Project ELSA

Europa Lander for Science Acquisition

Test Readiness 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 Overview
- Schedule
- Budget
- Test Readiness

Project Overview | Schedule | Budget | Test Readiness

Project Overview

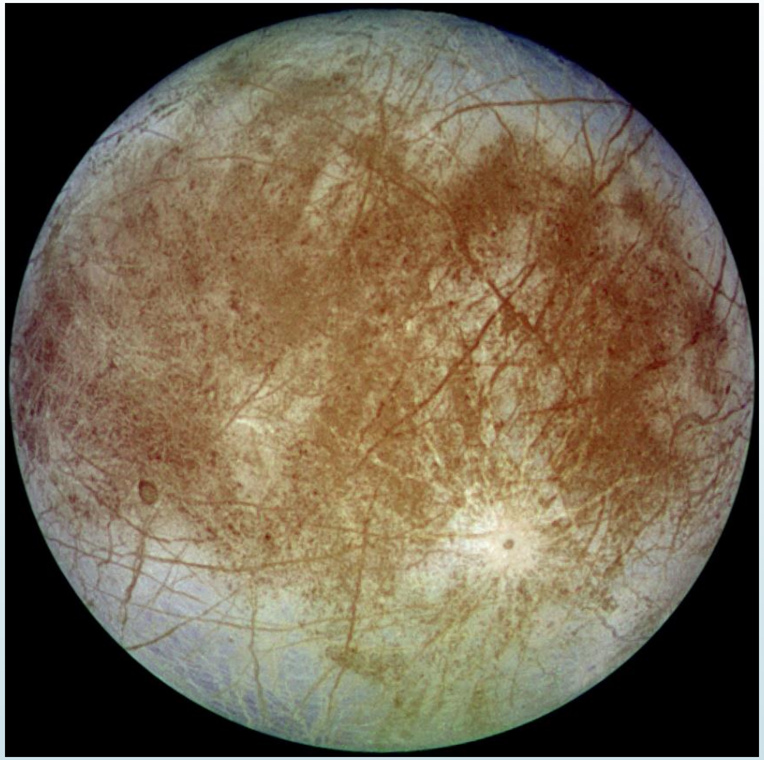
Project Statement

The ELSA team will **design and build a 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.

Motivation for Project: Europa Mission

- Moon of Jupiter **(85 hour orbit)**
- Icy surface with an active geology and possibility 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



Project Overview | Schedule | Budget | Test Readiness

ELSA Mission Objectives

"Do science, get it back."

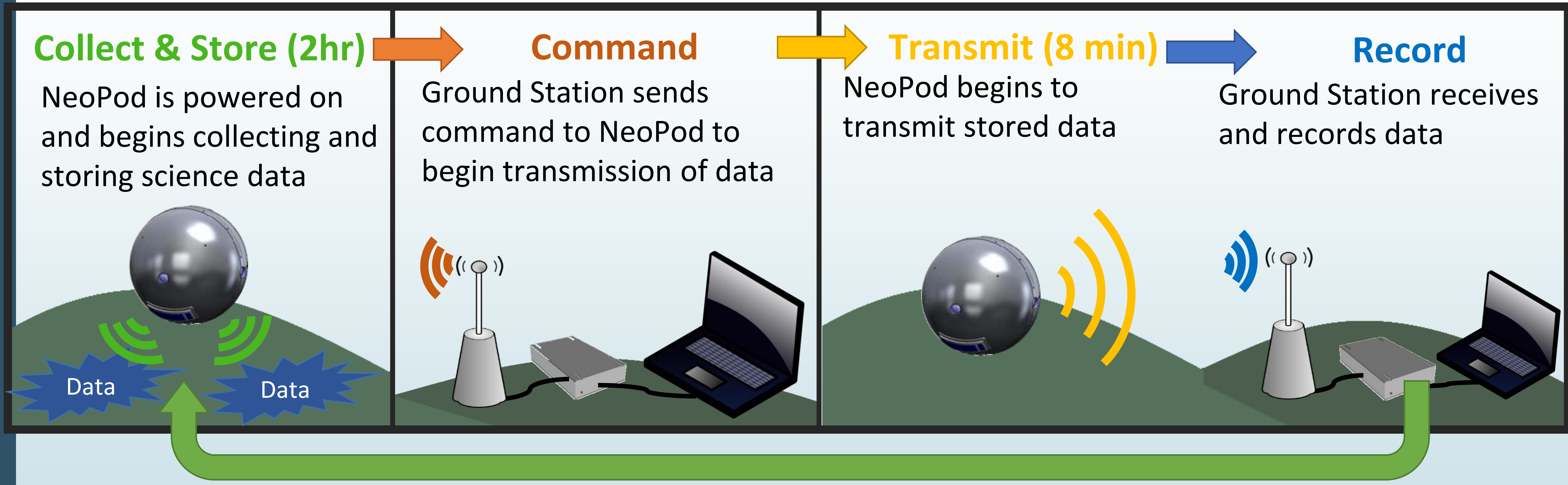
-Joe Hackel (Customer)

- **SCI 0:** *NeoPod shall collect scientific data relevant to the study of Europa*

- **COM 0:** *NeoPod shall communicate with the Ground Station*

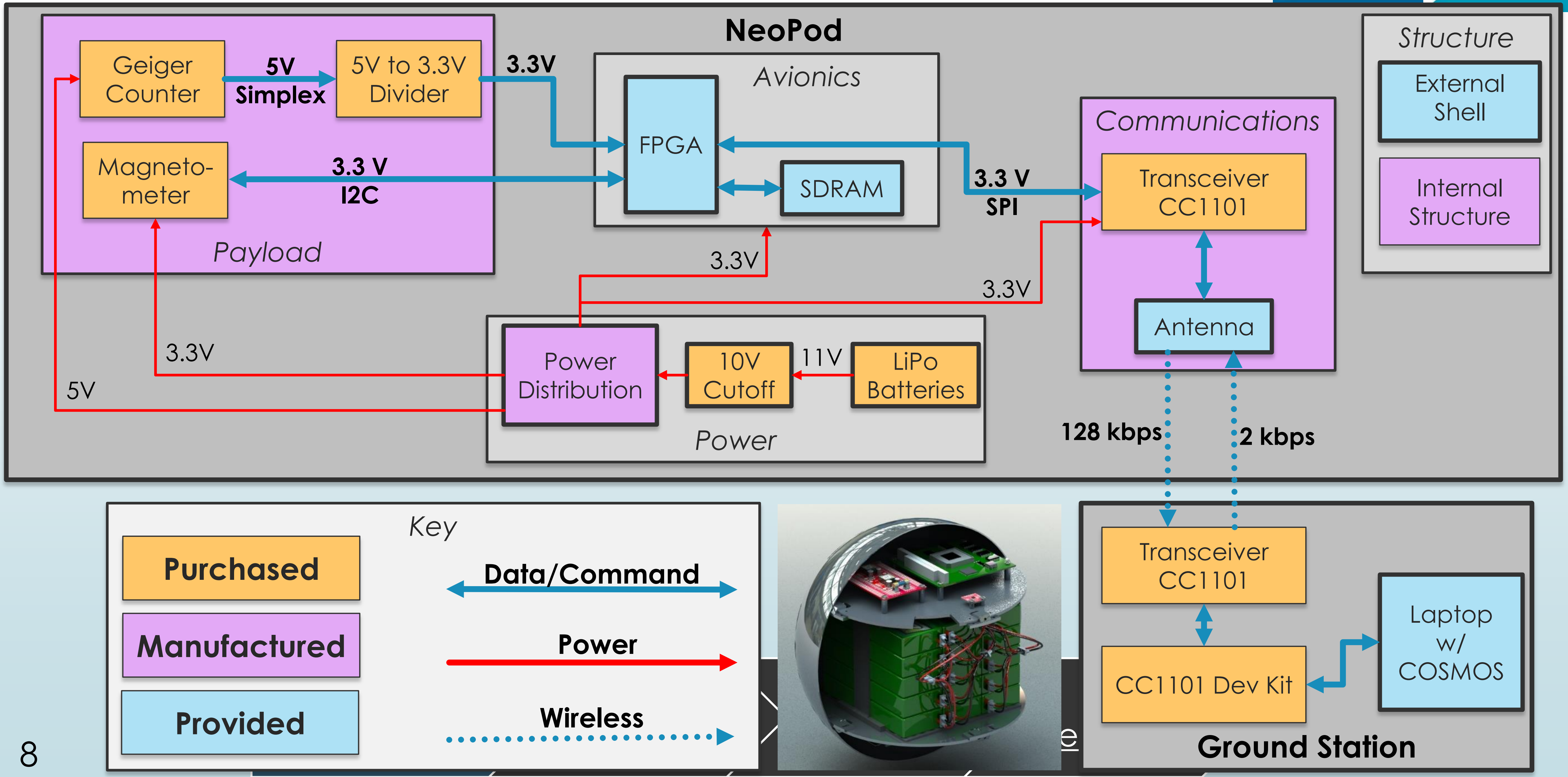
- **INT 0:** *NeoPod shall integrate with existing mission architecture*

ELSA CONOPS



Total: 100 hour mission timeline

FBD of ELSA System



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	Powers 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.

Full System Levels of Success Comparison

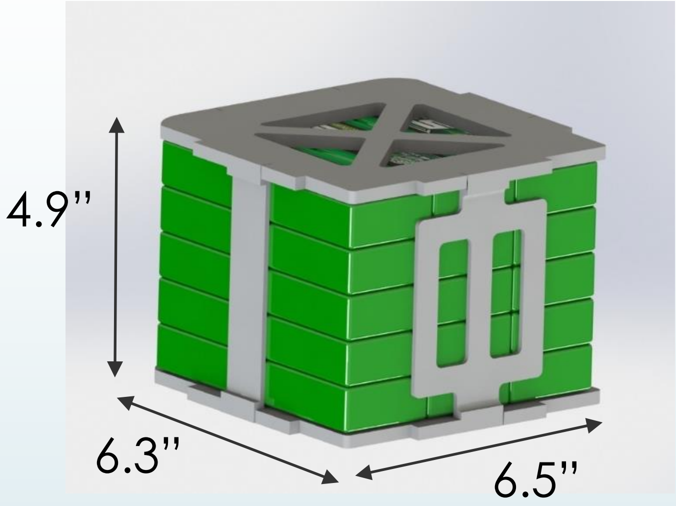
Level 3 Success	vs.	Level 4 Success
Flat-Sat Test Demonstration of Full Integration	vs	Fully Integrated Test
8 hours of Testing	vs	100 hours of Testing
Meets all Requirements (Some by Analysis)	vs	Demonstrates Full Success of Mission Design and Concept
Limited Battery and Thermal Model Validation	vs	Full Battery and Thermal Model Validation

Have Met **Level 1 Success**

On Track for Level 4 Success

Executive Summary

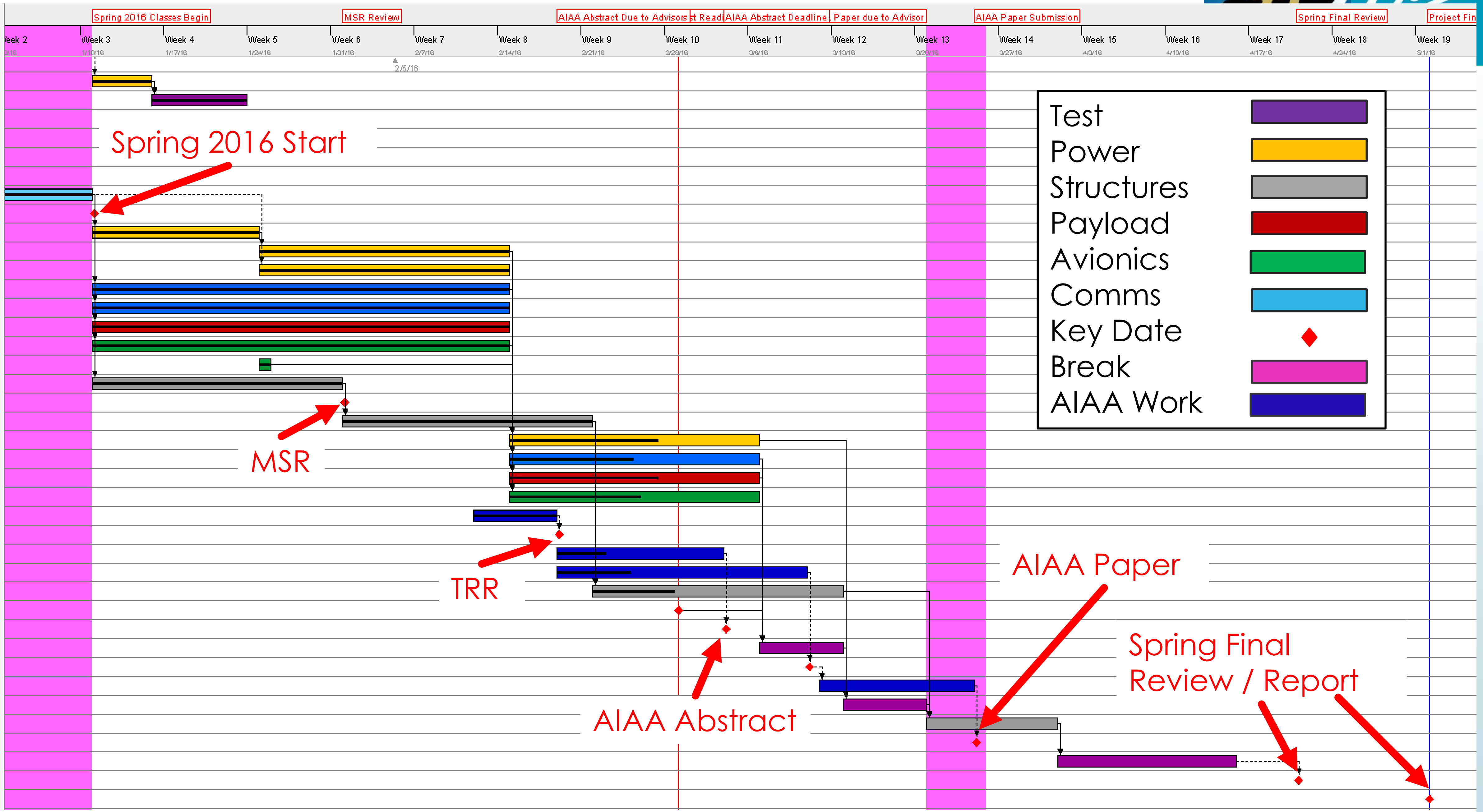
- Changes from MSR
  - New and Improved 3D printed casing
  - Test stand designed
  - **Changes to schedule** reflecting one week delay
- Schedule
  - **Completed Initial component testing** and development
  - Working on component integration now to prepare for testing in March
  - **15 days remaining margin + Spring Break**
- Budget
  - Majority of procurements acquired: **~$2800 remaining**
  - **No Budget Concerns**



