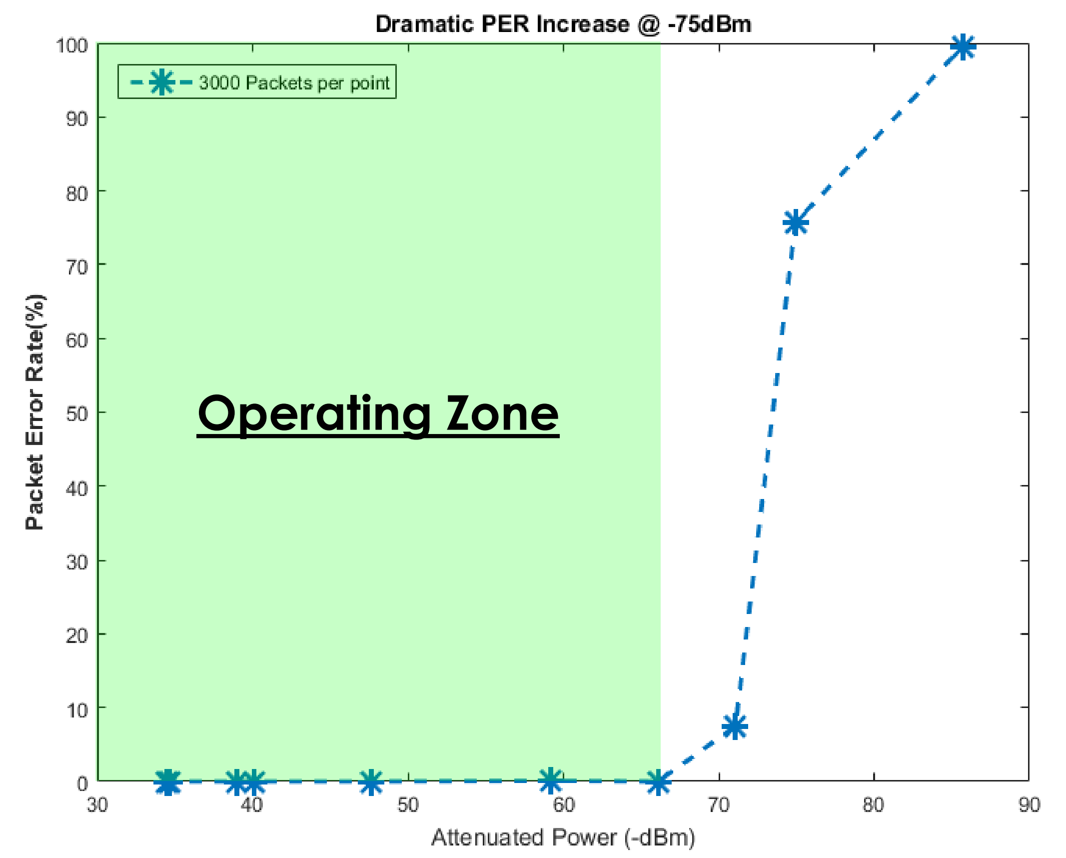
Requirement:	Description:	Motivation:
COM 1	NeoPod shall **receive commands** over RF	NeoPod must be able to receive a wireless command from the Ground Station in order to be able to begin the transmission of data.
COM 2	NeoPod shall **send data** over RF	NeoPod must be able to transmit data in order to successfully complete its mission
COM 3	Ground Station shall **transmit commands** over RF	Mimics the activity of an orbiter.
COM 4	Ground Station shall **receive data** over RF	Used for verification of data collection and transmission

Communications Testing:



In Operable Zone:

- **Achieved 0.01% PER**
- 3 Packet Errors out of 21000 sent
- Maximum Test Distance: 3.8 m

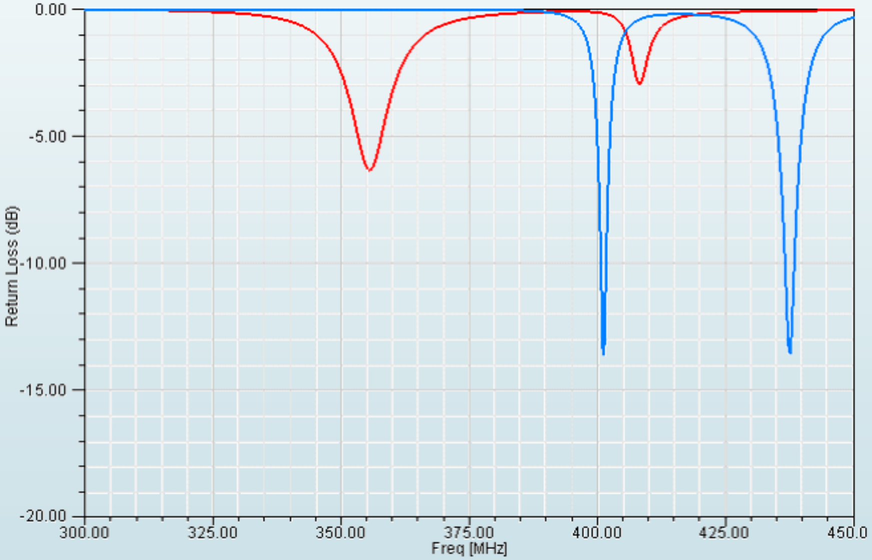


Communications Successes:

- **Ground Station**
  - Successfully interfaced SmartRF with COSMOS via Perl scripting
  - Automated Mission Schedule
  - Real-time display of multiple datatypes from a single stream
- **NeoPod Comms.**
  - Integrated with Avionics
  - Integrated with Patch Antenna

Commands & Data were successfully sent from Avionics to Ground Station through RF in a laboratory Environment (COM 1,2,3 & 4)

Designed Inside Narrow Band

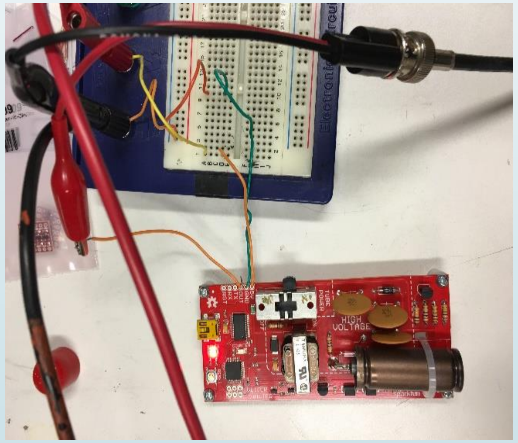


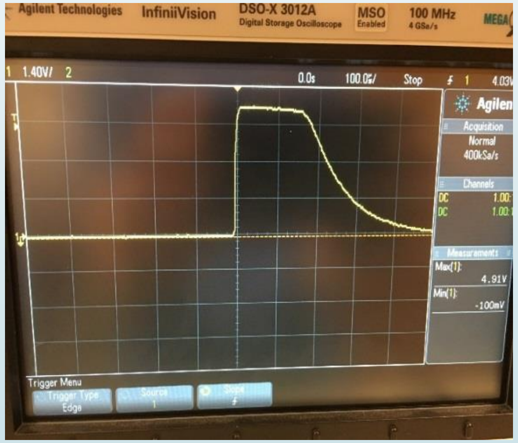
Patch Antenna Frequency Characteristics

Payload Test Requirements

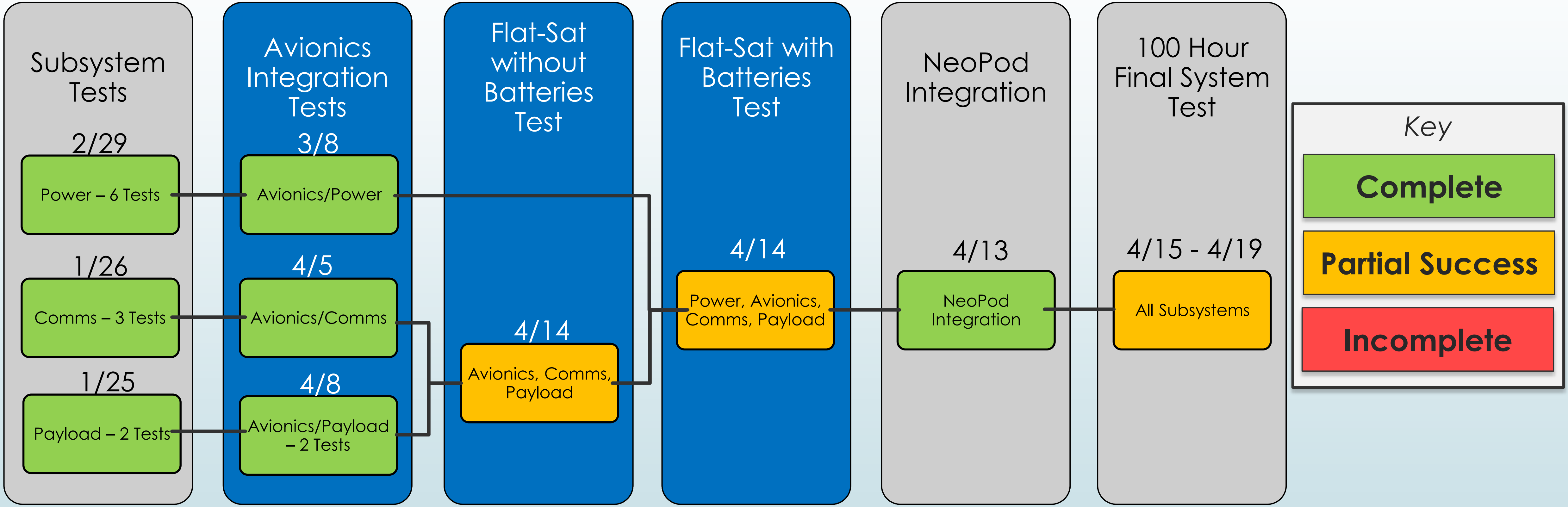
Requirement:	Description:	Motivation:
SCI 1	NeoPod shall contain **two scientific instruments**	Customer Specified Requirement. Will add potential scientific value of probe

- **Geiger Functionality Test:**
  - Using oscilloscope and PCB, the Geiger Counter output signal was characterized to ensure the Avionics system would be able to interact with it correctly.
- **Magnetometer Functionality Test:**
  - Used Arduino and Sparkfun code to test basic functionality of the magnetometer
  - The Sparkfun code was used as a baseline when developing the equivalent FPGA code.





Avionics Integration Test Results



Subsystem Tests

2/29 Power – 6 Tests

1/26 Comms – 3 Tests

1/25 Payload – 2 Tests

Avionics Integration Tests

3/8 Avionics/Power

4/5 Avionics/Comms

4/8 Avionics/Payload – 2 Tests

Flat-Sat without Batteries Test

4/14 Avionics, Comms, Payload

Flat-Sat with Batteries Test

4/14 Power, Avionics, Comms, Payload

NeoPod Integration

4/13 NeoPod Integration

100 Hour Final System Test

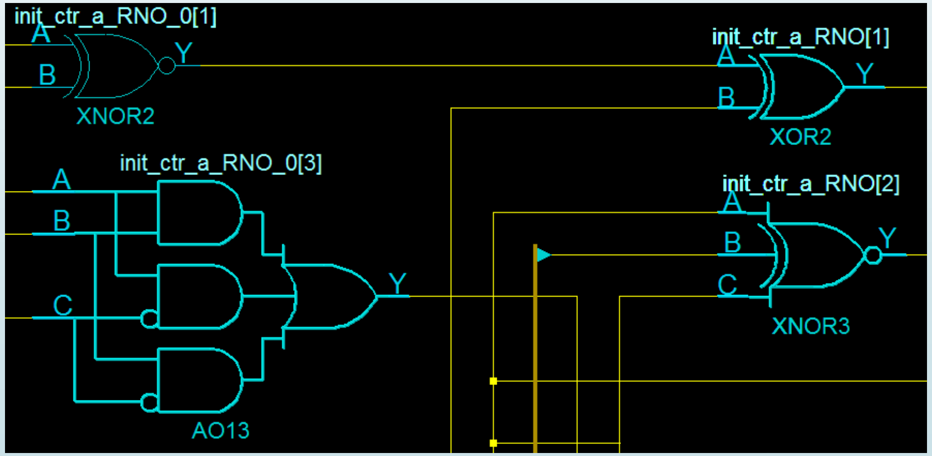
4/15 - 4/19 All Subsystems

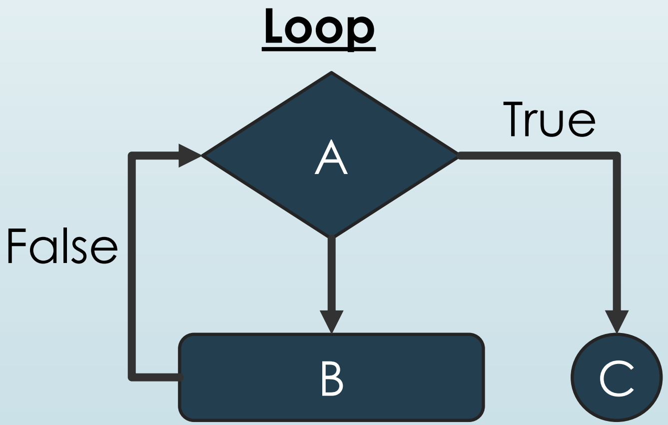
Key

- 🟩 **Complete**
- 🟨 **Partial Success**
- 🟥 **Incomplete**

What Makes FPGA Different?

FPGA	Microcontroller
Parallel Processing	Sequential Processing
No Structure	**Built on underlying OS/Architecture**
Describes Hardware/Circuit	Instruction Based/Decision Making
Strict Timing Constraints	Great for State Control and Logic Re-Use
Taught at E.E. Graduate Level	**Widely Taught at Undergrad Level**





Avionics Requirements

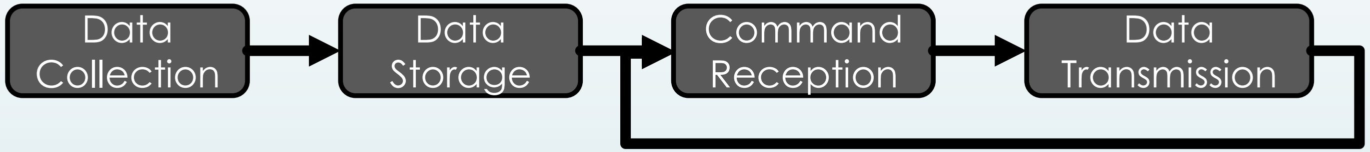
Avionics Hardware Integration and FPGA Software – CPE 1

Requirement:	Description:	Motivation:
SCI 3.1.4	Avionics subsystem shall **limit data flow** from sensors to less than 353 MB over the 100 hour mission	Communications system can transmit a maximum of 353 MB of data over 100 hours
SCI 3.2	Avionics subsystem shall **store data collected** from sensors	System must store all data collected from sensors
COM 5	Avionics subsystem shall **interface with communications** subsystem	Necessary in order to send data as well as accept commands

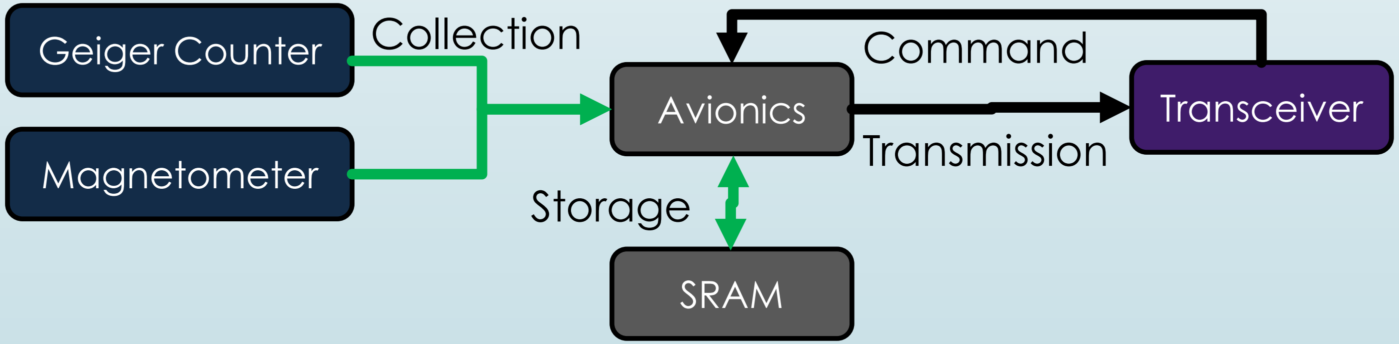
Flat Sat Test Description

Objective:	**Demonstrate operational timeline conditions**
Rationale:	**Each function is reliant on prior functions**
	Validates full system avionics functionality

Functionality Path



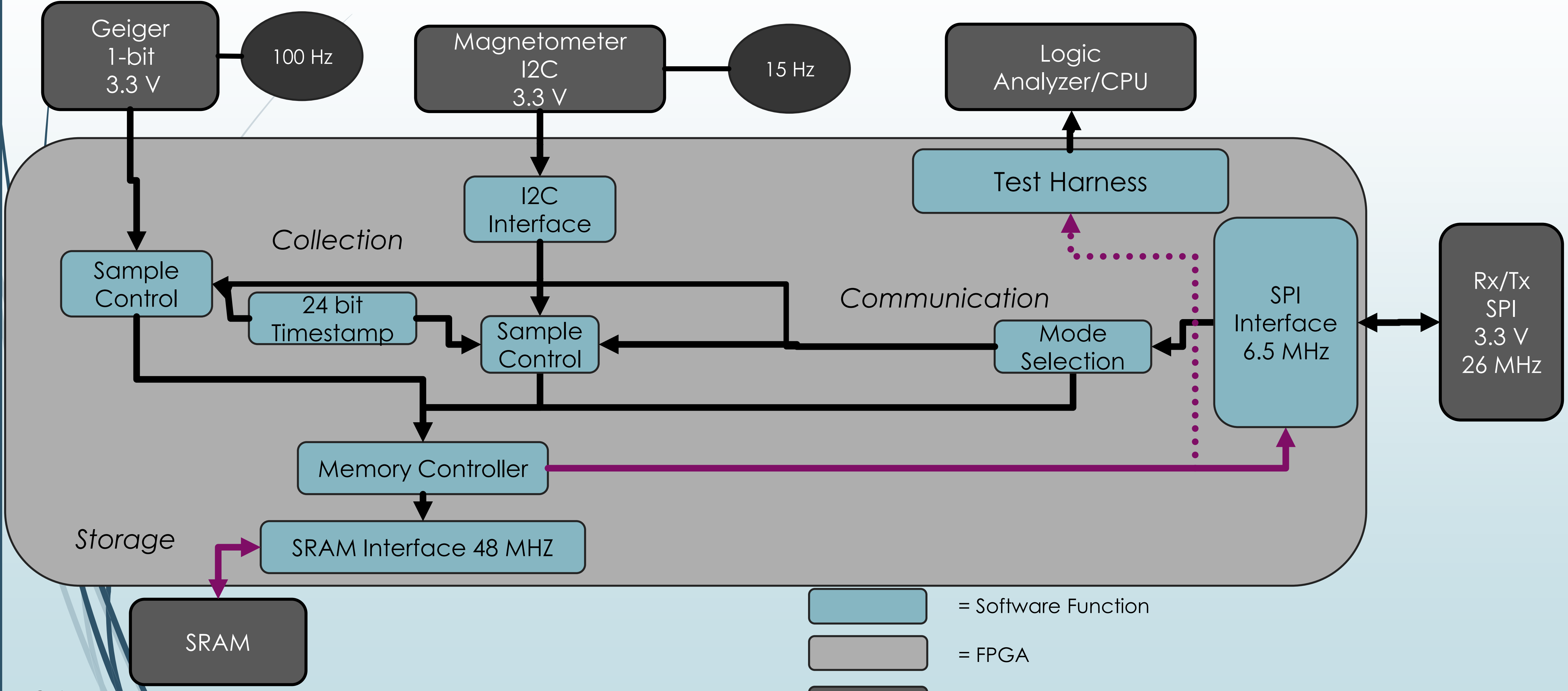
Subsystem Data Flow



Avionics Subsystem

Success

Limited



🟦 = Software Function

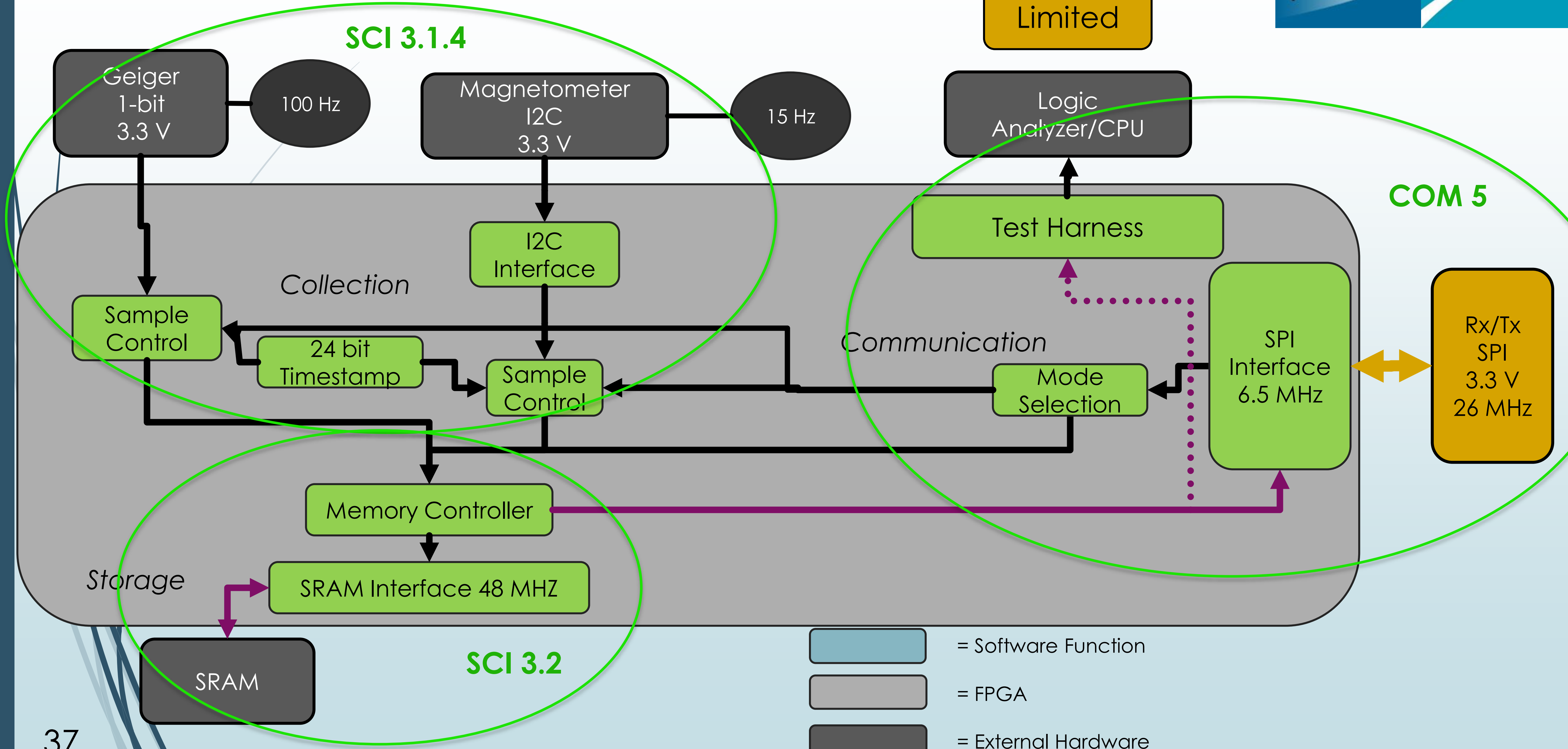
▨ = FPGA

⬛ = External Hardware

Avionics Subsystem Success

Success

Limited



SCI 3.1.4

Geiger
1-bit
3.3 V

100 Hz

Magnetometer
I2C
3.3 V

15 Hz

Logic
Analyzer/CPU

COM 5

Test Harness

I2C
Interface

Collection

Sample
Control

24 bit
Timestamp

Sample
Control

Communication

Mode
Selection

SPI
Interface
6.5 MHz

Rx/Tx
SPI
3.3 V
26 MHz

Memory Controller

Storage

SRAM Interface 48 MHZ

SRAM

SCI 3.2

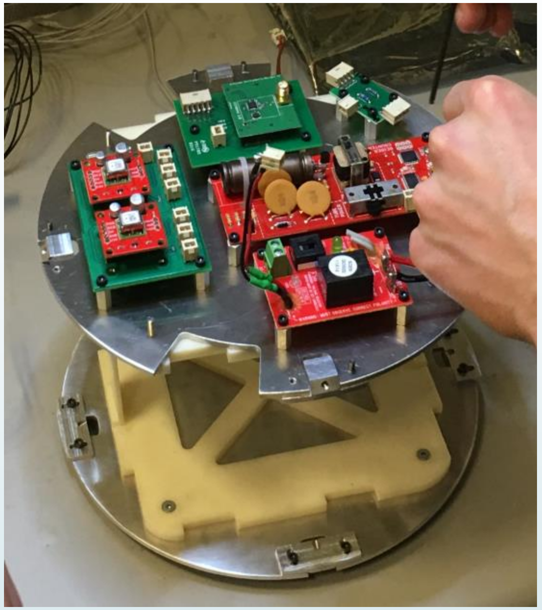
🟦 = Software Function

▨ = FPGA

⬛ = External Hardware

Flat Sat Success

- **Data Transmission Upon Command:**
  - Correct configuration of transceiver and reception state
  - Correct configuration of outgoing data and packet structure
  - Correct adherence to mission architecture
    - 8 Minute transmission window



COM 5: Avionics subsystem shall **interface with communications** subsystem

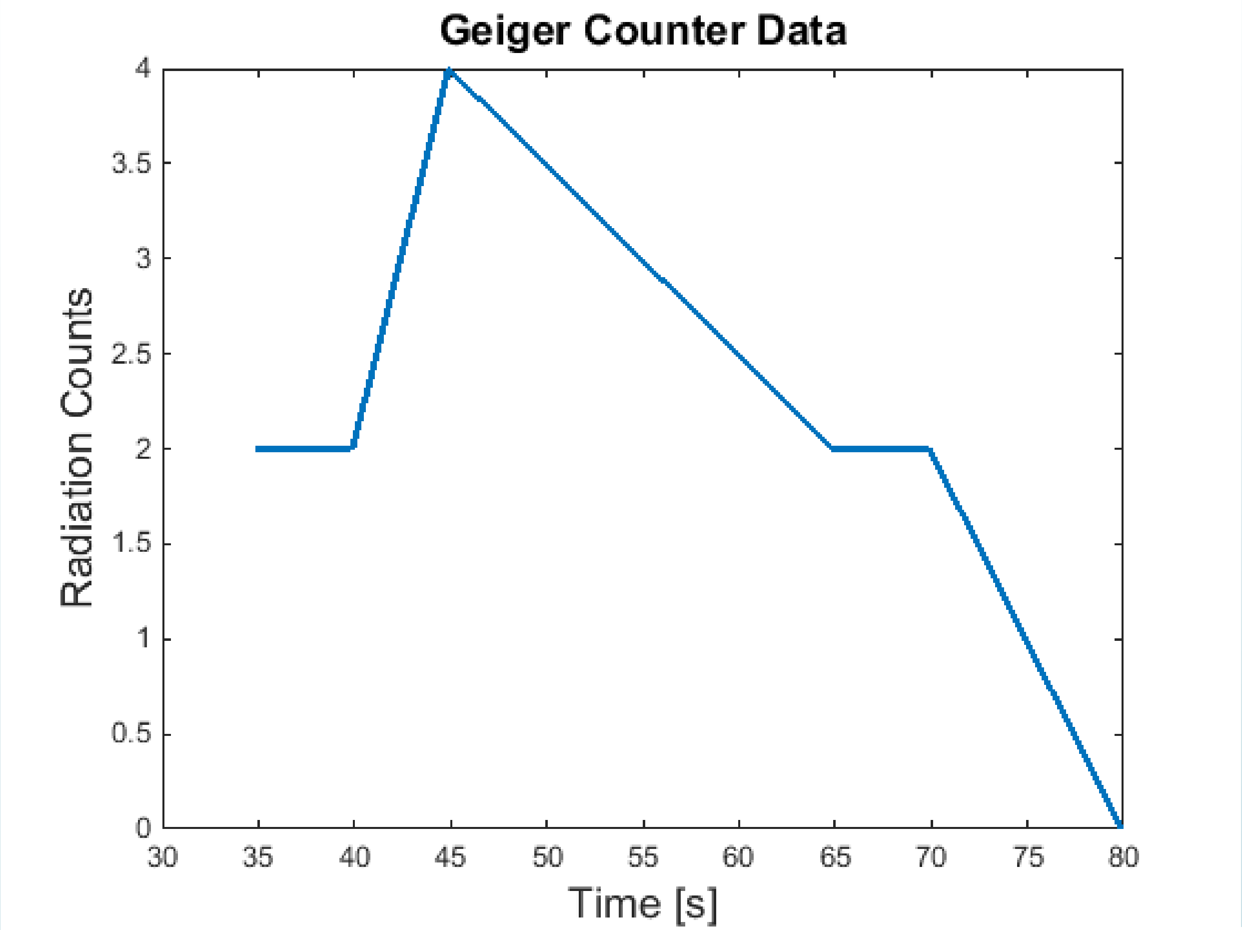
- **Data Collection and Storage**
  - Data integrity **preserved through collection, memory write, and memory read**
    - Sensor data within expected order of magnitude

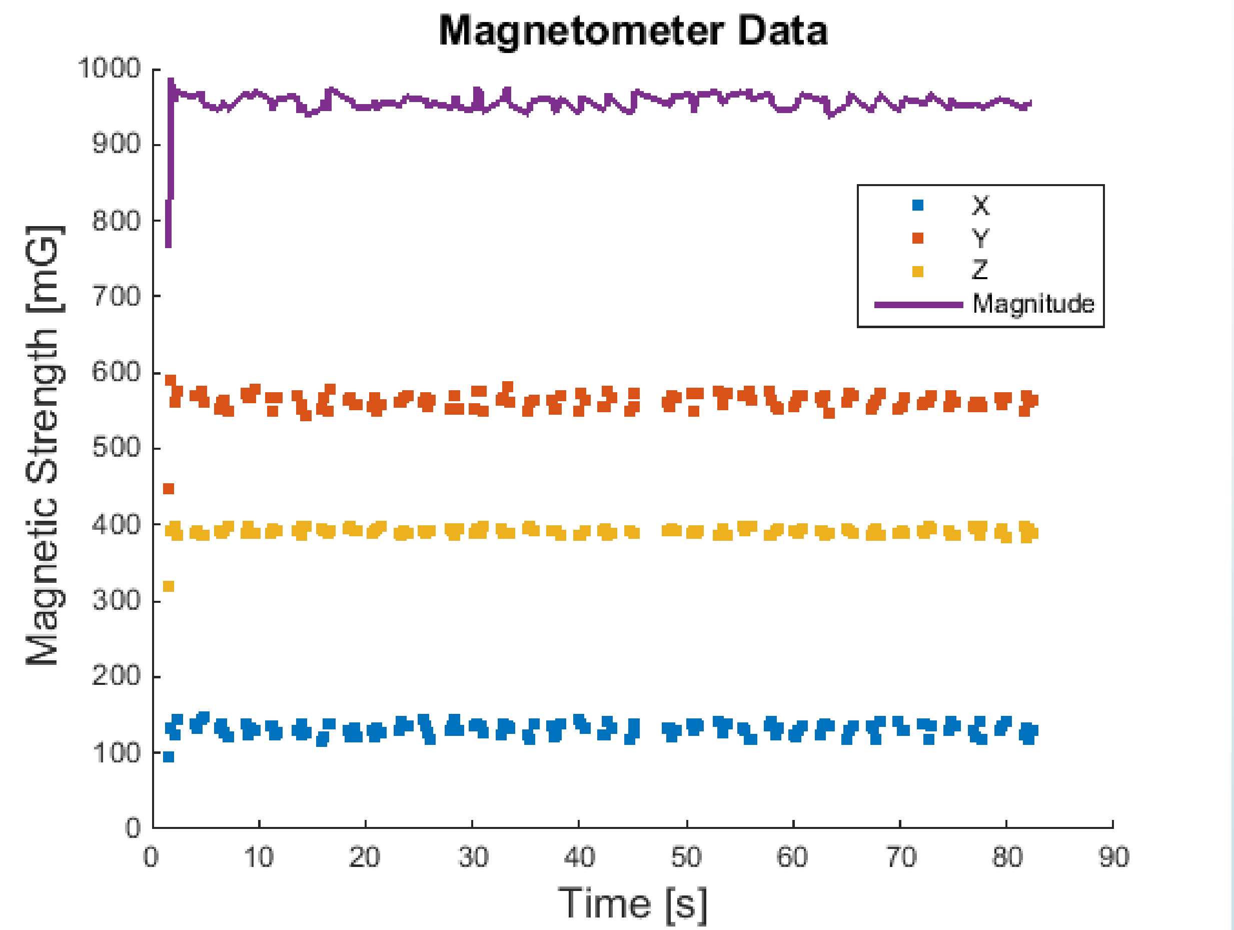
SCI 3.2: Avionics subsystem shall **store data collected** from sensors

SCI 3.1.4: Avionics subsystem shall **limit data flow** from sensors to less than 353 MB over the 100 hour mission