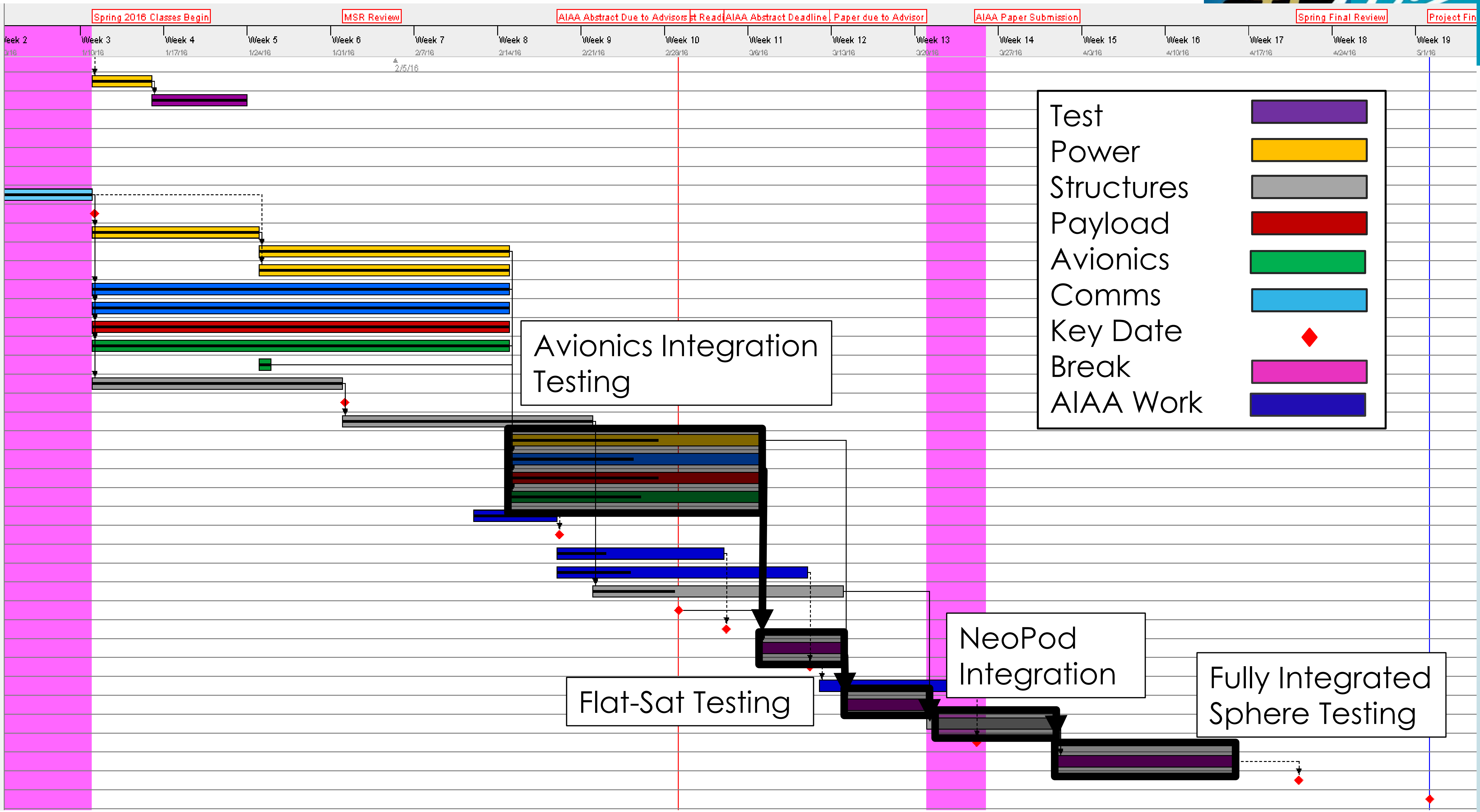
7” Diameter

Schedule

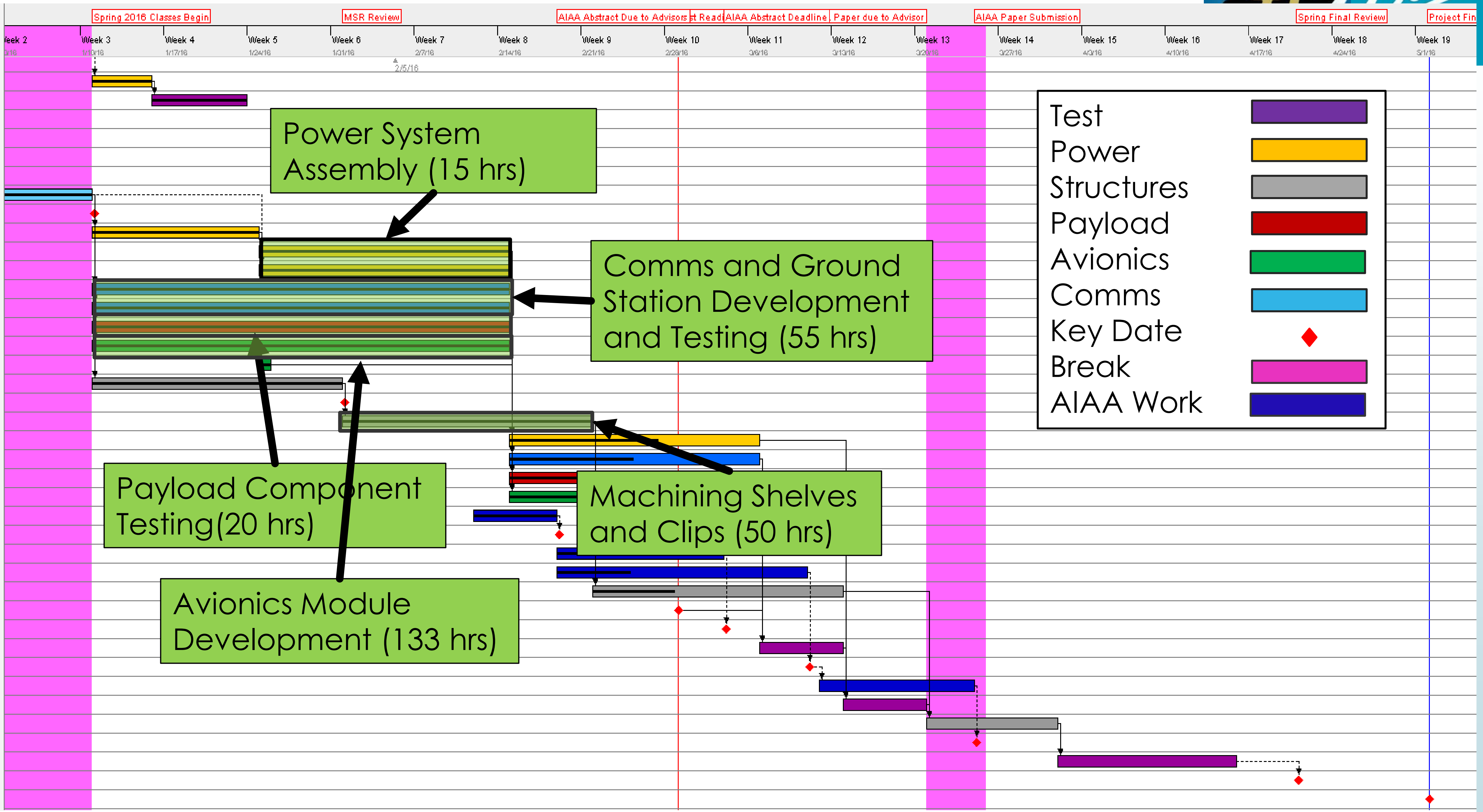
Spring Semester Schedule



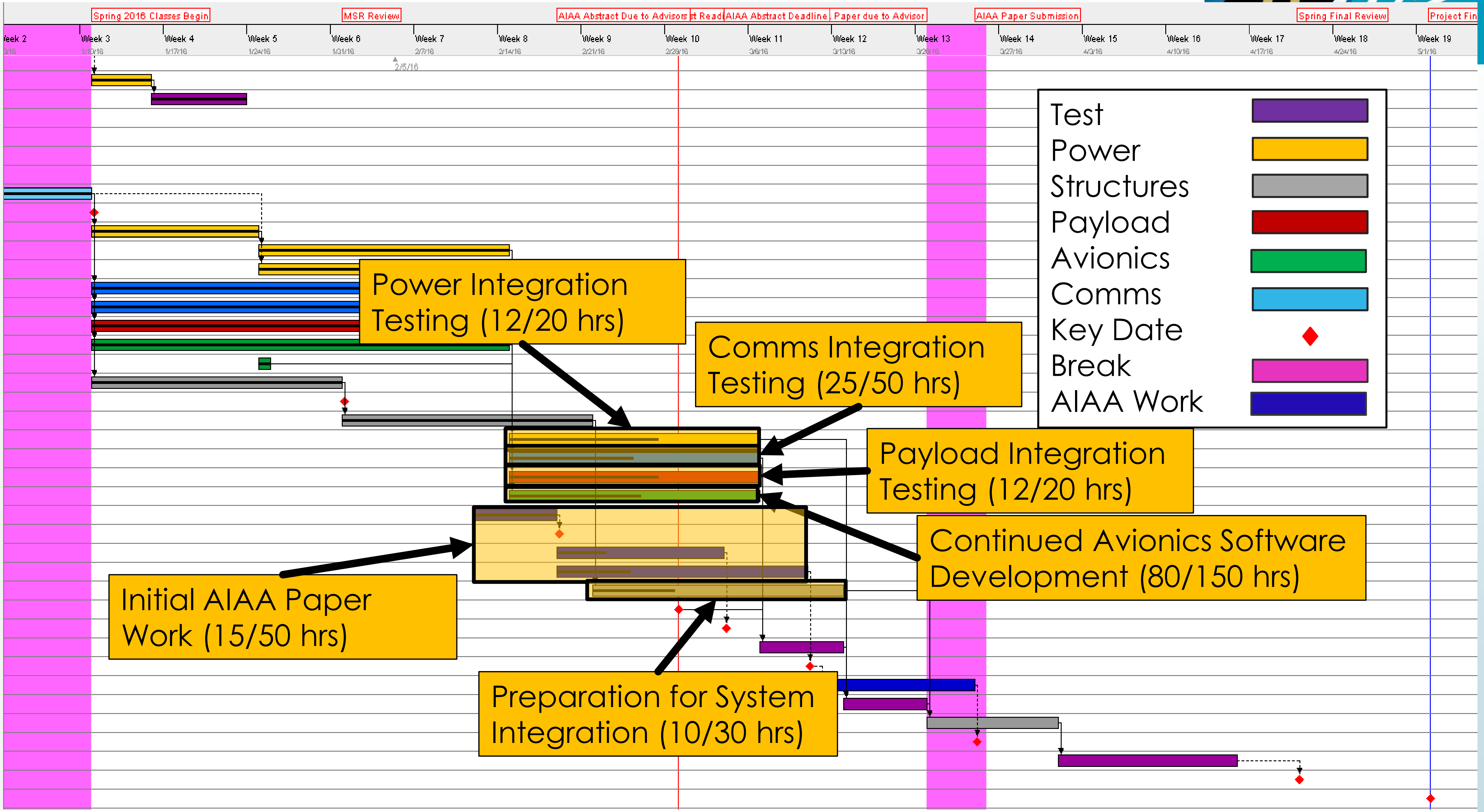
Spring Critical Path



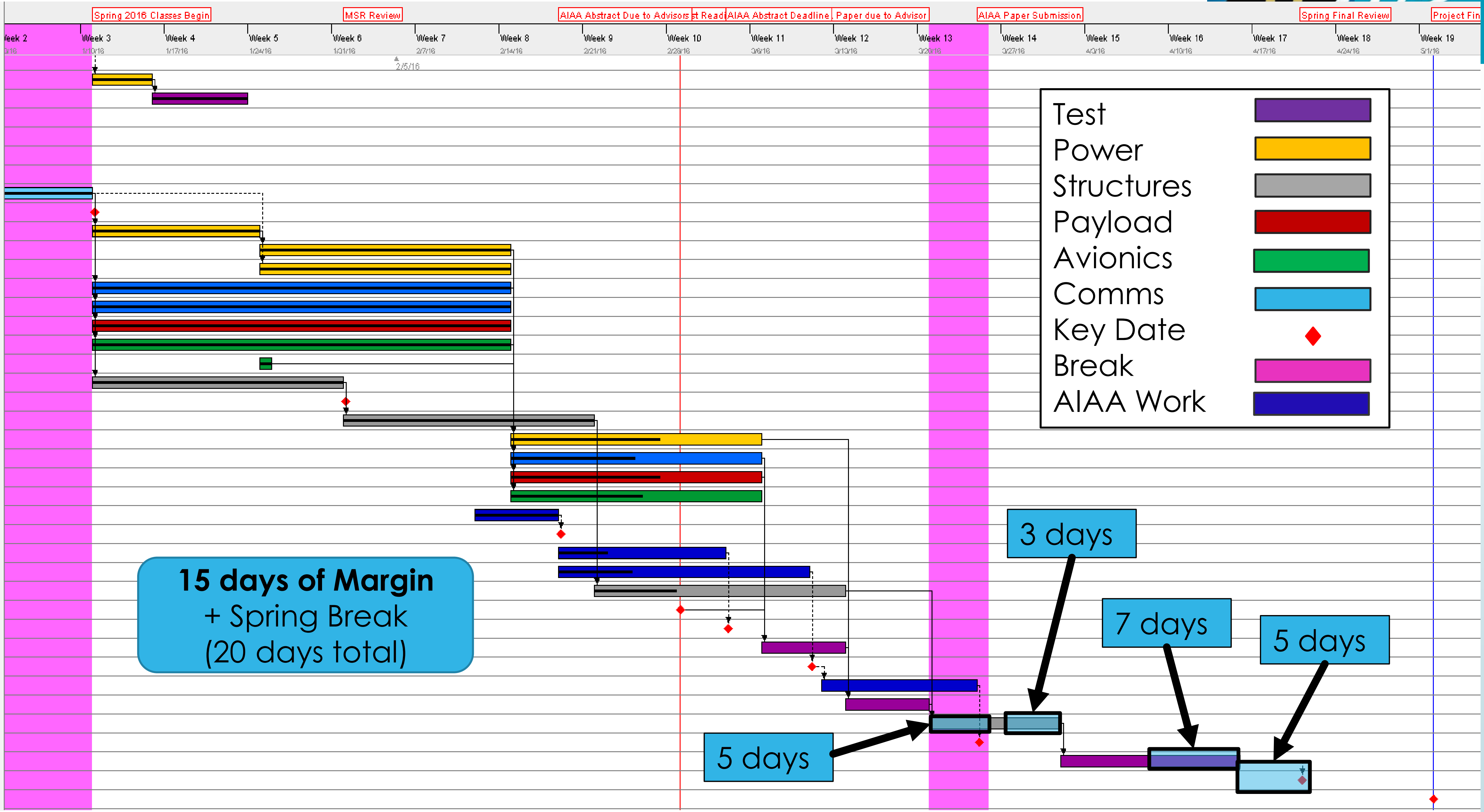
Completed Tasks Since MSR:



Tasks In Progress



Spring Semester Margin



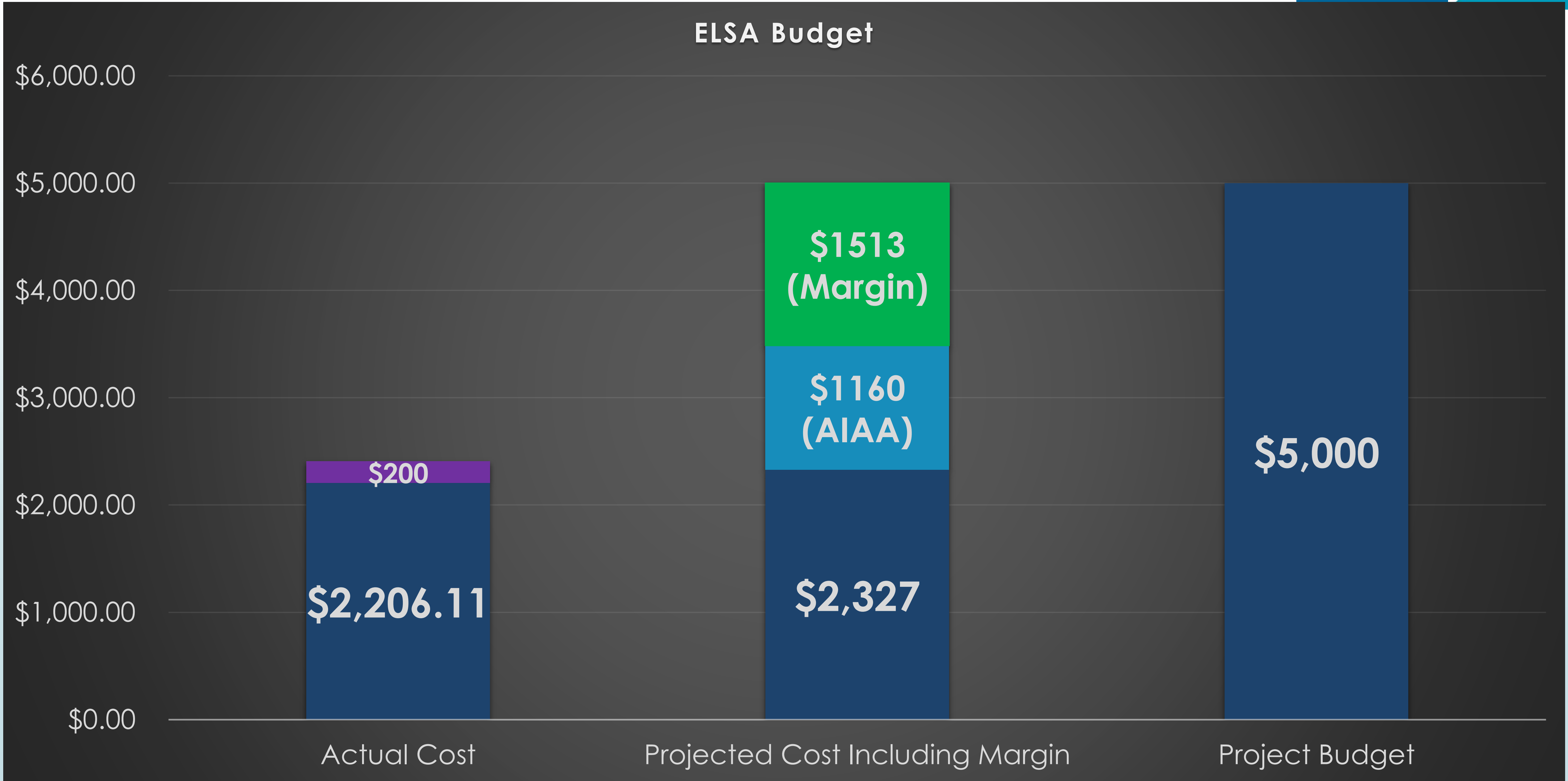
Budget

Project Overview | Schedule | Budget | Test Readiness

Procurement Status

- **Received Procurements**
  - Voltage Divider PCB Rev. 2: **DELIVERED**
  - ESD Ionizing Fan: **DELIVERED**
- **Pending/Future Procurements (Total: $200)**
  - Sensor PCB Revision 2 ~ $60
  - Material for Back-up Shelves ~$140
- **AIAA Conference**
  - Cost for 5 team members: $1160

No Budget Risk to Project



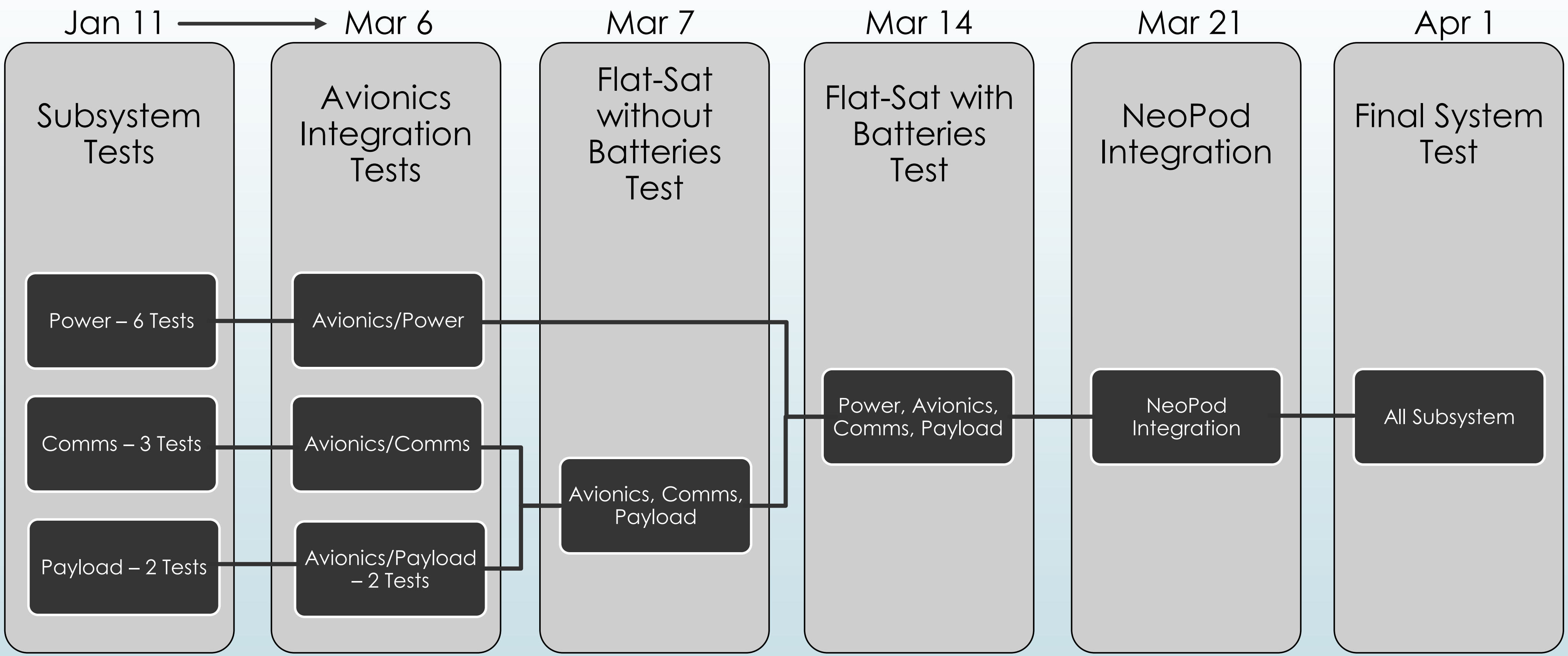
ELSA Budget
$6,000.00
$5,000.00
$4,000.00
$3,000.00
$2,000.00
$1,000.00
$0.00
$200
$2,206.11
$1513
(Margin)
$1160
(AIAA)
$2,327
$5,000
Actual Cost
Projected Cost Including Margin
Project Budget

Part	Projected Cost	Actual Cost	Difference	Projected + Margin
Batteries (x20)	$640.00	$404.88	$235.12	$768.00 (4 Batt.)
CC1101 Transceiver Kit	$500.00	$471.42	$28.58	$1000.00 (100%)
Wires, Connectors, Cables	$400.00	$239.09	$160.91	$1200.00 (200%)
Testing Equipment	$240.00	$236.35	$3.65	$265.00 (10%)
Metals and Fasteners	$177.00	$194.23	$17.23	$531.00 (200%)
Sensors	$165.00	$179.85	$14.85	$330.00 (100%)
Printed Circuit Boards	$100.00	$153.55	$53.55	$400.00 (300%)
Avionics Programmer	$50.00	$51.25	$1.25	$100.00 (100%)
DC/DC and Logic Converters	$35.00	$68.83	$33.83	$70.00 (100%)
Power Safety Devices	$20.00	$40.45	$20.45	$80.00 (300%)
Miscellaneous	-	$166.21	$166.21	-
Total:	**$2327**	**$2206.11**	**$120.89**	**$4744**

Test Readiness

Project Overview | Schedule | Budget | Test Readiness

Test Plan Overview



Requirement Mapping

Subsystem Tests	Avionics Integration Tests	Flat-Sat without Batteries Test	Flat-Sat with Batteries Test	NeoPod Integration Task	Final System Test
Payload L1 – L2	Payload L3	Power L1	Power L2	Structure L3 – L4	Power L4
Communication L1 – L4	–	–	–	–	–
Ground Station L1 – L4	Avionics L2 – L4	–	–	–	–
SCI 1	SCI 3	–	–	–	SCI 2
COM 1.1 – 1.2, 2.1 – 2.2, 2.4, 3.1 – 3.2, 4.2 – 4.3	COM 1.3, 5	COM 3.3, 4.1	–	–	COM 2.3
INT 3, 5.2 – 5.3	–	INT 6, 9	INT 6	INT 1 – 2, 4, 5.1, 8	INT 6, 7, 10
RF Link	–	*RF Link	*RF Link	–	*RF Link
–	–	–	Power	–	*Power
–	–	–	–	–	Thermal

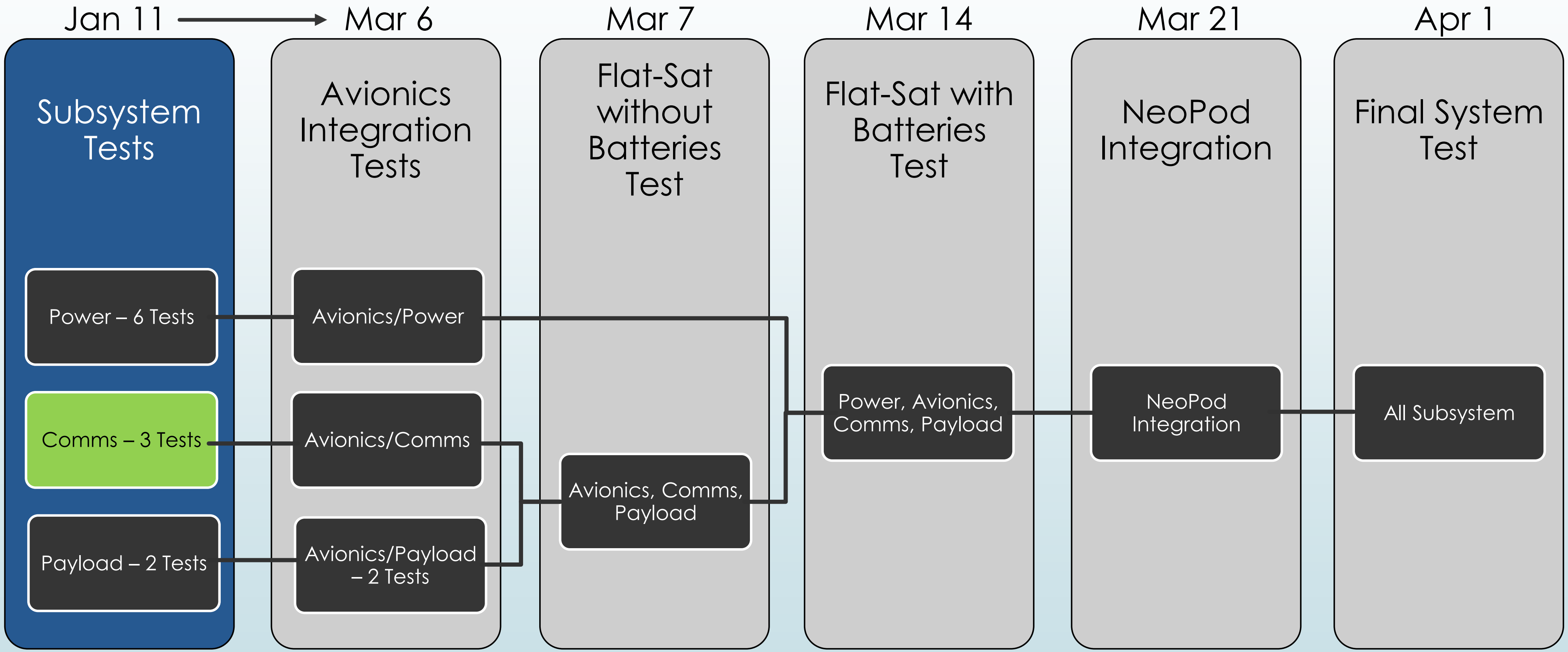
Key
Levels of Success
Functional Requirements
Models

All Requirements mapped to Verification Method

Project Overview | Schedule | Budget | Test Readiness

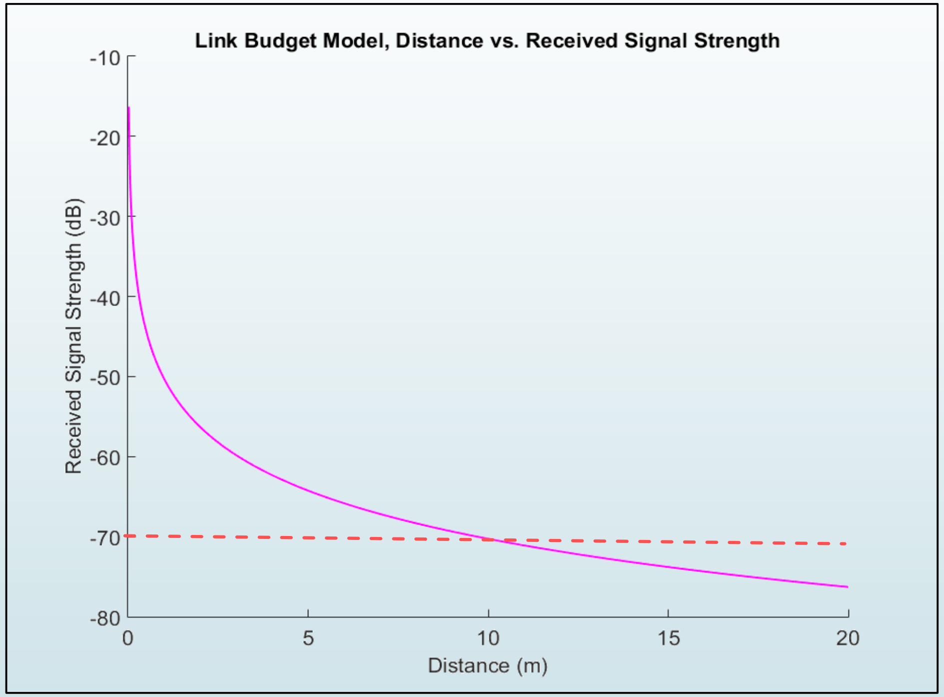
Subsystem Tests

Objective: Demonstrate subsystem functionality before integration with Avionics



RF Link Budget Test

- **Objective:**
  1. Determine the operating capabilities of communications system
  2. Find optimal location at which to run future tests
  3. Validate RF Link Model
- **Key Requirements:**
  1. COM 2 – ***NeoPod shall send data over RF***
  2. COM 4.1: ***Ground Station shall store received data from NeoPod***
- **Levels of Success:**
  1. Communications Level 1: Transmit and validate a known packet of 10 bytes over RF
  2. Ground Station Level 1: Record and validate a known packet of 10 bytes over RF
- **How It Reduces Risk:**
  1. Demonstrates that RF link is realistic and matches expected link budget
- **Associated Model:** Link Budget Model



Project Overview | Schedule | Budget | Test Readiness

Link Budget Test Logistics

Objective: **Determine Operating Capabilities of Communications System**

Location: **Bobby's Lab on 01/26/16**

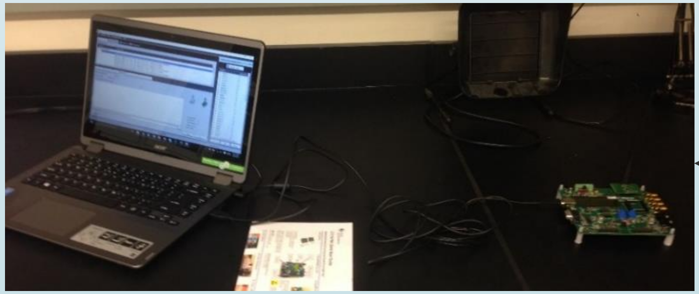
Duration: **2.5 Hour Test**

Measurements: **Received Signal Strength (RSSI) and Packet Error Rate (PER)**

Equipment	Procurement
CC1101 Development Kits x 2	Procured from Texas Instruments
NeoPod Patch Antenna	Ball Aerospace
Attenuators x 3 (5dB, 6dB, 11dB)	Professor Palo/Bobby's Lab
Laptops x 2 w/ Smart RF Software	Installed from Texas Instruments

Test Procedure:

1. Assemble **10 different attenuation configurations** to simulate increased distance
2. Send **3 trials of 1000 packets** at each simulated distance



1.8 meters

Link Budget Test Results

<u>In Operable Zone:</u>

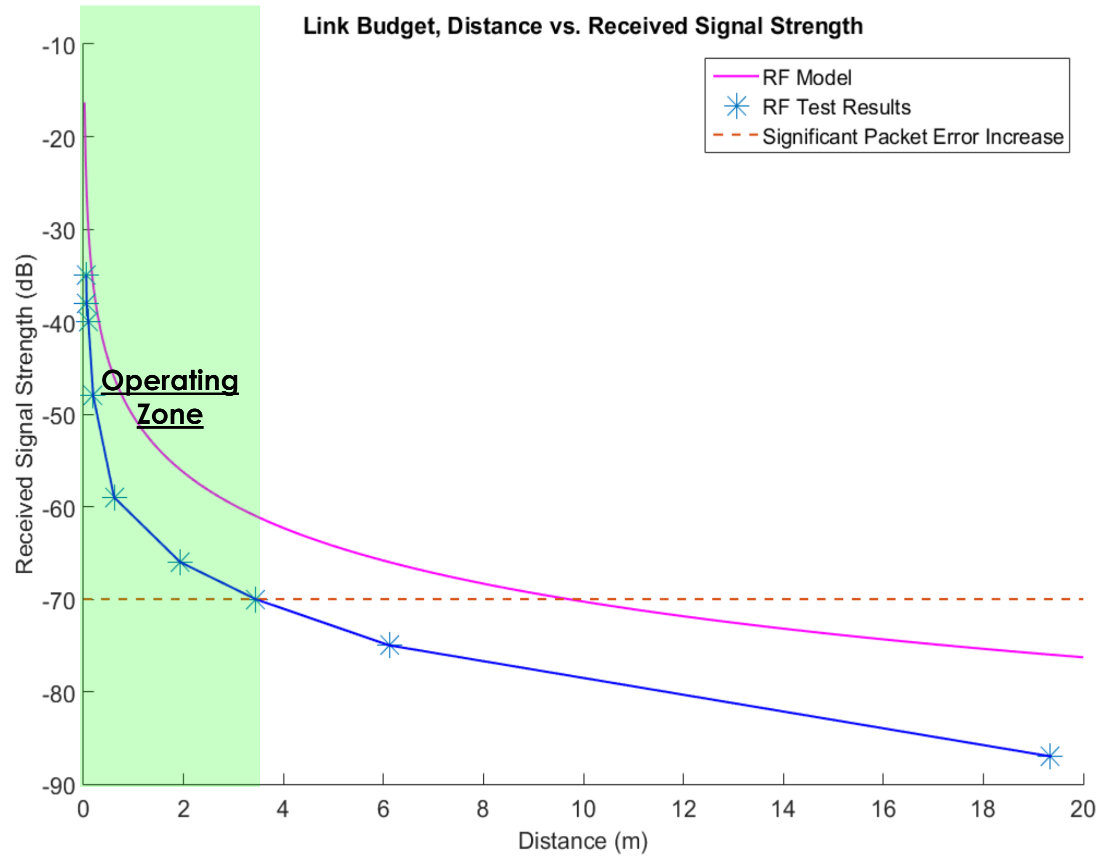
- **Achieved 0.005% PER**
- 3 Packet Errors out of 21000 sent
- Maximum Test Distance: 3.8 m

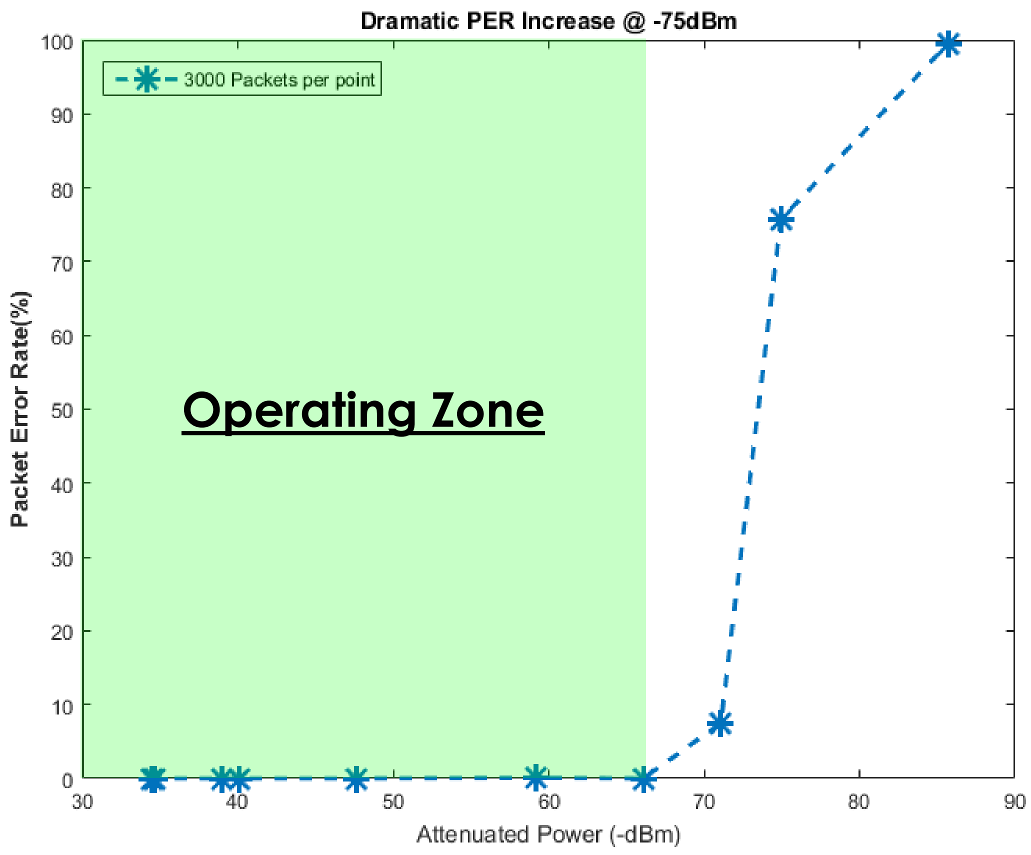
<u>Requirements Verified:</u>

1. COM 2 – NeoPod shall send data over RF

2. COM 4.1/4.3 – Ground Station shall store received data and display metrics on performance of system

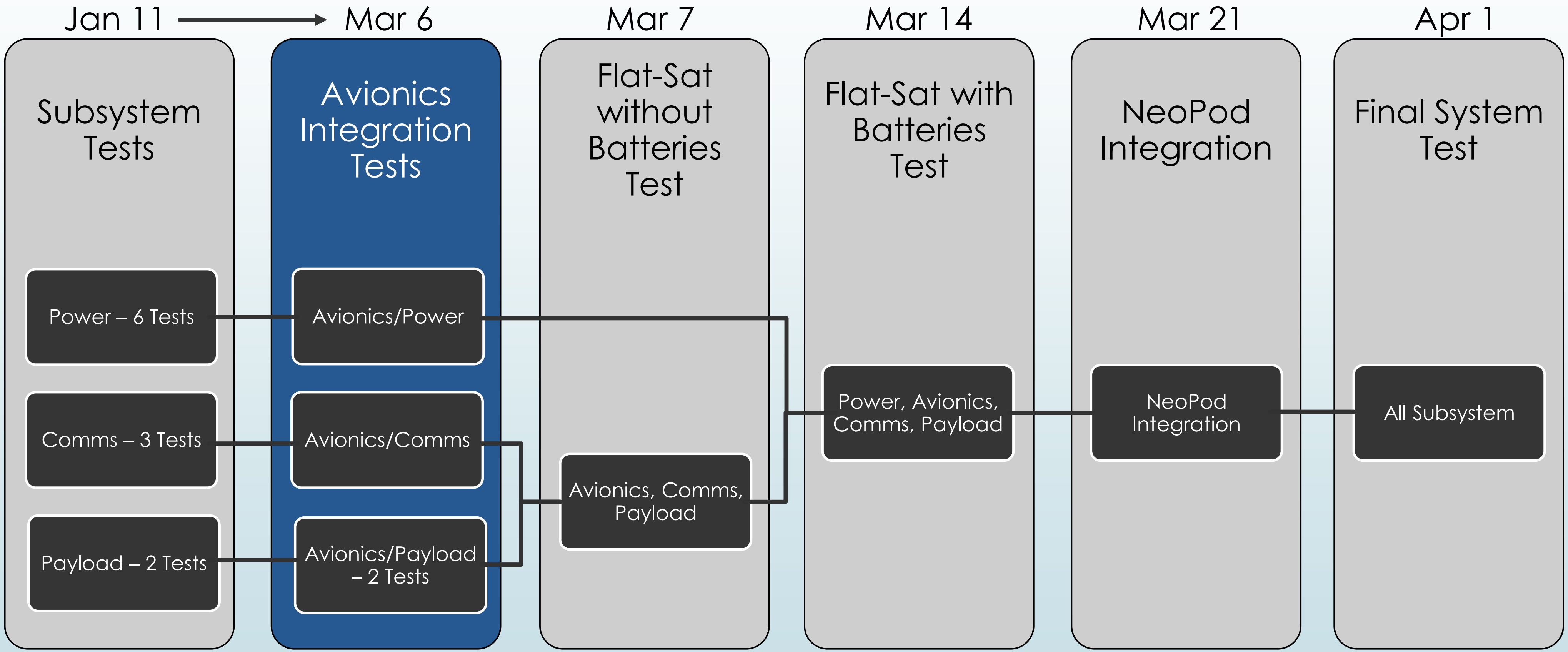
3. Level 1 Success Achieved for Communications System





Avionics Integration Tests

Objective: Test functionality of avionics system and other subsystems



Avionics Integration Tests

- **Objective:**
  1. Demonstrate functionality of various subsystems integrated with avionics system

- **Key Requirements:**
  1. COM 5: ***NeoPod communications system shall interface with avionics system***
  2. SCI 3.1: ***Avionics subsystem shall control data flow from sensors***

- **Levels of Success:**
  1. Avionics Level 2: Ball provided board handles data input and sends to communication system in real time
  2. Payload Level 3: Sensor sends collected data from instrument to avionics system