Flat Sat Success

Demonstrated full data path success

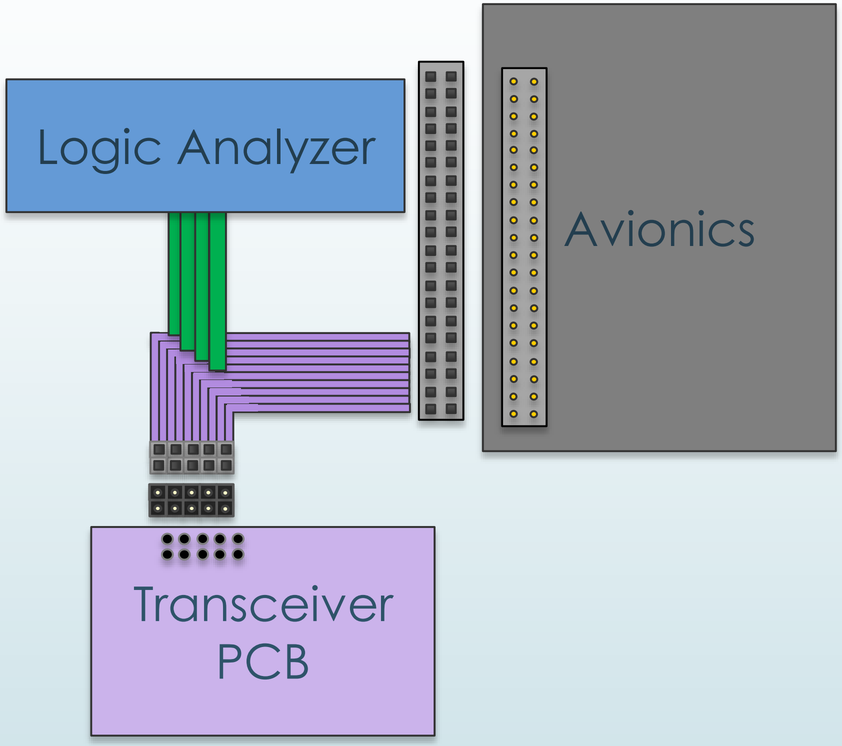




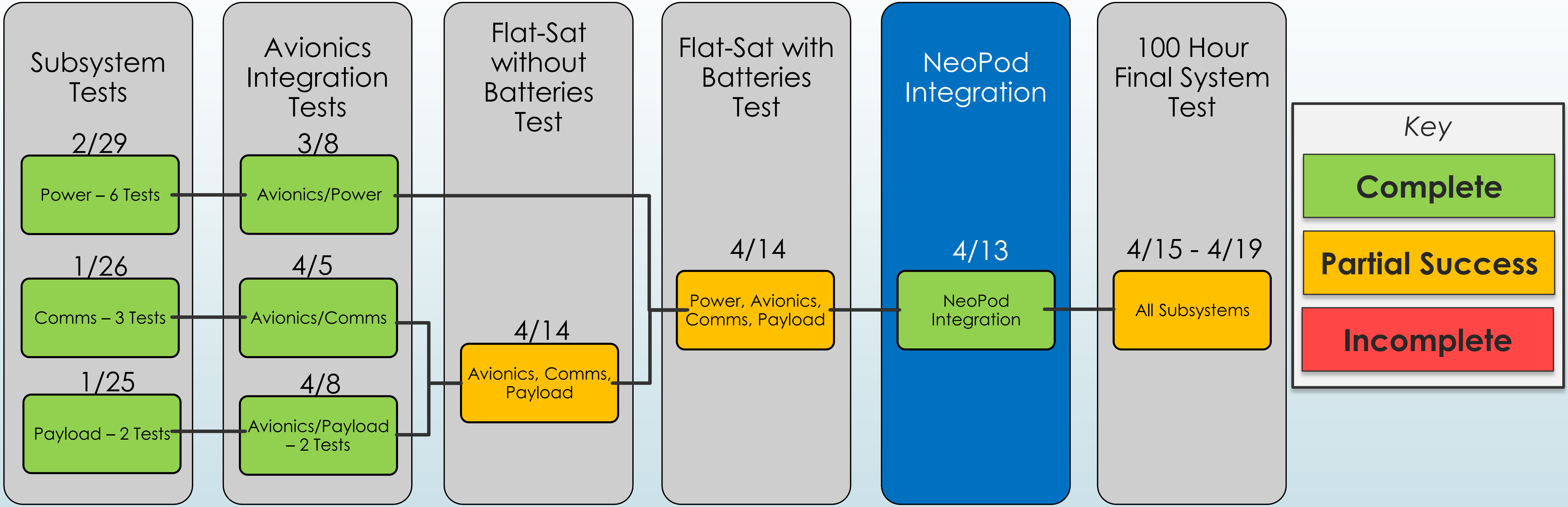
Avionics Subsystem Limitations

- **Transceiver SPI Line Issues**
  - Only functional when Logic Analyzer in parallel
    - Possible grounding or impedance mismatch
      - Equivalent resistor loads non-successful
  - Feasible for flat-sat and mounted configurations
- **Packet structure breakdown after first pass**
  - Most likely caused by TXFIFO length byte issues
- **Transceiver Robustness**
  - Issues staying powered for extended time periods

- **Given more time, above issues could be fixed**
  1) Replicate logic analyzer load with RC circuit
  2) Flush TXFIFO after pass
  3) Expand fault detection with transceiver resets



NeoPod Integration Results



Subsystem Tests

2/29 Power – 6 Tests

1/26 Comms – 3 Tests

1/25 Payload – 2 Tests

Avionics Integration Tests

3/8 Avionics/Power

4/5 Avionics/Comms

4/8 Avionics/Payload – 2 Tests

Flat-Sat without Batteries Test

4/14 Avionics, Comms, Payload

Flat-Sat with Batteries Test

4/14 Power, Avionics, Comms, Payload

NeoPod Integration

4/13 NeoPod Integration

100 Hour Final System Test

4/15 - 4/19 All Subsystems

Key

🟩 **Complete**

🟨 **Partial Success**

🟥 **Incomplete**

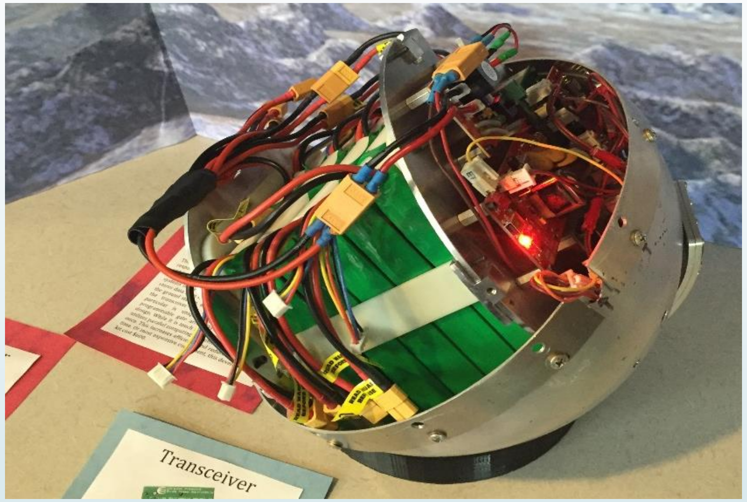
Integration Requirements

Mechanical Integration – CPE 4

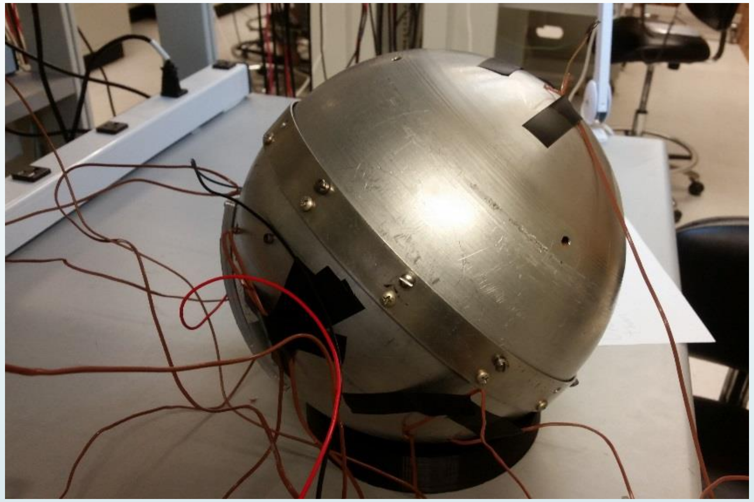
Requirement:	Description:	Motivation:
INT 1	NeoPod shall have a **mass less** than **10 kg**	Mass limitation based on orbiter. This does not include radiation CAD model.
INT 2	NeoPod shall have a **maximum diameter** of **30cm**	Volume limitation based on orbiter.

Dimensional Requirements

- Integrated system weight was measure to be **7.51kg.**



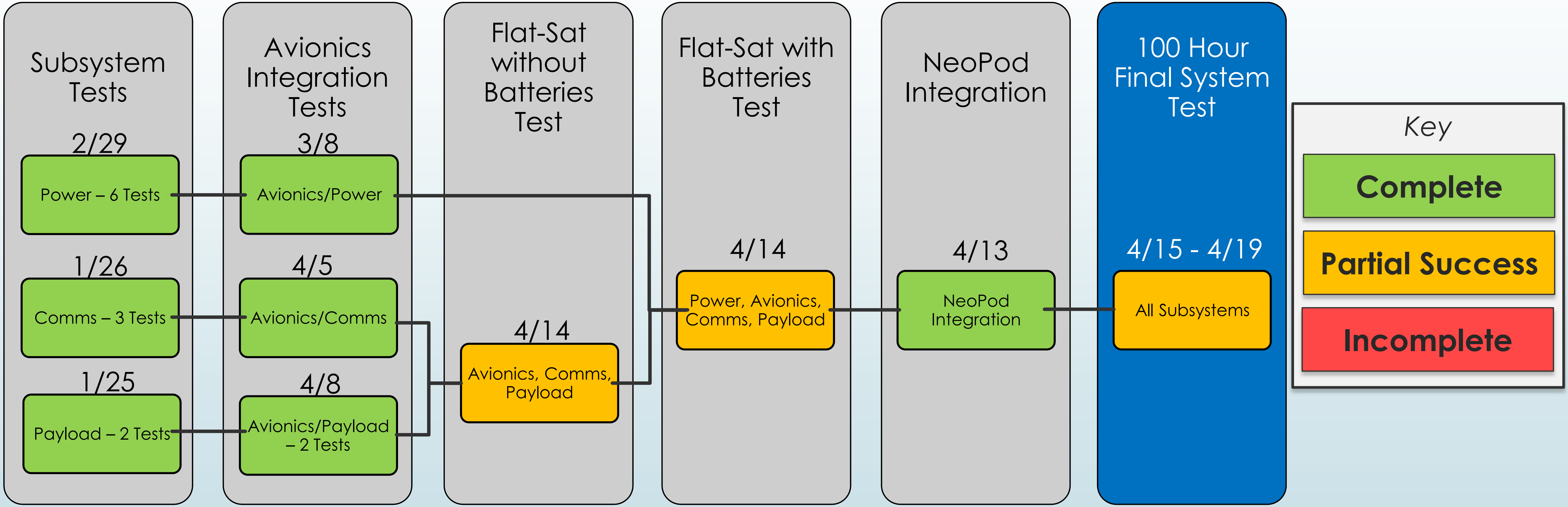
- Full system integrated in 10 inch (25.4 cm) diameter sphere



Satisfies INT 1: Mass less than 10 kg

Satisfies INT 2: Maximum diameter and fit within sphere

100 Hour System Test Results



Subsystem Tests

2/29
Power – 6 Tests

1/26
Comms – 3 Tests

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Payload – 2 Tests

Avionics Integration Tests

3/8
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4/15 - 4/19
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Key

🟩 **Complete**

🟨 **Partial Success**

🟥 **Incomplete**

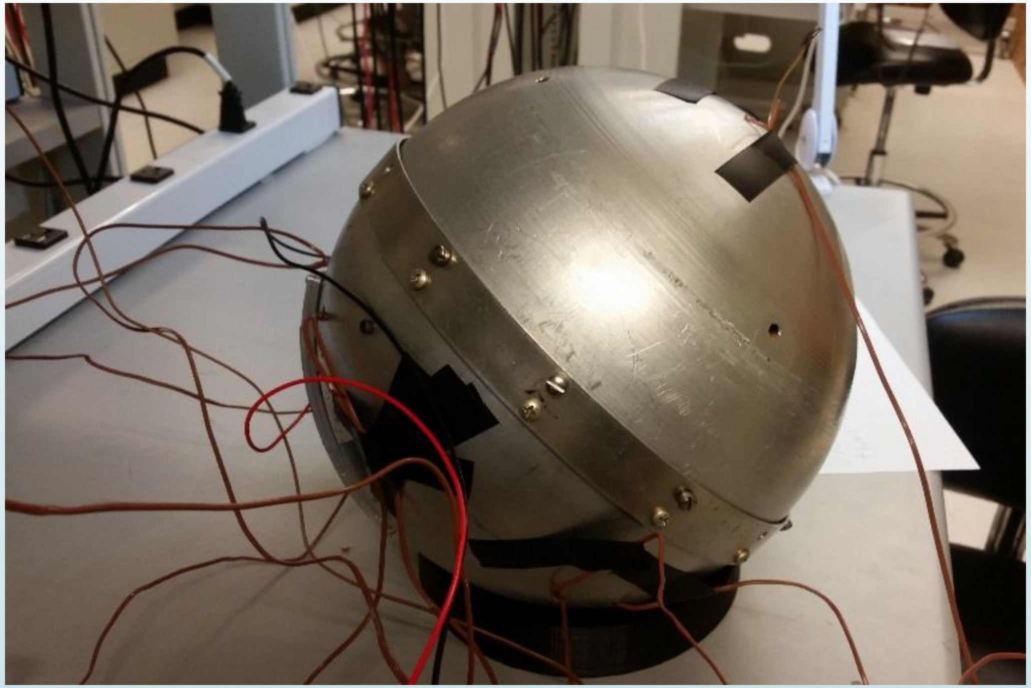
100 Hour Test Requirements

Power System and Mechanical Integration

Requirement:	Description:	Motivation:
SCI 3.3.1, SCI 2.2.1, SCI 2.1.2, COM 6.1	Power subsystem shall provide **voltage** lines of **5 V, and 3.3 V**.	The power system must support the Geiger counter at 5±0.25 V, and the magnetometer, transceiver, and avionics board at 3.3±0.3 V.
SCI 2, SCI 3, COM 6	Power subsystem shall **provide power** to subsystems for a total of **100 hours**	Duration of mission. Incorporates one full Europa orbit. Mission timeline requires powering sensors for 96 hours and avionics/communication for 100 hours
INT 6	The NeoPod's internal components shall operate **under** their **maximum operating temperatures** for the duration of the mission.	Safety of components, ensure no components will be damaged due to operation temperature.

100 Hour Testing

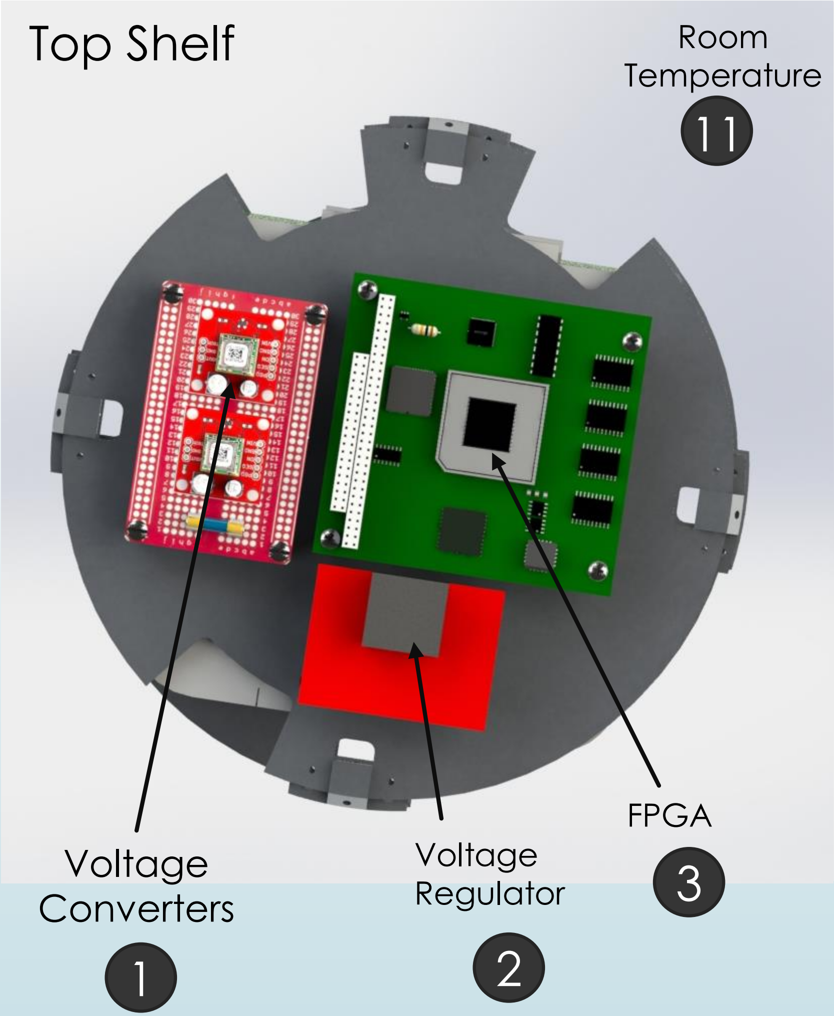
Verifies Requirements: **INT 6 – INT 10**
Meets all Power Subsystem Levels of Success



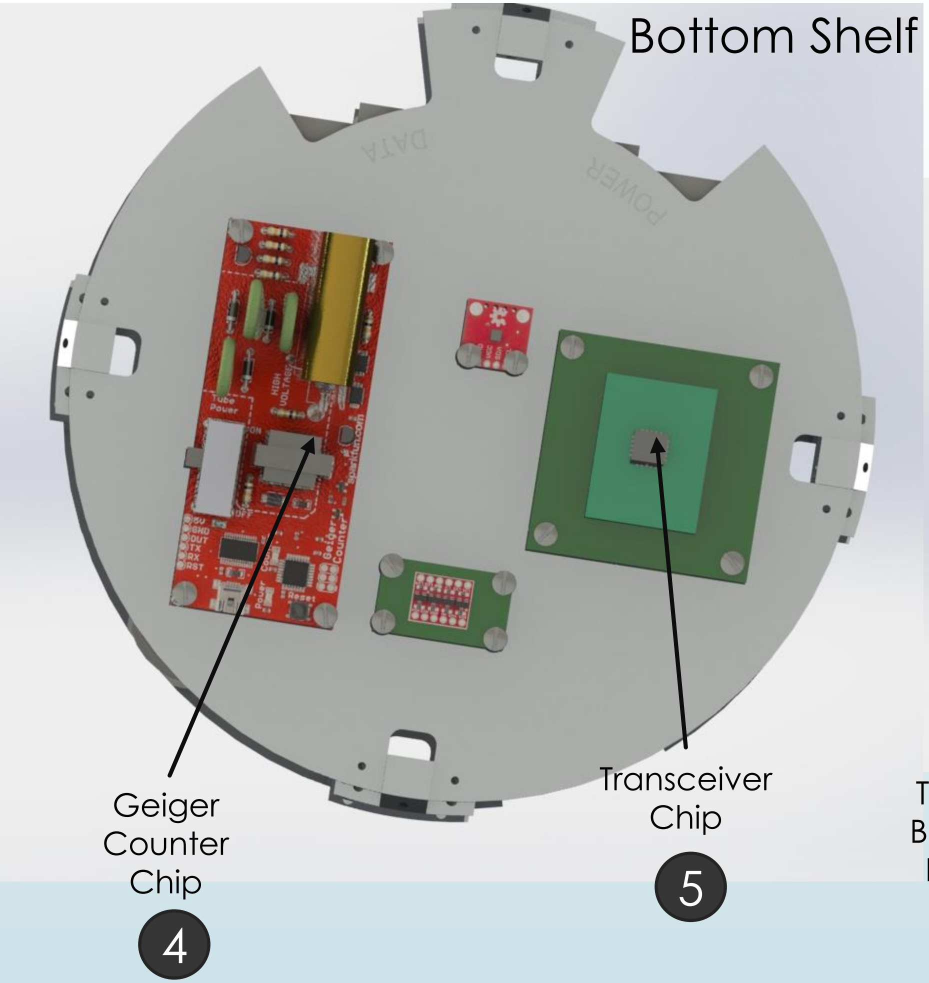
- **Objective:** Validate Power Model and Thermal Model
- **Where:** Performed in Bobby's Lab
- **When:** (6:00 PM) Friday 15th - (10:00 PM) Tuesday 19th
- **How:** Integrated Neopod
  Alternated shifts – with 2 people per shift
  Fluke 287 Multimeter
  Used NI9213 & NI9219 DAQ
  12 k-type thermocouples

100 Hour Test – Thermocouple Placement

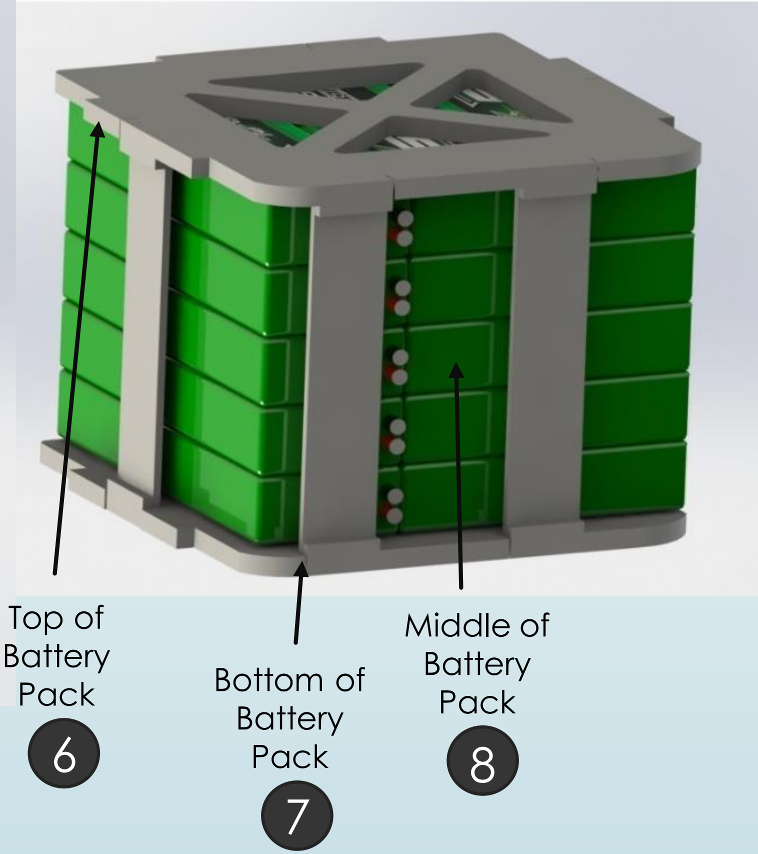
Top Shelf



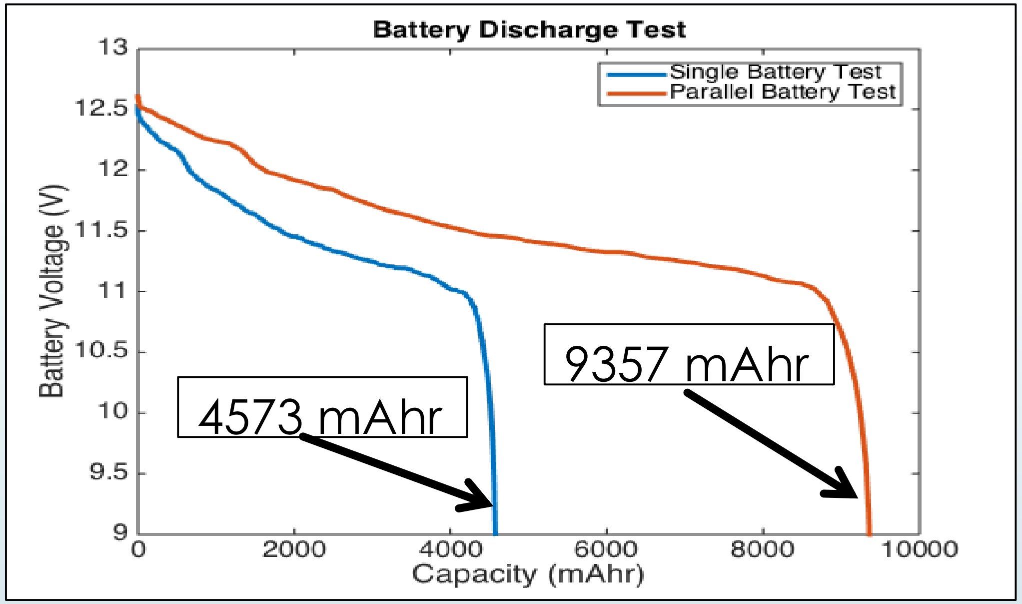
Bottom Shelf

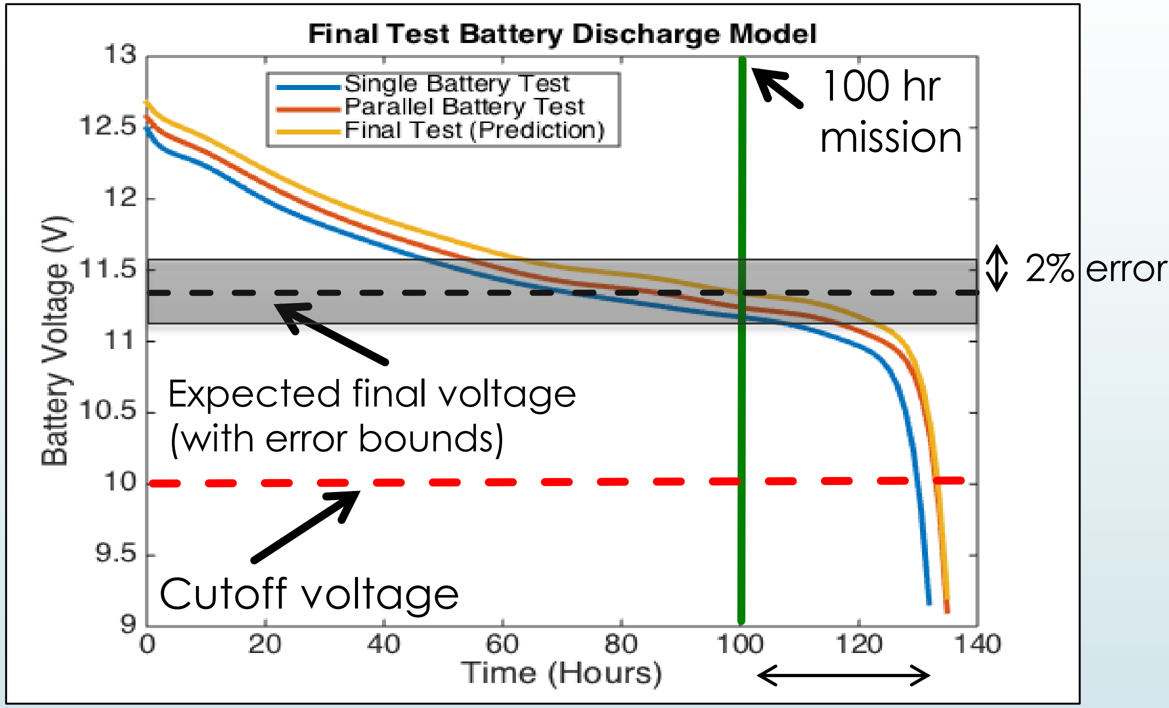


Battery Stack



Battery Discharge Model





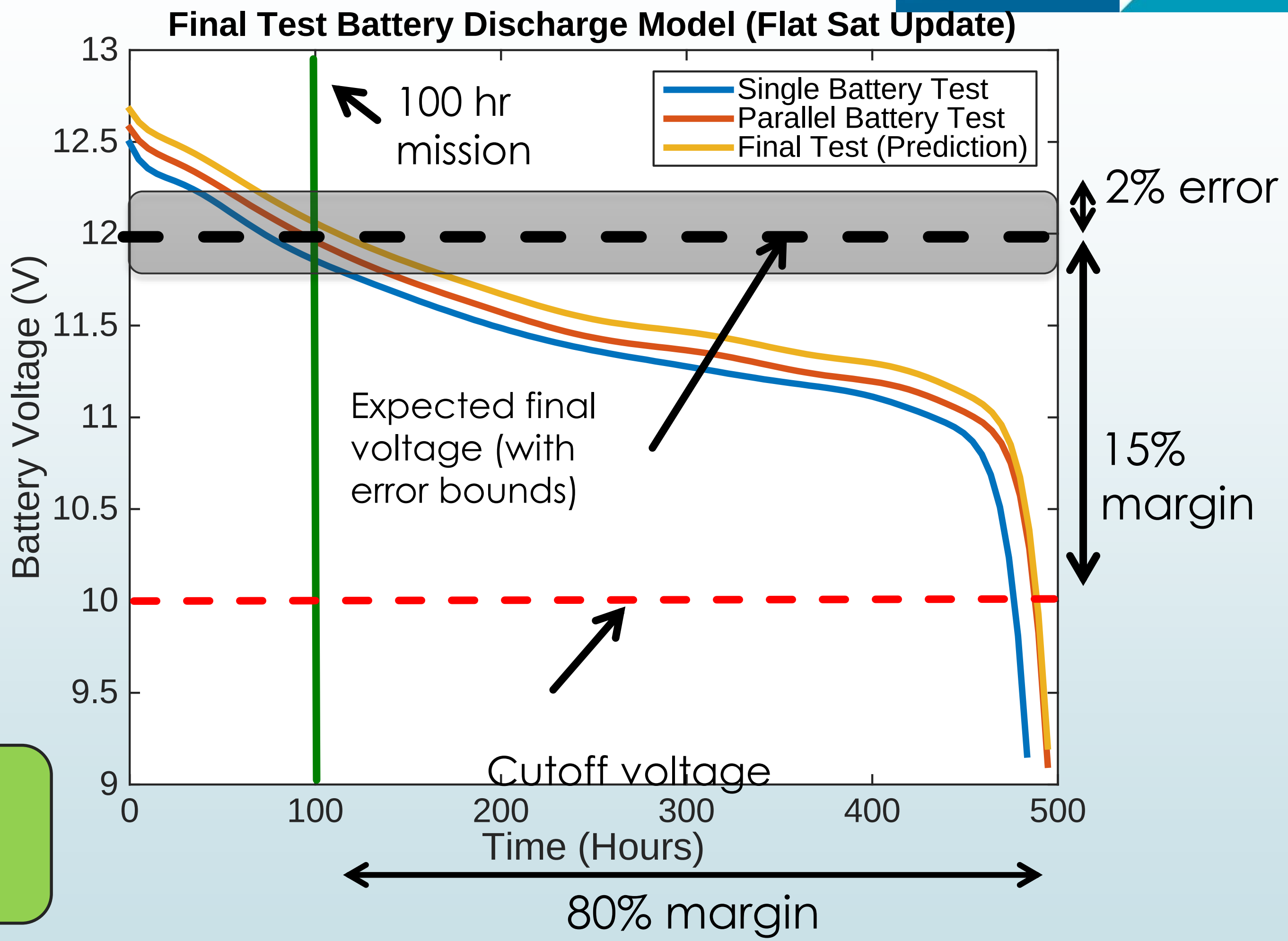
- Tests were scaled to create a model for 15 batteries
- Possible error from avionics power budget → 2% = 0.226 V
- Possible min of 11.1 V, max of 11.6 V

- **Expected final voltage of 11.3 V (20% margin)**

Project Objectives | Design Description | Test Overview | Test Results | Systems Engineering | Project Management

Refined Power Model:

- System was not tested for full 8 hours as originally planned
- Integrated system collected and transmitted data while connected to battery power
- Actual current draw of 0.15 A
- 27% of predicted 0.55 A
- Updated voltage discharge model predicts mission lifetime will increase by 360% (to 460 hrs)

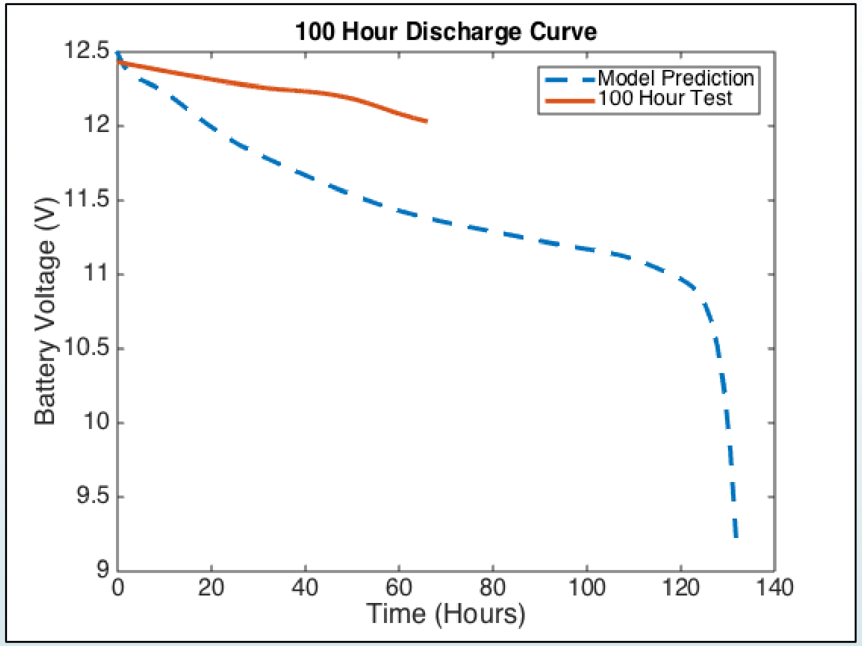


- **Expected final voltage of 11.8 V (80% margin)**

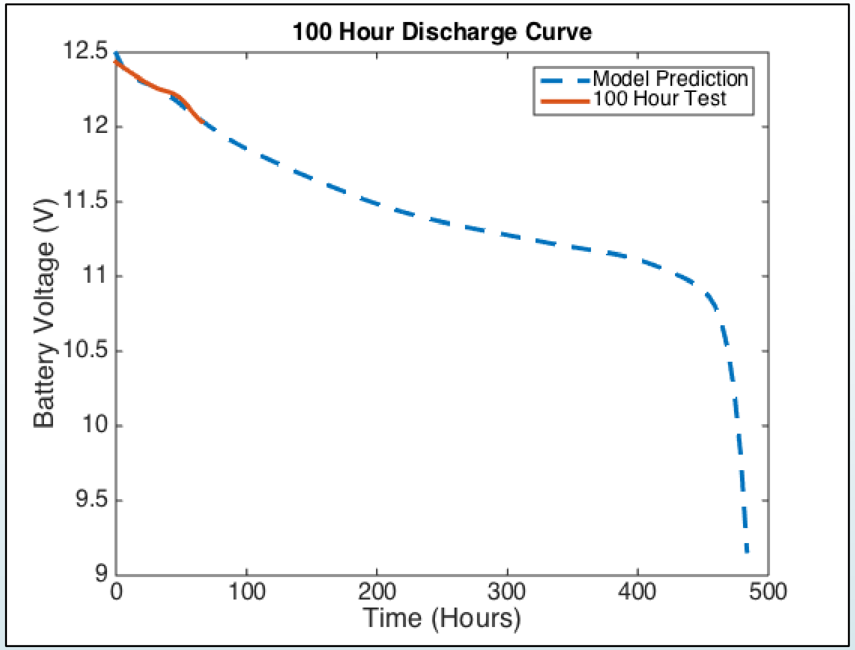
100 Hour Discharge Results

- Final test currently in progress
- Current will be constant at 0.105 A based on initial values (transceiver in idle mode)
- Experimental data more closely matches updated model

Satisfies 100 hour lifespan requirement (SCI 2, SCI 3, COM 6)



Compared to <u>Original Model</u> (0.55 Amp draw)