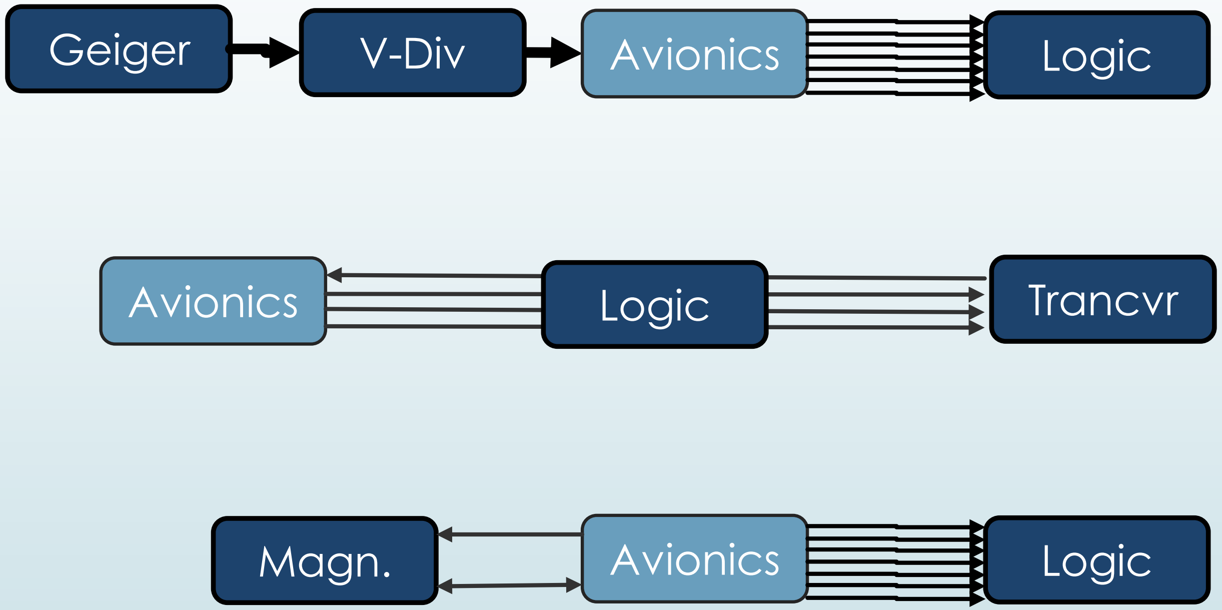
- **How It Reduces Risk:**
  1. Demonstrates that software functions as intended and increases confidence before integrating into full system

Payload → Avionics

Avionics → Communications

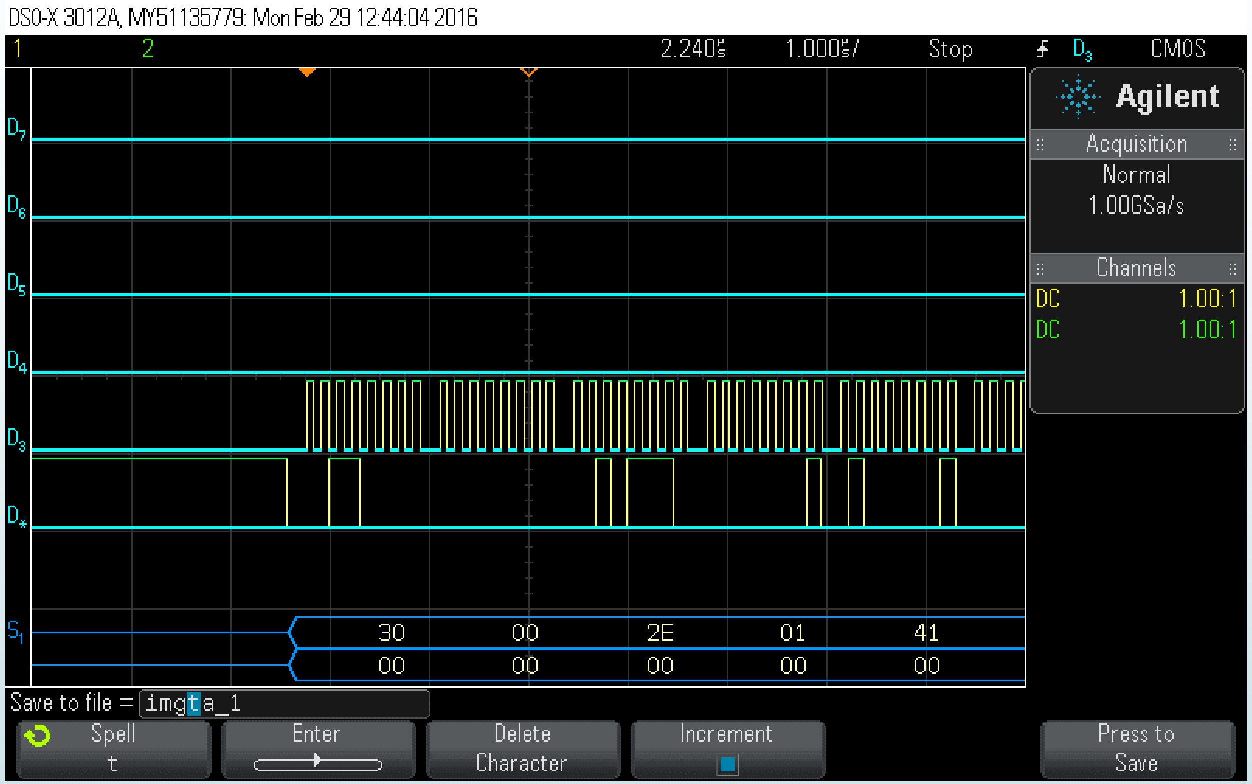
Avionics Integration Logistics

- **Power Connections**
  - Subsystems receive independent power with common ground
- **Digital Connections** over Avionics GPIO's
  - Geiger Test: Data Stream
  - Transceiver: SS, SCLK, MISO, MOSI
  - Magnetometer: SCL, SDA
- **Test Data Outputs** over Avionics GPIO's
  - Desired data can be monitored for debugging
- All connections recorded with **Logic Analyzer**
- All operations will follow **ESD Safety Protocols**



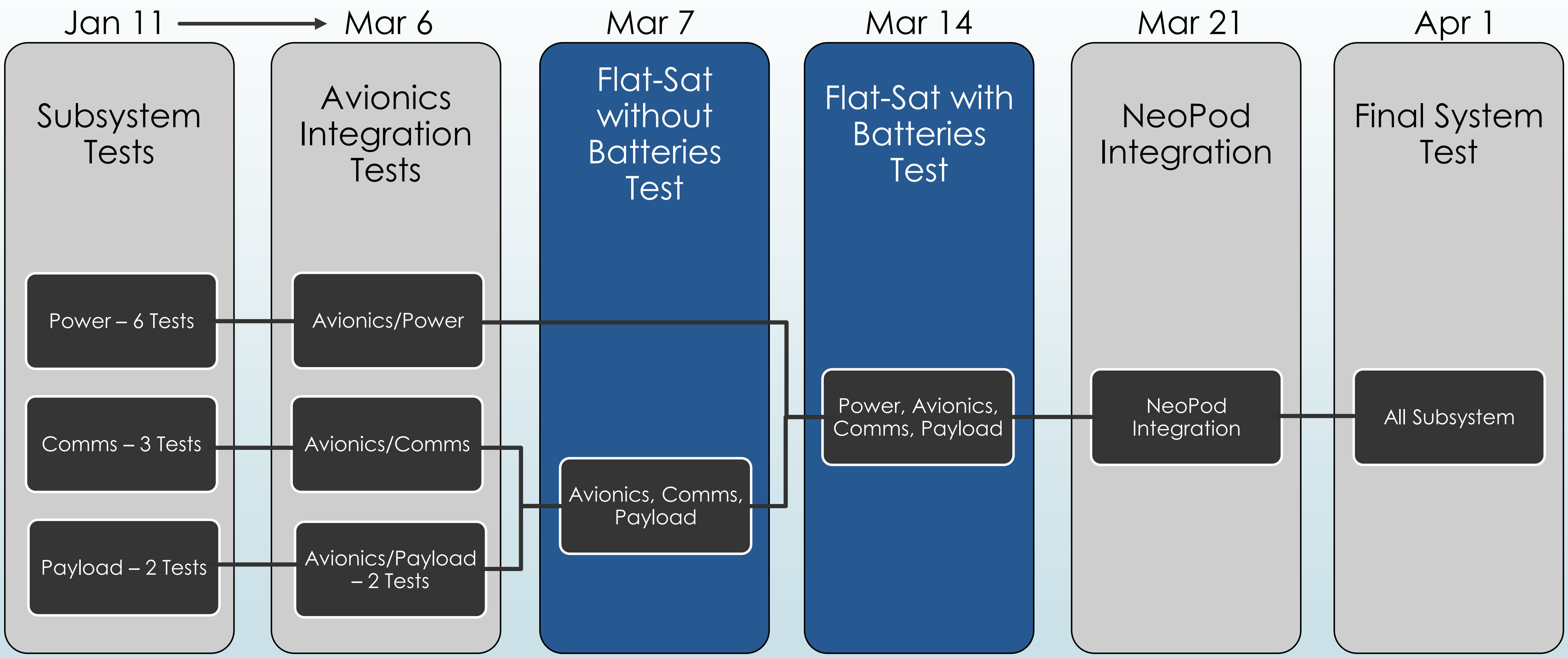
Results / Expected Results

- Geiger Counter Test
  - **ID Byte: ASCII "G"**
  - **First Timestamp: 600**
  - **Manual Counts = Output Data**
- Transceiver Test
  - **Correct Register Values on Boot Up**
  - Command Reception
  - Data Transmission / Reception on Ground Station
- Magnetometer Test
  - ID Byte: ASCII "M"
  - Data at .066 sec intervals
  - Similar Data to Arduino Test



Flat-Sat Testing

Objective: Early demonstration of system functionality prior to integration with the structure



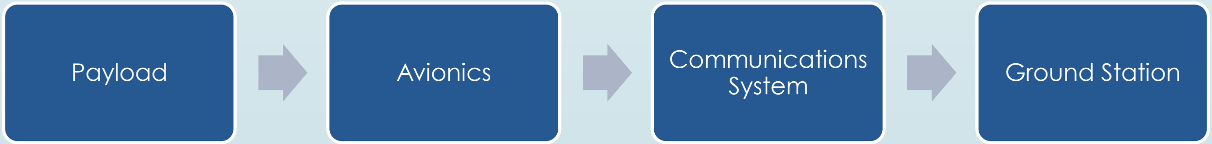
Flat Sat without Batteries Test

- **Objective:** First test of fully integrated data path
  1. Demonstrates primary functionality of system
  2. Proves capability of Comms. system for full data collection period
  3. Provides better fidelity for thermal model

- **Key Requirements:**
  1. SCI 3.5: ***Avionics Subsystem shall store data collected from sensors***
  2. COM 3: ***Ground Station shall transmit commands over RF***
  3. COM 5.1.2: ***NeoPod communication system shall remain in transmit mode for 8 minutes upon command***

- **Levels of Success**
  1. Power Level 1 – Power supplied to system using external power supply

- **How it Reduces Risk:**
  1. By demonstrating data flow, this test reduces the risk to this aspect of future testing.



Flat-Sat without Batteries Test Logistics

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

Location: **Trudy's Lab week of March 7th, 2016**

Duration: **3 Hour Test**

Measurements: **Preliminary Component Temperatures, Redundant RSSI and PER Readings**

Equipment	Procurement
Laptop w/ Smart RF	Installed
TENMA EX354 Power Supply	Trudy's Lab
K-type thermocouples (x11)	Trudy's Lab
NI9213 DAQ	ITLL

Test Procedure:

1. Collect data for **8 minutes**
2. Automated command from Ground Station
3. Transmit and receive data for 8 minutes
4. **Repeat 4x**

5. Collect data for **2 hours**
6. Automated command
7. Transmit and receive data for 8 minutes

Safety:

1. ESD Safety Procedure in place

Flat Sat with Batteries Test

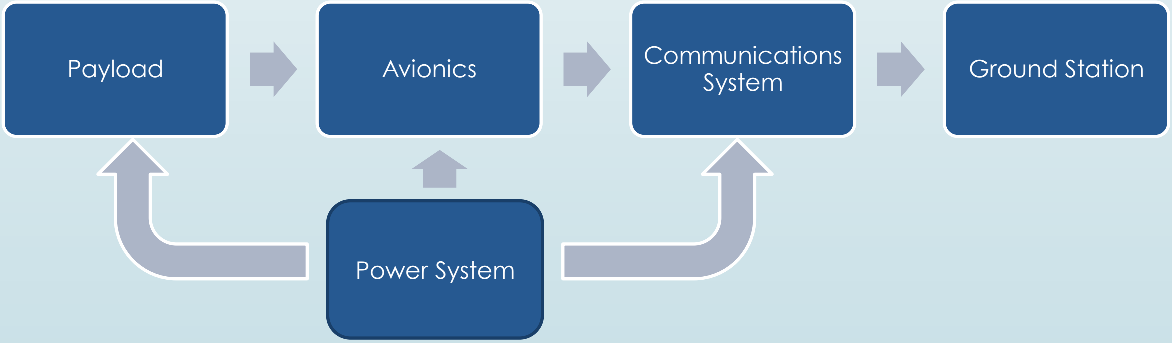
- **Objective:** Test of full system functionality
  1. Validates first 6 hours of battery curve
  2. Additional confidence in overall functionality of system

- **Levels of Success**
  1. Power Level 2 – Regulated self-contained power system that supplies needed voltages within 0.3 V tolerance
  2. **Meets Level 3 System Success**

- **Key Requirements:**
  1. INT 5: ***NeoPod shall have an independent power system***

- **How it Reduces Risk:**
  1. Demonstrates confidence that system can last for full 100 hours
  2. All requirements can be met if this test is successful

- **Associated Model:**
  1. Battery Discharge Model



Flat-Sat with Batteries Test Logistics

Objective: **Fully Integrate Payload-Avionics-Communications with Power System**

Location: **Trudy's Lab, week of March 14th, 2016**

Duration: **6 Hour Test**

Measurements: **Battery Voltage Readings, Preliminary Temperatures, PER**

Equipment	Procurement
Laptop w/ Smart RF	Installed
FLUKE 287 True RMS Multimeter	Trudy's Lab
K-type thermal couples (x11)	Trudy's Lab
NI9213 DAQ	ITLL

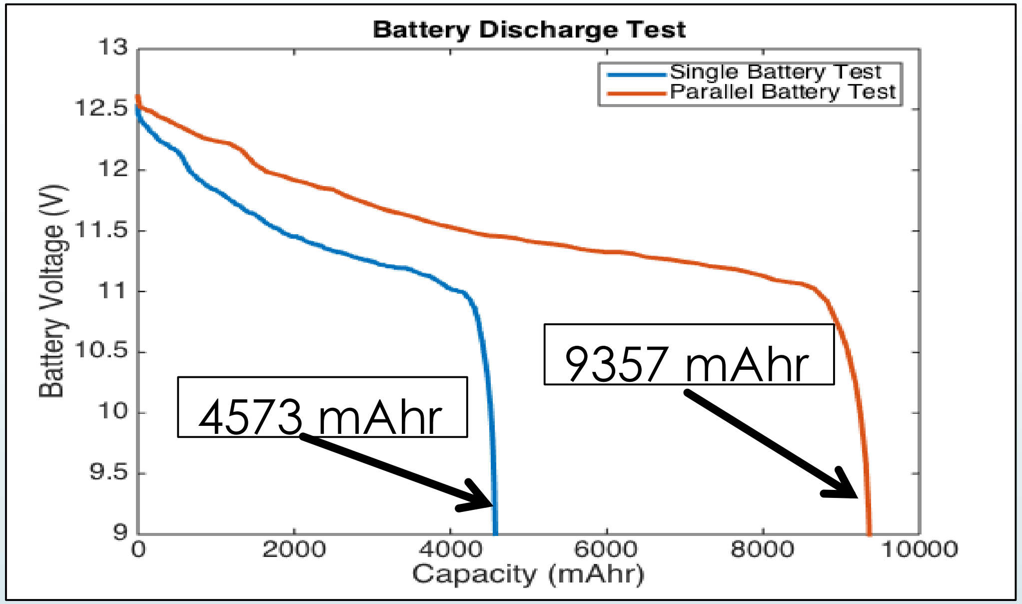
Test Procedure:

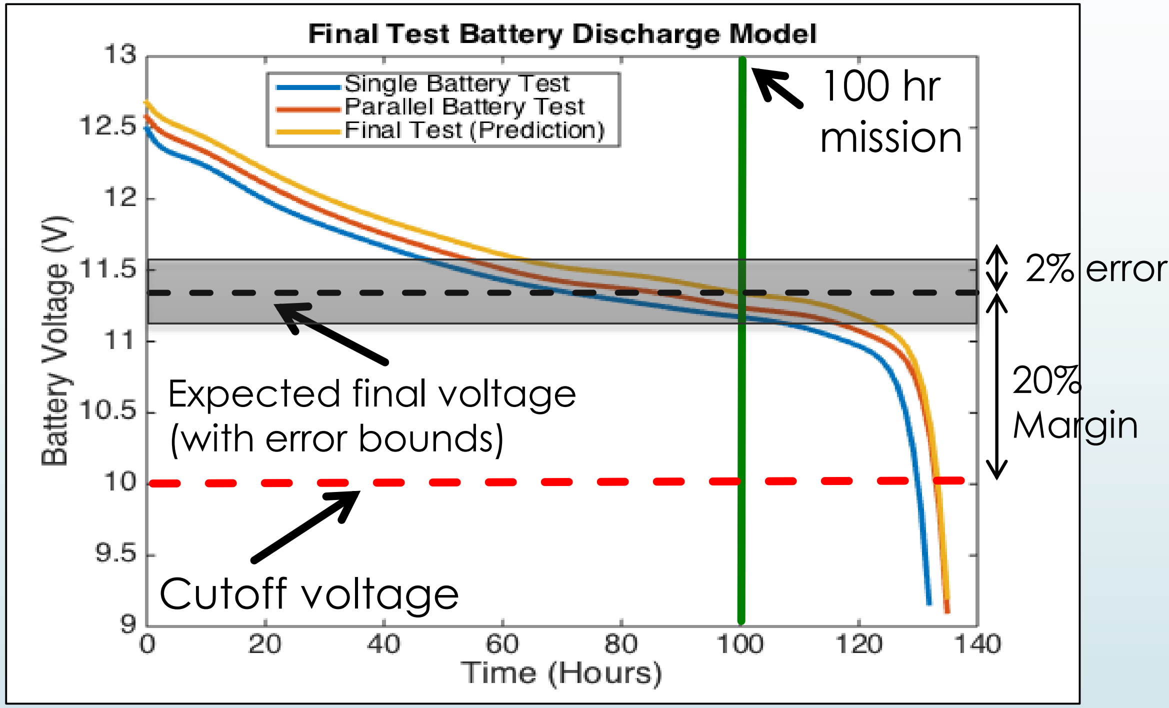
1. Collect data for **2 hours**
2. Automated command
3. Transmit and receive data for 8 minutes
4. **Repeat 3x**

Safety:

1. ESD Safety Procedure in place

Flat Sat with Batteries Test Results:
Battery Discharge Model



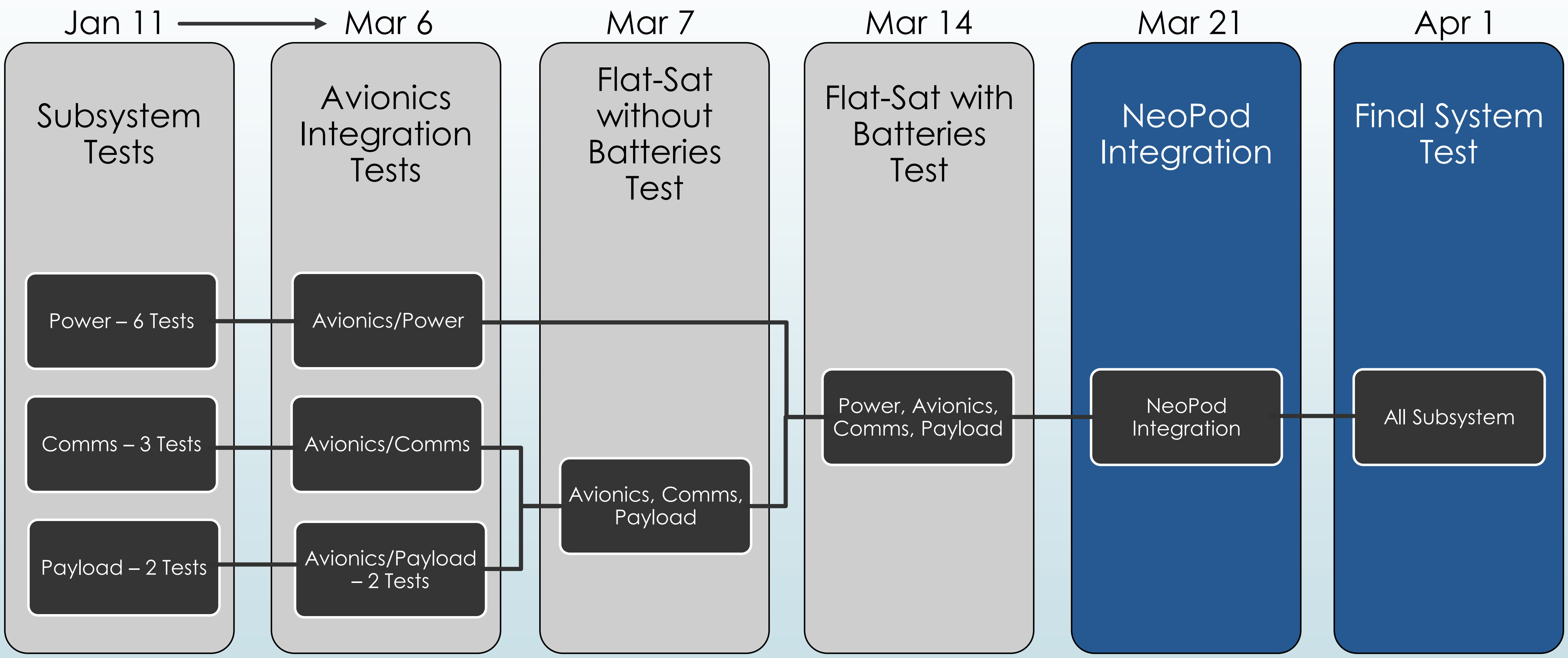


- Tests were scaled to create a model for 15 batteries
- Possible error from avionics power budget → 2% = 0.226 V
- Possible min of 11.1 V, max of 11.6 V

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

Full Integrated Testing

Objective: Demonstration of fully integrated system functioning within the closed sphere for 100 hours



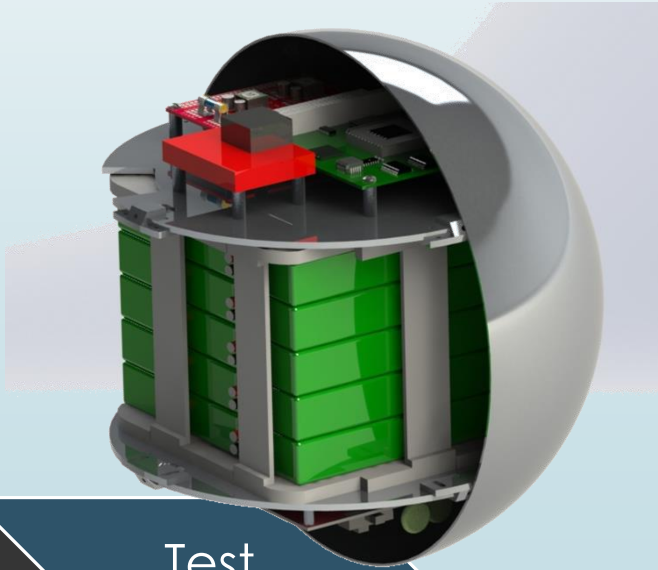
Full Integrated Test

- **Objective:**
  1. Fully integrated, closed ball sphere successfully runs for 100 hours

- **Key Requirements:**
  1. INT 6: ***The NeoPod's internal components shall operate under their maximum operating temperatures for duration of 100 hour test***
  2. INT 10: ***NeoPod shall be capable of being powered for a 96 hour period***
  3. SCI 2: ***NeoPod shall limit scientific data collection over a 100 hour period to less than 353 MB***
  4. INT 4.2: ***All components and wiring shall be contained within the external shell***

- **Levels of Success:**
  1. **Full System Success (Level 4)**
  2. Power Level 4: 100 hour lifespan with continuous data collection and two hour transmission cycles
  3. Structure Level 3/4: Internal structure integration within 25 cm spherical shell and mass less than 10 kg

- **Associated Models:**
  1. Battery Discharge Model (Fully Validated)
  2. Thermal Model



Fully Integrated Test Logistics

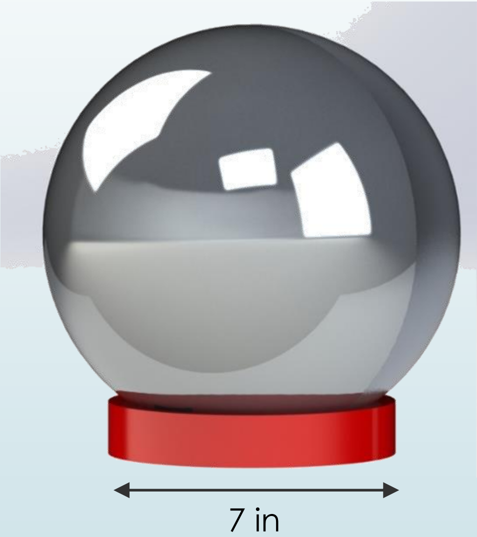
Objective: **Fully integrated, closed ball NeoPod runs for 100 hours**

Location: **Trudy's Lab week of April 1, 2016**

Duration: **100 Hour Test**

Measurements: **Internal Temperatures, Redundant RSSI and PER Readings**

Equipment	Procurement
Laptop w/ Smart RF	Installed
FLUKE 287 True RMS Multimeter	Trudy's Lab
K-type thermocouples (x11)	Trudy's Lab
NI9213 DAQ	ITLL



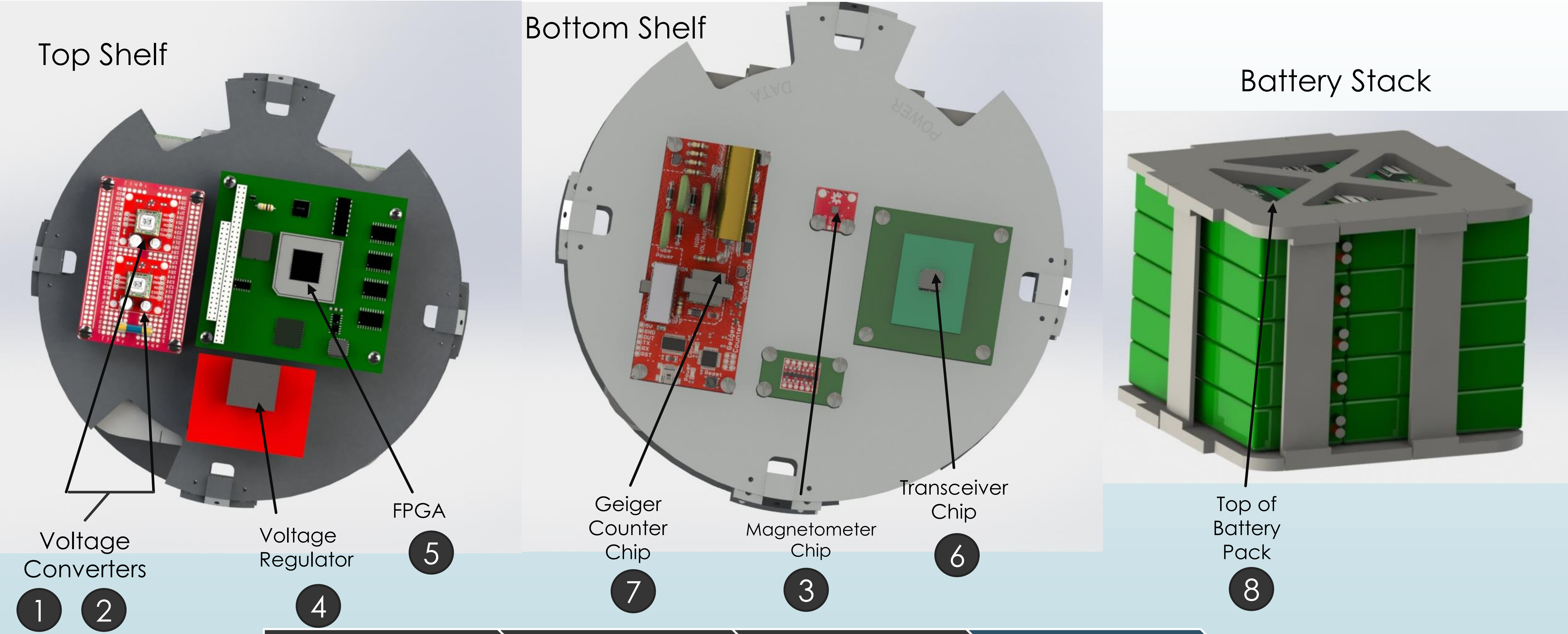
Test Procedure:

1. Collect data for **120 minutes**
2. Automated command from Ground Station
3. Transmit and receive data for 8 minutes
4. **Repeat 47x**

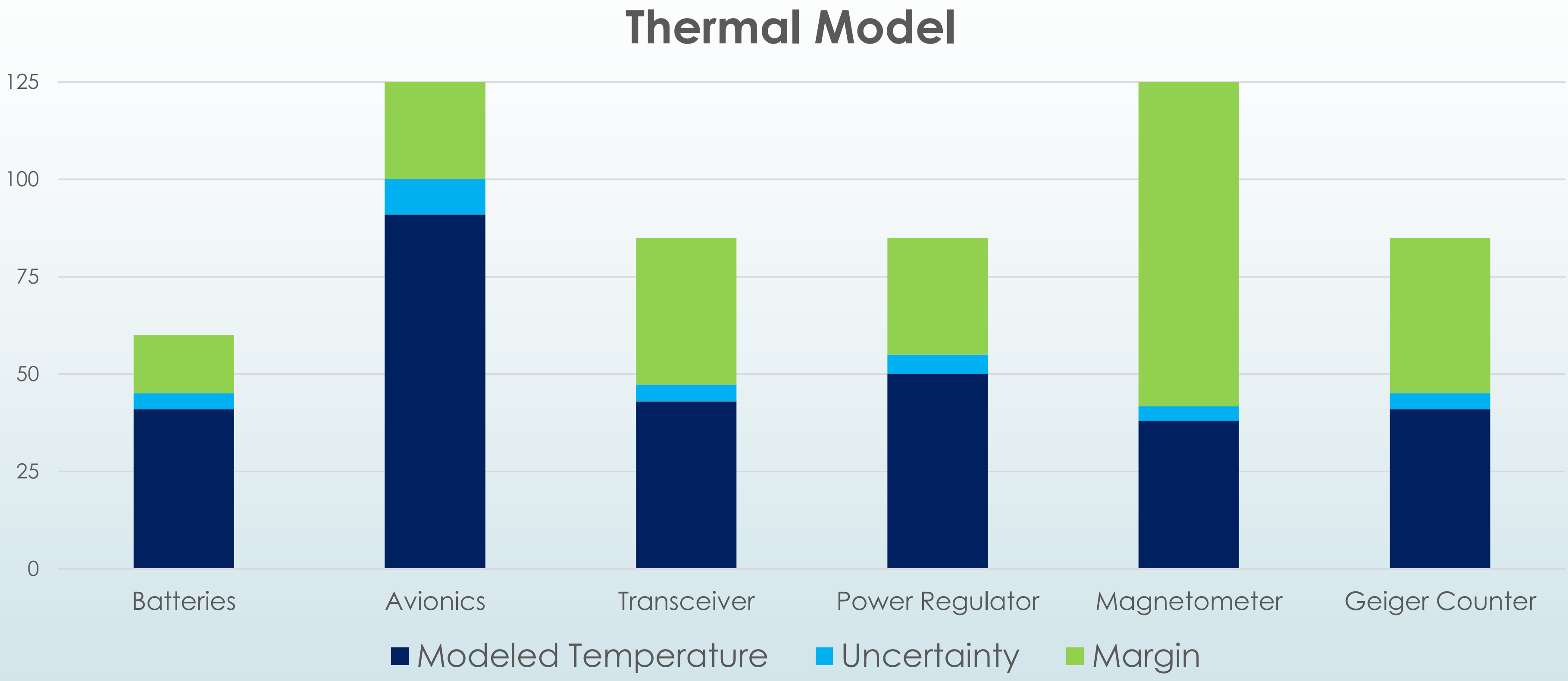
Safety:

1. ESD Safety Procedure in place
2. Cutoff Values set for monitored temperatures and voltages
3. Two team members watching at all times in alternating 2 hour shifts

Fully Integrated Test Logistics: Thermocouple Placement



Fully Integrated Test Expected Results



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

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

Other Key Expected Results:

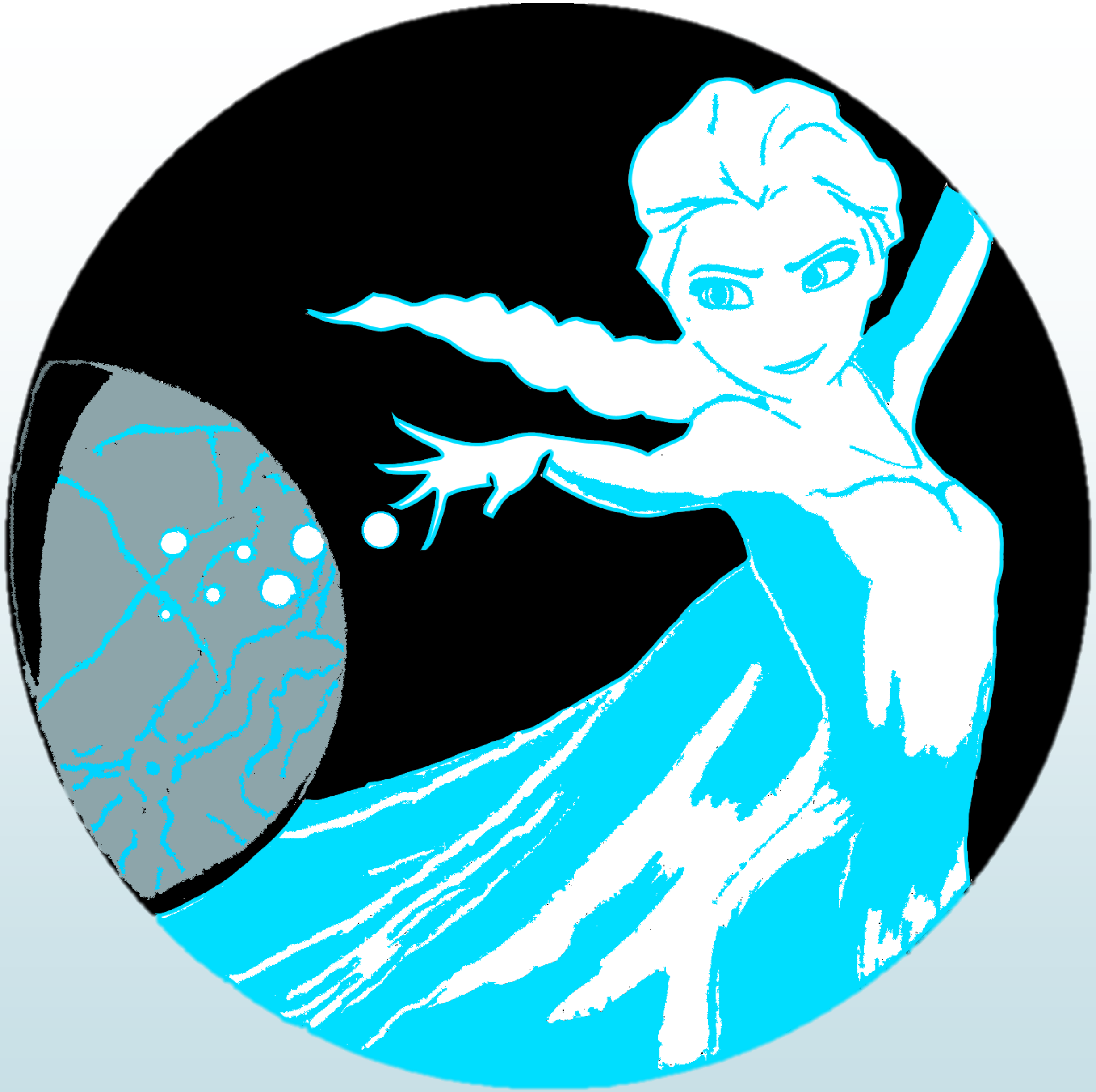
Total Expected Data:
54.06 MB

Total Expected Packets:
865,000 Packets

Expected Packet Error Rate:
0.005%

SCI 2: ***NeoPod shall limit scientific data collection over a 100 hour period to less than 353 MB***

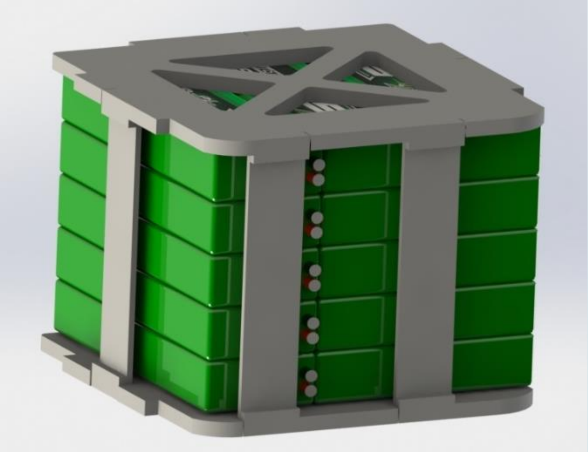
Questions?