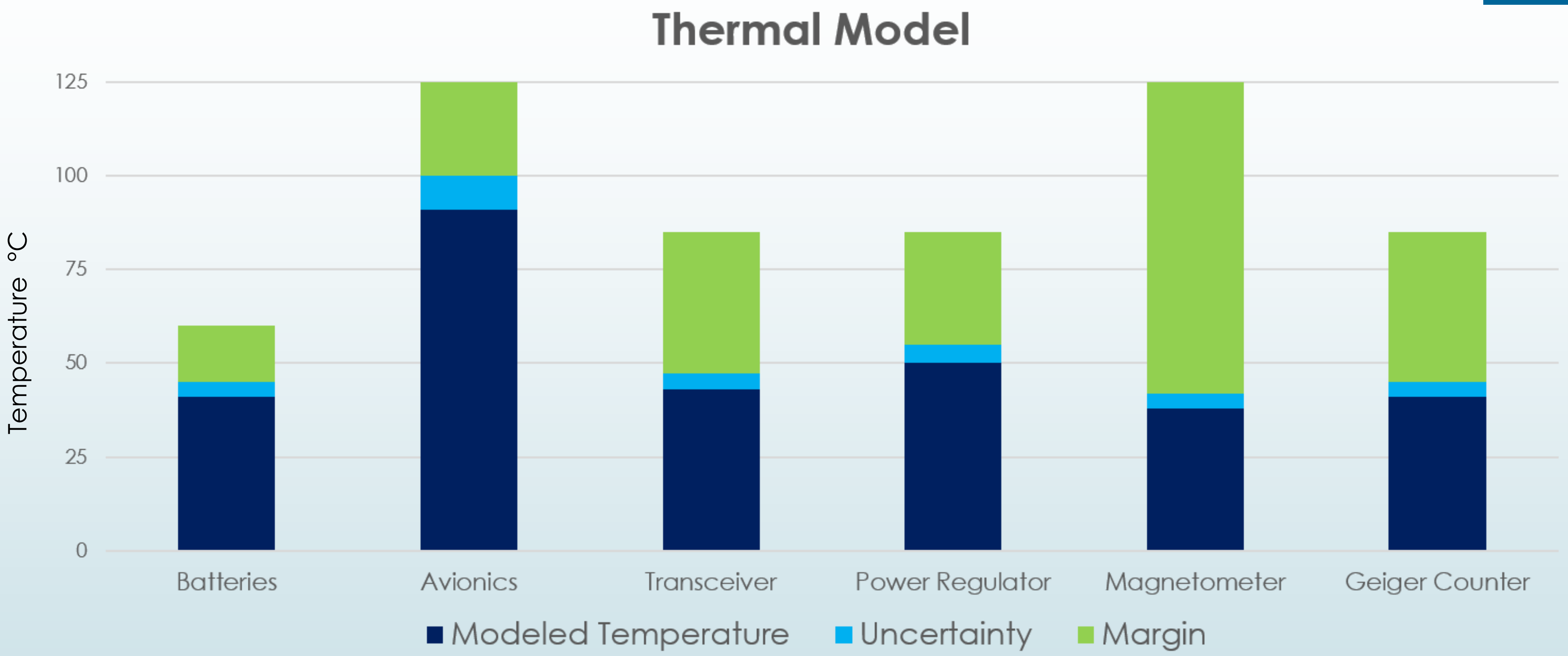
Compared to <u>Refined Model</u> (0.15 Amp draw)

Analysis and Explanation

- Gross **overestimate of current draw** caused power budget to be significantly inaccurate
- True values for **current draw** were **not know until far into testing** process
- Could have reduced number of batteries, but there would have been little benefit
- Reducing the number of batteries would have reduced volume, mass, and budget, but still **met all requirements**

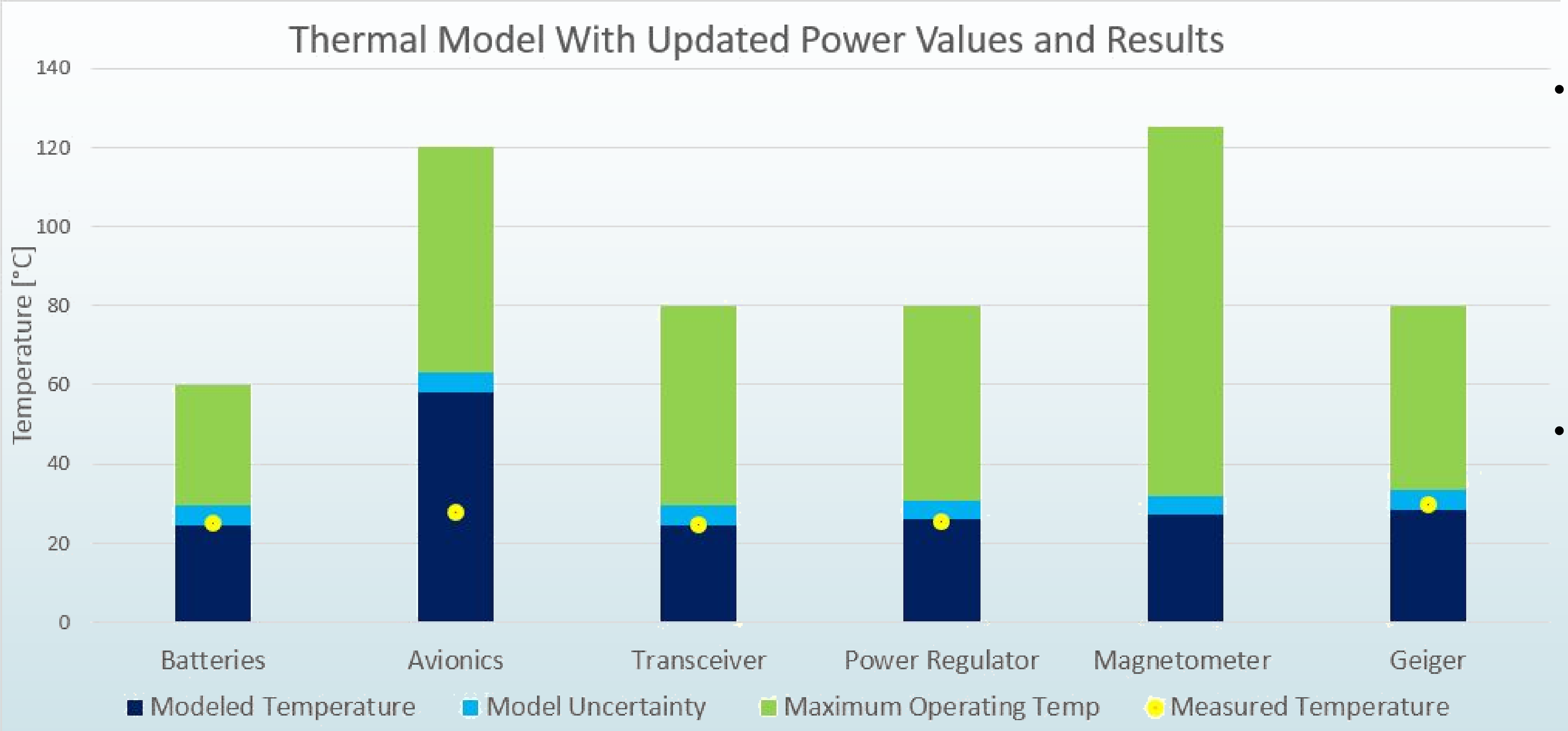
- Two major challenges for **path forward** can be solved in part with extra power
  - Low temperature environment requires heating
  - Increased transmission distance requires increased power

Original Thermal Model



*Note: Avionics assumes unexpected, **worst case power draw** for thermal model

Refined Thermal Model and Results

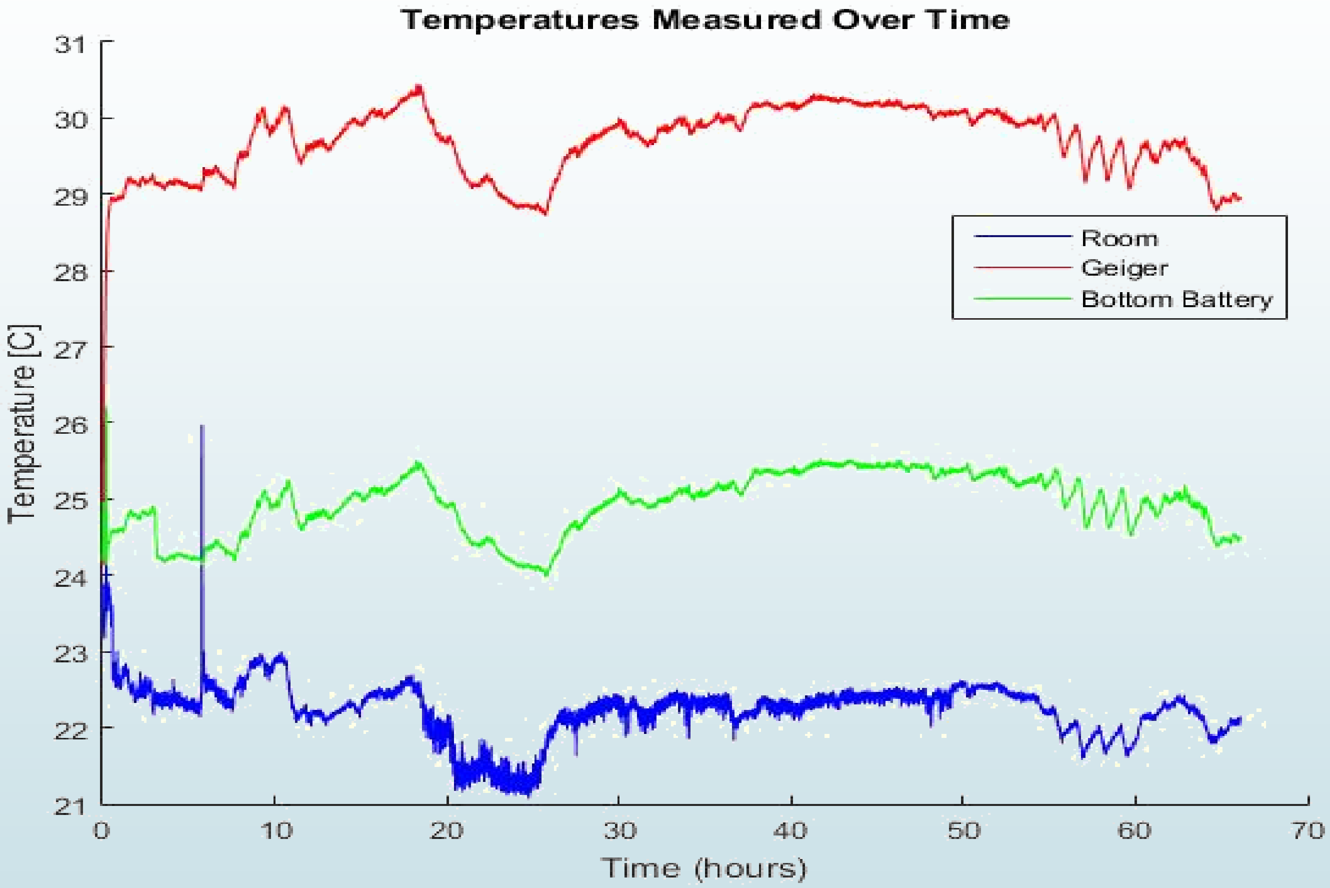


- **Assumes realistic power draw for components.** All components **remained under maximum operating temperatures** and were close to model predicted values
- For analysis of NeoPod on Europa, thermal conditions for extreme cold temperatures must be considered

*Note: Unable to measure magnetometer temperature

INT 6: ***The NeoPod's internal components shall operate under their maximum operating temperatures for duration of 100 hour test***

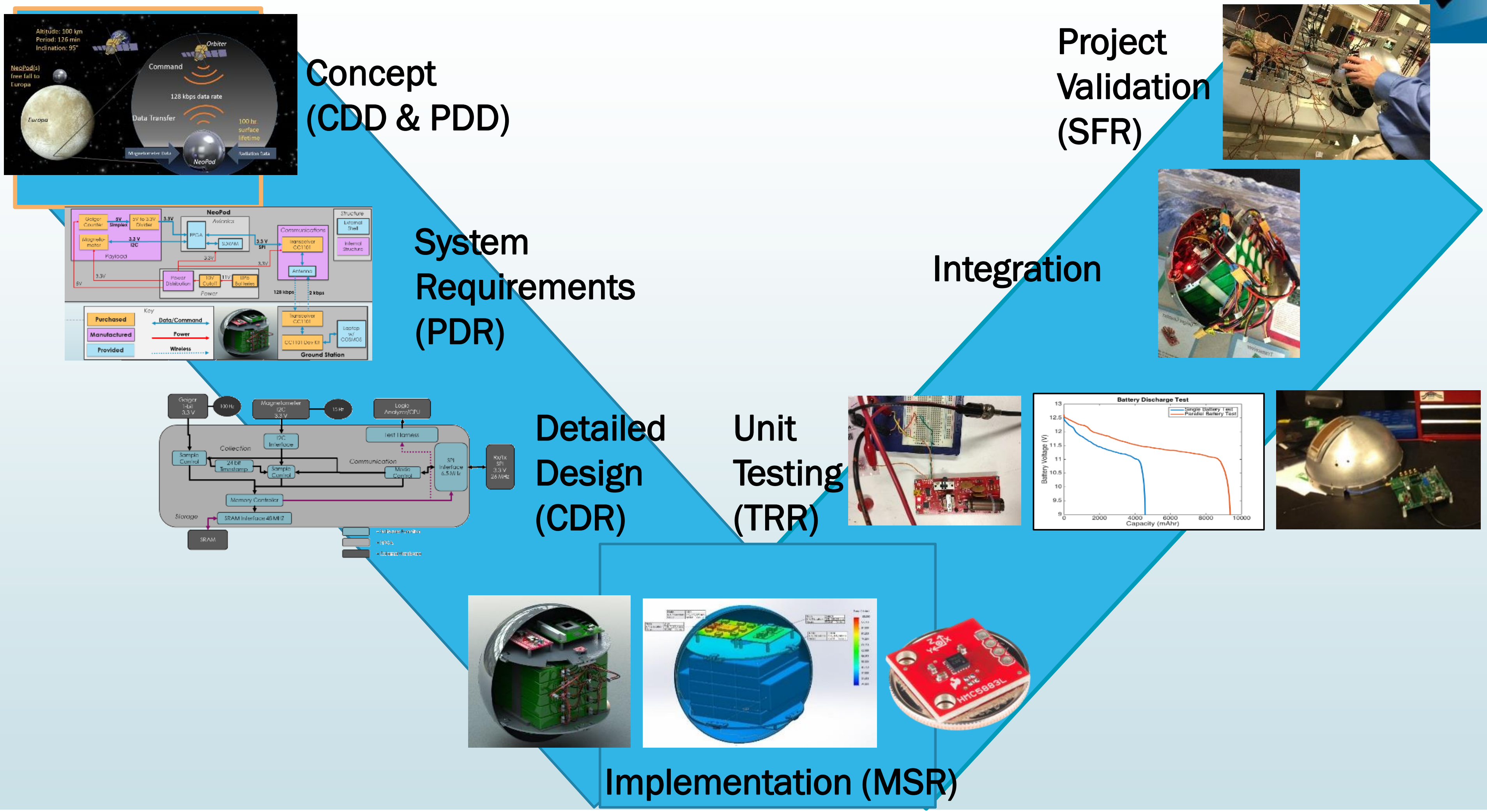
Final Test Select Component Temperatures



*Note: Through 70 hours of testing

Systems Engineering

Systems Engineering



Concept (CDD & PDD)

System Requirements (PDR)

Detailed Design (CDR)

Implementation (MSR)

Unit Testing (TRR)

Integration

Project Validation (SFR)

Risk Assessment

Risk	Mitigation	Result
🟨 **RP1: FPGA Software/Schedule Slip**	Early learning curriculum, and Microsemi training. **15 days of critical path margin.** Off-ramp: Ability to transfer third person to avionics.	🟨 **Implemented mitigation and off-ramp plan.** Third person was difficult to integrate into team because of steep learning curve. **Schedule margin was not quite enough.**
🟩 **RP2: ESD Component Safety**	**ESD safe environment** and training required for all avionics and communications testing. Purchased ionizing fan, and **additional transceiver and avionics board as backup**.	🟩 Trained and implemented ESD safe environment. **Not a risk after avionics board off-ramp.**
🟨 **RP3: FPGA Hardware Procurement**	**Majority of developed software applies to both design solutions. Off-ramp: COTS development FPGA** has been acquired	🟩 Had to take planned off-ramp early March after **Ball Aerospace avionics board failed to function. Successful off-ramp**
🟩 **RP4: Unable to Dissipate Heat**	**Conduct extensive thermal model.** Off-ramp: Open NeoPod during testing to reduce heat and protect system	🟩 Thermal model suggests low chance of component overheat. **100 hour test was successful.**
🟩 **RP5: Power Failure**	Conduct battery characterization model. Safety systems include **fuse to prevent overcurrent** and **voltage cutoff circuit** to protect batteries.	🟩 Safety systems implemented. Power model suggests extremely low risk of power failure. **100 hour test was successful.**

Severity

Likelihood

	1	2	3	4	5
5 (Very High)	🟨	🟨	🟥	🟥	🟥
4 (High)	🟨	🟨	🟨	🟥	🟥
3 (Moderate)	🟩	🟨	🟨	🟨	🟥
2 (Low)	🟩	🟩	🟨	🟨 **RP3**	🟨 **RP2**
1 (Very Low)	🟩	🟩 **RP4**	🟩 **RP5**	🟨 **RP1**	🟨

🟥	**Unacceptable**
🟨	**Acceptable with Mitigation**
🟩	**Acceptable**

System Summary

System Successes:

- **Requirements Mapped to Tests Early:**
  - Good understanding on how the test plan continued to verify requirements throughout semester
  - Ensured all requirements were testable and kept them visible
- **Wiring and System Integration Plan developed in January.**
  - Made physical integration efficient
  - Saved time later in semester
- **Identified and Mitigated Risk**
  - Move from Ball Aerospace board to Microsemi board had minimal effect, even early in March

System Issues:

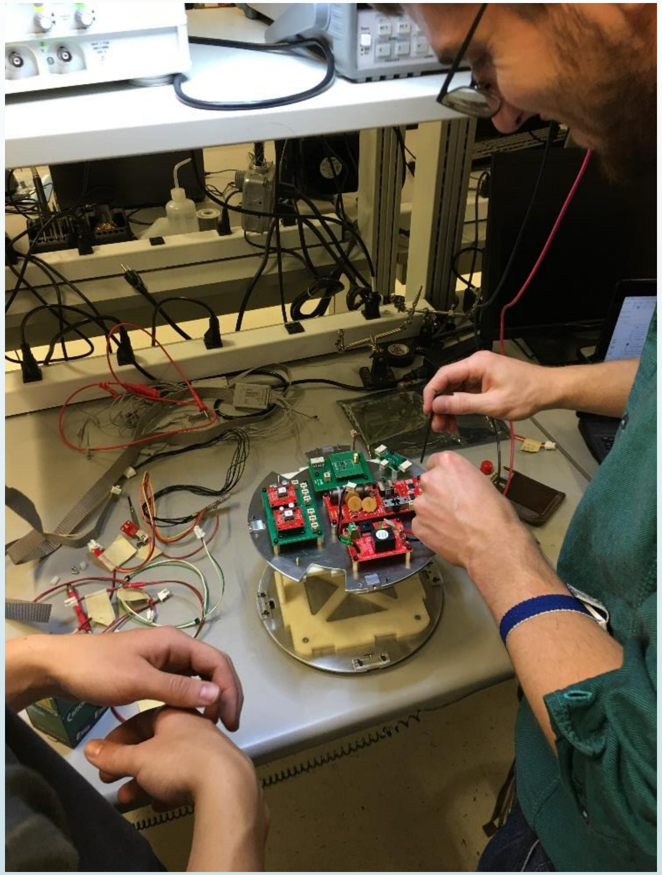
- **Technical Knowledge Distribution:**
  - Subsystem teams became highly technical early on
  - Difficult to redistribute team resources due to high learning curve
- **Integration Process Underestimated:**
  - Large, unforeseen, integration related problems that pushed back schedule
    - Avionics – Communications interface

Lessons Learned

- **A well scoped project is key**
  - Develop qualitative requirements early on, and be sure they adequately define project
  - Ensure requirements are testable

- **Begin integrating components as soon as possible**
  - Catches early development mistakes
  - Test early and often

- **Off-ramps are crucial to success**
  - Had to employ major off-ramp to use Microsemi FPGA
    - Plan was in place
    - Minimal effect on schedule



Project Management

Project Management Approach

- **Goal Driven**
  - Set **large long term goals** for subsystems (2-3 weeks goals)
  - Often based on functionality or completion of milestone
  - Left the **smaller task breakdown** and time management on those tasks to **each subsystem**
  - Had team members **report each week in meetings** (Tuesday and Thursday)

- **Systems Focused**
  - I tried to have an understanding of each subsystem and how it functioned to speak intelligently with each group
  - **Facilitated inter-subsystem discussions** and problem solving
  - Had to manage all these subsystems with the context of the overall mission

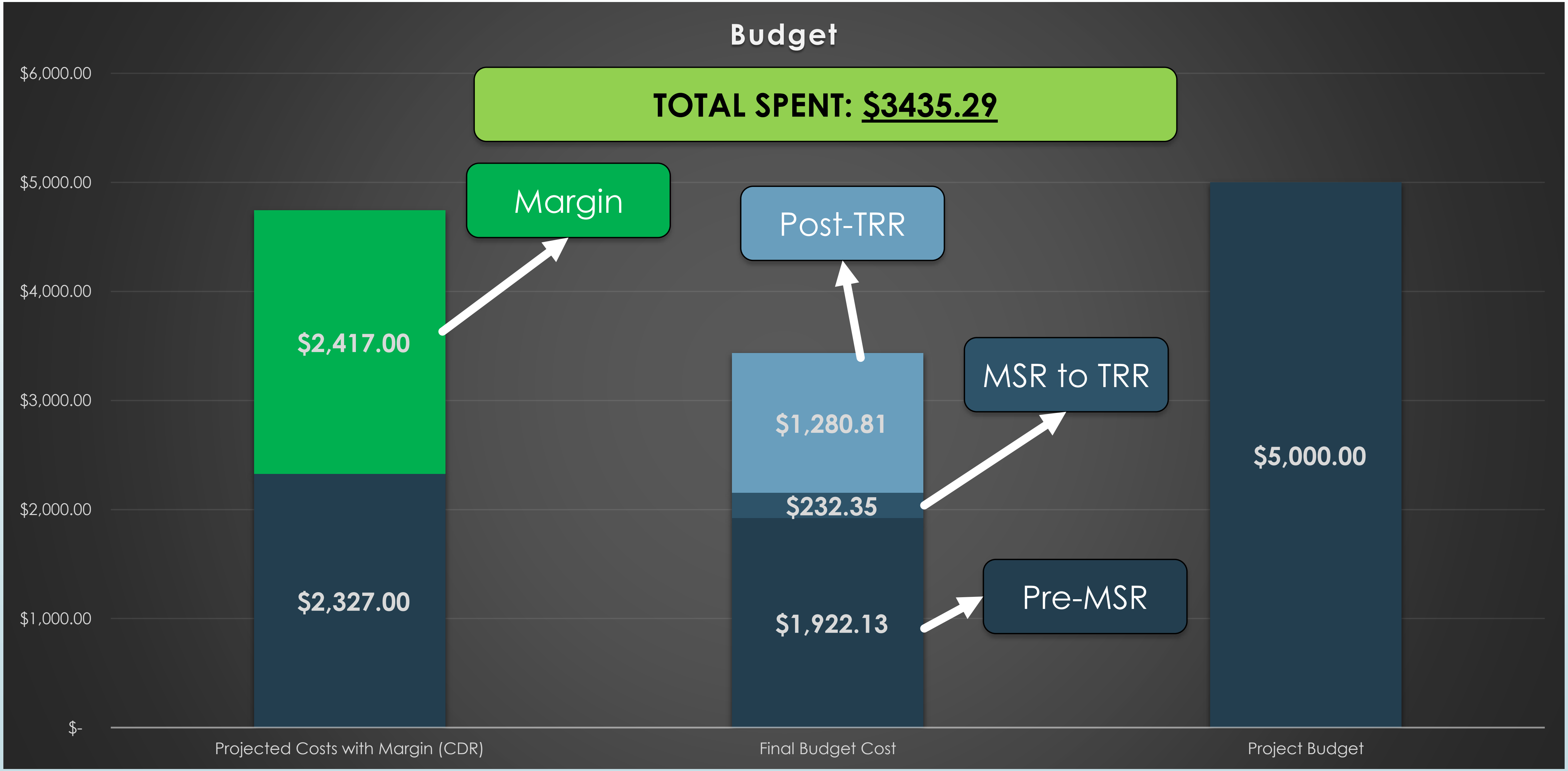
Successes, Difficulties, and Lessons Learned

- **Successes**
  - Had effective and informative weekly meetings
  - **Subsystems** were able to achieve **highest levels of success**
  - Good team chemistry and respect for everyone's opinions

- **Difficulties**
  - Difficult to address FPGA development slips and issues late in the project
    - Proved hard to get new people on and to divide up work on

- **Lessons Learned**
  - Throwing more people at a problem (especially programming) does not solve that problem
  - Having a hardworking and motivated team makes all of the difference in the world
    - Dealt with project issues, not internal team issues

Final Budget:



Equivalent Industry Cost

- Average yearly salary of $65,000.00 for entry level aerospace engineers
  - Assuming 2080 hours a year, rate is $31.25 an hour
  - Include a typical overhead of 200%

- Team spent 4,580 hours over the past year working on this project

Equivalent Industry Cost of
<u>$432,810.29</u>

Summary

- **Designed and constructed TRL 4 NeoPod**
  - Completed in 8 months
  - Total Cost: $3435.29
  - Team of 9 undergraduate students

- **System Accomplishments**
  - Developed FPGA as central C&DH system
  - Incorporated two-way RF communication
  - Integrated relevant sensors to study of Europa
  - Lightweight materials
  - Capability to last entire Europa orbit (~100 hours)

Path Forward:

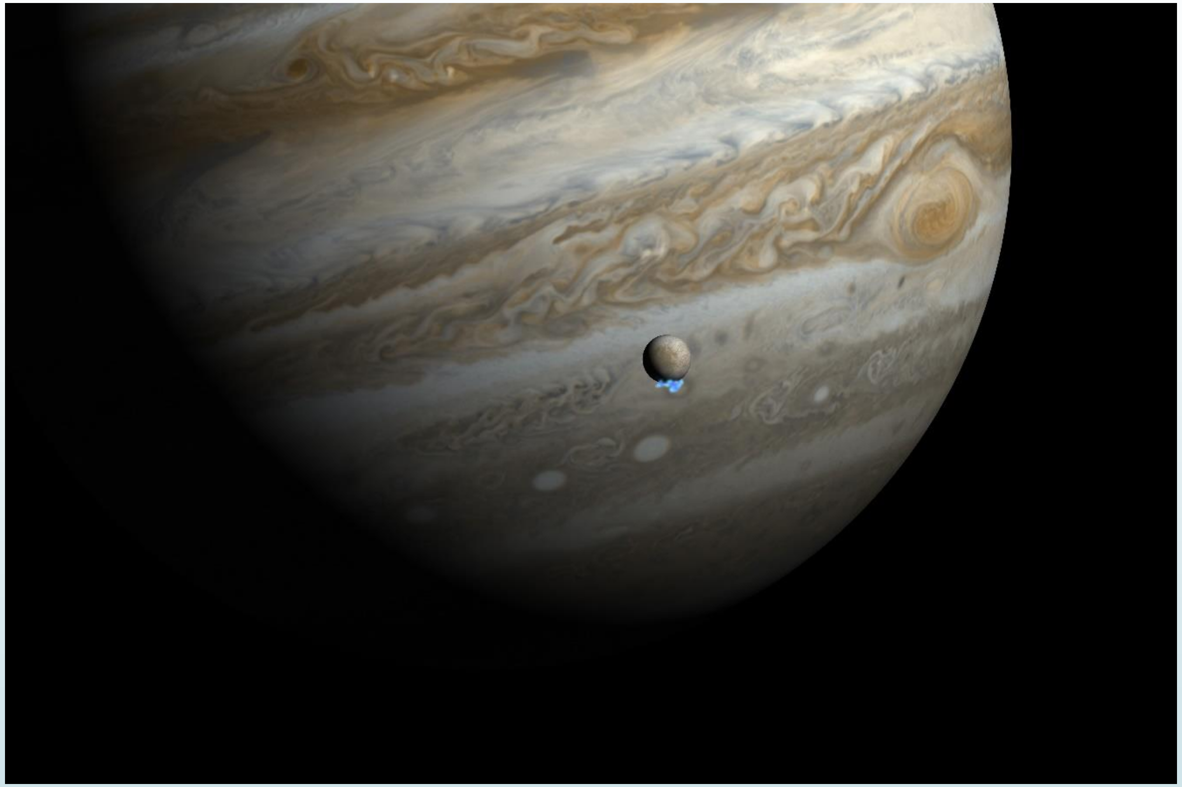


Photo Credit: http://www.spacetelescope.org

- Path to TRL 5:
  - More robust sensor package
  - Radiation hardened components
    - Radiation shielding
  - Design for impact structural loading
  - Enhanced Communications System
  - Testing in Europa-like environment
    - Extreme temperature testing
    - Radiation testing

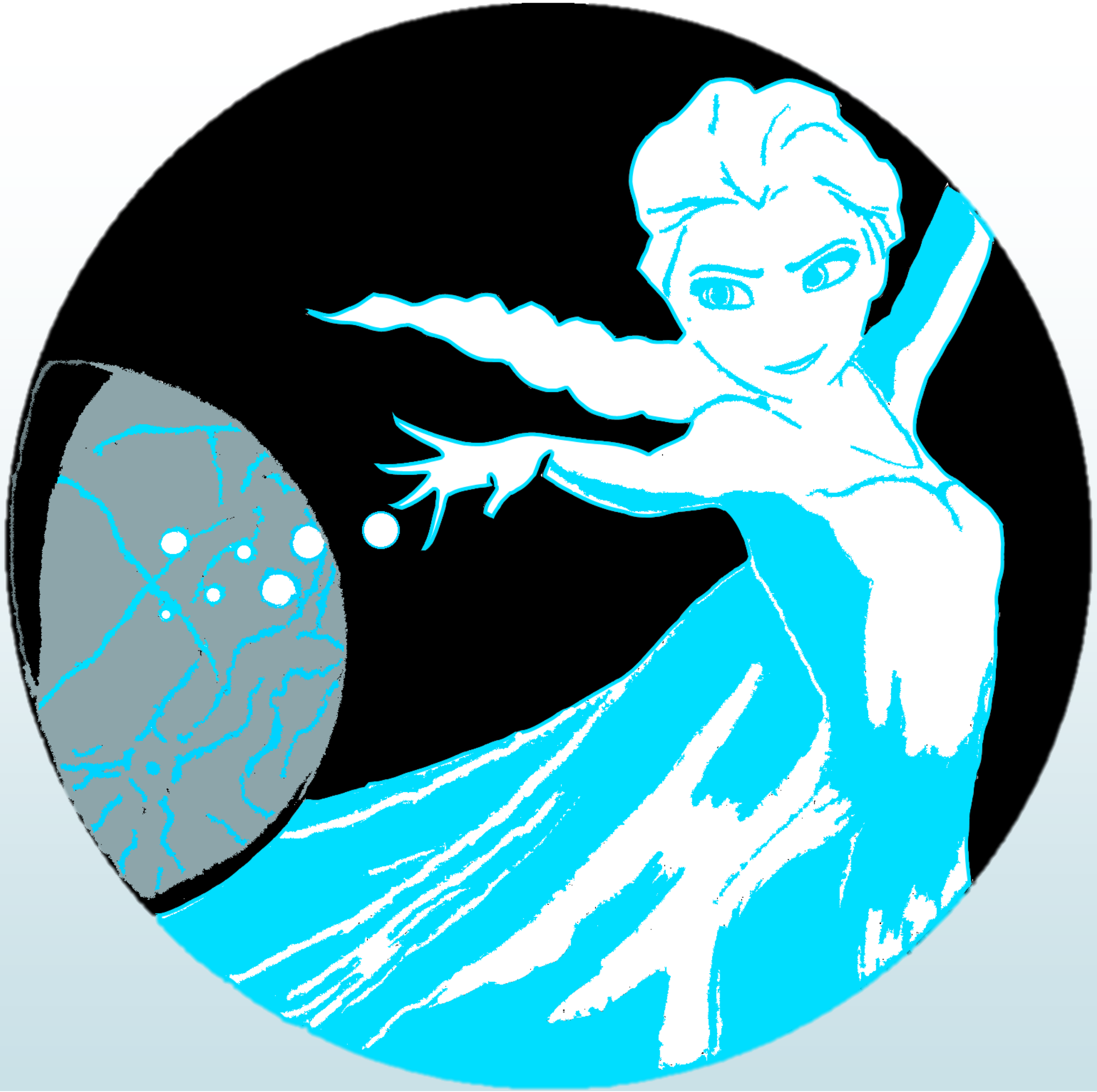
Acknowledgments

- **Thank you for your time**

Acknowledgements:

- University of Colorado Aerospace Faculty and Staff
- Faculty Advisor
  - Dr. Robert Marshall
- Our Customer
  - Ball Aerospace
  - Joe Hackel
- ELSA Senior Projects Team

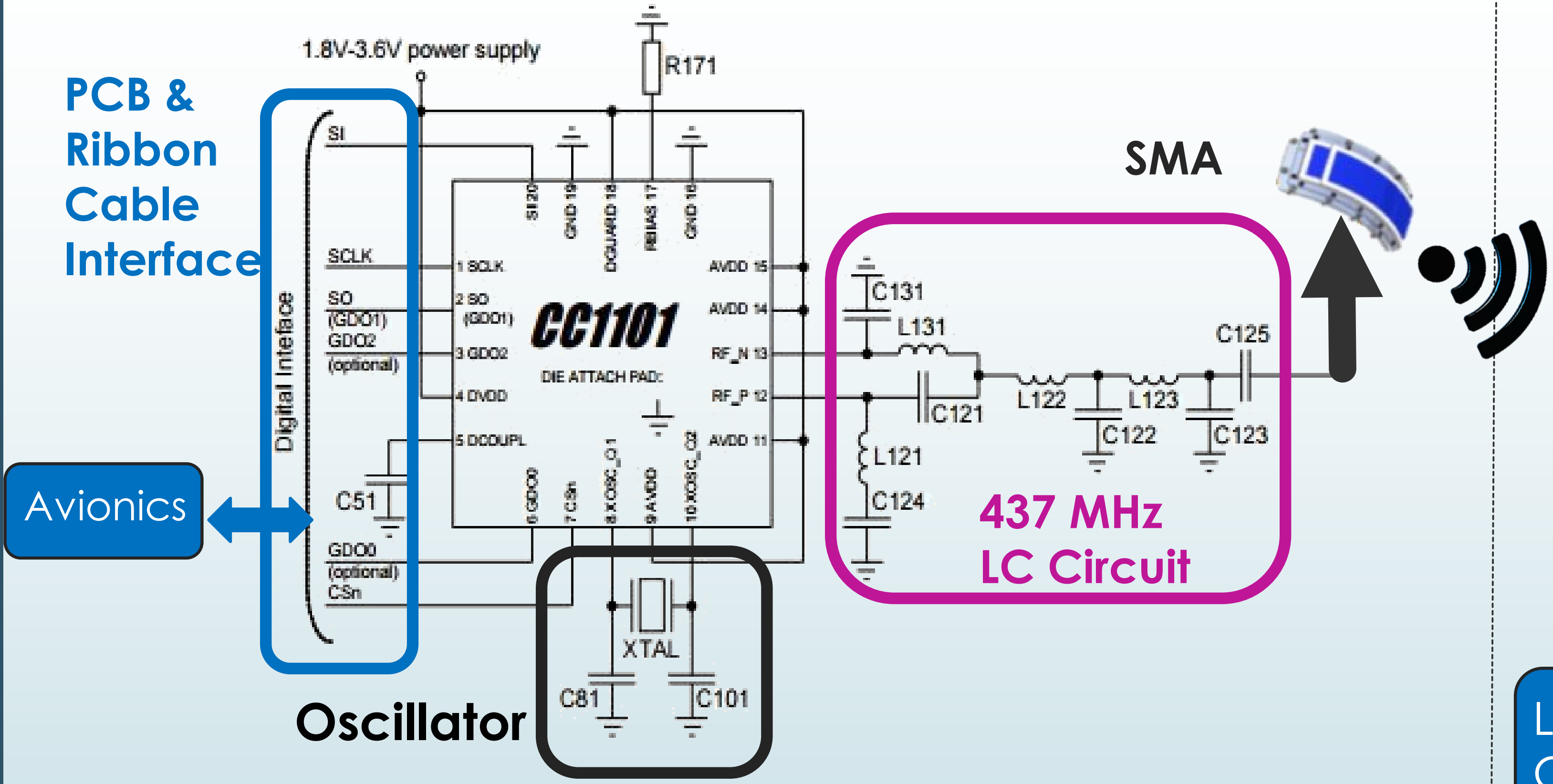
Questions?