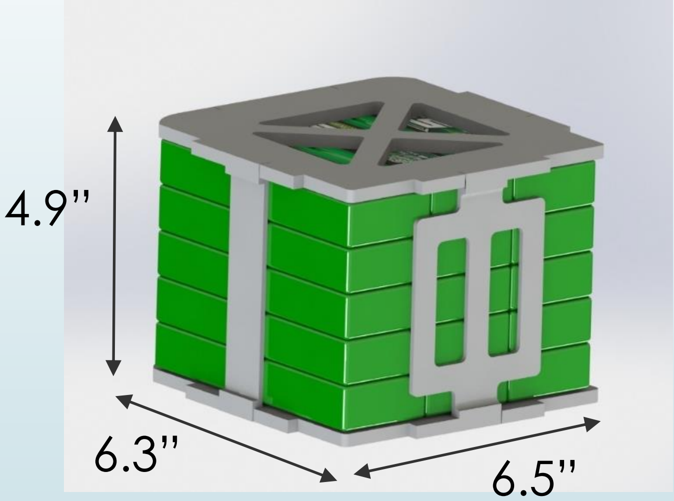
Backup Slides

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)



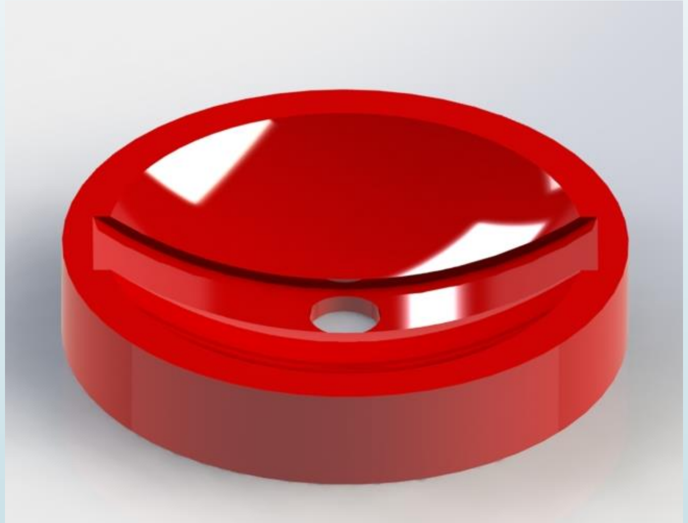
Front



Back

Stand for Testing

- Will 3D print in ITLL using PLA material
- Contoured to fit NeoPod (with outer metal band)
- Rubber pads will be placed 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

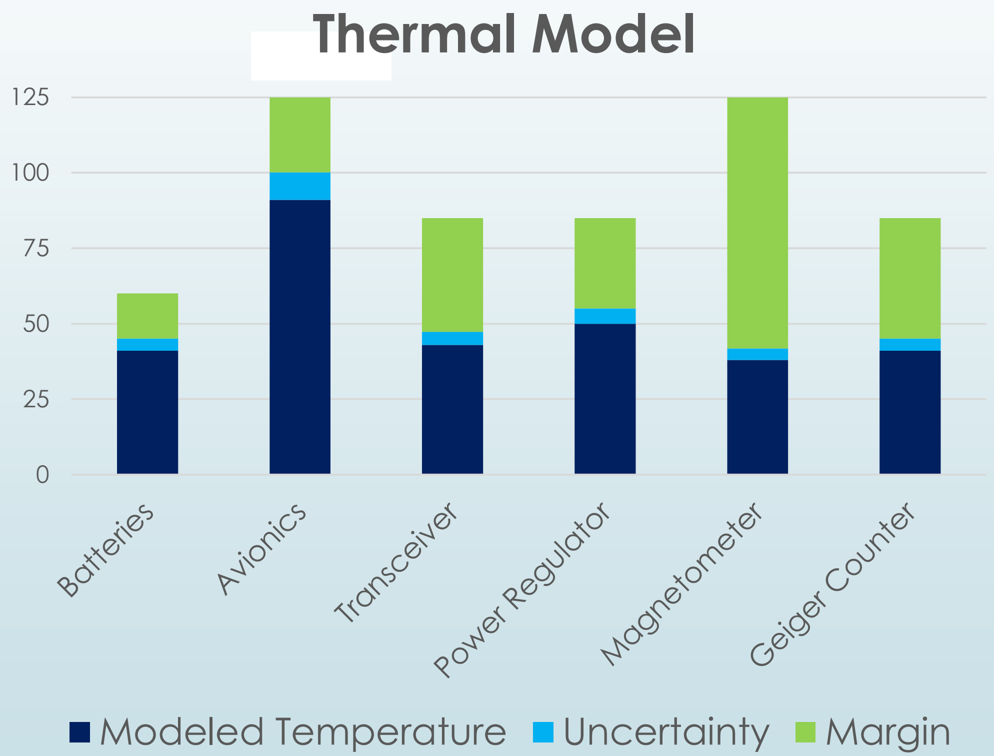
- **Successfully integrate independent power system**
- **Reduce risk and increase confidence of power system before final test**
- **Further validate battery characterization model**

Achieves **System Level 3 Success**

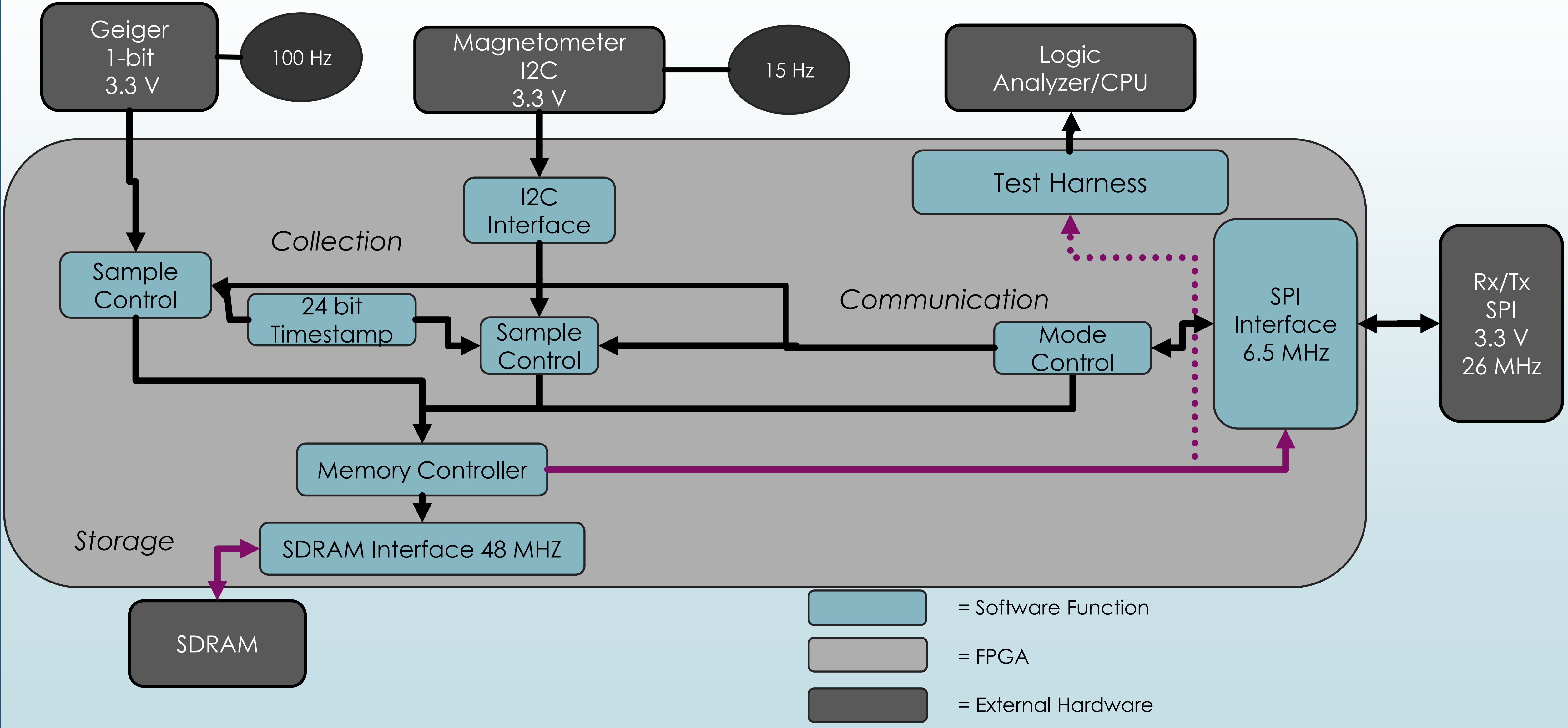
Thermal Model Validation

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

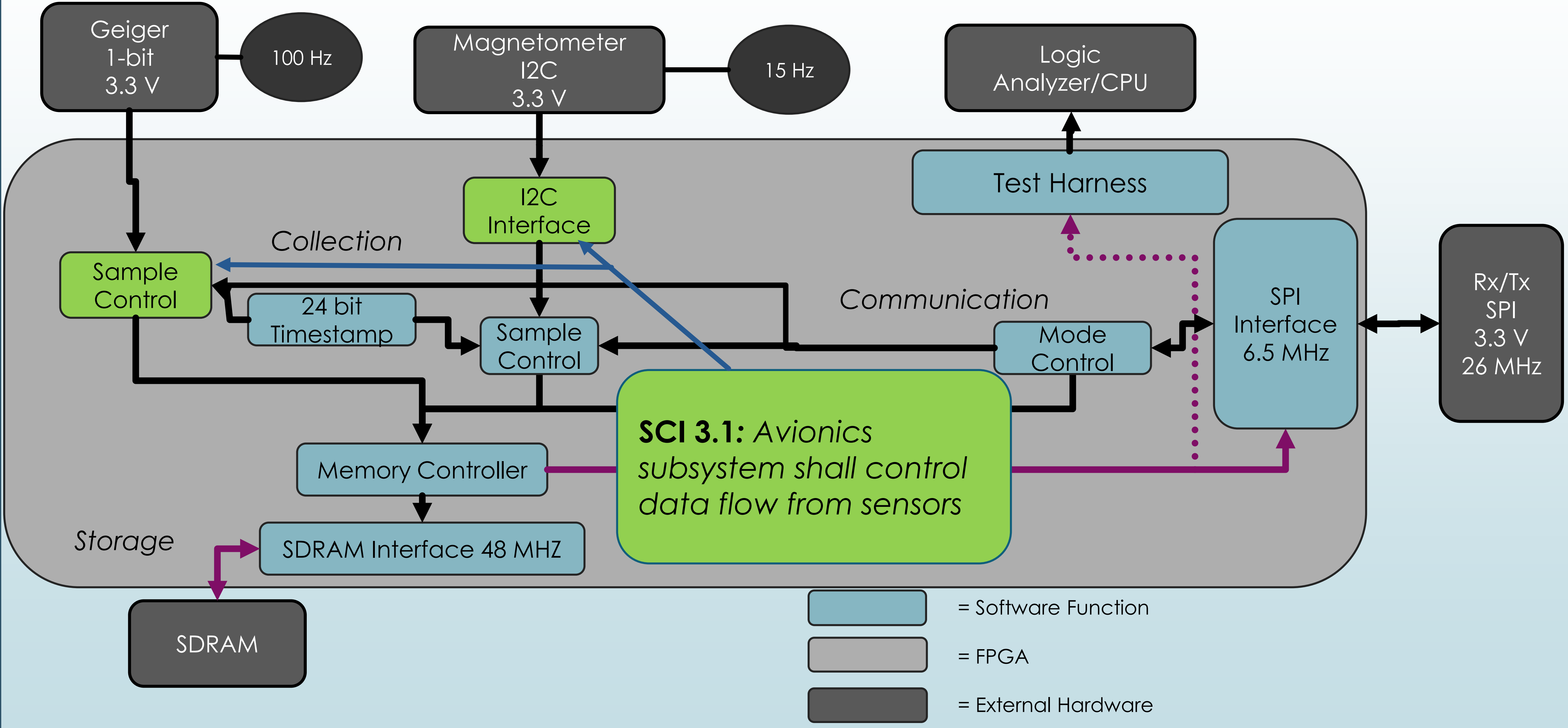
Equipment*	Resolution	Procurement
(10) K-type Thermocouples	1.1 °C	Trudy's Lab
NI9213 DAQ	0.02 °C	ITLL
Full NeoPod Assembly	-	-



CPE-1: Avionics Software

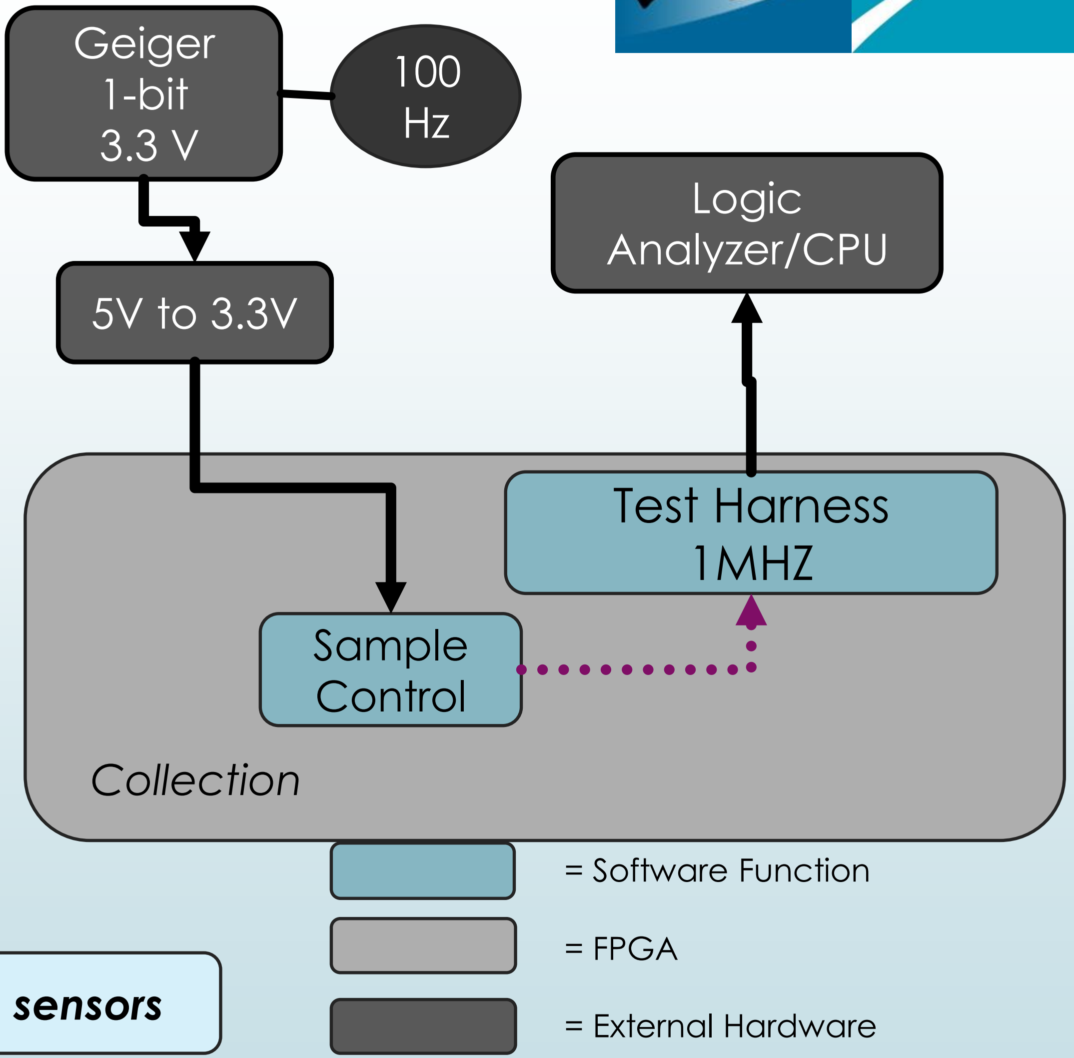


CPE-1: Avionics Software



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**



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

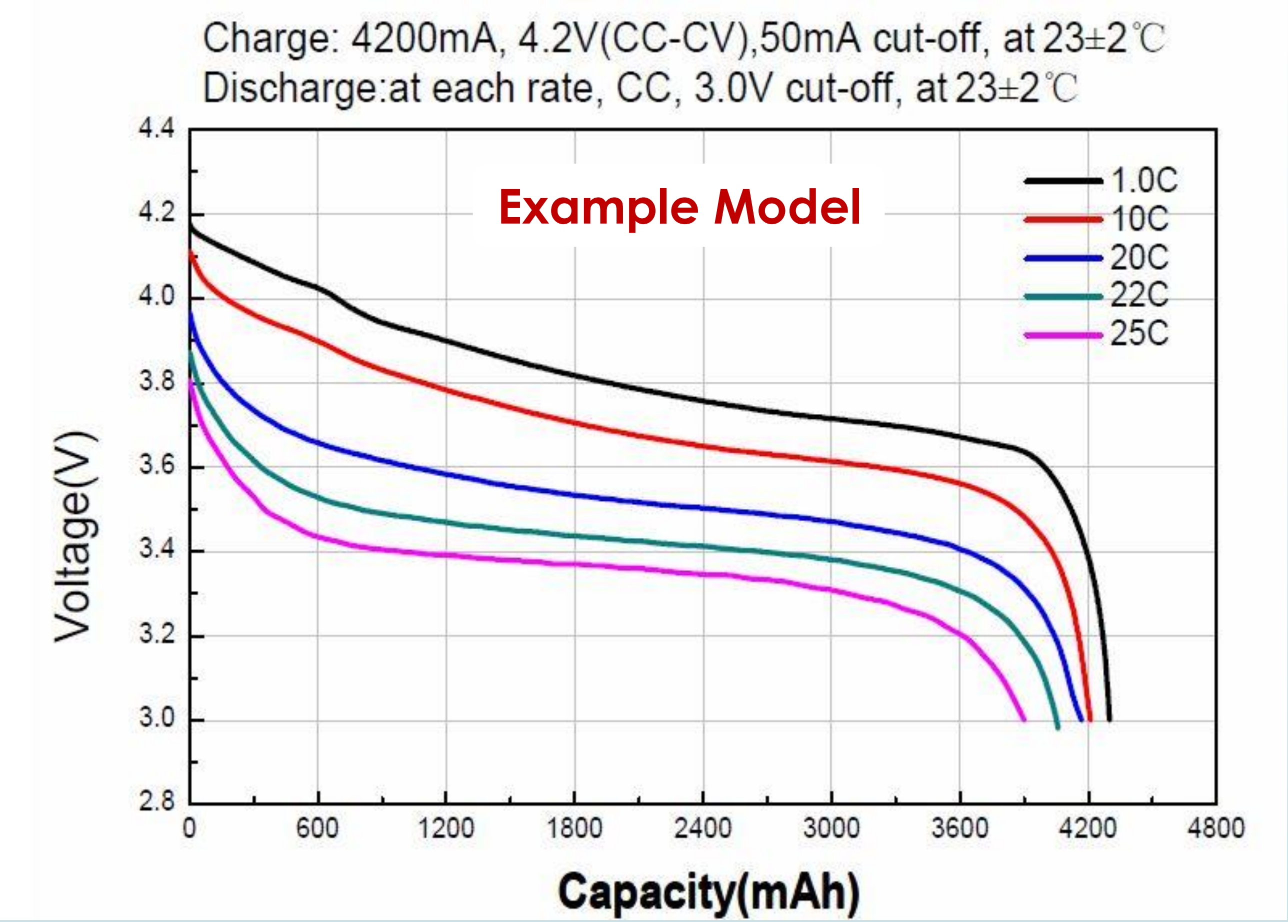
Payload → Avionics Test Results

- 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*

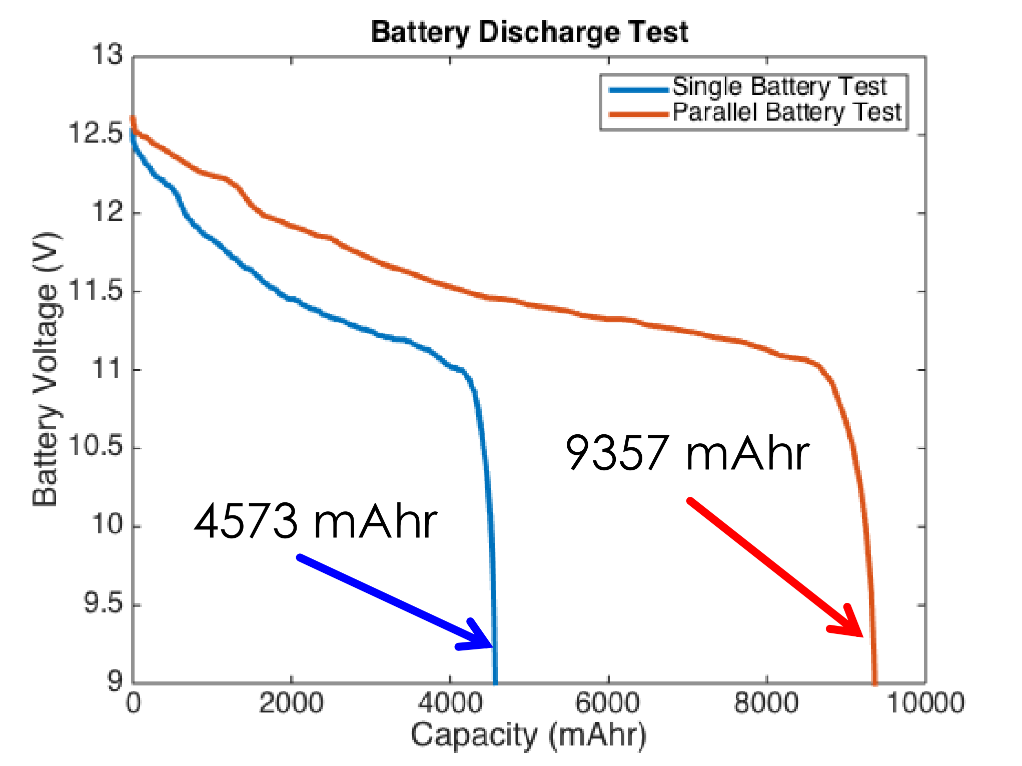
Battery Discharge Model

- 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

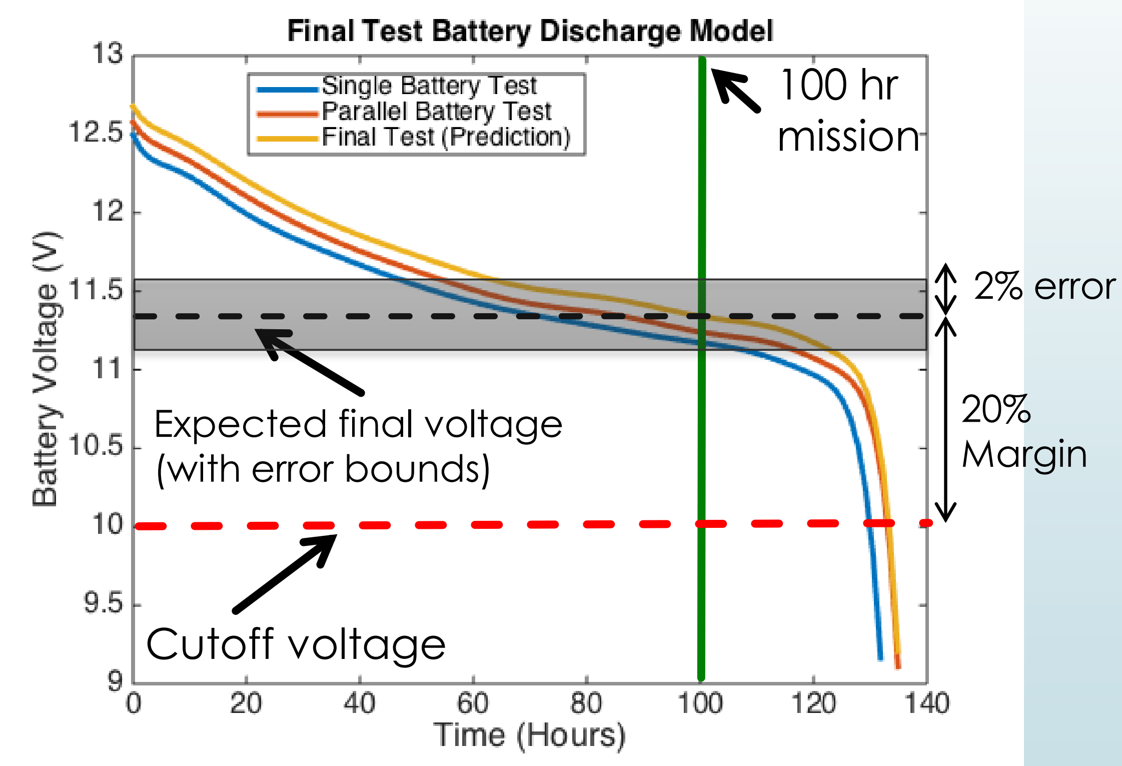


Battery Discharge Test: Results

- 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



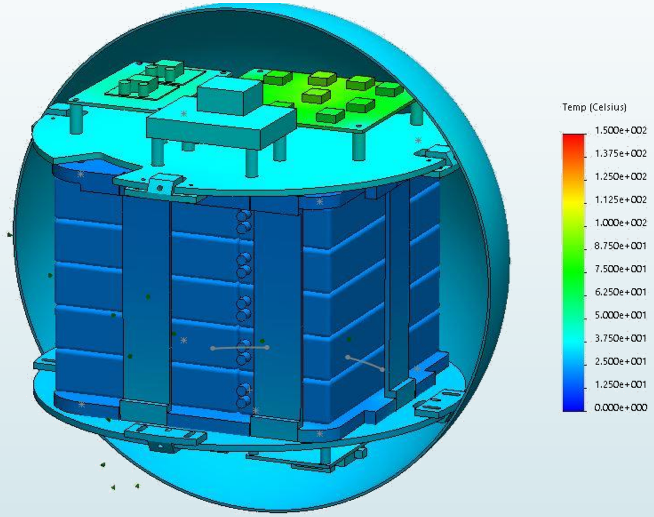
Project Overview | Schedule | Budget | Test Readiness

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



Project Overview | Schedule | Budget | Test Readiness

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

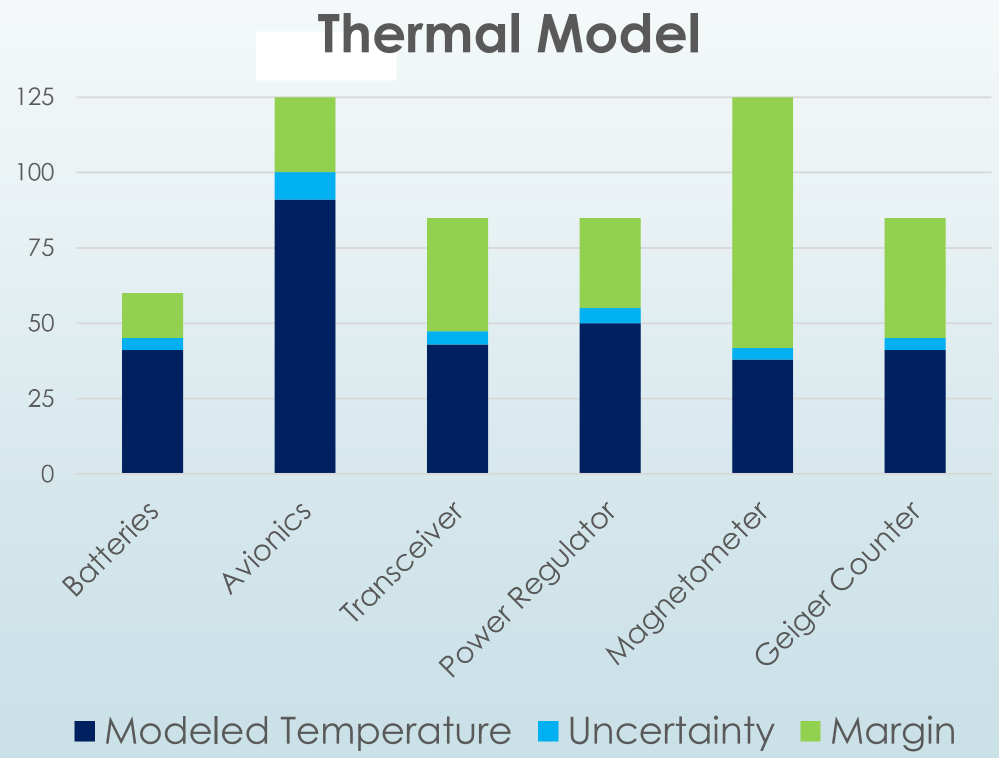
Proposed Observation Schedule:

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**

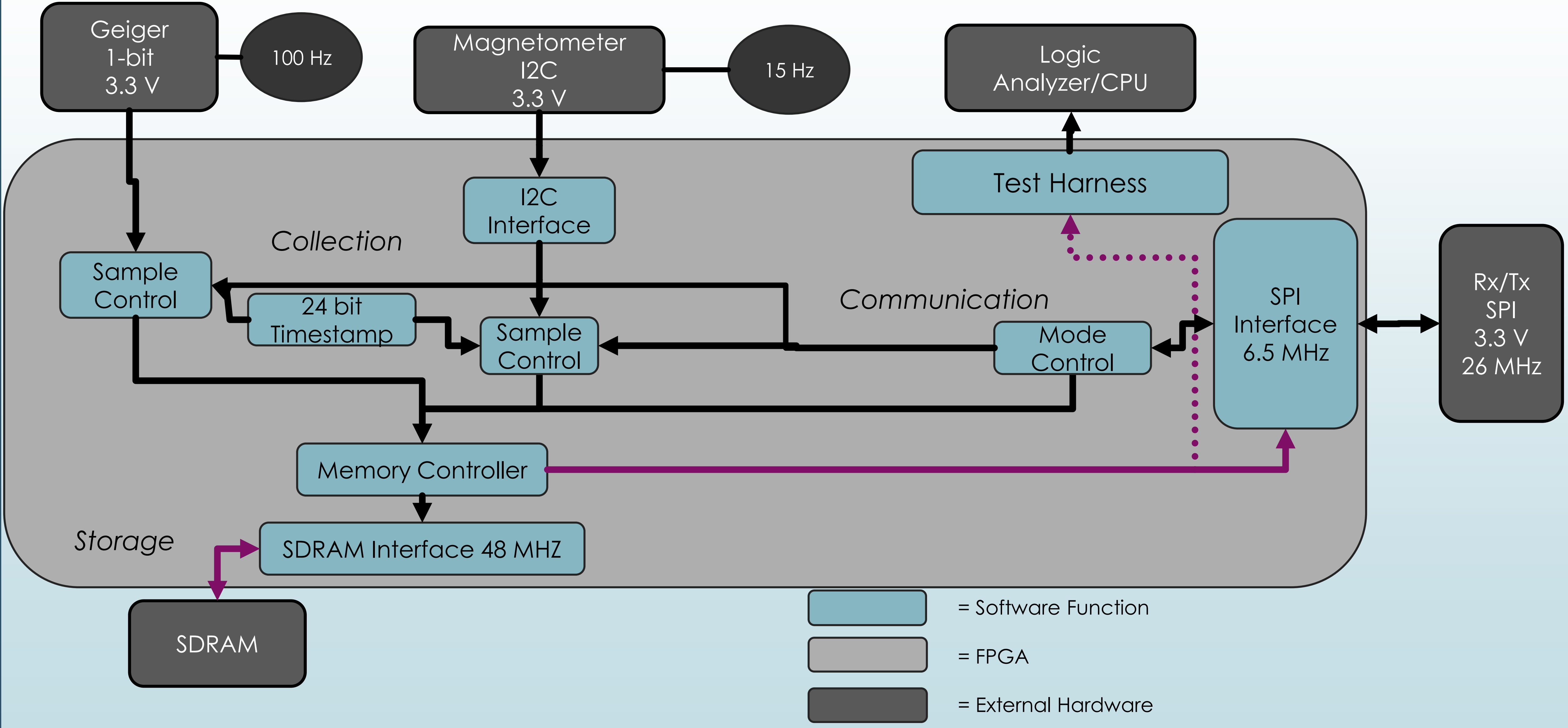
Avionics

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

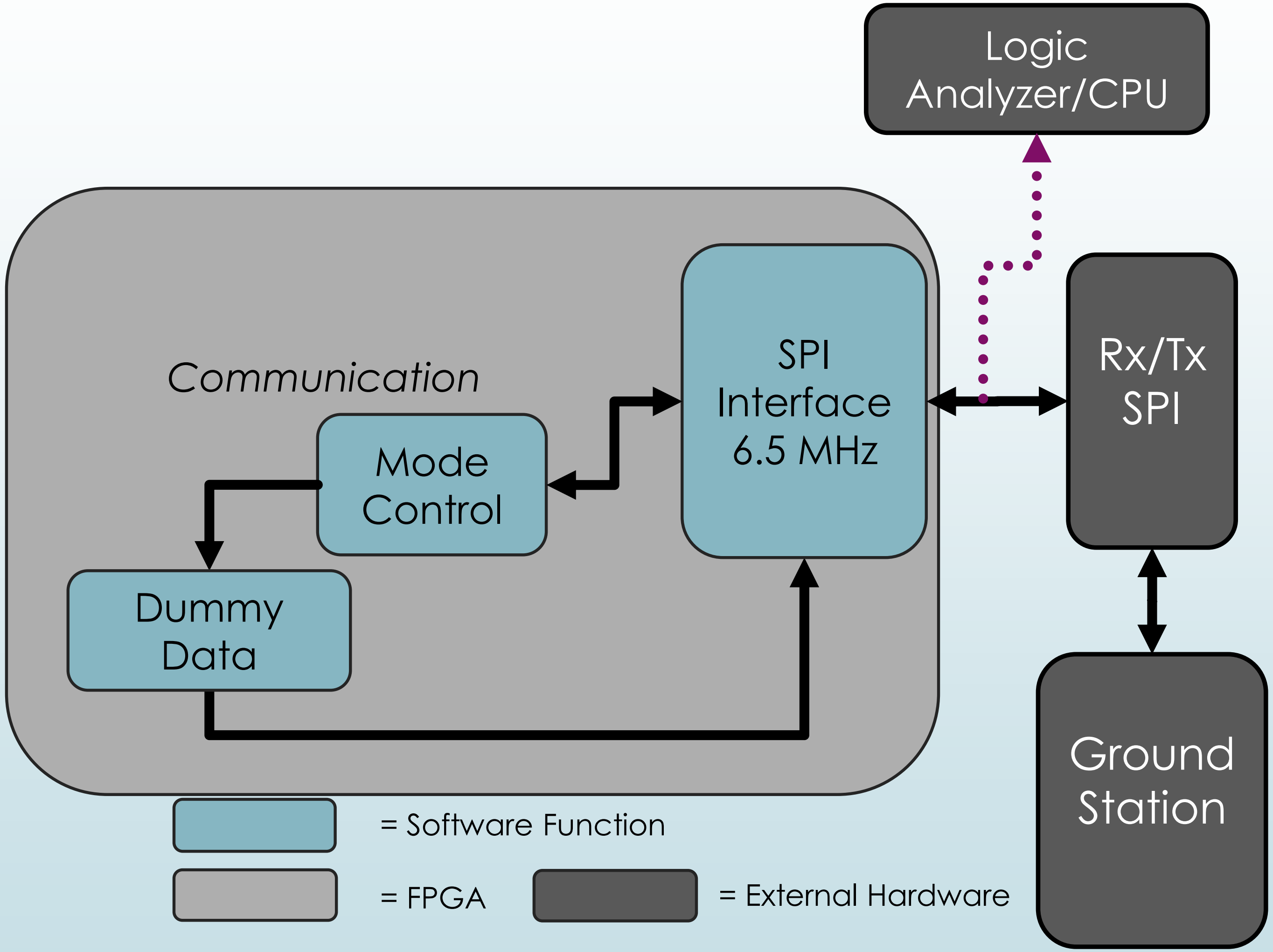
COM 5: *NeoPod communications system shall communicate with avionics system*
SCI 3.1: *Avionics subsystem shall control data flow from sensors*
INT 5: *NeoPod shall have an independent power system*

Avionics Software



Transceiver → Avionics Test

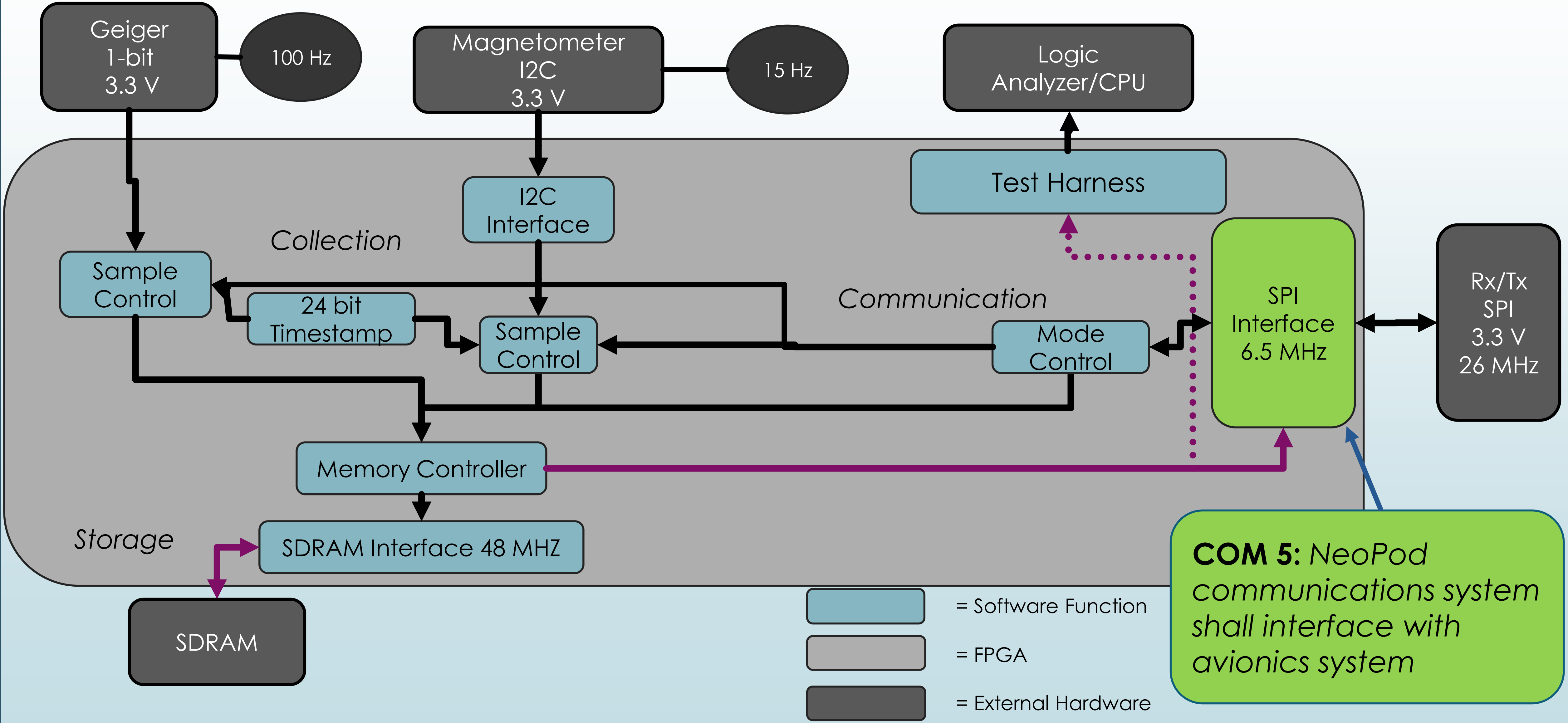
- Boot Up Test
  - Verify initial register writes are correct
- Transmission Test
  - Send command from ground station, monitor data transmission
- Protocols
  - ESD Safety Procedures
  - 1.5m Transmit Distance
- **Date: 2/25/2016**