Project Objectives
Design Description
Test Overview
Test Results
Systems Engineering
Project Management

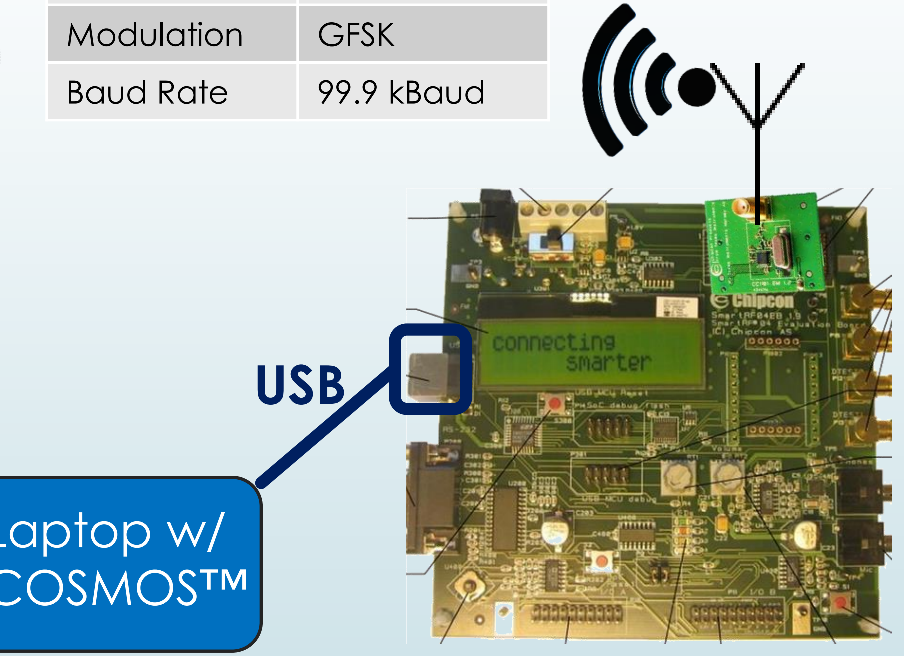
Backup Slides

Communications Design (Hardware)



NeoPod Comm. System

Parameter:	Value:
Frequency	437.5 MHz
Deviation	5.2 kHz
Modulation	GFSK
Baud Rate	99.9 kBaud



CC1101 Development Kit

Ground Station

Avionics Subsystem Tests

Demonstrate end to end data throughput through avionics

Subsystem Tests
- Power – 6 Tests
- Comms – 3 Tests
- Payload – 2 Tests

Avionics Integration Tests
- Avionics/ Power
- Avionics/ Comms
- Avionics/ Payload - 2 Tests

Flat-Sat without Batteries Test
- Avionics, Comms, Payload

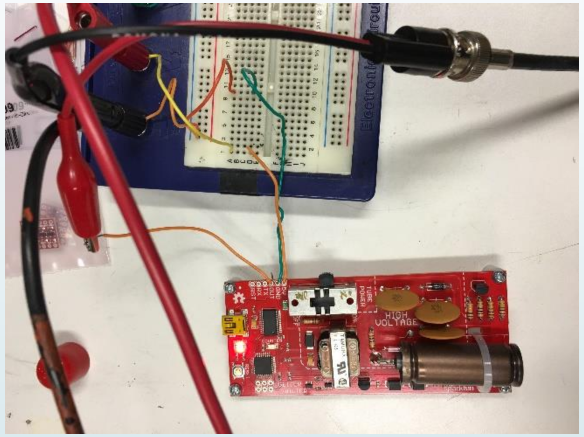
Flat-Sat with Batteries Test
- Power, Avionics, Comms, Payload

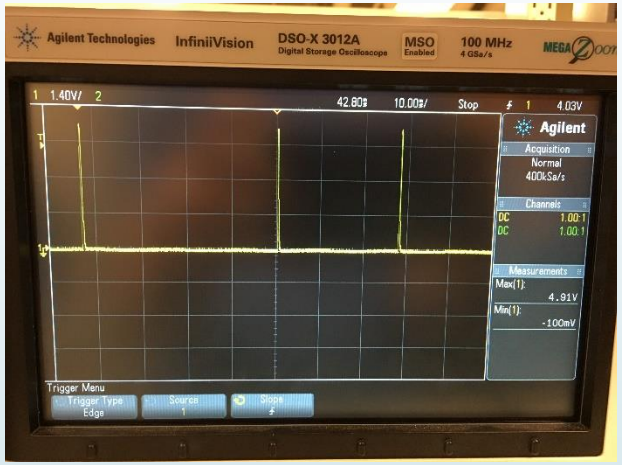
NeoPod Integration
- NeoPod Integration

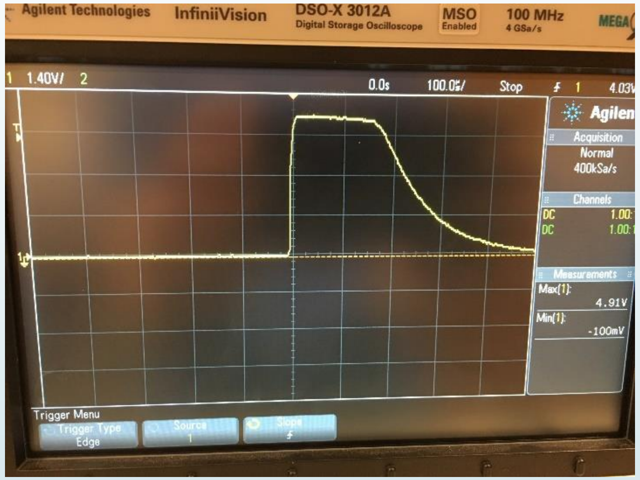
Final System Test
- All Subsystem

Sensor Test Results

- **Geiger Functionality Test:**
  - Using oscilloscope and PCB, the Geiger Counter output signal was characterized to ensure the Avionics system would be able to interact with it correctly.



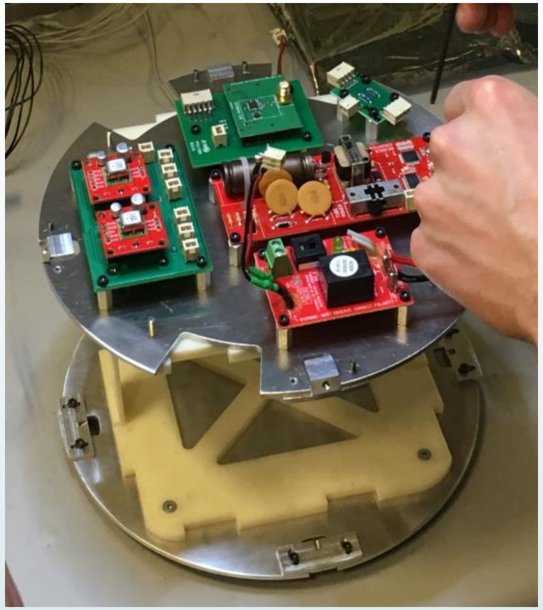




- **Magnetometer Functionality Test:**
  - Used Arduino and Sparkfun code to test basic functionality of the magnetometer
  - The Sparkfun code was used as a baseline when developing the equivalent FPGA code.

Avionics Subsystem Success

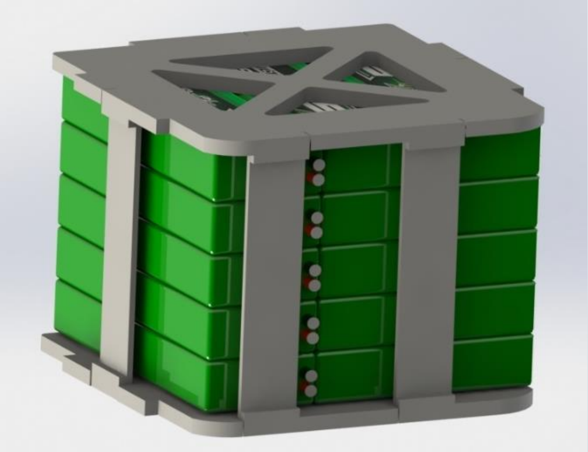
- **Data Transmission Upon Command:**
  - Correct configuration of transceiver and reception state
  - Correct configuration of outgoing data and packet structure
  - Correct adherence to mission architecture
    - 8 Minute transmission window
  - Requirements Validated: Avionics interfaced with transceiver



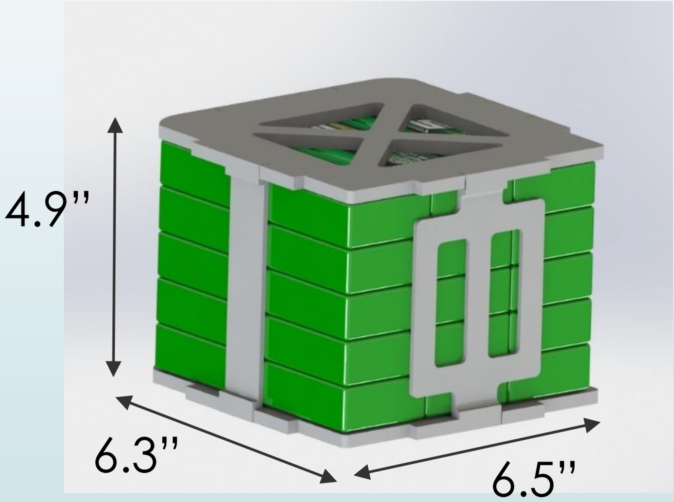
- **Data Collection and Storage**
  - Data integrity preserved through collection, memory write, and memory read
  - Geiger Counter Accuracy: Earth Estimate ~ 30 CPM Measured: 24 CPM
  - Magnetometer Accuracy: Earth Magnitude Estimate ~ 650 mG Measured: 955 Mg
  - Requirements Validated: 2 Science Instruments, Data Limited to 353 MB, All Data Stored

Battery Case Backup

- Encloses battery stack on all sides – 3D printed PLA
- Top and bottom case components screwed to shelves
- Three sides will be glued together
- Front face will be pressure fit (easy battery removal)



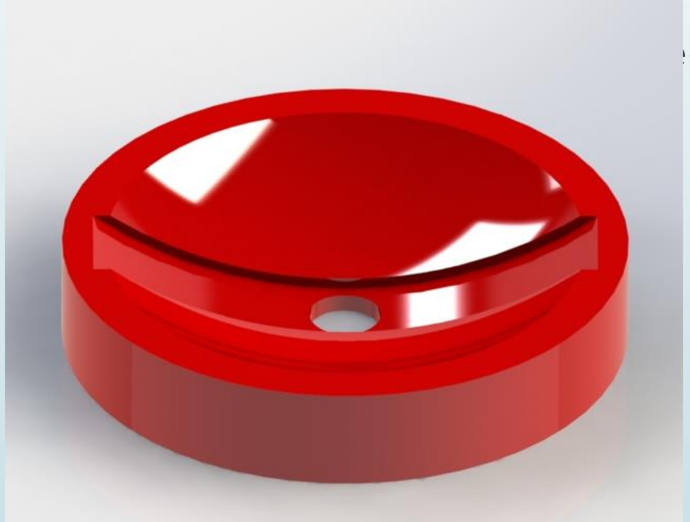
Front



Back

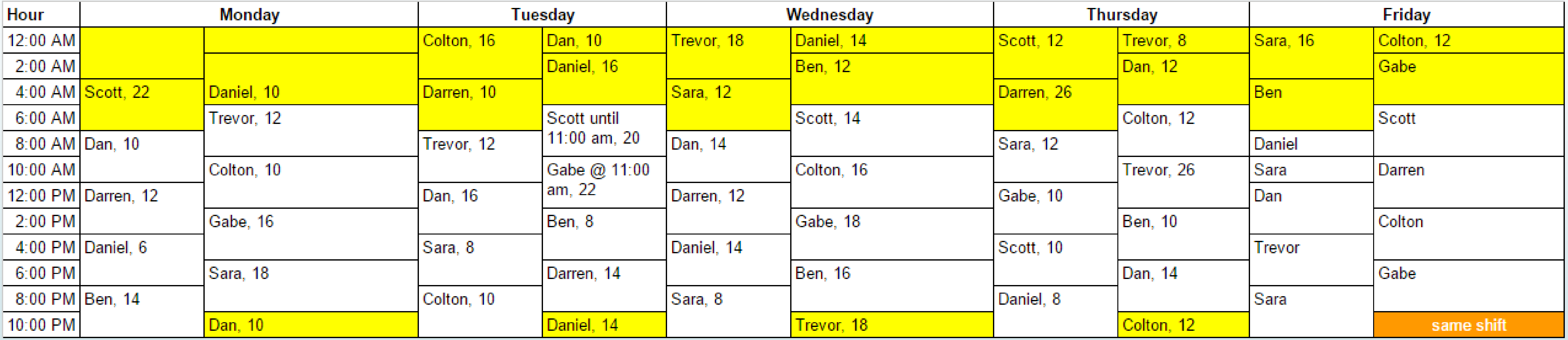
Stand for Testing

- Will 3D print in ITLL using PLA material
- Contoured to fit NeoPod (with outer metal band)
- d on bottom for grip



7” Diameter

100 hour test schedule



Hour	Monday		Tuesday		Wednesday		Thursday		Friday	
12:00 AM			Colton, 16	Dan, 10	Trevor, 18	Daniel, 14	Scott, 12	Trevor, 8	Sara, 16	Colton, 12
2:00 AM				Daniel, 16		Ben, 12		Dan, 12		Gabe
4:00 AM	Scott, 22	Daniel, 10	Darren, 10		Sara, 12		Darren, 26		Ben	
6:00 AM		Trevor, 12		Scott until 11:00 am, 20		Scott, 14		Colton, 12		Scott
8:00 AM	Dan, 10		Trevor, 12		Dan, 14		Sara, 12		Daniel	
10:00 AM		Colton, 10		Gabe @ 11:00 am, 22		Colton, 16		Trevor, 26	Sara	Darren
12:00 PM	Darren, 12		Dan, 16		Darren, 12		Gabe, 10		Dan	
2:00 PM		Gabe, 16		Ben, 8		Gabe, 18		Ben, 10		Colton
4:00 PM	Daniel, 6		Sara, 8		Daniel, 14		Scott, 10		Trevor	
6:00 PM		Sara, 18		Darren, 14		Ben, 16		Dan, 14		Gabe
8:00 PM	Ben, 14		Colton, 10		Sara, 8		Daniel, 8		Sara	
10:00 PM		Dan, 10		Daniel, 14		Trevor, 18		Colton, 12		same shift

Flat-Sat Without Batteries

Objective: **Fully Integrate Payload-Avionics-Communications**

Test: **Flat-Sat without Batteries Test → March 7th, 2016**

Duration: **3 Hour Test** (Includes one full two hour data collection)

Location: **Trudy's Lab**

Data Needed	Resolution Needed	Sampling Rate
Temperature	2 degrees Celsius	Once every 15 minutes
RSSI (Comm)	1 dB	6.5 Hz
PER (Comm)	1 packet	Every packet

Equipment	Resolution	Procurement
11 K-Type Thermocouples	1.1 degrees Celsius	Trudy's Lab
N19213 DAQ	0.02 degrees Celsius	Trudy's Lab
Laptop w/ Smart RF	0.1 dB	Installed
TENMA EX354 Power Supply	0-34 V, 0-4 Amp	Trudy's Lab

- Demonstrates **Successful Payload-Avionics-Communications Integration**
- Demonstrate that system can **successfully transmit a full two hours of data collection in under 8 minutes**

Achieves **System Level 2 Success**

Flat-Sat With Batteries

Objective: **Integrate Independent Power System**

Test: **Flat-Sat with Batteries Test → March 14th, 2016**

Duration: **6 Hour Test** (Includes three full two hour data collections)

Location: **Trudy's Lab**

Data Needed	Resolution Needed	Sampling Rate
Temperature	2 degrees Celsius	Once every 15 minutes
Voltage	0.01 V	Once every 15 minutes
PER (Comm)	1 packet	Every packet

Equipment	Resolution	Procurement
Laptop w/ Smart RF	0.1 dB	Installed
FLUKE 287 True RMS Multimeter	.001 Volts	Trudy
K-type thermal couples (x11)	1.1 deg C	Trudy's Lab
NI9213 DAQ	.02 deg C	ITLL

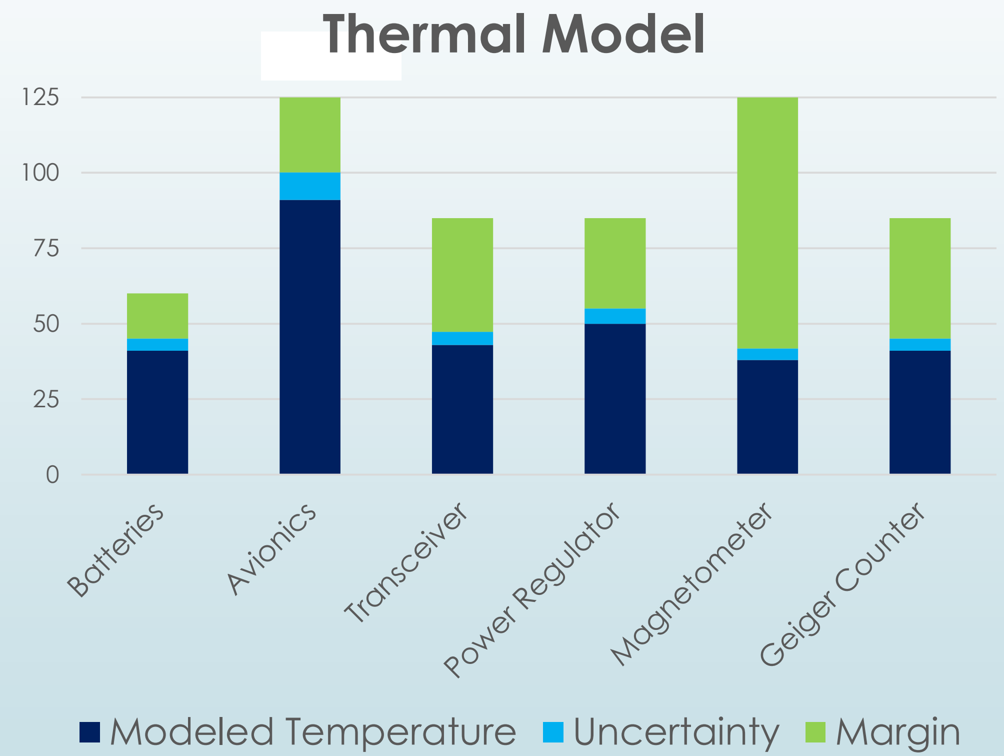
- **Successfully integrate independent power system**
- **Reduce risk and increase confidence of power system before final test**
- **Further validate battery characterization model**

Achieves **System Level 3 Success**

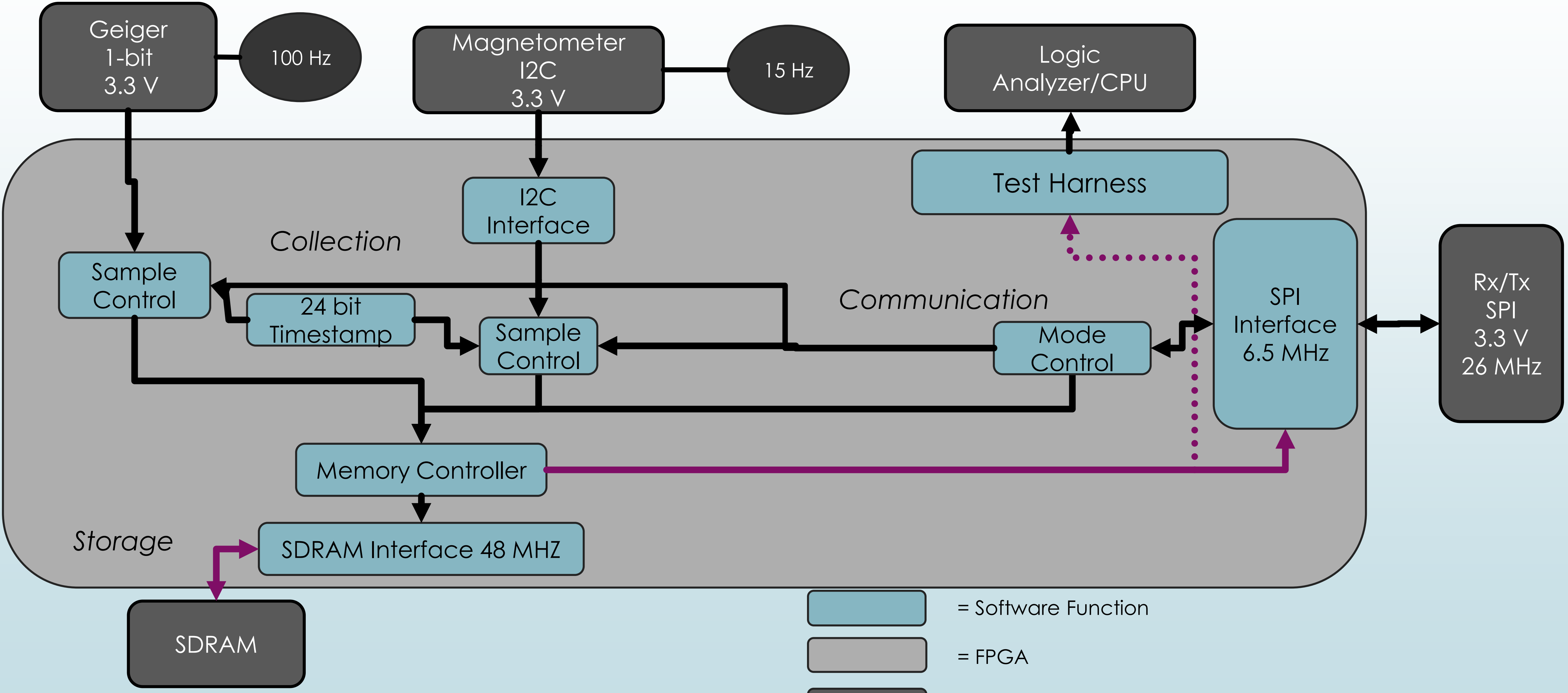
Thermal Model Validation

Data Needed*	Resolution Needed	Sampling Rate
Temperature	2 °C	Once every 15 minutes
Time	1 minute	

Equipment*	Resolution	Procurement
(10) K-type Thermocouples	1.1 °C	Trudy's Lab
NI9213 DAQ	0.02 °C	ITLL
Full NeoPod Assembly	-	-



CPE-1: Avionics Software



Geiger
1-bit
3.3 V

100 Hz

Magnetometer
I2C
3.3 V

15 Hz

Logic
Analyzer/CPU

Test Harness

I2C
Interface

Collection

Sample
Control

24 bit
Timestamp

Sample
Control

Communication

Mode
Control

SPI
Interface
6.5 MHz

Rx/Tx
SPI
3.3 V
26 MHz

Memory Controller

Storage

SDRAM Interface 48 MHZ

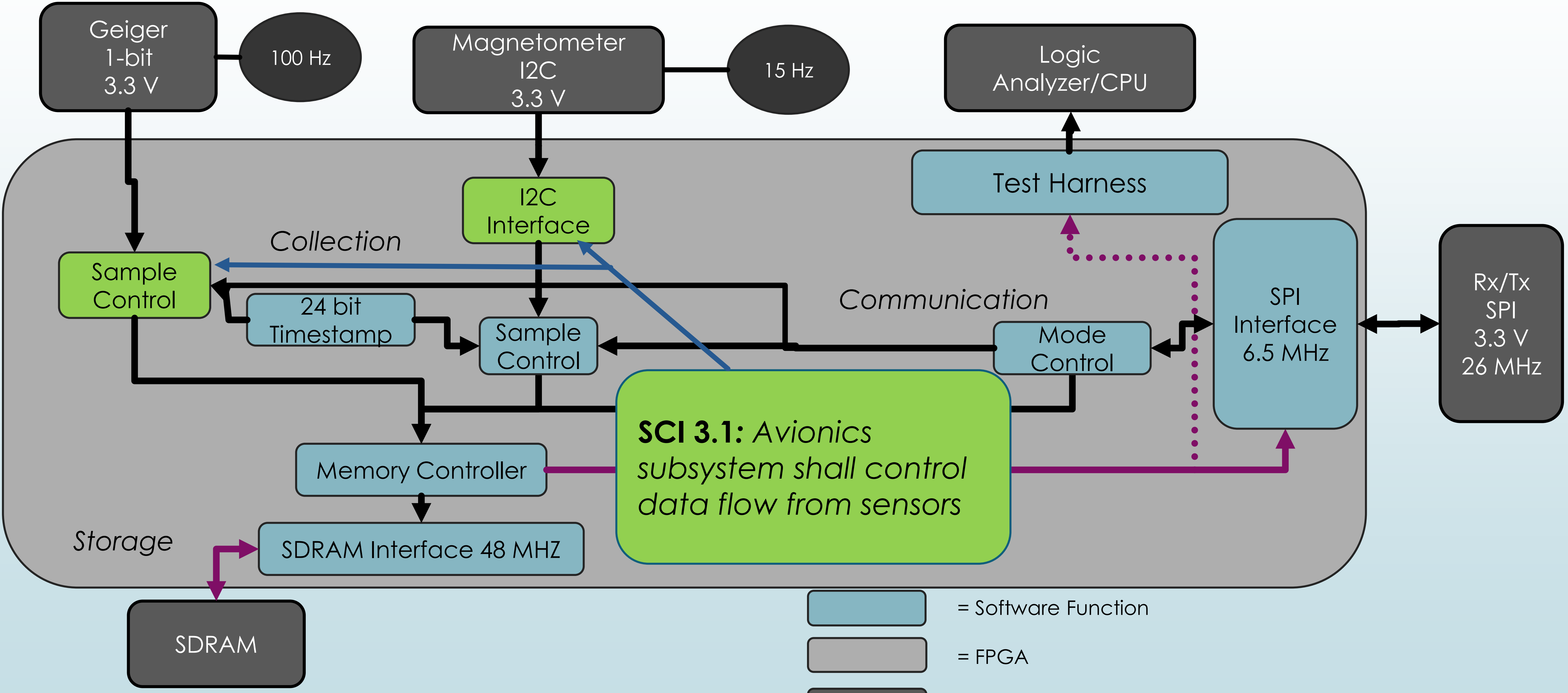
SDRAM

▨ = Software Function

▨ = FPGA

■ = External Hardware

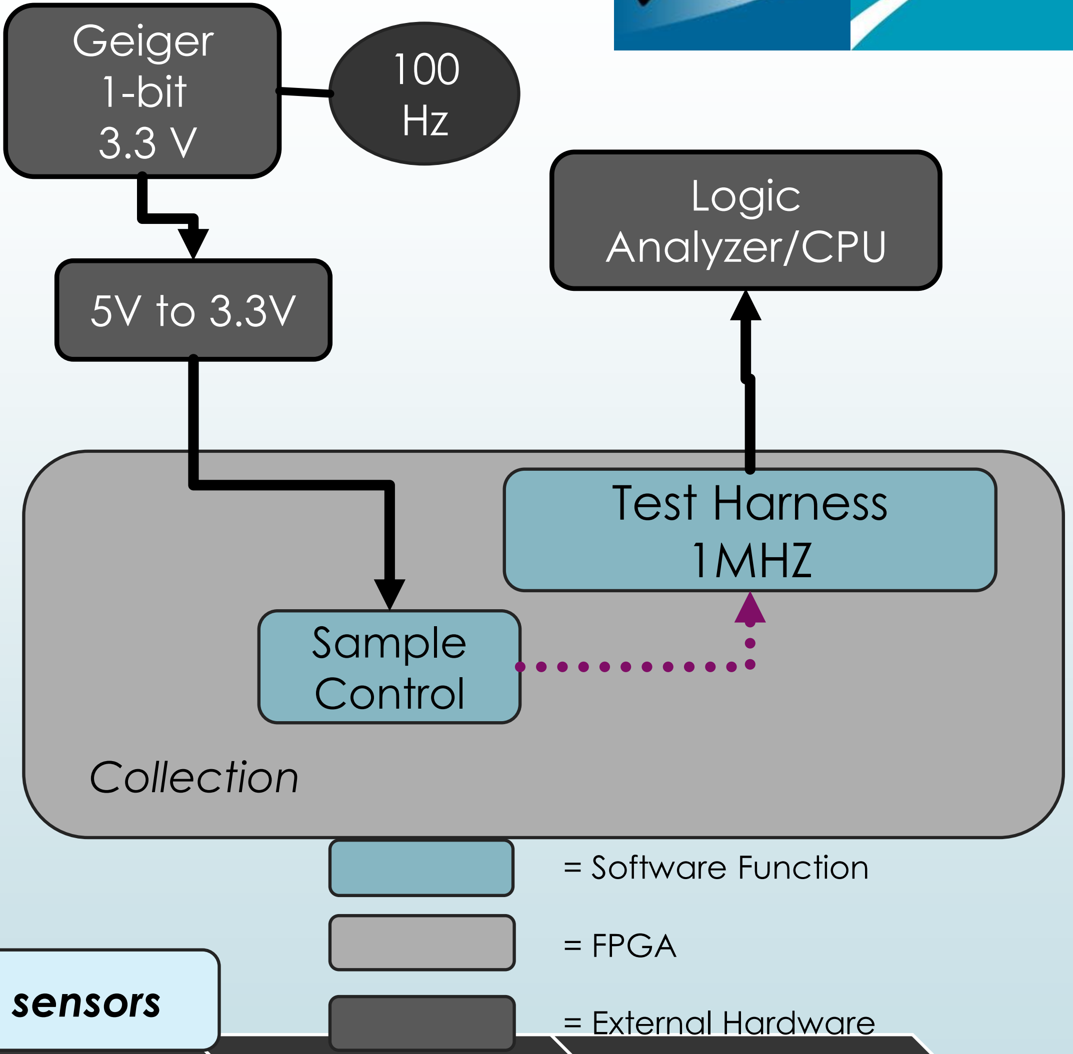
CPE-1: Avionics Software



SCI 3.1: *Avionics subsystem shall control data flow from sensors*

🟦	= Software Function
⬜	= FPGA
⬛	= External Hardware

Payload → Avionics Test



- Geiger Counter Output Voltage
  - Verify 3.3V logic output from voltage divider
- Output Data
  - ID Byte: ASCII ‘G’
  - 1st Timestamp: 599 or 59.9 sec
  - Data: Output counts match manual counts
  - Output Frequency: 60 seconds
- Protocols
  - ESD Safety Procedures

Relates to: ***SCI 3.1: Avionics subsystem shall control data flow from sensors***

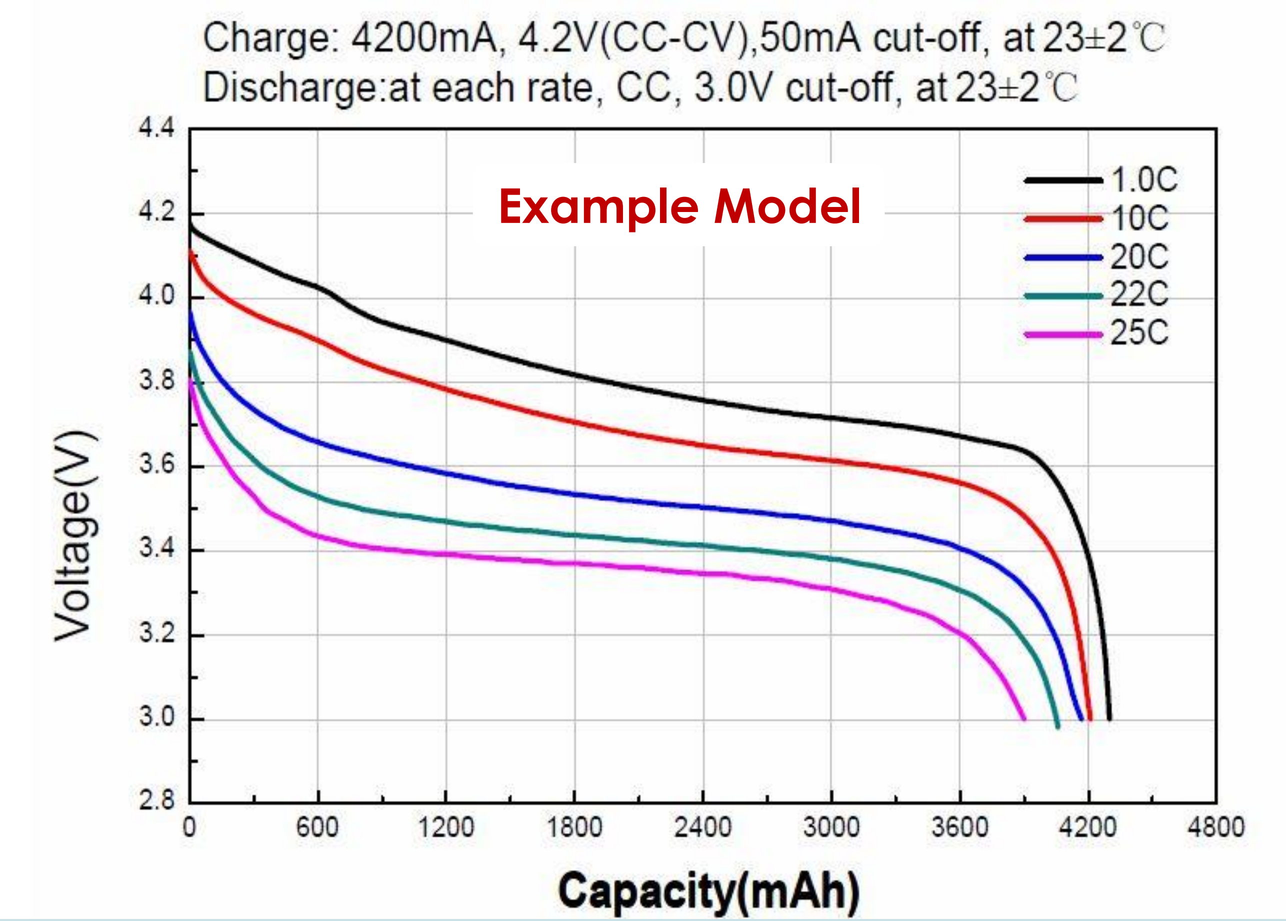
Payload → Avionics Test Results

- Voltage Divider Output: **Success**
  - **3.2V Maximum, 3.0V Leveloff**
- FPGA Output on Logic Analyzer: **Success**
  - **ID Byte:** ASCII ‘G’
  - **1st Timestamp:** 599
  - **Manual Geiger Counts:** 19
  - **FPGA Geiger Counts:** 20

Satisfied: SCI 3.1: *Avionics subsystem shall control data flow from sensors*

Battery Discharge

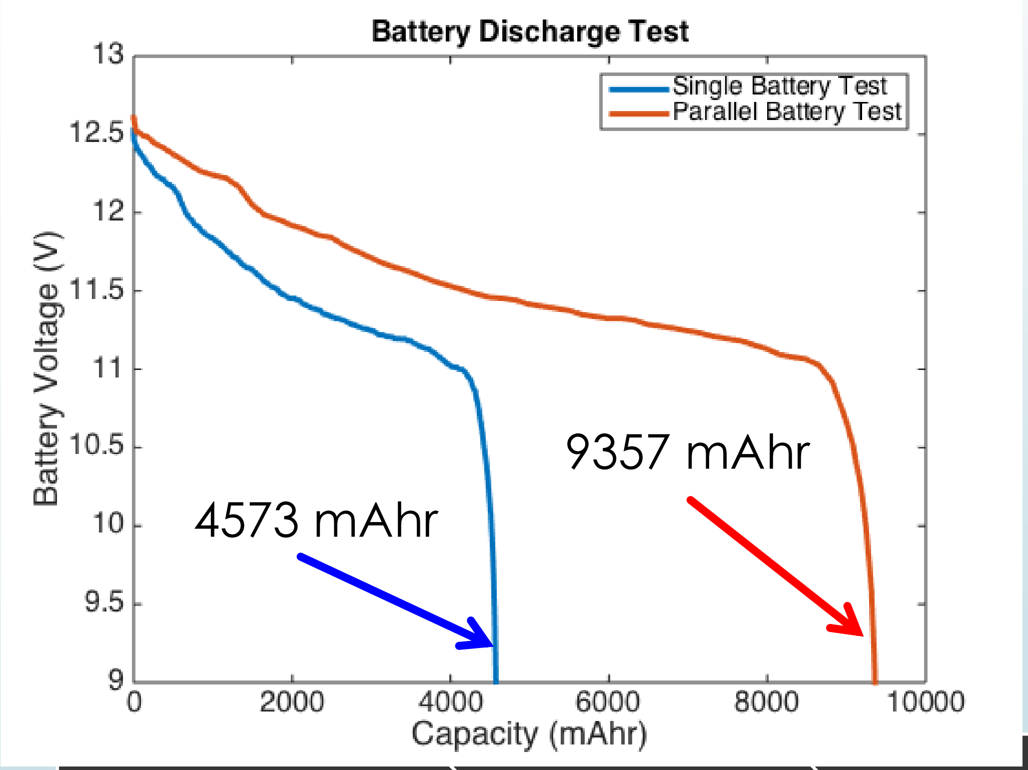
- First model from research gave expected shape of curve
- One battery was discharged from 12.4 V to 9 V to characterize the discharge curve
- Two batteries were discharged in parallel to determine the effect of using multiple batteries

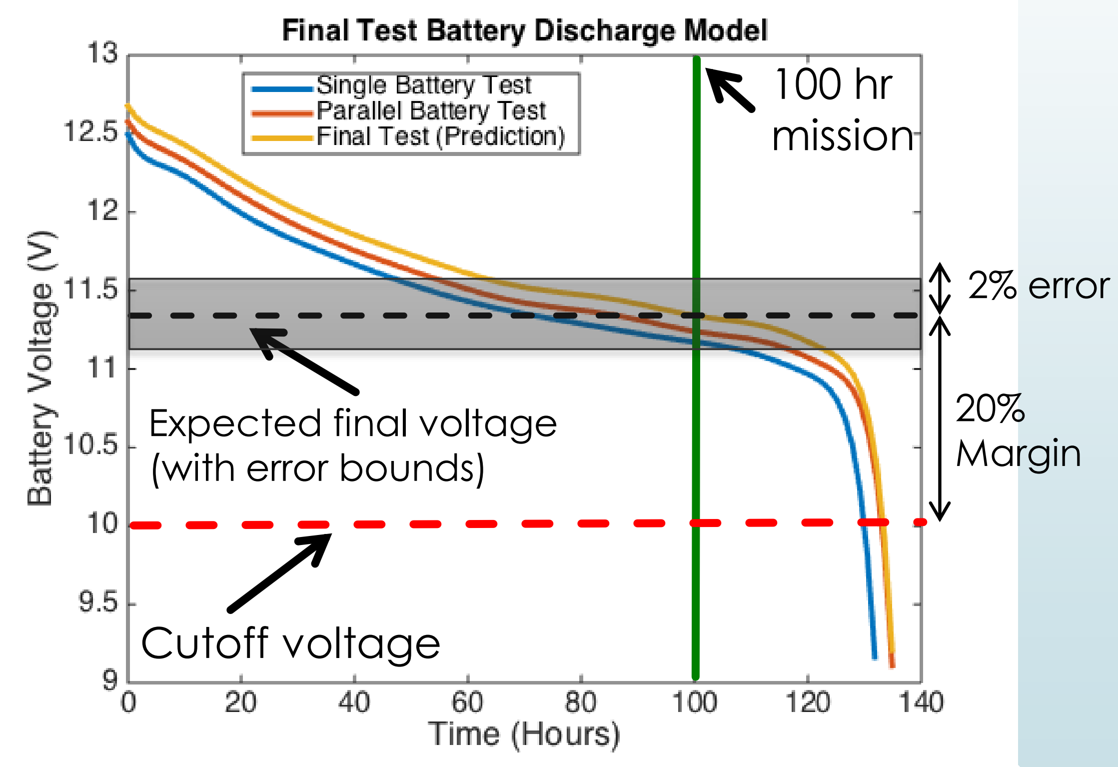


Battery Discharge Test: Results

- The capacity of two batteries is approximately twice that of a single battery and the shapes are similar

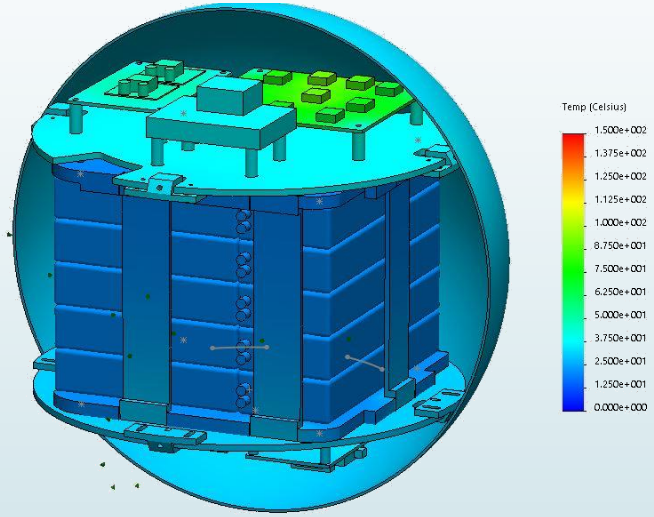
- Both tests were scaled to create a model for 15 batteries
- Expected final voltage of 11.3 V (20% margin)
- Possible error from avionics power budget → 2% = 0.226 V
- Possible min of 11.1 V, max of 11.6 V





Final Integrated System Test Plan

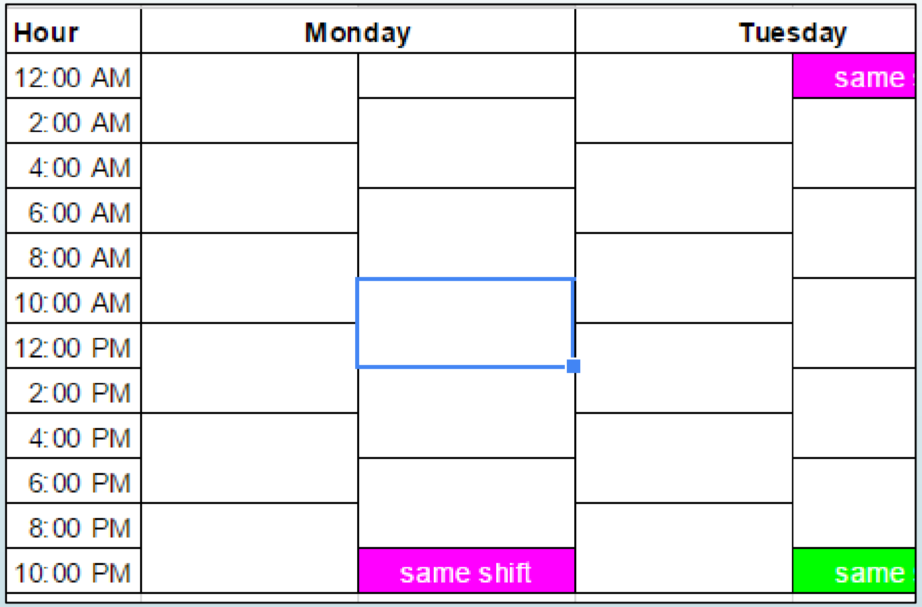
- **Description:** A 100 hour test with all subsystems fully integrated into a closed sphere.
- **Scheduled Test Dates:** April 1-5, 2016
- **Objectives:**
  1. **Validate all requirements and levels of success (Level 4)**
  2. **Validate full thermal model**
  3. **Full (100 hour) validation of power model**
  4. Redundant validation of RF link model



Full System Test Details / Logistics

- **Location:** Trudy's Lab
- **Measurements Needed:**
  - Component Temperatures
    1. K type thermal couples (1.1 degree C)
    2. NI9213 DAQ (16 channels) from ITLL
  - Battery Voltages
    1. FLUKE 287 True RMS Multimeter (0.001 V resolution)
- **Safety Precautions:**
  - ESD Safe Procedure Document
  - Cutoff Values set for monitored Temperatures and Voltages
  - 2 Team Members watching at all times in alternating 2 hour shifts

Proposed Observation Schedule:

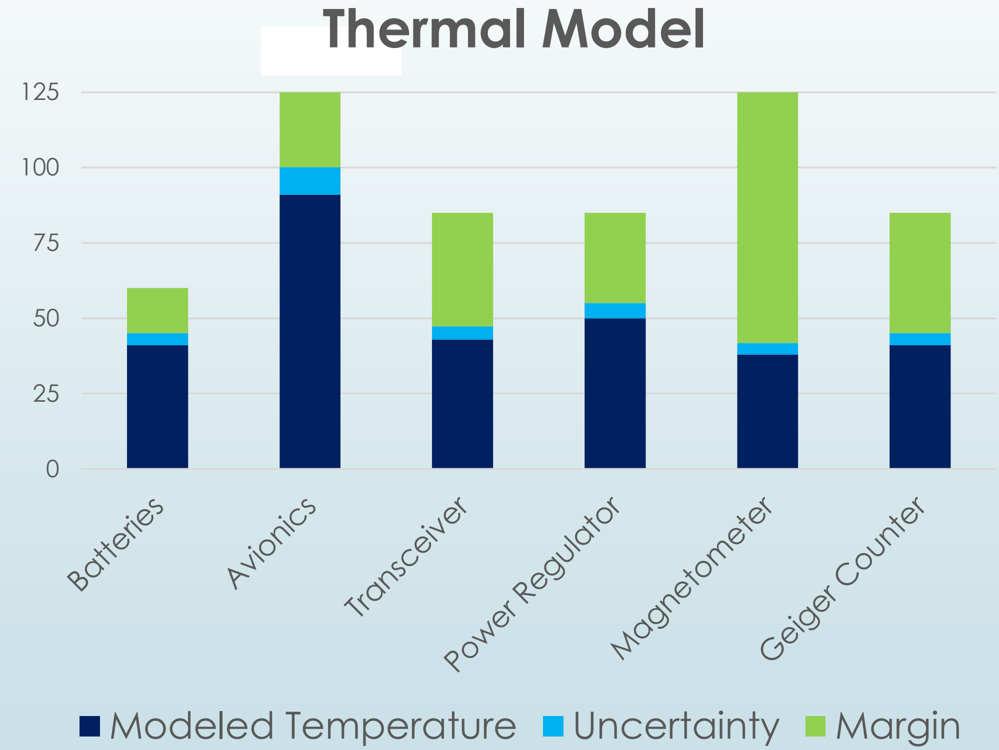


Hour	Monday		Tuesday	
12:00 AM				same
2:00 AM				
4:00 AM				
6:00 AM				
8:00 AM				
10:00 AM				
12:00 PM				
2:00 PM				
4:00 PM				
6:00 PM				
8:00 PM				
10:00 PM		same shift		same

Thermal Model Validation

Data Needed*	Resolution Needed	Sampling Rate
Temperature	2 °C	Once every 15 minutes
Time	1 minute	

Equipment*	Resolution	Procurement
(10) K-type Thermocouples	1.1 °C	Trudy’s Lab
NI9213 DAQ	0.02 °C	ITLL
Full NeoPod Assembly	-	-



Flat-Sat With Batteries Test Plan

- **Description:** A six hour test that simulates three full two hour data collection periods
- **Scheduled Test Dates:** March 14th, 2016
- **Objectives:**
  1. Successfully integrate independent power system
  2. Reduce risk and increase confidence of power system before final test
  3. Further validate battery characterization model

Flat-Sat without Batteries Test Plan

- **Description:** A three hour test that shows functionality of data collection system and transmission. **Demonstrates successful full first pass.**
- **Scheduled Test Dates:** March 7th, 2016
- **Objectives:**
  1. **Successfully collect data from sensors**, use avionics system and **communications system to transmit back to ground station**
  2. Demonstrate that system can **successfully transmit a full two hours of data collection in under 8 minutes**

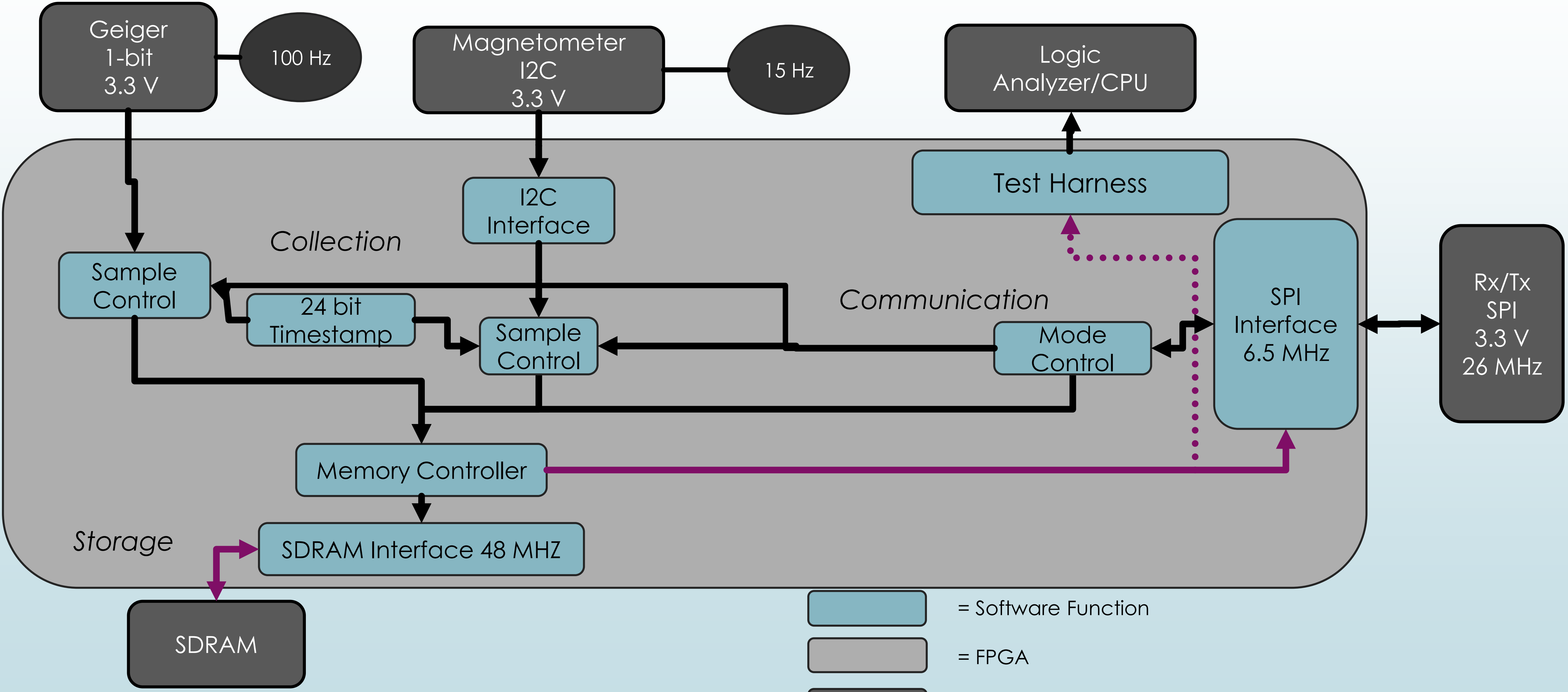
Avionics

Avionics Peripherals Tests

Test	Levels of Success	Requirements Validation	Models
Transceiver → Avionics	Ground Station L3 Avionics L2 – L4	COM 5	–
Magnetometer → Avionics	Payload L3	SCI 3.1	–
Geiger Counter → Avionics	Payload L3	SCI 3.1	–
Power → Avionics	Power L2	INT 5	Power Budget

COM 5: *NeoPod communications system shall communicate with avionics system*
SCI 3.1: *Avionics subsystem shall control data flow from sensors*
INT 5: *NeoPod shall have an independent power system*

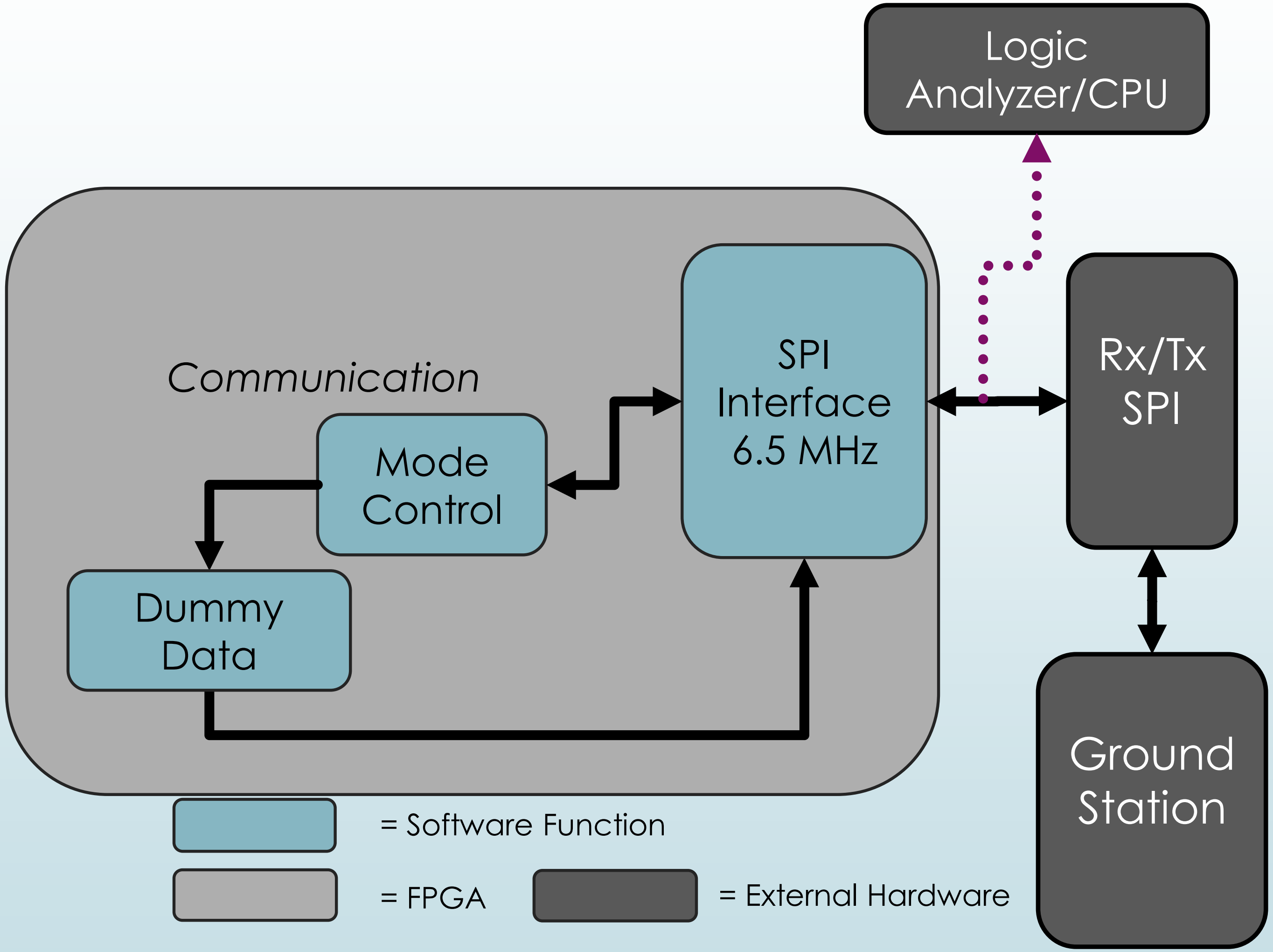
Avionics Software



🟦	= Software Function
⬜	= FPGA
⬛	= External Hardware

Transceiver → Avionics Test

- Boot Up Test
  - Verify initial register writes are correct
- Transmission Test
  - Send command from ground station, monitor data transmission
- Protocols
  - ESD Safety Procedures
  - 1.5m Transmit Distance
- **Date: 2/25/2016**

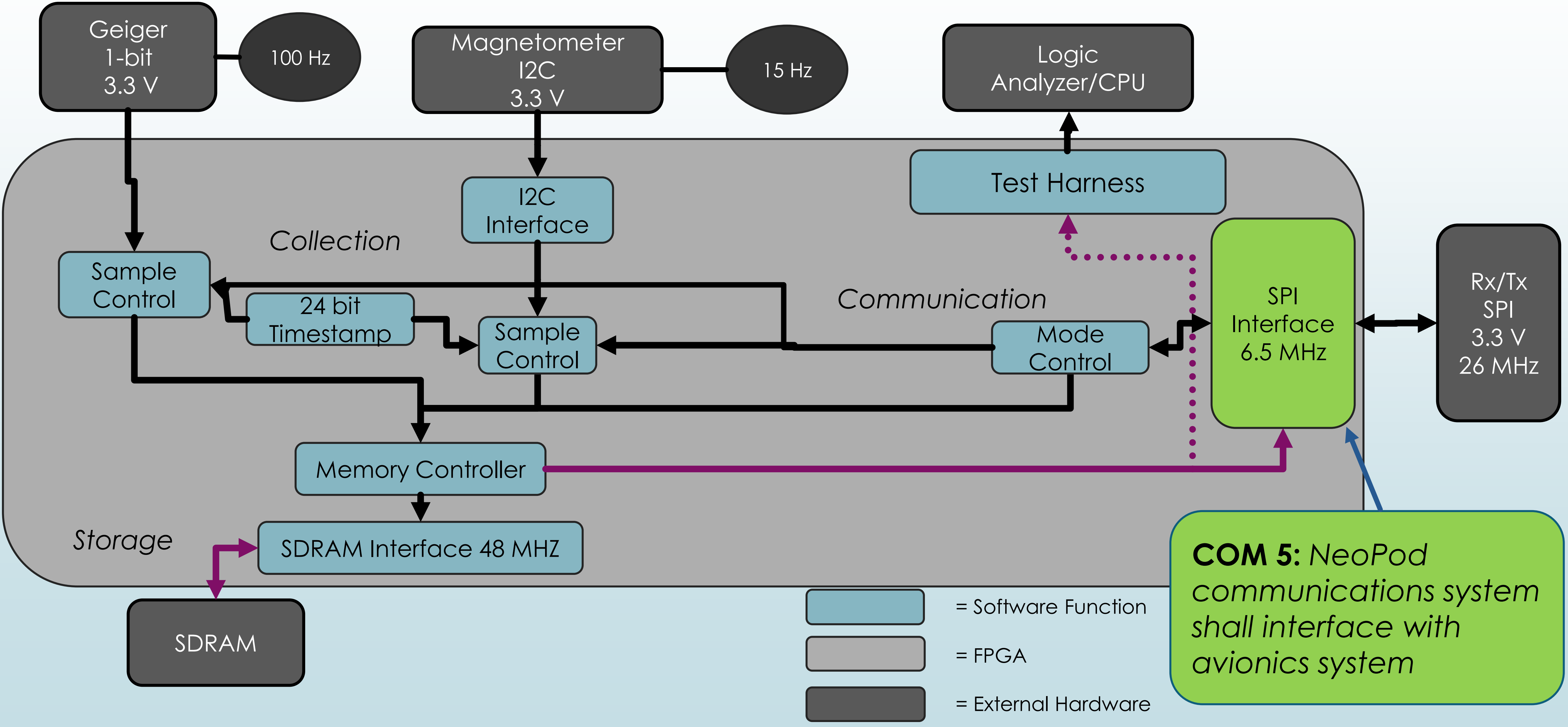


Transceiver → Avionics Test Results

- Boot Up Process:
  - Register Status

- Data Transmission:
  - Data Over Logic Analyzer
  - Data Received at Ground Station

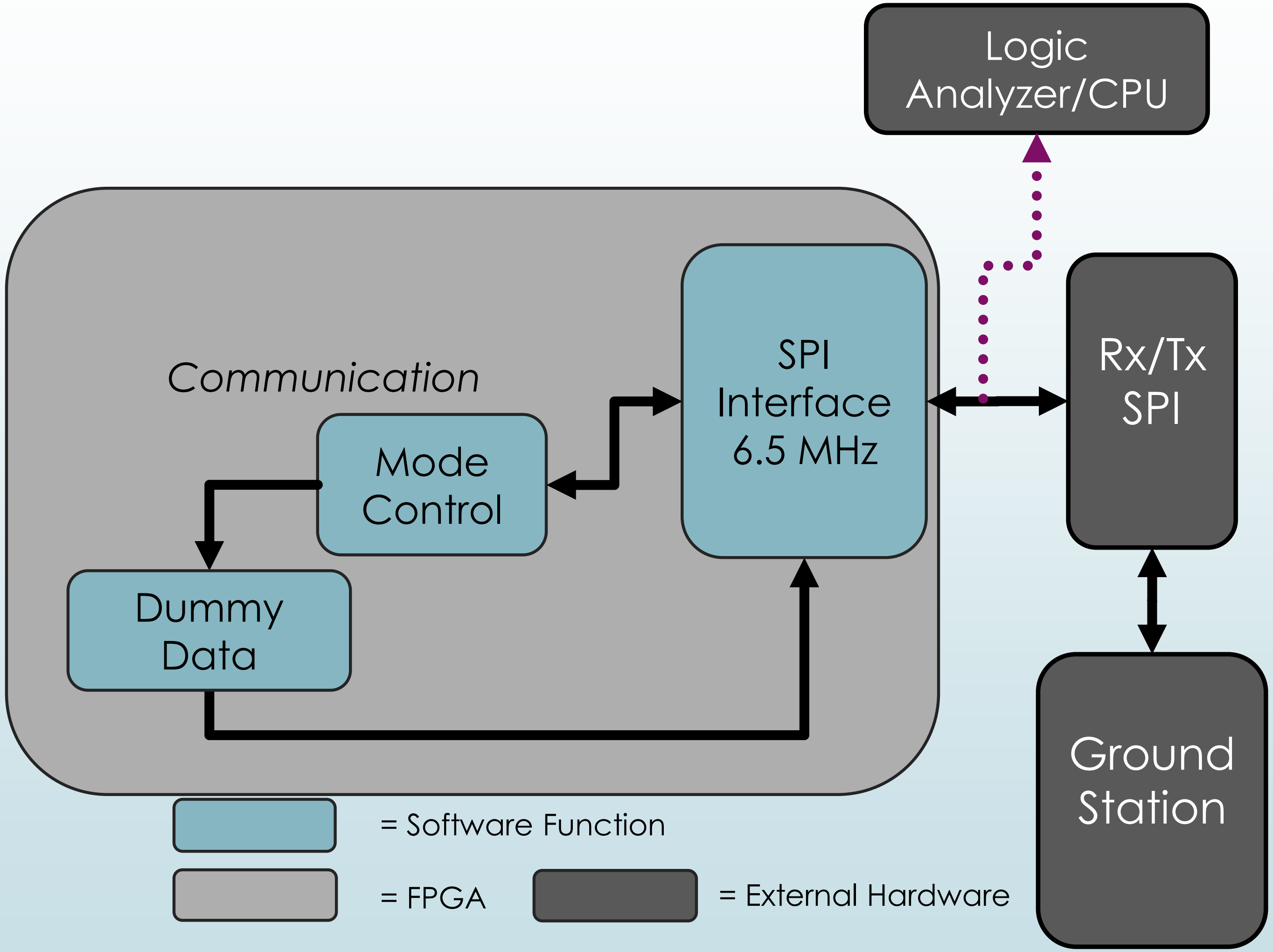
CPE-1: Avionics Software



COM 5: *NeoPod communications system shall interface with avionics system*

Transceiver → Avionics Test

- Boot Up Test
  - Verify initial register writes are correct
- Transmission Test
  - Send command from ground station, monitor data transmission
- Protocols
  - ESD Safety Procedures
  - 1.5m Transmit Distance
- **Date: 2/25/2016**



Transceiver → Avionics Test Results

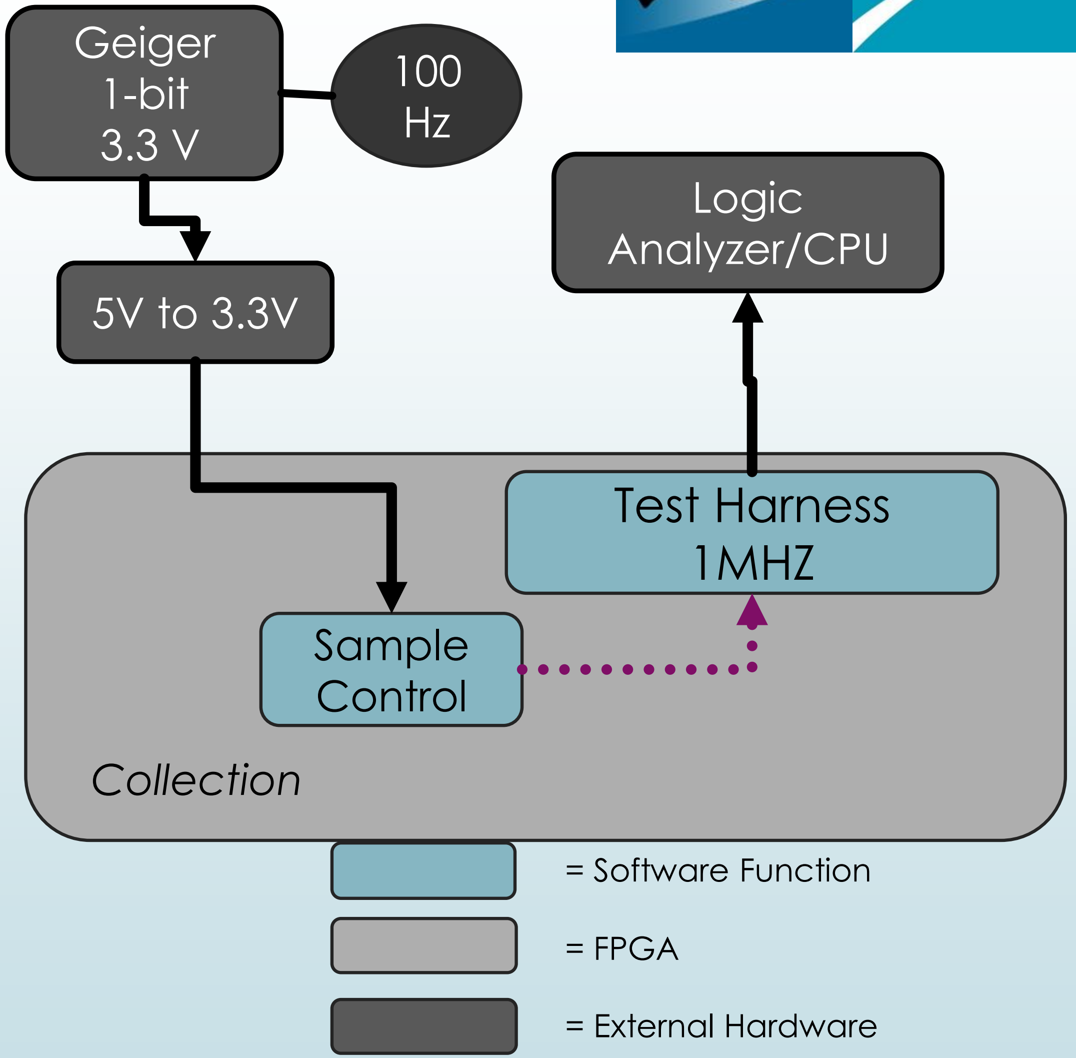
- Boot Up Process:
  - Register Status
- Data Transmission:
  - Data Over Logic Analyzer
  - Data Received at Ground Station

Satisfied:
COM 5: *NeoPod communications system shall interface with avionics system*

Payload → Avionics Test

- Geiger Counter Output Voltage
  - Verify 3.3V logic output from voltage divider
- Output Data
  - ID Byte: ASCII ‘G’
  - 1st Timestamp: 599 or 59.9 sec
  - Data: Output counts match manual counts
  - Output Frequency: 60 seconds
- Protocols
  - ESD Safety Procedures

- **Date: 2/24/2016**



Geiger 1-bit 3.3 V

100 Hz

5V to 3.3V

Logic Analyzer/CPU

Test Harness 1MHZ

Sample Control

Collection

▨ = Software Function

▨ = FPGA

▨ = External Hardware

Payload → Avionics Test Results

- Voltage Divider Output: **Success**
  - **3.2V Maximum, 3.0V Leveloff**
- FPGA Output on Logic Analyzer: **Success**
  - **ID Byte:** ASCII 'G'
  - **1st Timestamp:** 599
  - **Manual Geiger Counts:** 19
  - **FPGA Geiger Counts:** 20

Communications Backup

Communications Subsystem Tests: CPE 2

Test	Levels of Success	Functional Requirements	Models
Link Budget Validation	Ground Station L1 – L3 Comms L1 – L4	COM 1.1 – 1.2, COM 2.1 – 2.1, 2.4 COM 3.1	RF Link Model
Save 2 data sets from 1 stream	–	COM 4.2 – 4.3	–
Automated commanding test	Ground Station L4	COM 3.2	–

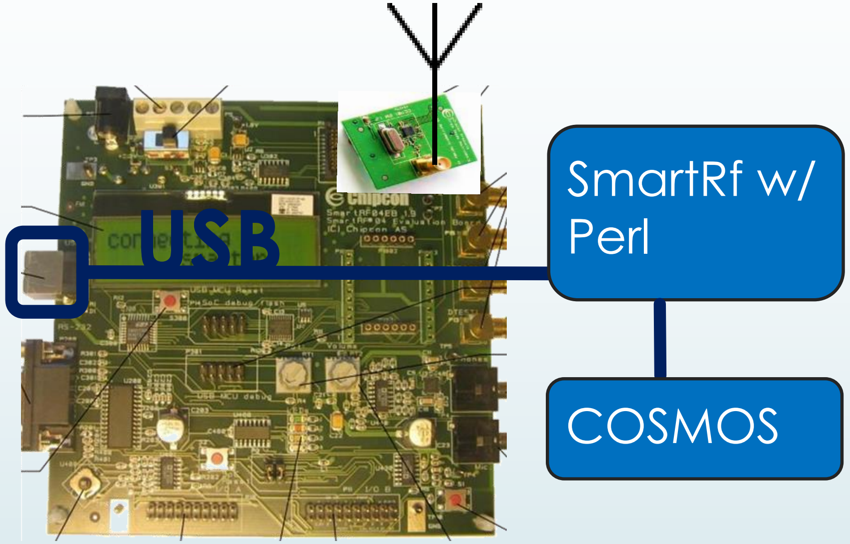
CPE-2
Test
Completed:
01/26/16

Ground Station Backup

- SmartRF V.7 controls ground Station
- Using SmartRF Perl scripting module to automate tests and send commands
- Set up TCP/IP connection to COSMOS to graph packet data *real time*.
- All integration tests have been 100% automated
- Ground Station discards and logs “bad” packets (too long or too short) in text file
- Real time display in command window of pass number and pass progress
- Can easily vary satellite pass length.
- Parses 50 byte packets at a time

Ground Station Software (COSMOS Integration)

- The only program capable of interfacing with the dev. Kit via USB is SmartRF (without re-writing driver software)
- A SmartRF friendly **Perl** script will automatically send commands as well as direct telemetry to **COSMOS** for parsing
- Data will be displayed **real-time** and commands will be sent **automatically**
- **Future Work:**
  - Mission-specific automation and parsing software development is **yet to be completed**



Ground Station

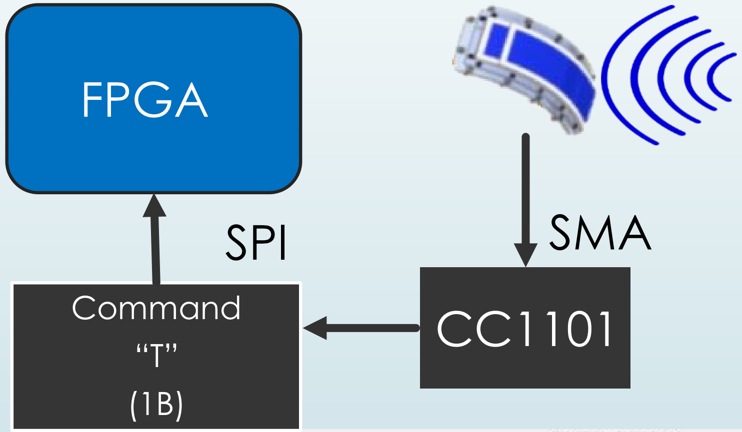
Expected Completion Date: 02/05/16

Communication Timeline

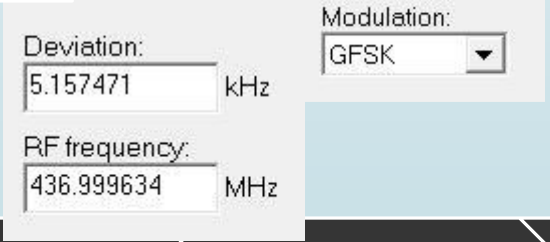
- 1. *Avionics* configure *transceiver* mode to RECEIVE .... **< 1 ms**
- 2. Wait for *ground station* to send TX command .... **120 min**
    - *Ground Station* sends TX command.
    - *Ground Station* transitions to receive mode.
- 3. *Avionics* process command, configure *transceiver* mode to TRANSMIT.......... **< 1 ms**
- 4. *Avionics* sends data to *transceiver*.. **8 min**
    - Simultaneous write/read. Max read/write time allowable: 833 µs
        - Read Time ~ 300 ns
        - Write Time ~ 200 ns
- 5. **Return** to step 1.

Comm: NeoPod Command Reception

Driver: COM 1.1: NeoPod shall use provided patch antennas from Ball Aerospace
COM 1.2: NeoPod shall use same modulation scheme as ground station
COM 1.3: NeoPod shall receive commands within 1 MHz of 437 MHz



“Begin Telemetry Transmission” Command		
Sync Word “SA” (2B)	Command “T” (1B)	CRC Checksum (2B)



Modulation: GFSK

Deviation: 5.157471 kHz

RF frequency: 436.999634 MHz

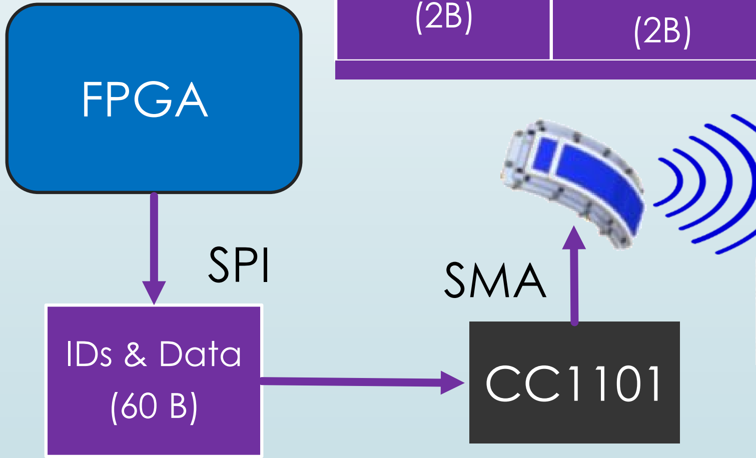
- FPGA will receive command and reconfigure CC1101 into transmit mode and begin transmitting data
- Data and configuration both done via SPI

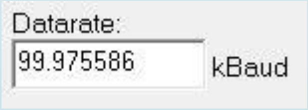
Comm: NeoPod Data Transmission

Driver: COM 2.1: NeoPod shall use provided patch antennas from Ball Aerospace
COM 2.3: NeoPod data transmission shall not exceed 128 kbps
COM 2.5: NeoPod shall packetize data with appropriate overhead for RF transmission

Outgoing Telemetry Packet

Preamble “10101010” (2B)	Sync Word “EL” (2B)	IDs & Sensor Data (60B)	CRC Checksum (2B)

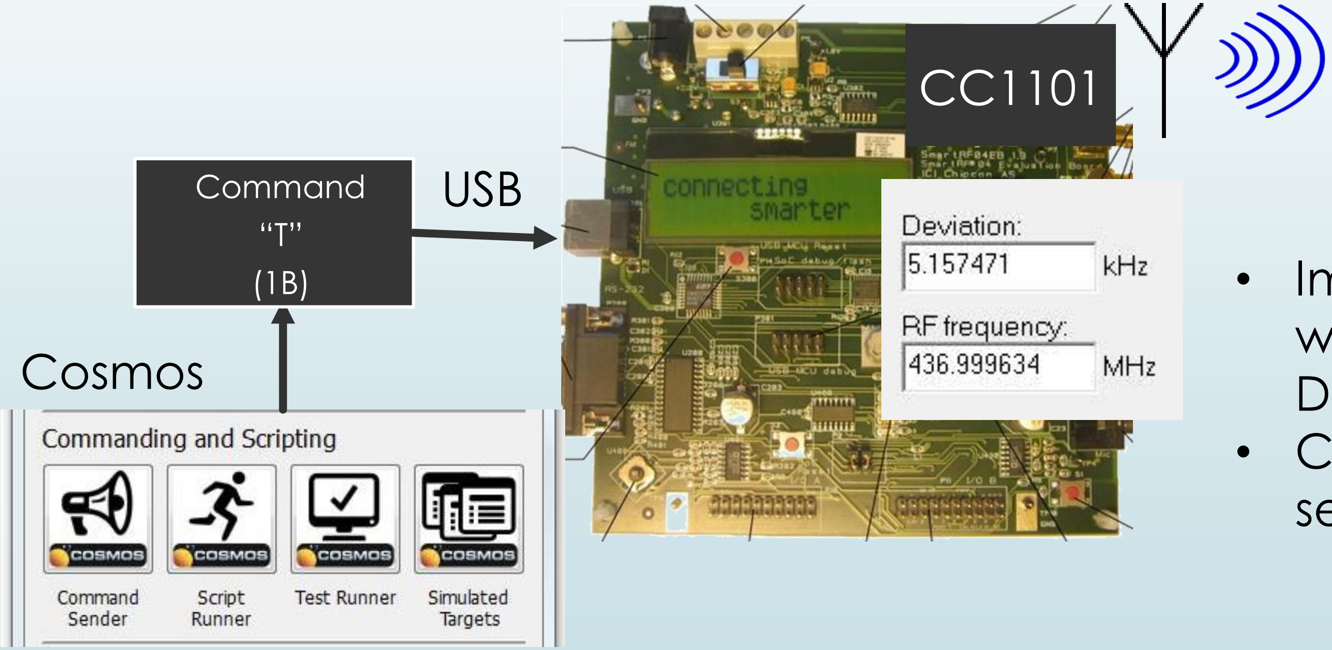



Datarate: 99.975586 kBaud

- SPI will be connected via PCB and ribbon cables
- CC1101 will packetize data and transmit at 437.5 MHz & +10 dBM
- CC1101 will be powered via on board power at 3.3 V & 30 mA
- Data rate programmable in steps of 0.2 kBaud

Comm: Ground Station Command Transmission

Driver: COM 3.1: Ground Station shall be compatible with 437 MHz frequency
COM 3.2: Ground Station shall send command every 120 minutes
COM 3.3: Ground Station shall packetize commands with appropriate overhead for RF transmission



Deviation: 5.157471 kHz

RF frequency: 436.999634 MHz

“Begin Telemetry Transmission” Command		
Sync Word “SA” (2B)	Command “T” (1B)	CRC Checksum (2B)

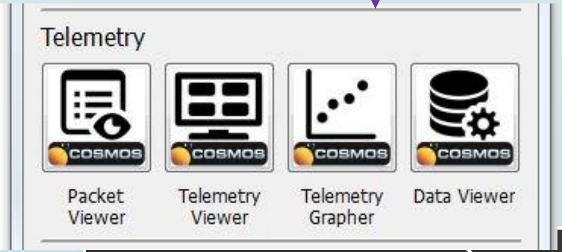
- Immediately after command CC1101 will be go into receive mode (Half Duplex)
- Commands will be automated and sent using Cosmos

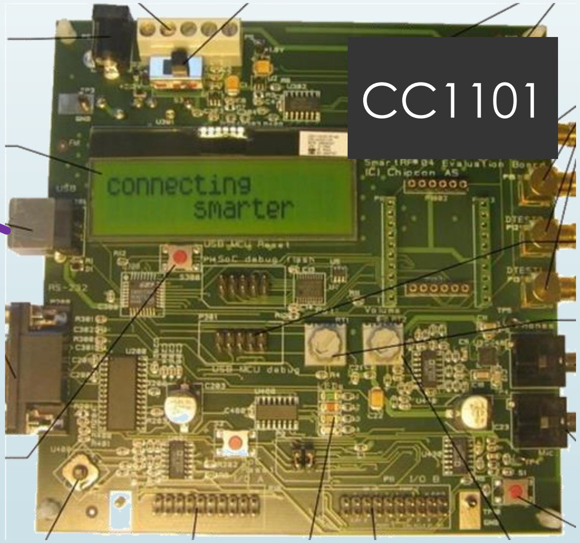
Comm: Ground Station shall receive data over RF

Driver: COM 4.1: Ground Station shall store received data from NeoPod
COM 4.2: Ground Station shall separate data into appropriate file location and format
COM 4.3: Ground Station shall display metrics on performance of communications system

IDs & Data
(60 B)

Cosmos



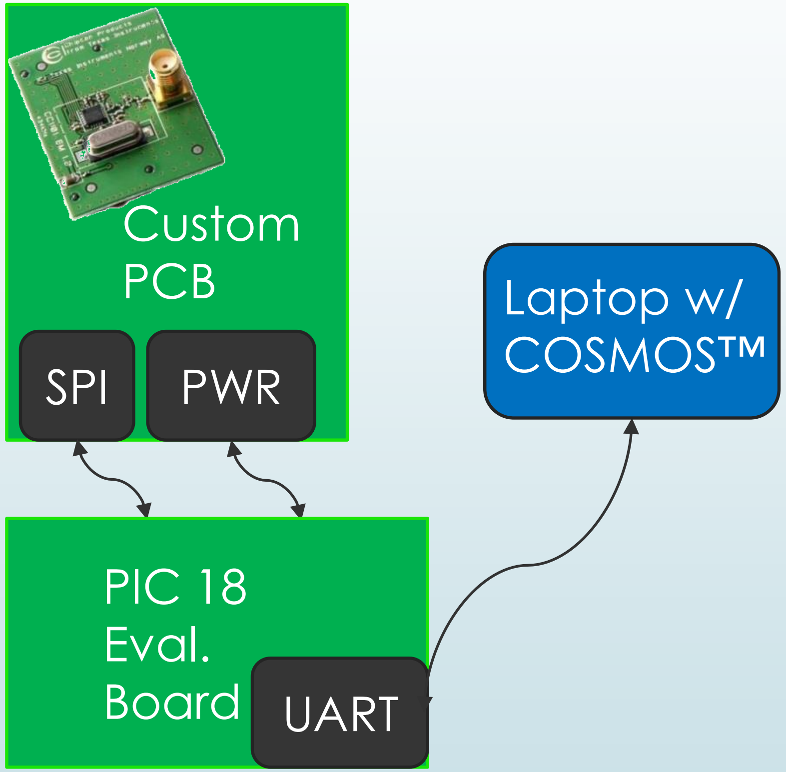


Incoming Telemetry			
Preamble "10101010" (16)	Sync Word "10101010" (32)	IDs & Data (60 B)	CRC Checksum (16)

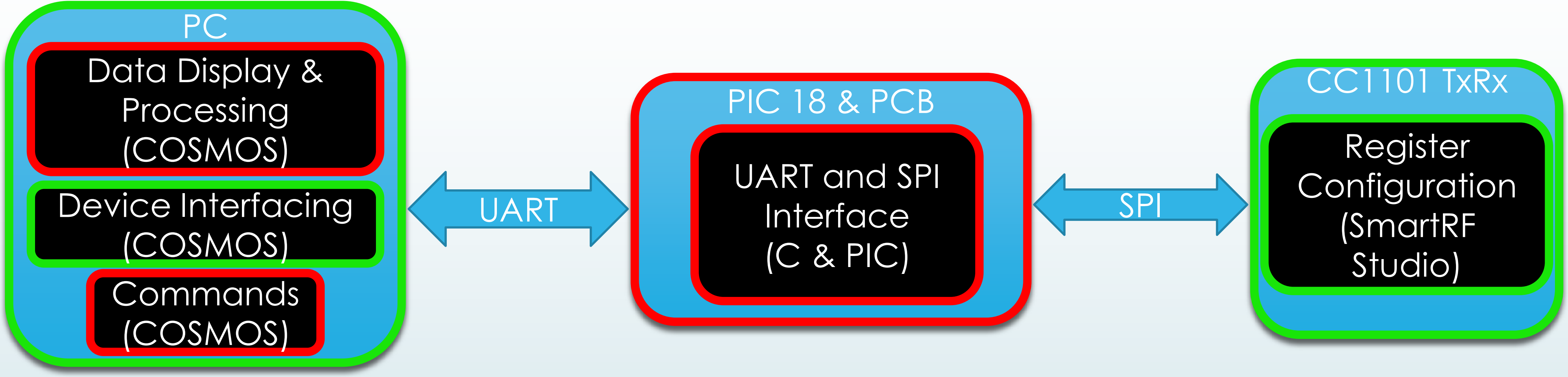
- CC1101 will de-packetize data
- Cosmos will identify separate data files using the 1 Byte ID attached to each data point
- Smart RF will be used to Debug CC1101 and display RSSI and LQI

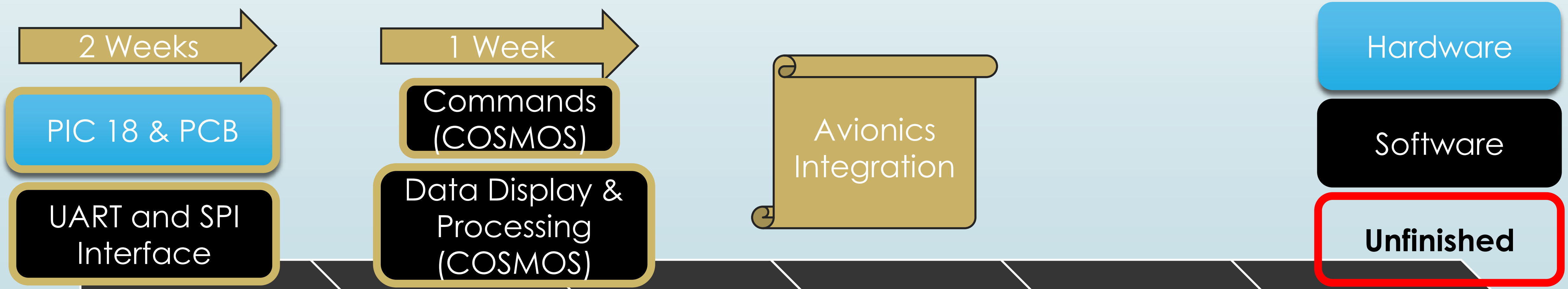
Alternative Ground Station

- Successfully mechanically mated with CC1101 Transceiver headers
- Continuity has been proved
- Standoffs and avionics/power headers still need to be added on
- Functionality will be tested by attaching PCB and CC1101 to PIC18 dev. Kit provided by CU for rent



Alternative Ground Station Development Plan





Power Backup Slides

Power Subsystem Tests

Test	Levels of Success	Functional Requirements	Models
Characterize discharge curve for single battery	–	–	Power Supply
Characterize discharge curve for two batteries in parallel	–	–	Power Supply
Test individual power board components	–	INT 5.2 – 5.3	–
Test power board with TENMA EX354T Power Supply	–	–	–
Test power board with single battery	–	–	–
Test power board with battery pack	–	–	–

Power Testing

- CPE-3: Power system designed to ensure that power is supplied to all components for a 100 hour mission timeline.

- Completed Tests:
    - Power board component functionality (LVC, Fuse, DC converter)
    - Power board functionality with lab station power supply
    - Battery discharge voltage
    - Power board functionality with battery power source

- Future Tests:
    - Power board integration with other subsystems
    - Final 100 hour full system test

Component Functionality Tests

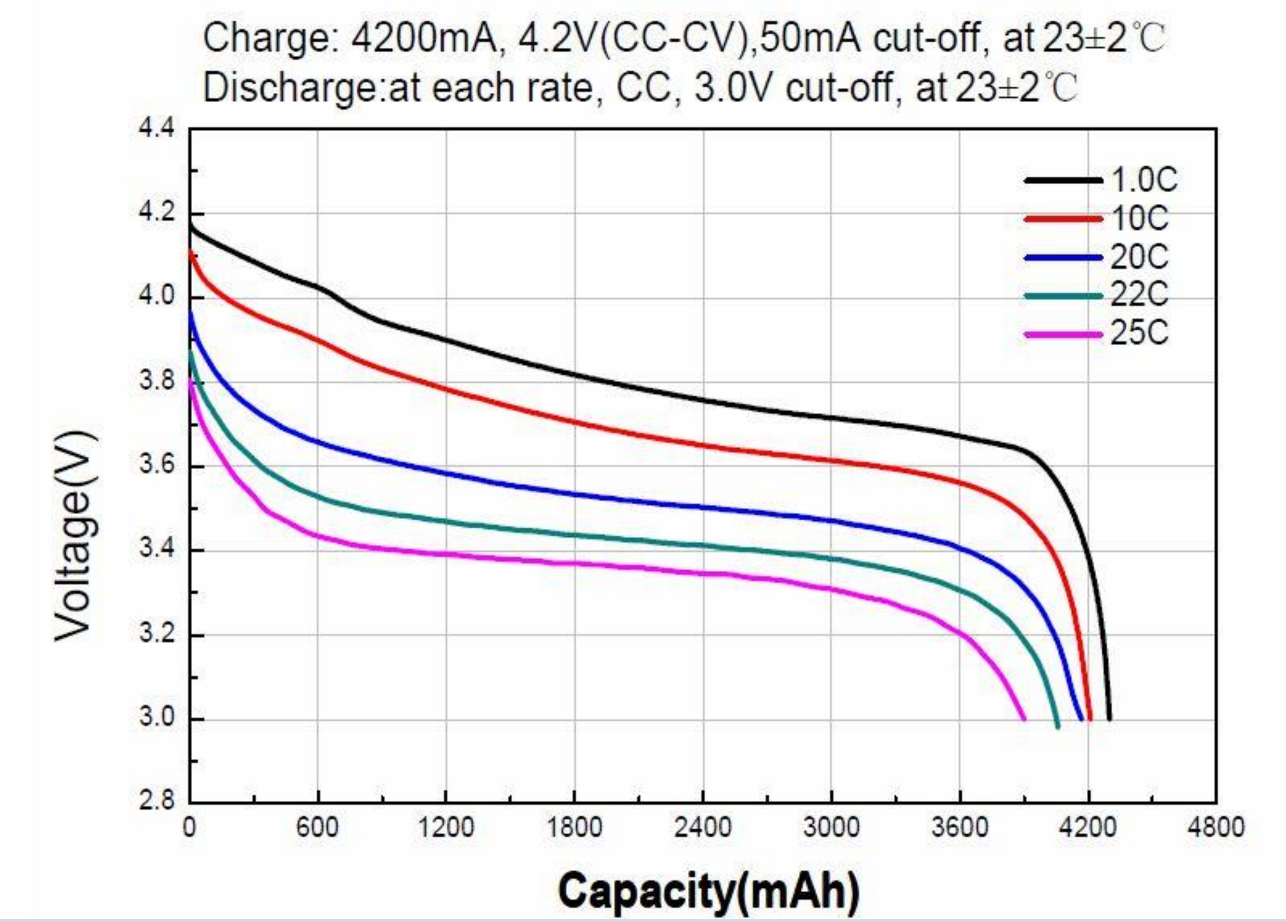
- Simple circuits designed to test each of the board components individually
- All components are operating within acceptable tolerances to meet requirements
  - LVC: Circuit broken at 10 V
  - Fuse: Circuit broken at 1.9 A
  - DC Converter: Output voltages of 5.04 V and 3.27 V (Req. 5±0.25 V and 3.3±0.3)
- Increased confidence that power board will be functional once assembled

Power Board Functionality

- Power board connected to lab station power supply
- Output voltages measured with a range of input voltages to simulate final test
  - Input: 13.13 V; Output: 5.03 V and 3.34 V
  - Input: 11.17 V; Output: 5.03 V and 3.34 V
  - Input: 9.05 V;   Output: 5.03 V and 3.34 V
    - (Req. 5±0.25 V and 3.3±0.3)
- Increased confidence in power board design

Battery Discharge

- First model from research gave expected shape of curve
- One battery was discharged from 12.4 V to 9 V to characterize the discharge curve
- Two batteries were discharged in parallel to determine the effect of using multiple batteries

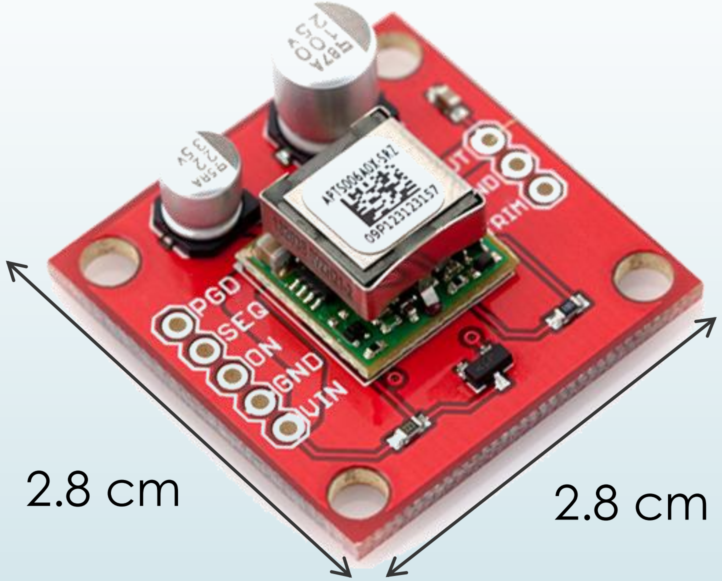


Power System Integration

- Full integration of all system components
- Battery pack connected to LVC
- LVC connected to power distribution board
- Output voltages measured using on average input voltage from battery
  - Input: 9.05 V; Output: 5.03 V and 3.34 V
    - (Req. 5±0.25 V and 3.3±0.3)

Voltage Supply Lines

- **We will use 2 SparkFun DC/DC Converter Breakouts**
- **Will step 11.1 V down to 5 V, then down to 3.3 V**
- **Switching regulators**
- **High efficiency (~95%)**
- **Maximum ±0.1V ripple voltage**

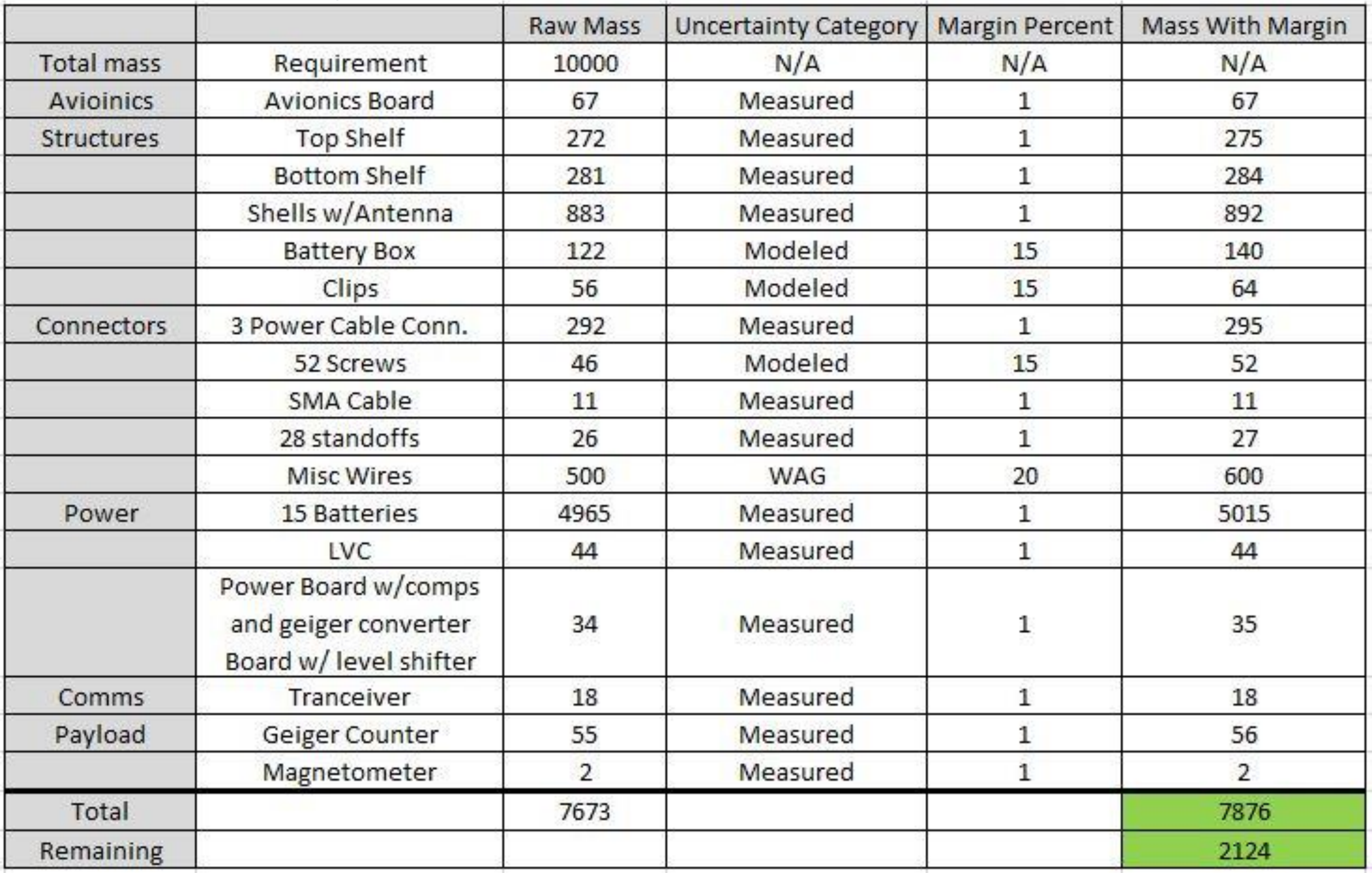


Battery Parallel Connectors (Hobbyking.com Website)

- XT-60 Parallel Connector
- Will cut off banana cable end and solder on female connector

Structure Backup

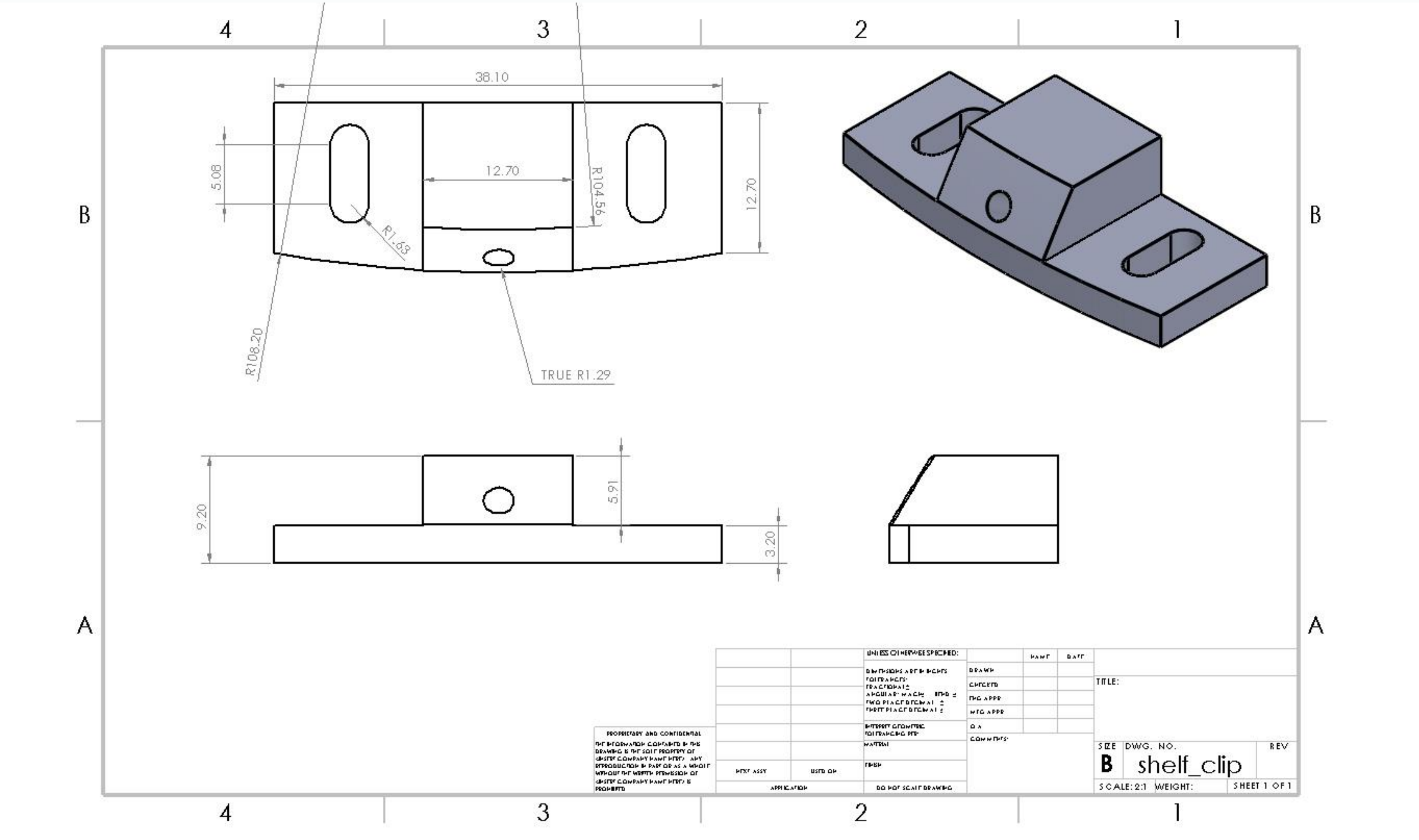
Updated Mass Budget



		Raw Mass	Uncertainty Category	Margin Percent	Mass With Margin
Total mass	Requirement	10000	N/A	N/A	N/A
Avioinics	Avionics Board	67	Measured	1	67
Structures	Top Shelf	272	Measured	1	275
	Bottom Shelf	281	Measured	1	284
	Shells w/Antenna	883	Measured	1	892
	Battery Box	122	Modeled	15	140
	Clips	56	Modeled	15	64
Connectors	3 Power Cable Conn.	292	Measured	1	295
	52 Screws	46	Modeled	15	52
	SMA Cable	11	Measured	1	11
	28 standoffs	26	Measured	1	27
	Misc Wires	500	WAG	20	600
Power	15 Batteries	4965	Measured	1	5015
	LVC	44	Measured	1	44
	Power Board w/comps and geiger converter Board w/ level shifter	34	Measured	1	35
Comms	Tranceiver	18	Measured	1	18
Payload	Geiger Counter	55	Measured	1	56
	Magnetometer	2	Measured	1	2
Total		7673			7876
Remaining					2124

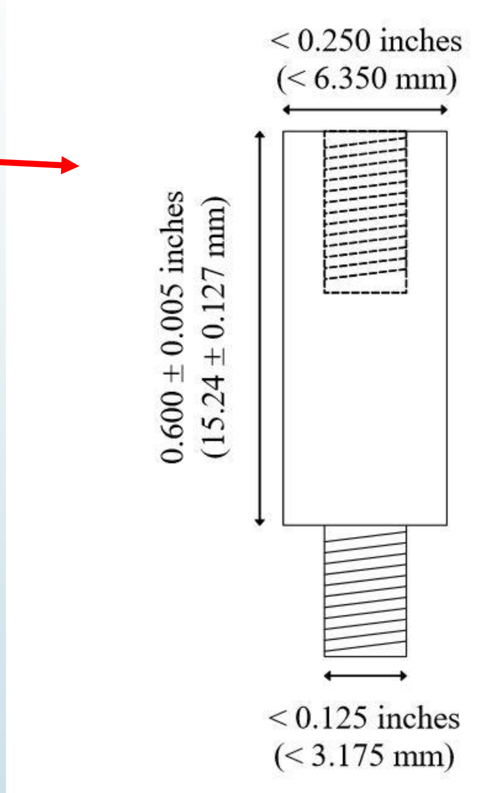
Meets mass requirement

Backup Clip Drawing (dimensions in mm)

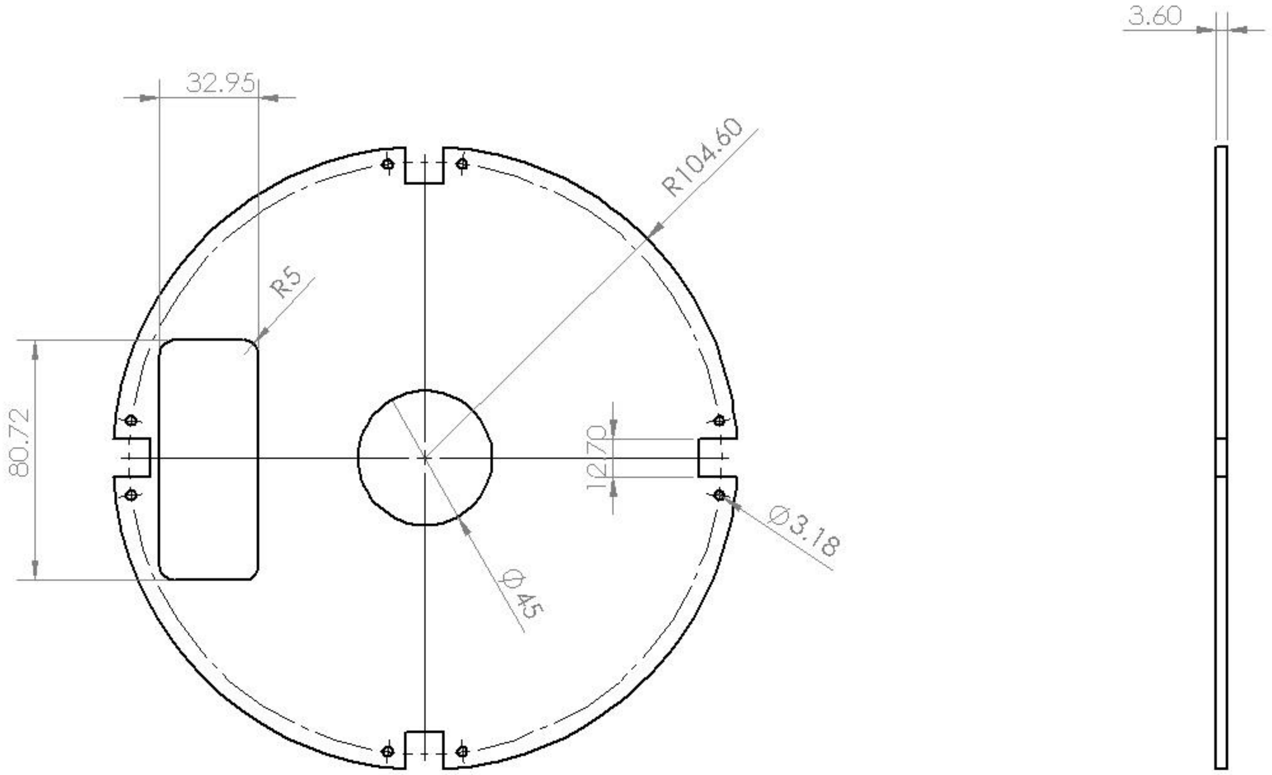


Standoffs and Battery Connectors

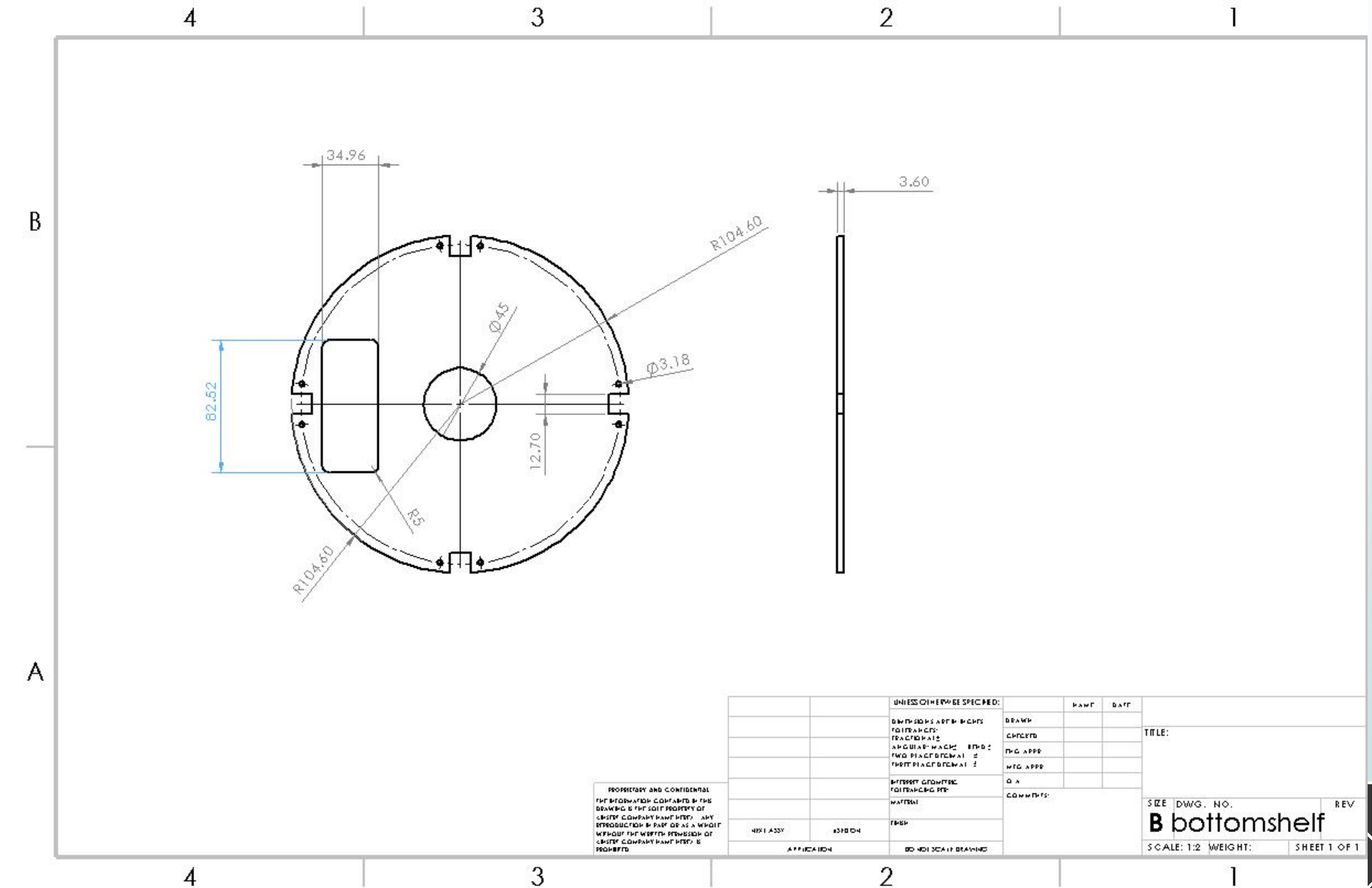
- Avionics/Power/Comms Board Standoff
- Sparkfun science instruments come with Standoffs



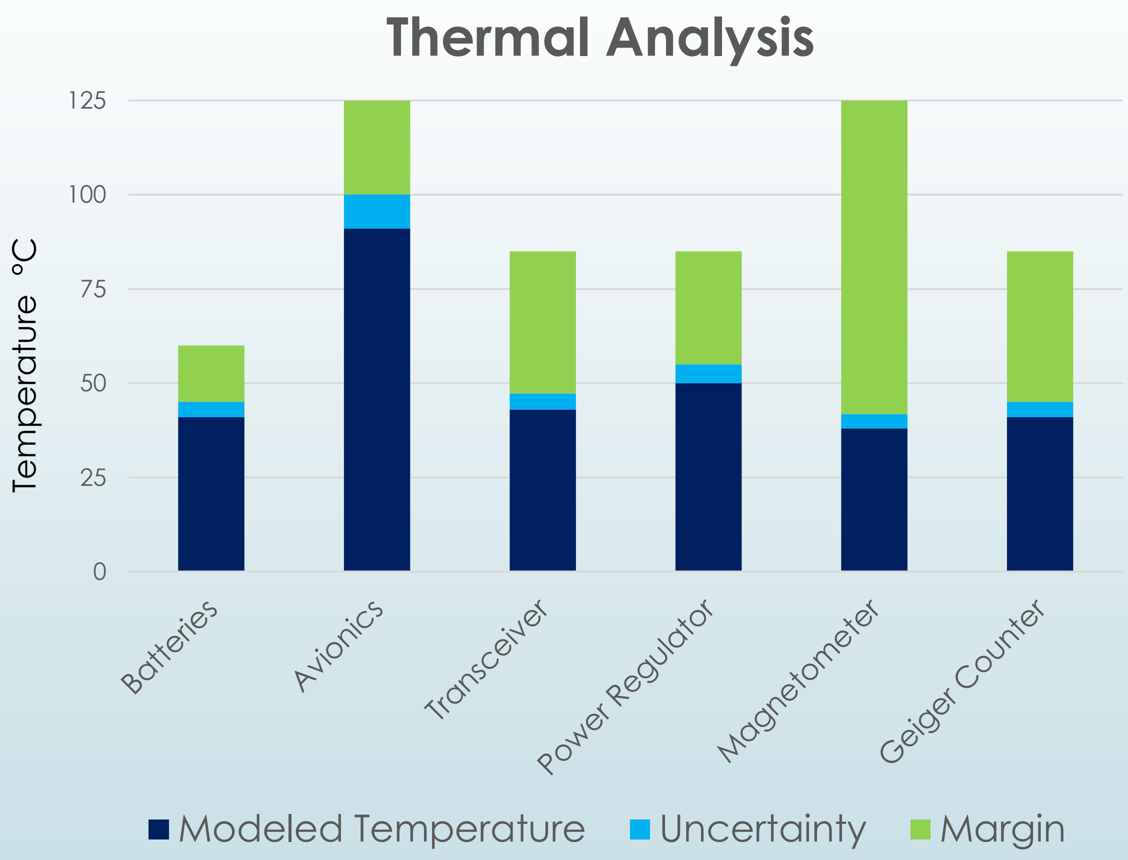
Top Shelf Drawing (dimensions in mm)

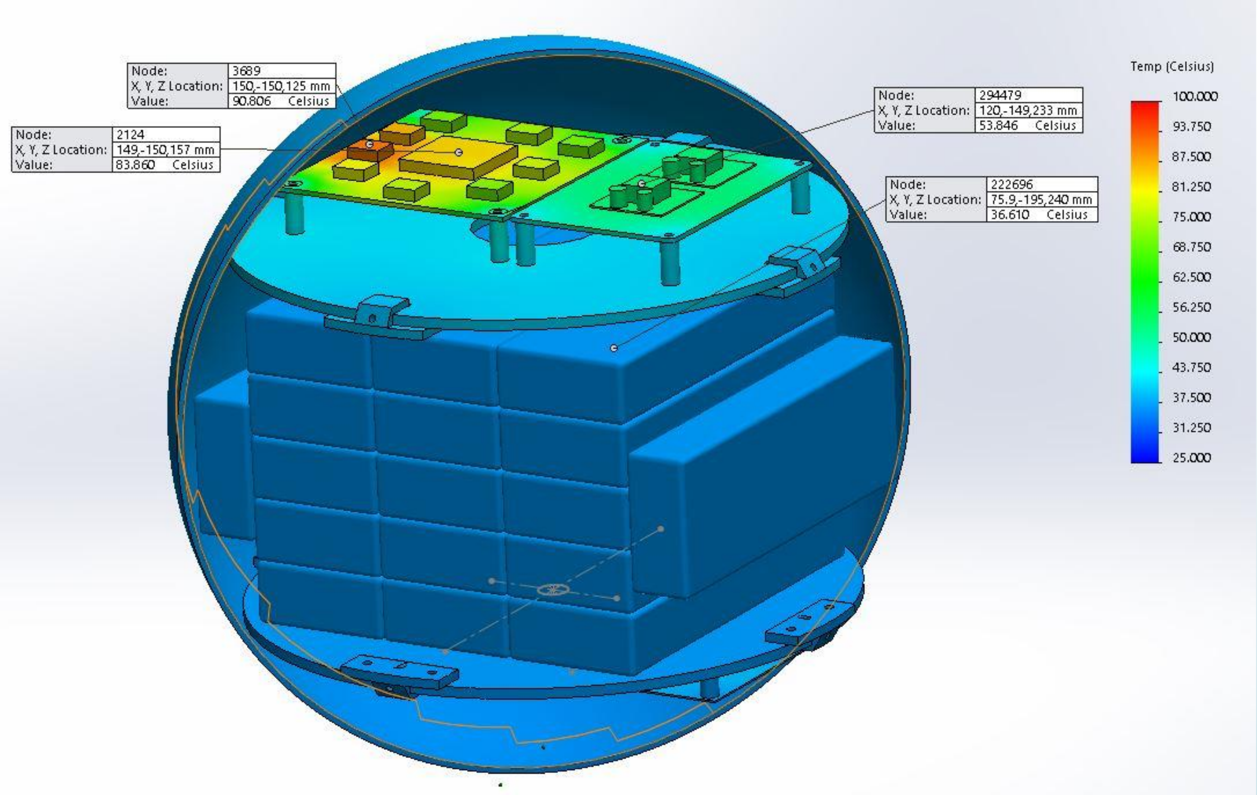


Top Shelf Drawing (dimensions in mm)



Temperatures within Operating Conditions





INT 6: All temperatures are within acceptable range of onboard components

Will be refining models through component testing

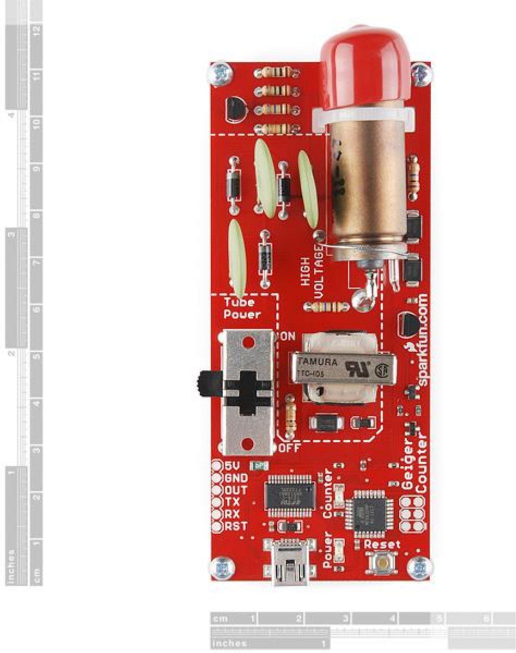
Payload

Sensor Payload

Magnetometer:

Key Specifications
Model: SparkFun Triple Axis Magnetometer HMC5883L
Interface: I2C
Sampling Rate: 0.75 – 75 Hz
Power and Logic: 3.3VDC and 3.3V Logic
Range: ± 8e5 nT
Resolution: 500 nT

Geiger Counter:



Key Specifications
Model: SparkFun Geiger Counter
Interface: Serial
Sampling Rate: Maximum of 100 Hz
Power and Logic: 5VDC and 5V Logic

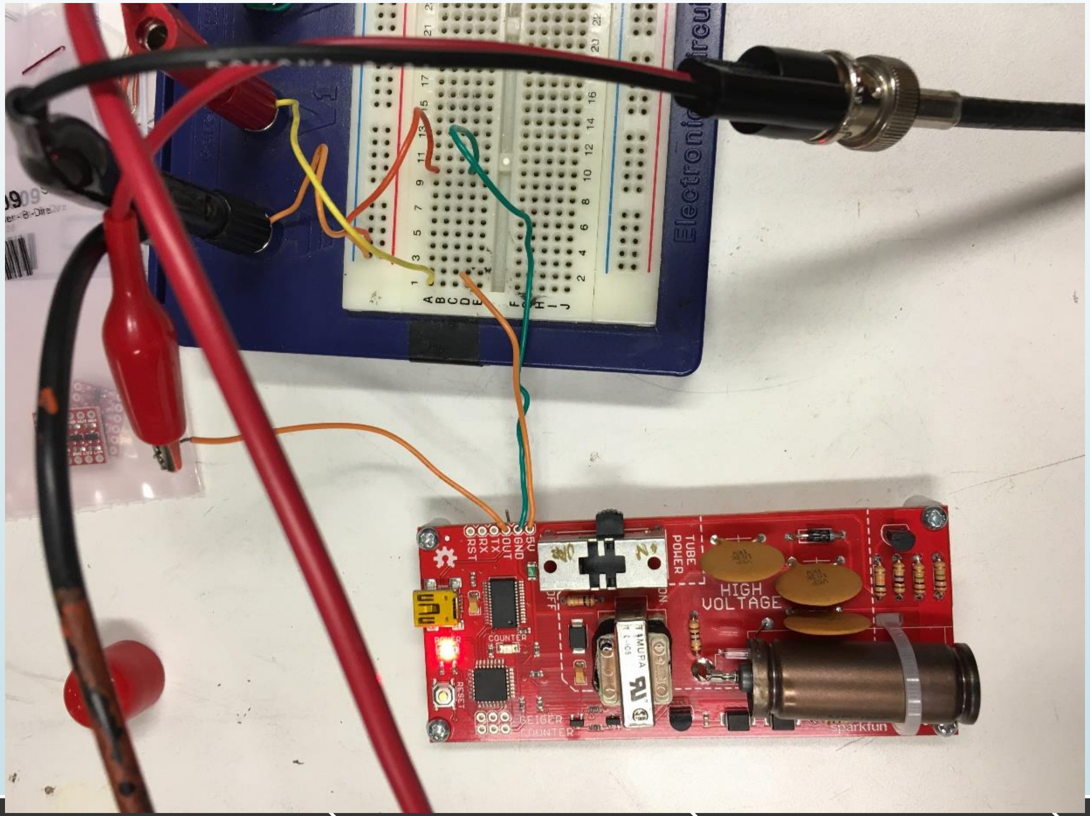
Highest Payload Level of Success: Samples data and relays it to Avionics Board for onboard storage

Payload Acquisition and Status

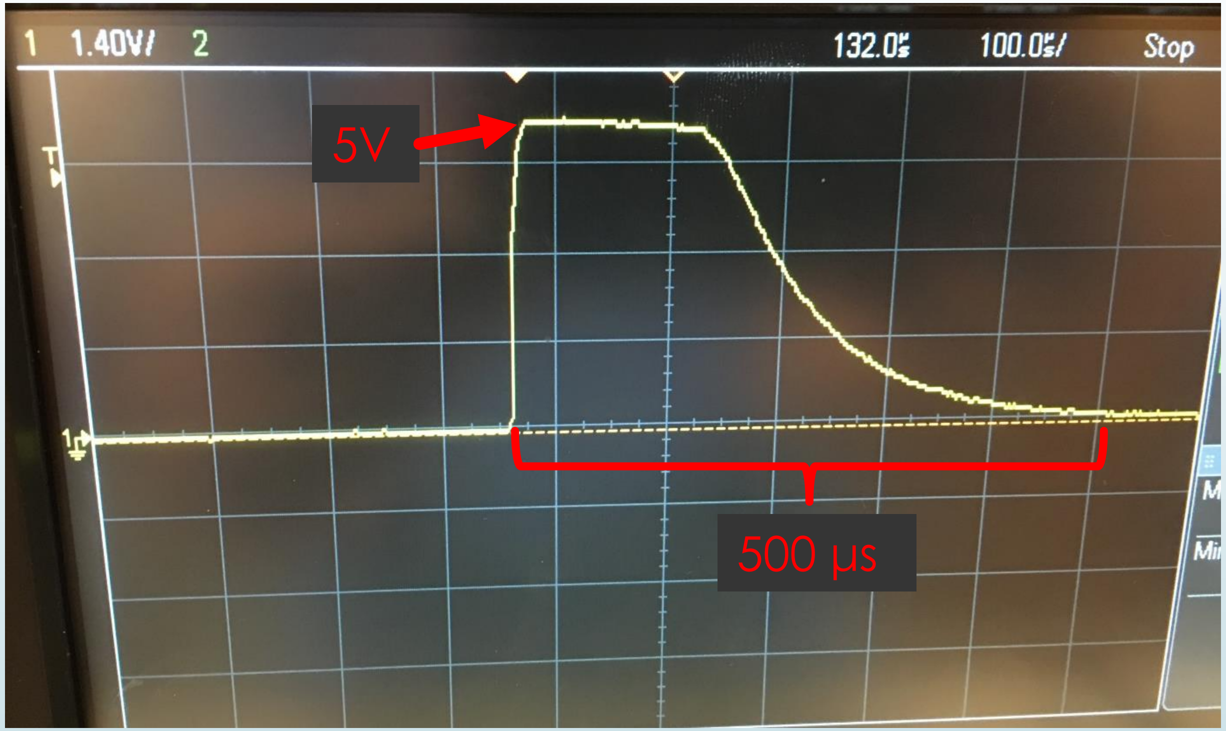
Hardware Component	**Acquisition Method**	**Status**
Magnetometer	Purchased	Received/ Successfully tested
Geiger Counter	Purchased	Received/ Successfully tested
Geiger Counter Logic Converter	Purchased	Received/ Unsuccessful testing → New revision
Geiger Counter Voltage Divider	Purchased	Design In Progress

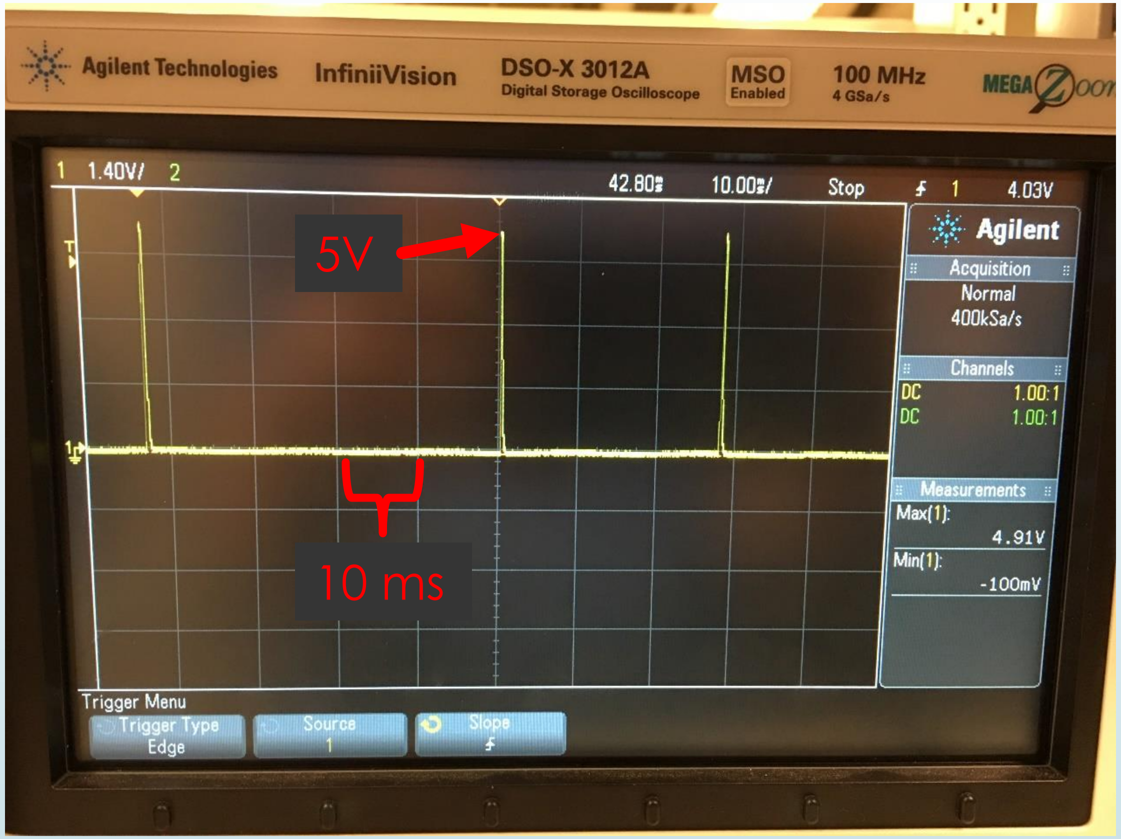
Geiger Counter Testing

- Connected to Power Supply and Oscilloscope to confirm output
- Plan to test with Americium (from smoke detector) to induce higher count rates this week (Feb 4)



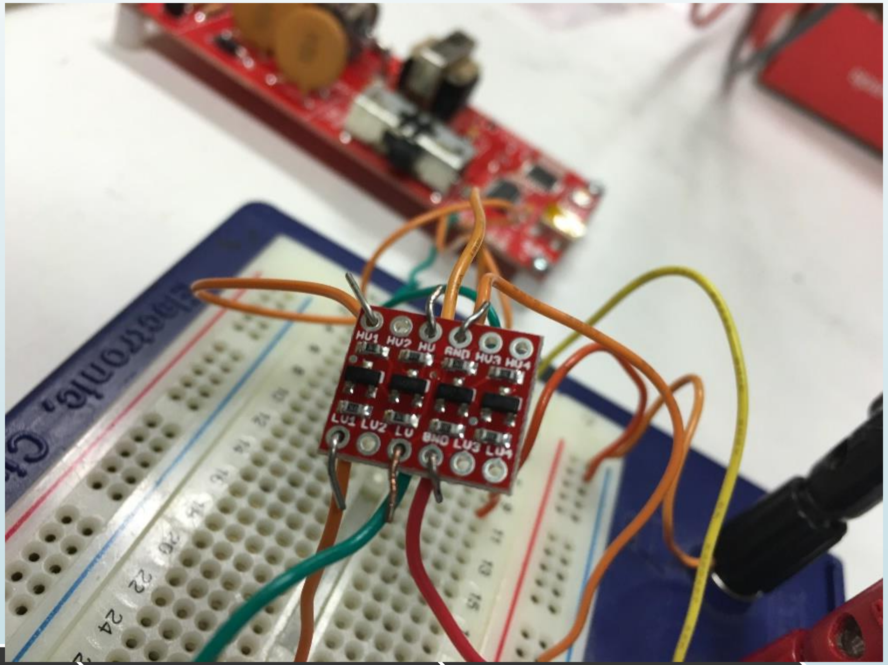
Results:


1 1.40V/ 2
132.0µs
100.0µs/
Stop
5V
500 µs


Agilent Technologies
InfiniiVision
DSO-X 3012A
Digital Storage Oscilloscope
MSO Enabled
100 MHz
4 GSa/s
MEGA Zoom
1 1.40V/ 2
42.80ms
10.00ms/
Stop
1 4.03V
Agilent
Acquisition
Normal
400kSa/s
Channels
DC 1.00:1
DC 1.00:1
Measurements
Max(1):
4.91V
Min(1):
-100mV
Trigger Menu
Trigger Type
Edge
Source
1
Slope
5V
10 ms

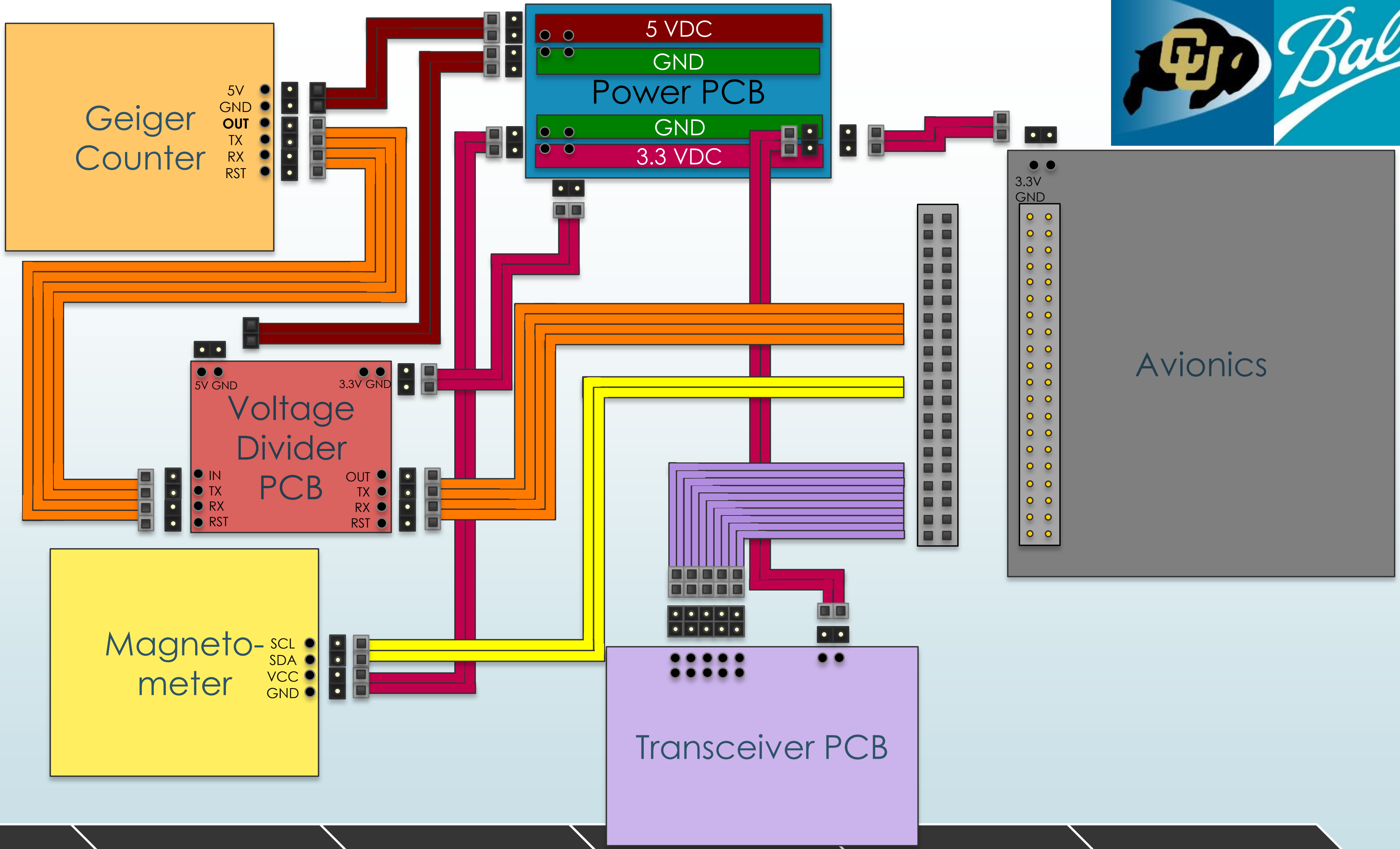
Change to Design:

- Bi-Directional Level Shifter does not work as anticipated due to signal from Geiger Counter not behaving like a digital signal.
- Pull up resistors on the Shifter mean that the signal always reads a high 5V and 3.3V
- Designing a Voltage Divider Circuit PCB to get same effect
  - Still need to test with Resistors from Trudy's Lab

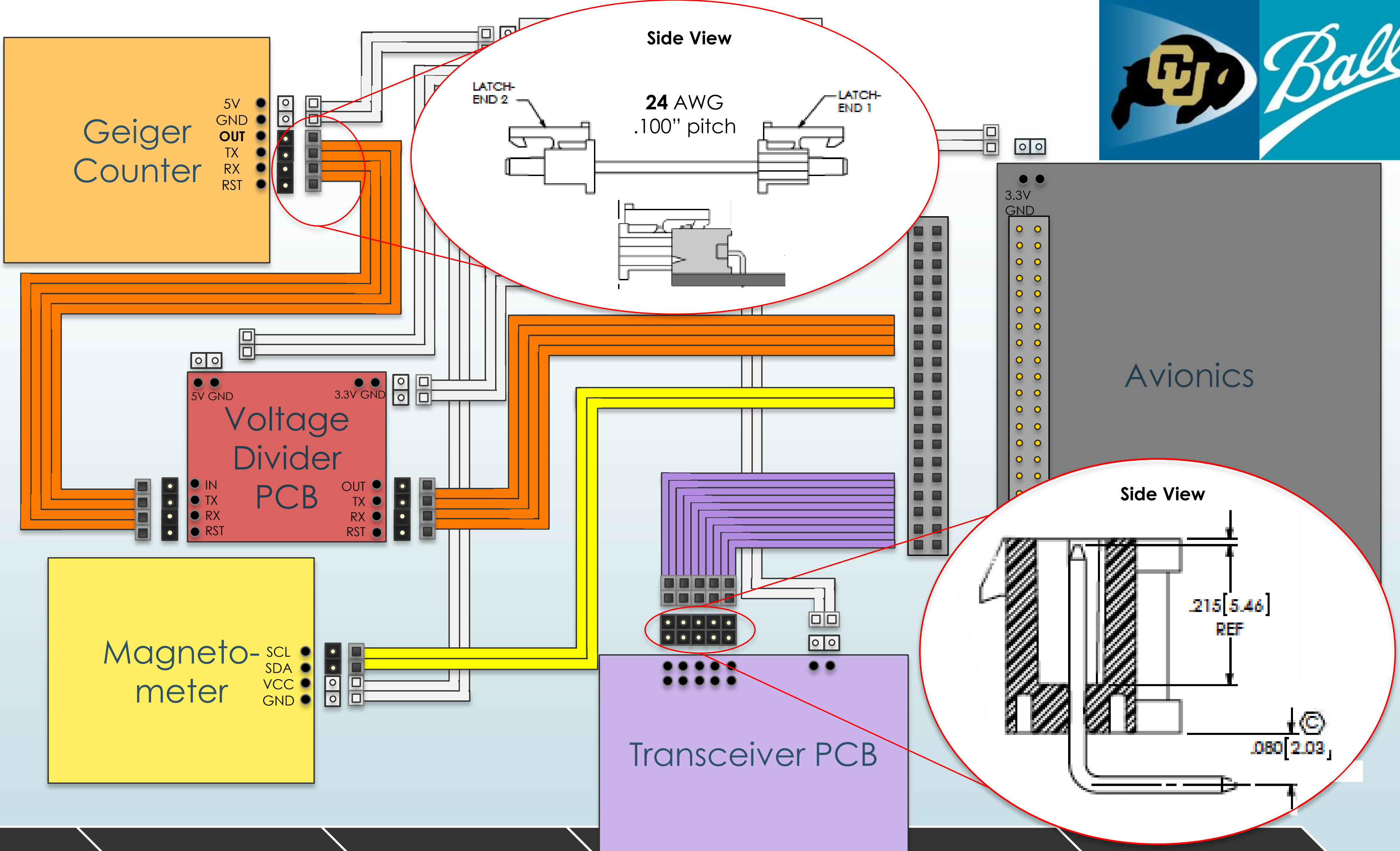


Systems Backup Slides

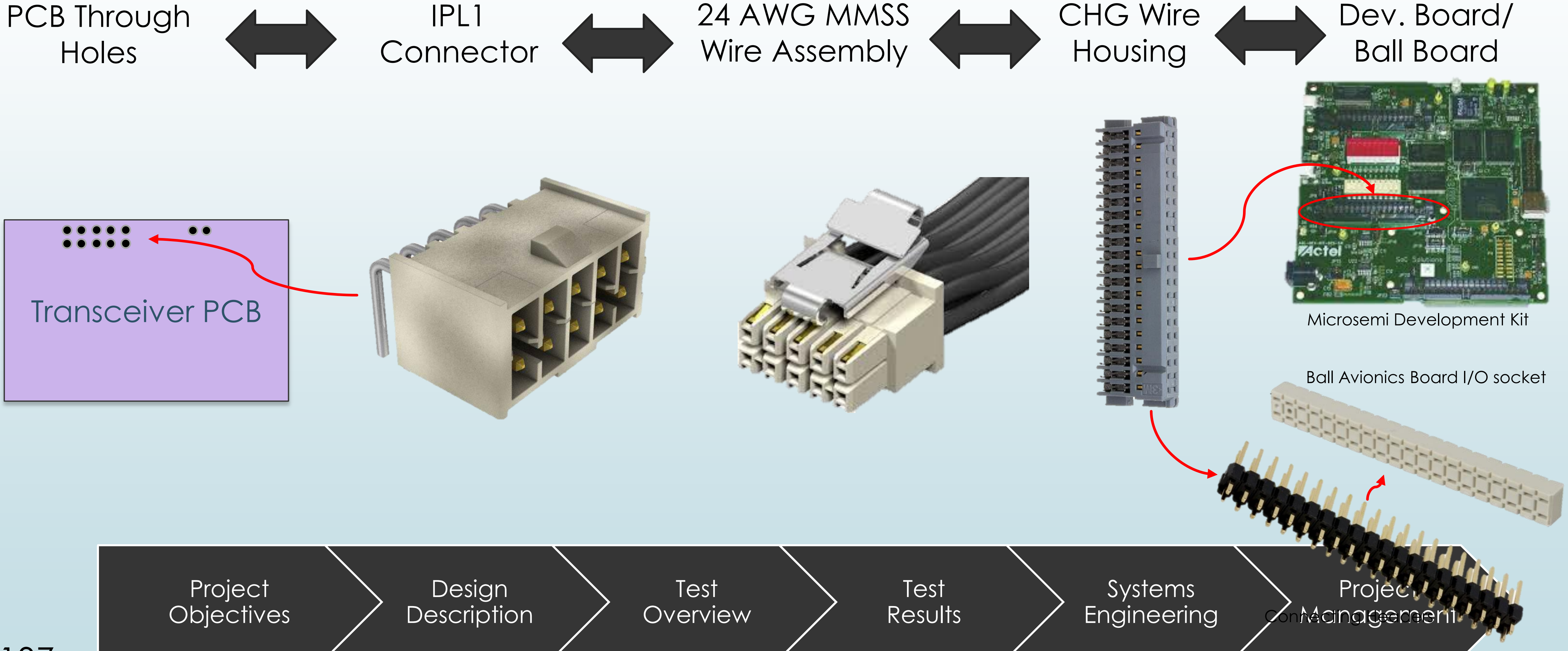
Wiring


5 VDC
GND
Power PCB
GND
3.3 VDC
Geiger Counter
5V
GND
OUT
TX
RX
RST
5V GND
3.3V GND
Voltage Divider PCB
IN
TX
RX
RST
OUT
TX
RX
RST
3.3V
GND
Avionics
Magneto-meter
SCL
SDA
VCC
GND
Transceiver PCB

Digital Wiring



Digital Connectors



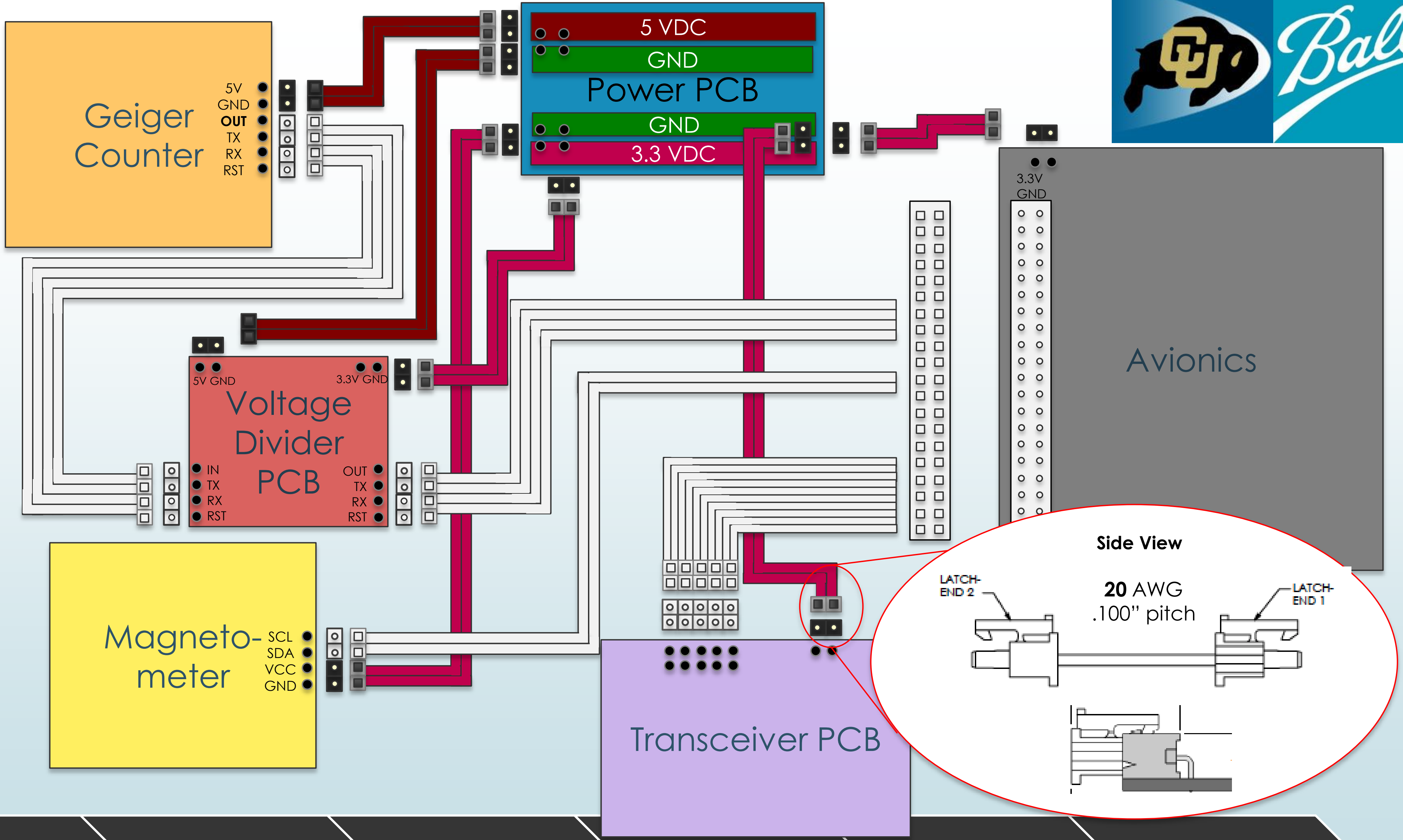
PCB Through Holes ⟷ IPL1 Connector ⟷ 24 AWG MMSS Wire Assembly ⟷ CHG Wire Housing ⟷ Dev. Board/ Ball Board

Microsemi Development Kit

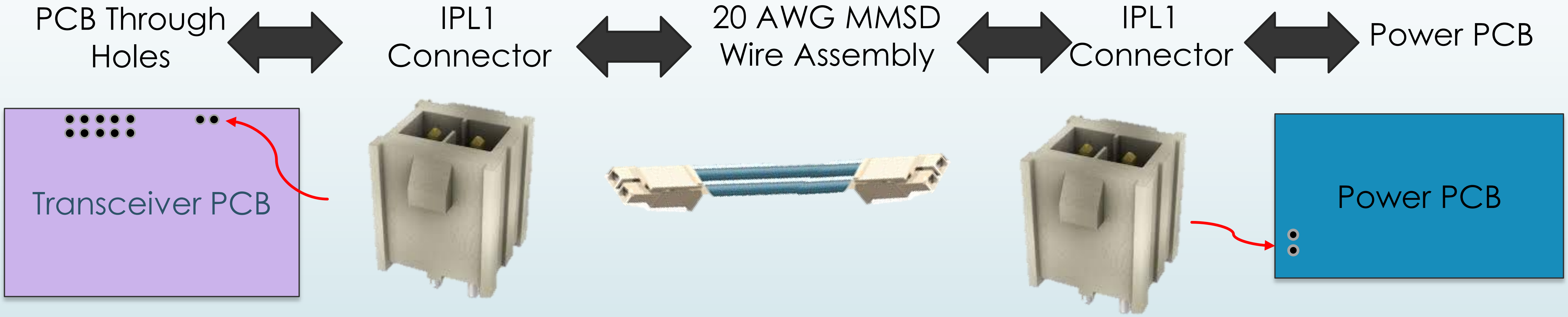
Ball Avionics Board I/O socket

Connecting Headers

Power Wiring



Power Connectors



PCB Through Holes

IPL1 Connector

20 AWG MMSD Wire Assembly

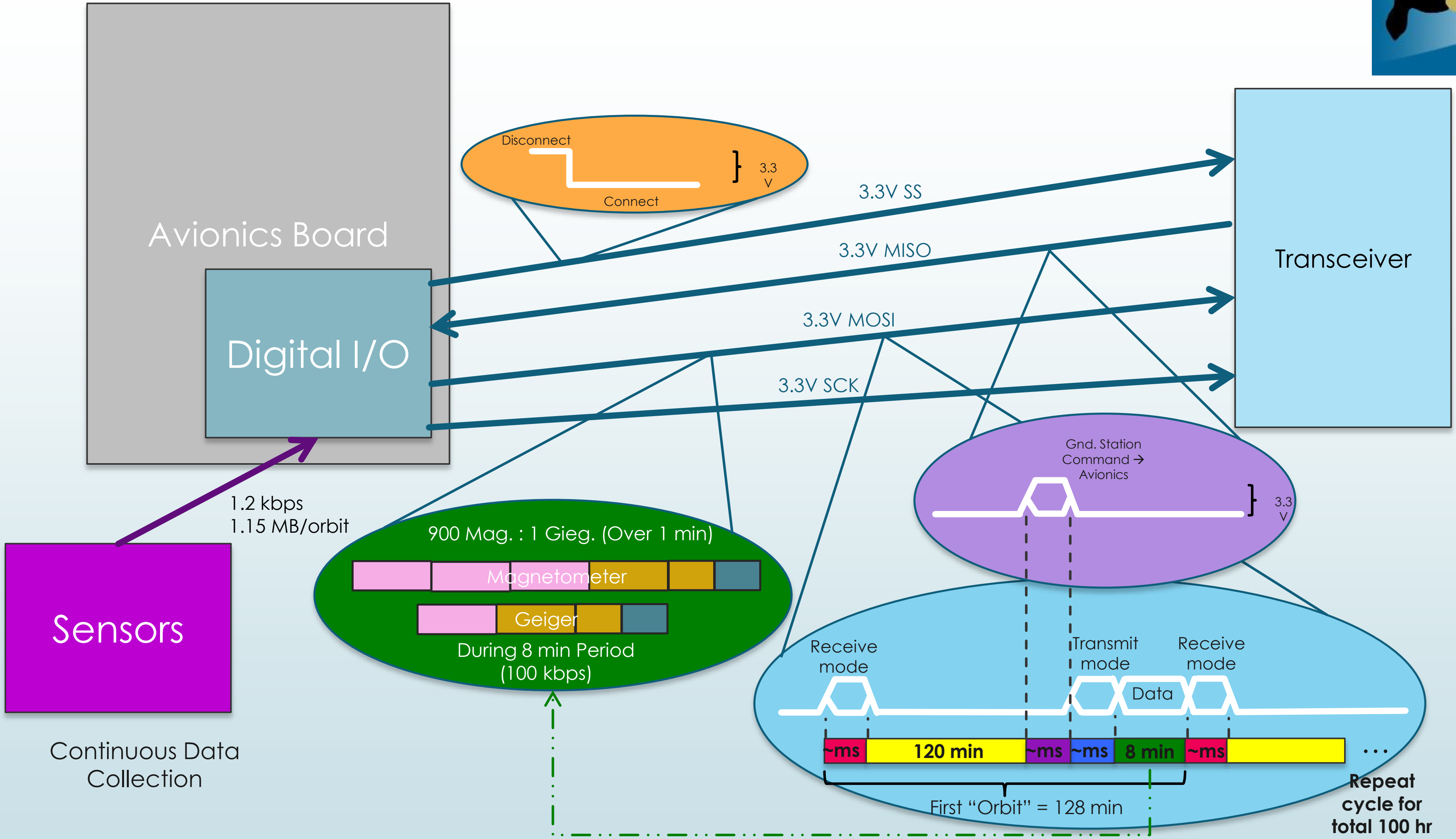
IPL1 Connector

Power PCB

Transceiver PCB

Power PCB

Timing



Avionics Board

Digital I/O

Transceiver

Disconnect

Connect

3.3 V

3.3V SS

3.3V MISO

3.3V MOSI

3.3V SCK

1.2 kbps
1.15 MB/orbit

Sensors

Continuous Data Collection

900 Mag. : 1 Gieg. (Over 1 min)

Magnetometer

Geiger

During 8 min Period
(100 kbps)

Gnd. Station Command → Avionics

3.3 V

Receive mode

Transmit mode

Receive mode

Data

~ms | 120 min | ~ms | ~ms | 8 min | ~ms | …

First "Orbit" = 128 min

Repeat cycle for total 100 hr

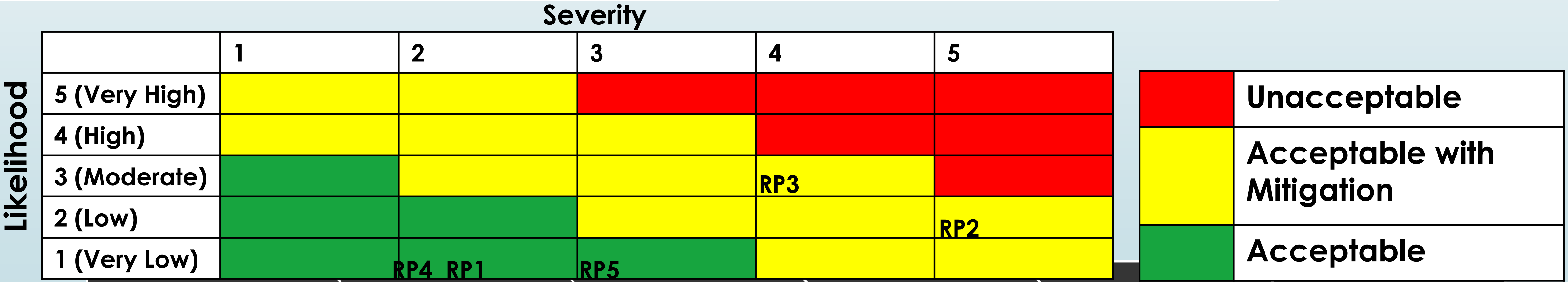
Risk Introduction

Likelihood	Rating
1	Very Low: 0-20%
2	Low: 21%-40%
3	Medium: 41%-60%
4	High: 61%-80%
5	Very High: 81-100%

Severity	Rating
1	No Effect on Cost/Schedule
2	Schedule Slip < 1 week
3	Moderate Schedule Slip (~2 weeks) , Not All Requirements Met
4	Major Schedule Slip (1 month), Majority of Reqs. Not Met
5	Project Failure, Damage to Components

Risk Assessment

Risk	Description	Mitigation
RP1: FPGA Software	FPGA Software Development learning curve. Related to CPE-1	**Learning curriculum** completion. Practice on **development FPGA**. Attend **Microsemi trainings** and seminars
RP2: ESD Component Safety	Possible component damage or failure if handled in non-ESD environment	**ESD environment** required for all avionics development and testing, this is provided through **Bobby and Trudy's lab.** Internal **ESD certification and training** for team members handling sensitive hardware.
RP3: Schedule Slip	Critical path on schedule (FPGA software development and procurement) falls behind schedule affecting final testing schedule	**Schedule margin** built in. Development of code begun before winter break. **1/3 of team devoted to FPGA development**. If Ball FPGA board is not delivered on time, **COTS development FPGA** has been acquired. **Developed software applies to both design solution.**
RP4: Unable to Dissipate Heat	Structure unable to dissipate the heat in an earth environment, components are damaged or inoperable	**Extensive thermal model** concludes that there will be **low chance of overheat**. Worst case, **ball will be opened** and placed under an **external desktop fan to remove heat.**
RP5: Power Failure	Power system unable to power system for full 100 hour test. Battery failure or damage. Over-current to system causing damage to components.	Safety systems include **fuse to prevent overcurrent** to system, as well as **voltage cutoff circuit** to stop power at minimum voltage limit. **Battery characterization test** provided evidence that power model is correct.



Severity

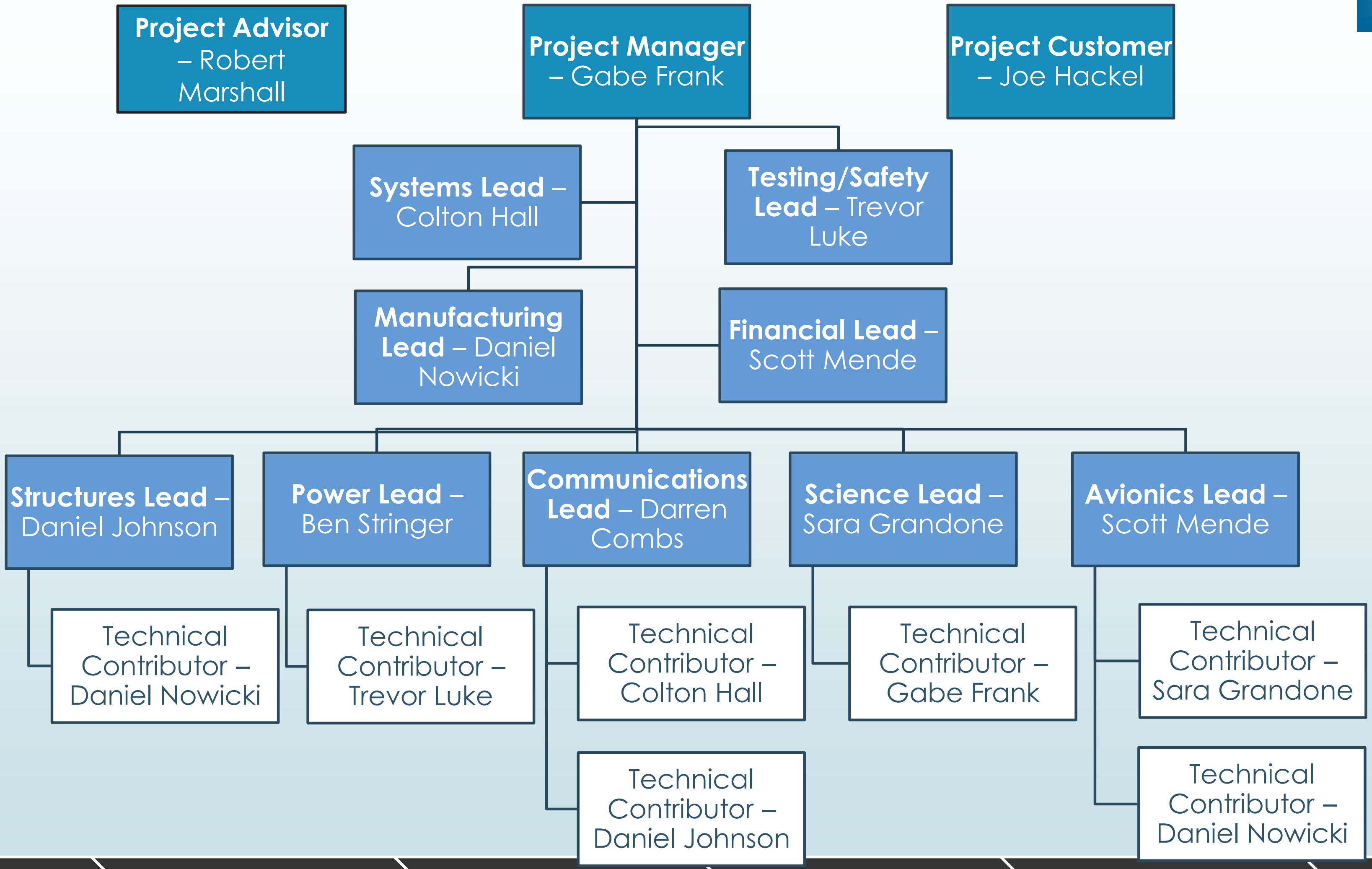
Likelihood

	1	2	3	4	5
5 (Very High)	🟨	🟨	🟥	🟥	🟥
4 (High)	🟨	🟨	🟨	🟥	🟥
3 (Moderate)	🟩	🟨	🟨	🟨 RP3	🟥
2 (Low)	🟩	🟩	🟨	🟨	🟨 RP2
1 (Very Low)	🟩	🟩 RP4 RP1	🟩 RP5	🟨	🟨

🟥	**Unacceptable**
🟨	**Acceptable with Mitigation**
🟩	**Acceptable**

Project Management Backup

Organizational Chart



Project Advisor – Robert Marshall

Project Manager – Gabe Frank

Project Customer – Joe Hackel

Systems Lead – Colton Hall

Testing/Safety Lead – Trevor Luke

Manufacturing Lead – Daniel Nowicki

Financial Lead – Scott Mende

Structures Lead – Daniel Johnson

- Technical Contributor – Daniel Nowicki

Power Lead – Ben Stringer

- Technical Contributor – Trevor Luke

Communications Lead – Darren Combs

- Technical Contributor – Colton Hall
- Technical Contributor – Daniel Johnson

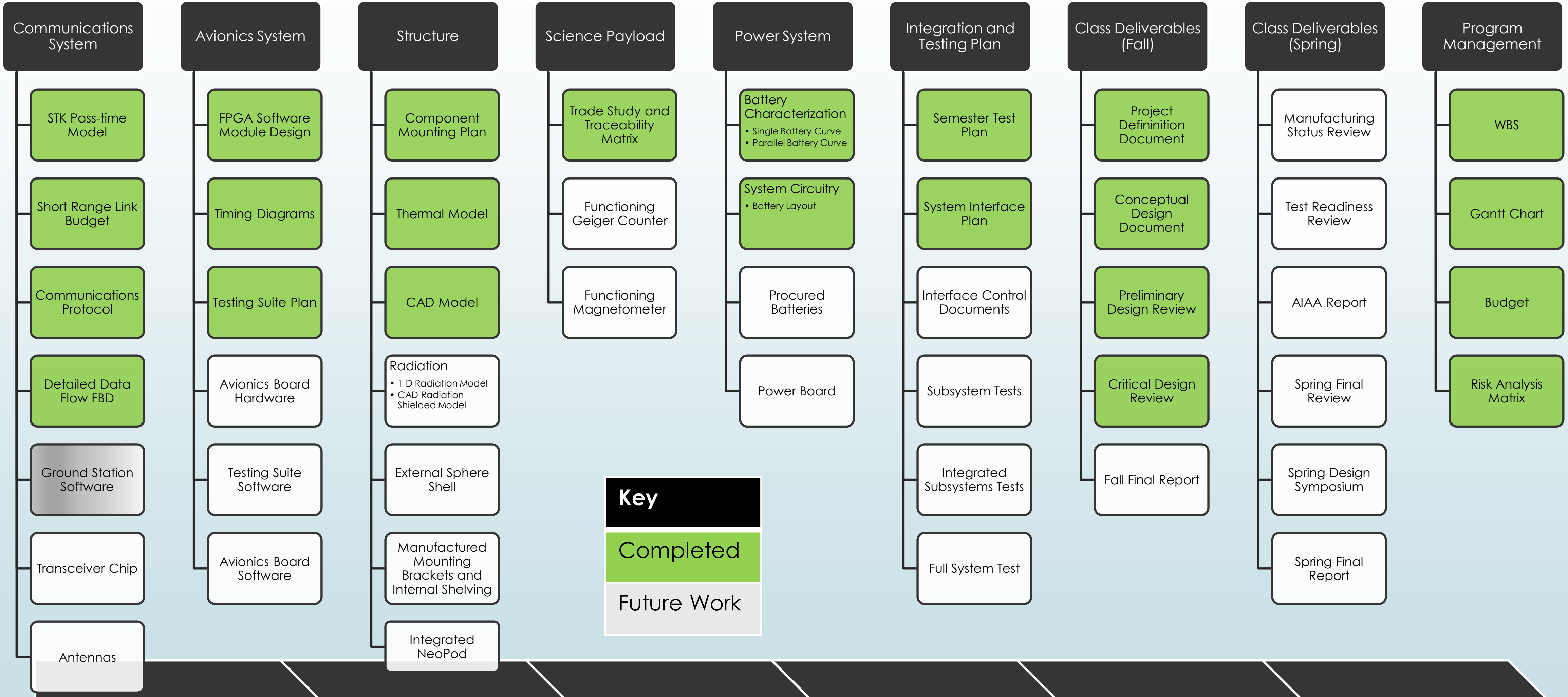
Science Lead – Sara Grandone

- Technical Contributor – Gabe Frank

Avionics Lead – Scott Mende

- Technical Contributor – Sara Grandone
- Technical Contributor – Daniel Nowicki

Work Breakdown Structure



- Communications System
  - STK Pass-time Model
  - Short Range Link Budget
  - Communications Protocol
  - Detailed Data Flow FBD
  - Ground Station Software
  - Transceiver Chip
  - Antennas
- Avionics System
  - FPGA Software Module Design
  - Timing Diagrams
  - Testing Suite Plan
  - Avionics Board Hardware
  - Testing Suite Software
  - Avionics Board Software
- Structure
  - Component Mounting Plan
  - Thermal Model
  - CAD Model
  - Radiation
    - 1-D Radiation Model
    - CAD Radiation Shielded Model
  - External Sphere Shell
  - Manufactured Mounting Brackets and Internal Shelving
  - Integrated NeoPod
- Science Payload
  - Trade Study and Traceability Matrix
  - Functioning Geiger Counter
  - Functioning Magnetometer
- Power System
  - Battery Characterization
    - Single Battery Curve
    - Parallel Battery Curve
  - System Circuitry
    - Battery Layout
  - Procured Batteries
  - Power Board
- Integration and Testing Plan
  - Semester Test Plan
  - System Interface Plan
  - Interface Control Documents
  - Subsystem Tests
  - Integrated Subsystems Tests
  - Full System Test
- Class Deliverables (Fall)
  - Project Definintion Document
  - Conceptual Design Document
  - Preliminary Design Review
  - Critical Design Review
  - Fall Final Report
- Class Deliverables (Spring)
  - Manufacturing Status Review
  - Test Readiness Review
  - AIAA Report
  - Spring Final Review
  - Spring Design Symposium
  - Spring Final Report
- Program Management
  - WBS
  - Gantt Chart
  - Budget
  - Risk Analysis Matrix

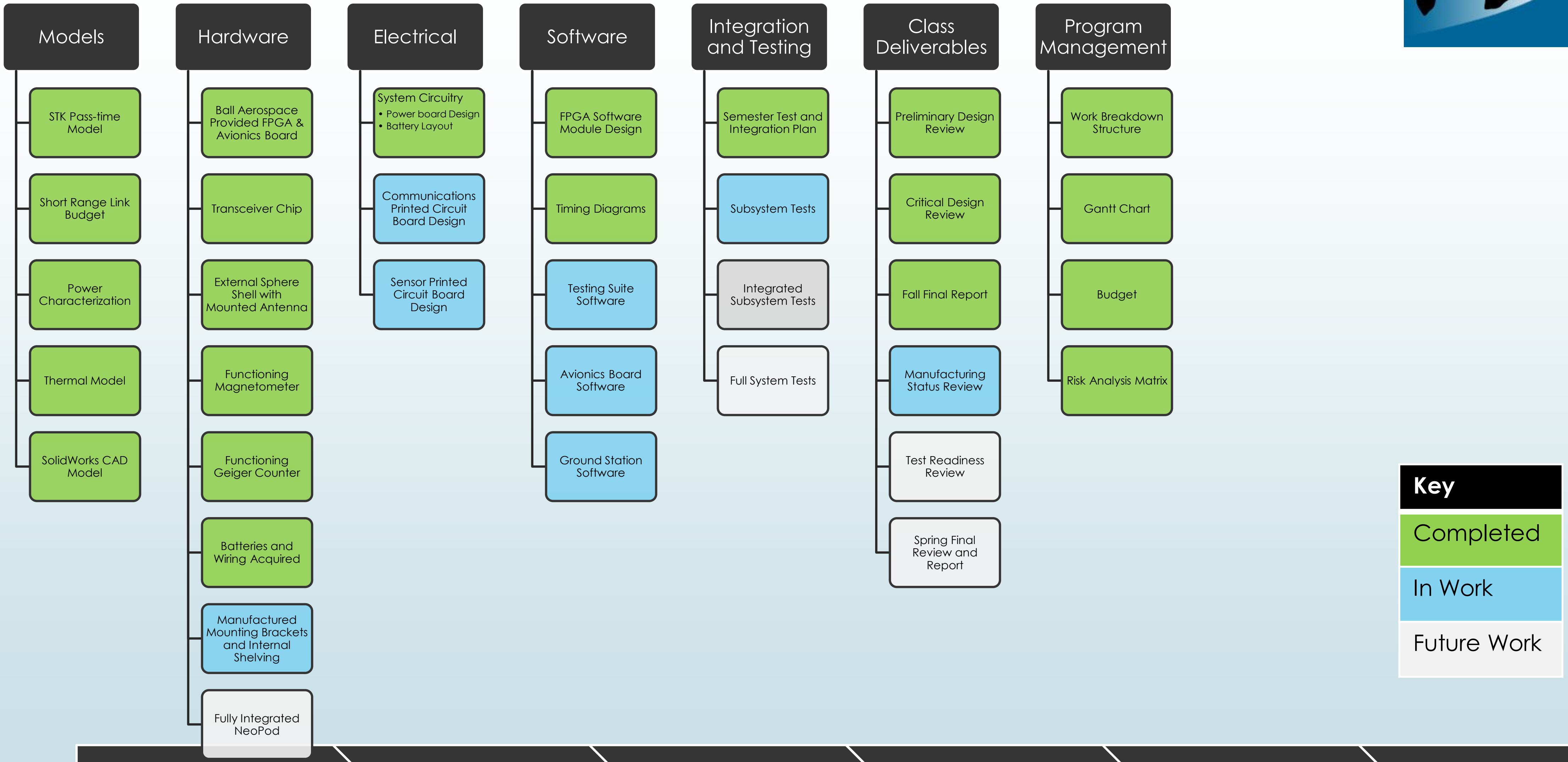
Key

🟩 Completed

⬜ Future Work

Project Objectives › Design Description › Test Overview › Test Results › Systems Engineering › Project Management

Manufacturing Work Breakdown Structure



- **Models**
  - STK Pass-time Model
  - Short Range Link Budget
  - Power Characterization
  - Thermal Model
  - SolidWorks CAD Model
- **Hardware**
  - Ball Aerospace Provided FPGA & Avionics Board
  - Transceiver Chip
  - External Sphere Shell with Mounted Antenna
  - Functioning Magnetometer
  - Functioning Geiger Counter
  - Batteries and Wiring Acquired
  - Manufactured Mounting Brackets and Internal Shelving
  - Fully Integrated NeoPod
- **Electrical**
  - System Circuitry
    - Power board Design
    - Battery Layout
  - Communications Printed Circuit Board Design
  - Sensor Printed Circuit Board Design
- **Software**
  - FPGA Software Module Design
  - Timing Diagrams
  - Testing Suite Software
  - Avionics Board Software
  - Ground Station Software
- **Integration and Testing**
  - Semester Test and Integration Plan
  - Subsystem Tests
  - Integrated Subsystem Tests
  - Full System Tests
- **Class Deliverables**
  - Preliminary Design Review
  - Critical Design Review
  - Fall Final Report
  - Manufacturing Status Review
  - Test Readiness Review
  - Spring Final Review and Report
- **Program Management**
  - Work Breakdown Structure
  - Gantt Chart
  - Budget
  - Risk Analysis Matrix

Key

- 🟩 Completed
- 🟦 In Work
- ⬜ Future Work

Project Objectives → Design Description → Test Overview → Test Results → Systems Engineering → Project Management

Science Traceability Backup

Science Trade

Metric	Weight	Magnetometer	Seismometer	Imager Visual	Imager IR	Imager Micro
Science Value	15%	5	5	3	1	5
Cost	15%	4	3	3	3	1
Availability	16%	5	3	4	3	1
Complexity	20%	4	3	3	1	1
Size	22%	4	2	3	4	1
Mass	12%	4	2	4	4	1
Total	100%	4.31	2.96	3.28	2.64	1.44

Science Trade Cont.

Metric	Weight	Imager Zoom	Spectrometer	Radiation	Temperature	Pressure
Science Value	15%	3	5	5	1	1
Cost	15%	3	1	4	5	5
Availability	16%	4	1	4	5	5
Complexity	20%	2	1	4	3	3
Size	22%	3	2	2	5	5
Mass	12%	3	2	4	5	5
Total	100%	2.96	1.94	3.71	4.00	4.00

Science Traceability

Requirement ID	Magnetometer	Seismometer	Imager Visual	Imager IR	Imager Micro
SCI 0: Neopod shall collect scientific data relevant to Europa	✓ Ice shell characterization	✓ Surface geology characterization	✓ Surface geology characterization	✗ Stationary probe leads to static and not unique results	✓ Surface geology characterization
SCI 2.1: Neopod Power Subsystem shall sustain the scientific instruments for a 96 hour period.	✓ Low Power	✓ Low Power	✓ Low Power	✓ Low Power	✓ Low Power
SCI 2.2: Neopod sensors shall mechanically and electrically	✓ Only internal interface	✓ Only internal interface	✗ Must interface with external structure	✗ Must interface with external structure	✗ Must interface with external structure
INT 1: Neopod shall have a mass less than 10 kg.	✓ m_{mag} << .5 kg	✗ m_{mag} >.5 kg	✓ m_{mag} < .5 kg	✓ m_{mag} < .5 kg	✗ m_{mag} >.5 kg
INT 2: Neopod shall have a maximum diameter of 30cm	✓ Largest Dimension << 5 in	✗ Largest Dimension >> 5 in	✓ Largest Dimension << 5 in	✗ Largest Dimension >> 5 in	✗ Largest Dimension >> 5 in
Requirements Met	5	3	4	2	2
Trade Score	4.31	2.96	3.28	2.64	1.44

Science Traceability

Requirement ID	Imager Zoom	Spectrometer	Radiation	Temperature	Pressure
SCI 0: Neopod shall collect scientific data relevant to Europa	✓ Surface geology characterization	✓ Surface composition characterization	✓ Surface composition characterization	✗ Little desired scientific value	✗ Little desired scientific value
SCI 2.1: Neopod Power Subsystem shall sustain the scientific instruments for a 96 hour period.	✓ Low Power	✓ Low Power	✓ Low Power	✓ Low Power	✓ Low Power
SCI 2.2: Neopod sensors shall mechanically and electrically	✗ Must interface with external structure	✗ Must interface with external structure	✓ Only interfaces internally	✗ Must be isolated from electronics and interface externally	✗ Must interface with external structure
INT 1: Neopod shall have a mass less than 10 kg.	✓ m_{mag} < .5 kg	✗ m_{mag} >.5 kg	✓ m_{mag} << .5 kg	✓ m_{mag} << .5 kg	✓ m_{mag} << .5 kg
INT 2: Neopod shall have a maximum diameter of 30cm	✓ Largest Dimension < 5 in	✗ Largest Dimension >> 5 in	✓ Largest Dimension < 5 in	✓ Largest Dimension << 5 in	✓ Largest Dimension << 5 in
Requirements Met	4	2	5	3	3
Trade Score	2.96	1.94	3.71	4.00	4.00

Backup Slide Index