Transceiver → Avionics Test Results

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

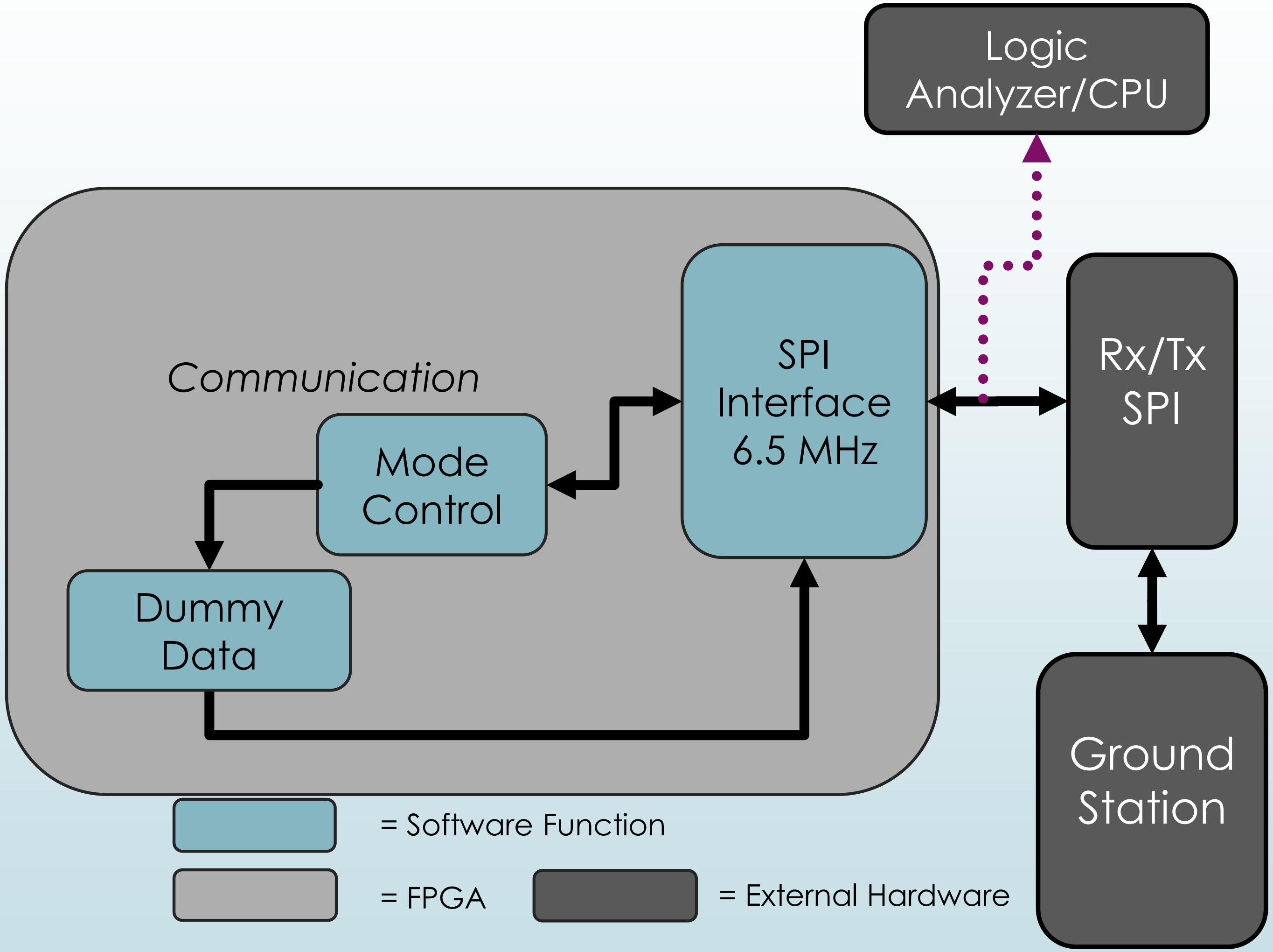
CPE-1: Avionics Software



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

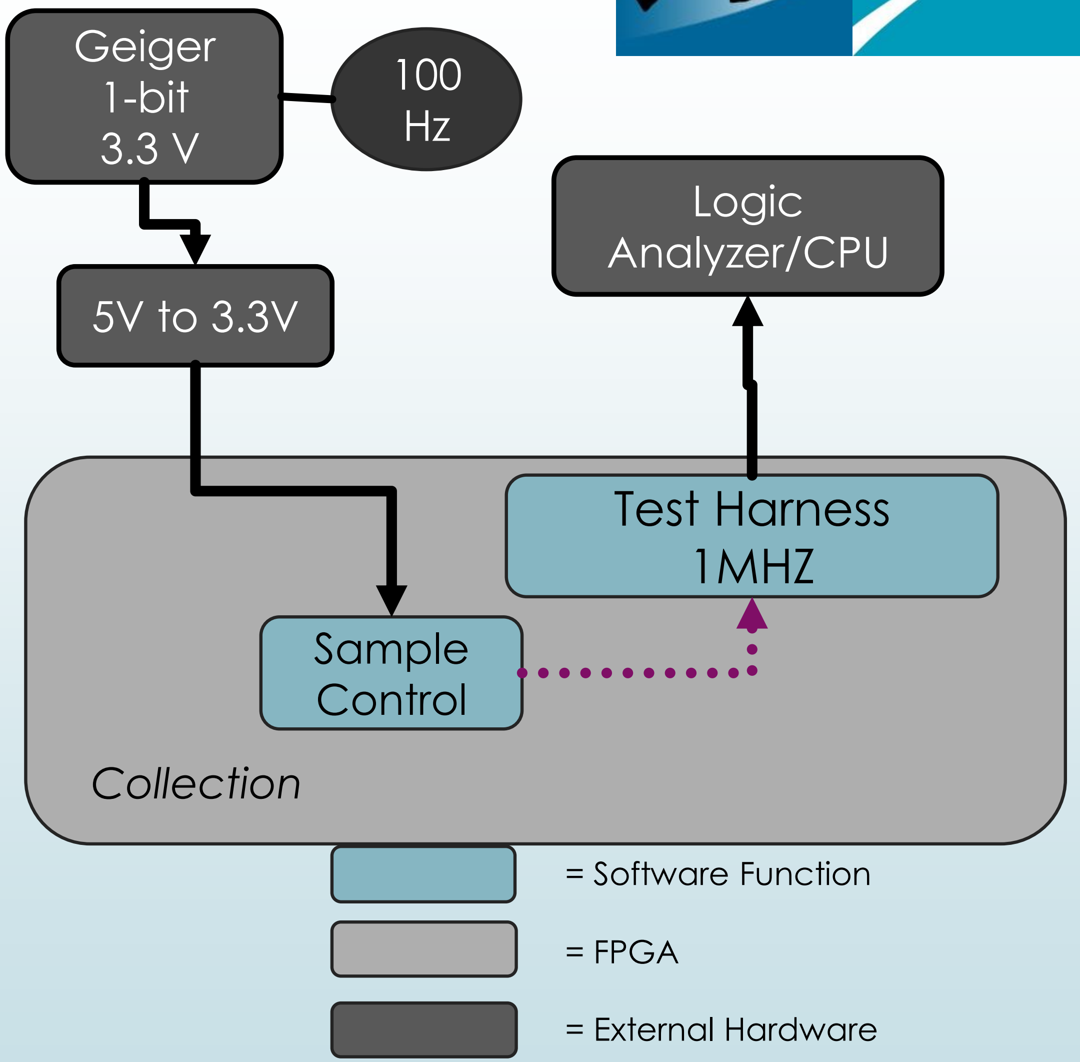
- Boot Up Process:
  - Register Status
- Data Transmission:
  - Data Over Logic Analyzer
  - Data Received at Ground Station

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**



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	–

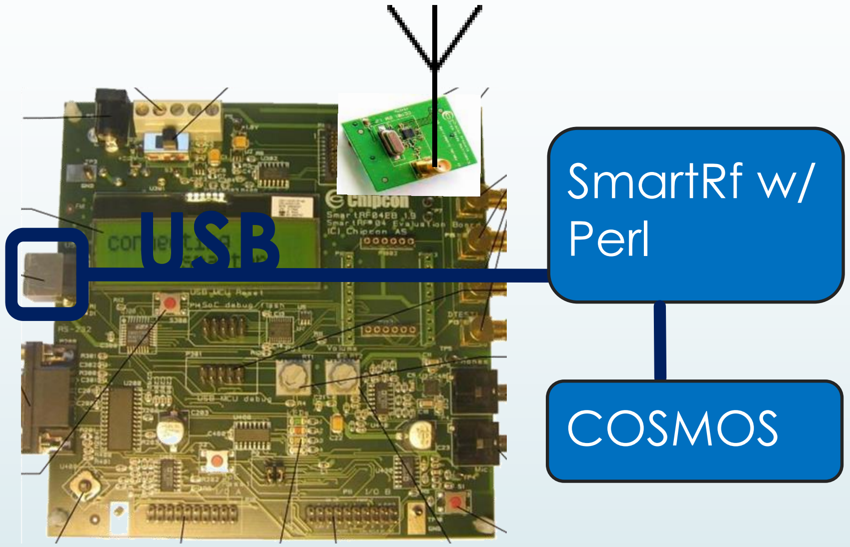
CPE-2
Test
Completed:
01/26/16

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

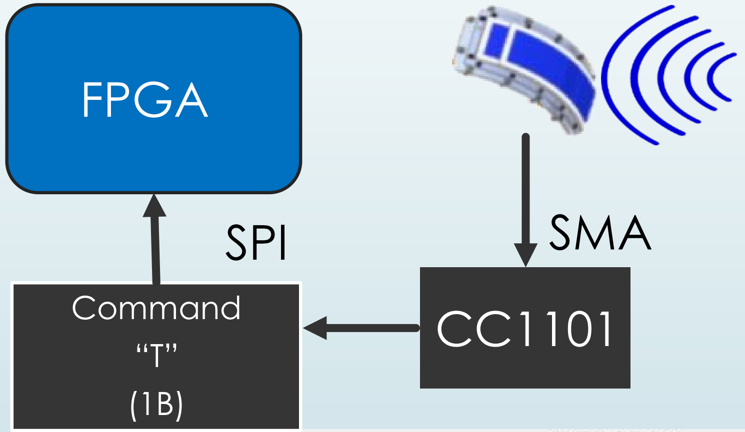
Expected Completion Date: 02/05/16

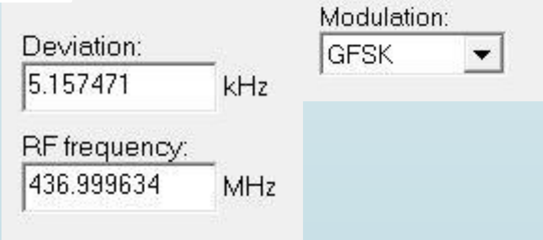
Communication Timeline

- 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





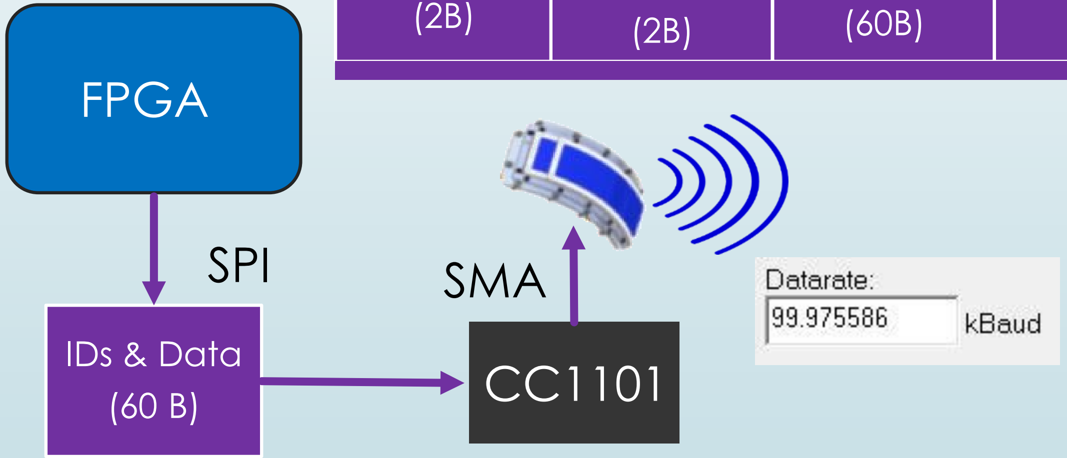
"Begin Telemetry Transmission" Command		
Sync Word "SA" (2B)	Command "T" (1B)	CRC Checksum (2B)

- 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

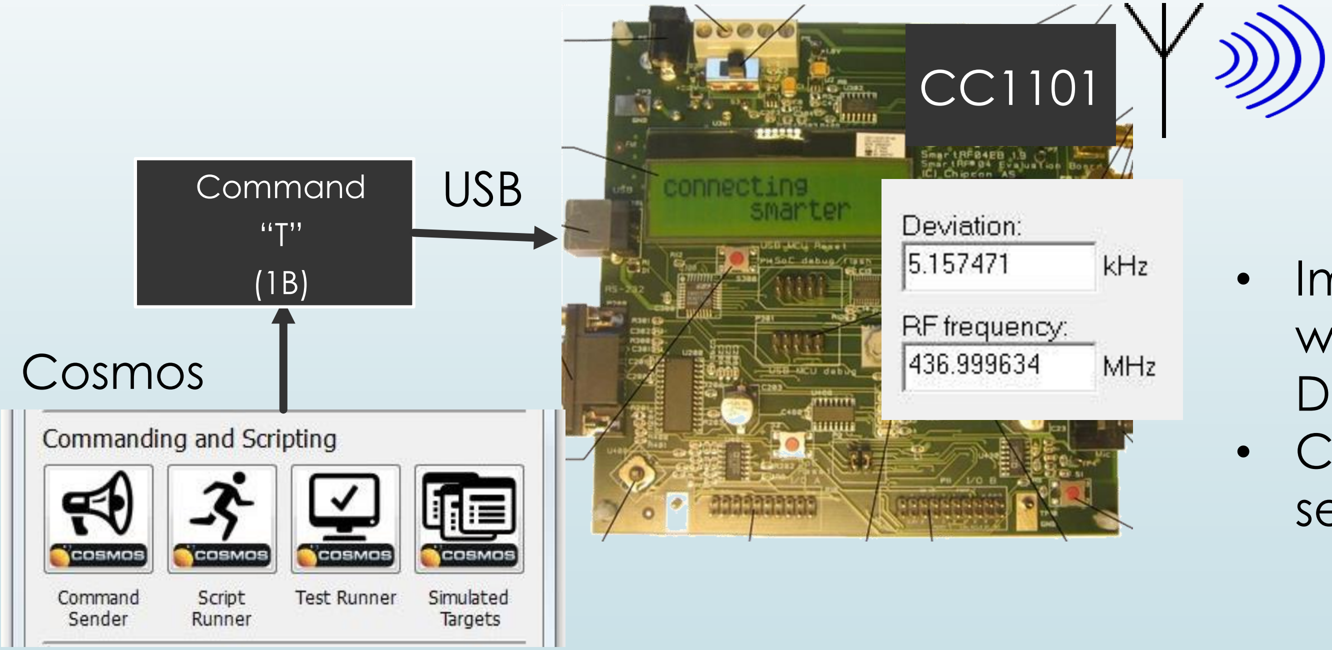
Outgoing Telemetry Packet			
Preamble “10101010” (2B)	Sync Word “EL” (2B)	IDs & Sensor Data (60B)	CRC Checksum (2B)



- 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



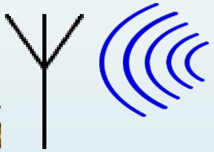
"Begin Telemetry Transmission" Command		
Sync Word "SA" (2B)	Command "T" (1B)	CRC Checksum (2B)

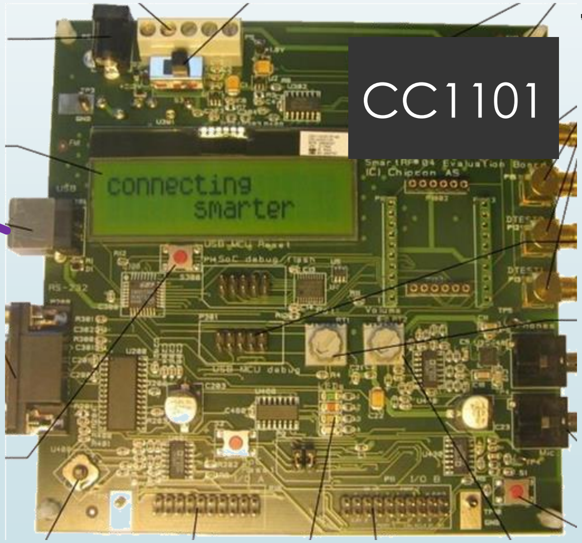
- Immediately after command CC1101 will be go into receive mode (Half Duplex)
- Commands will be automated and sent using Cosmos

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

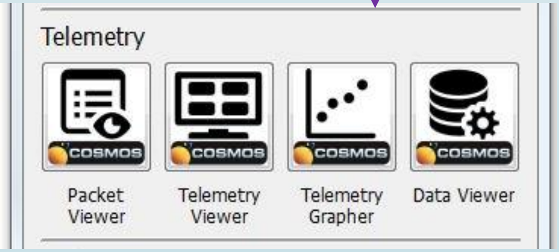
Incoming Telemetry			
Preamble "10101010" (16)	Sync Word "10101010" (32)	IDs & Data (60 B)	CRC Checksum (16)





IDs & Data (60 B)

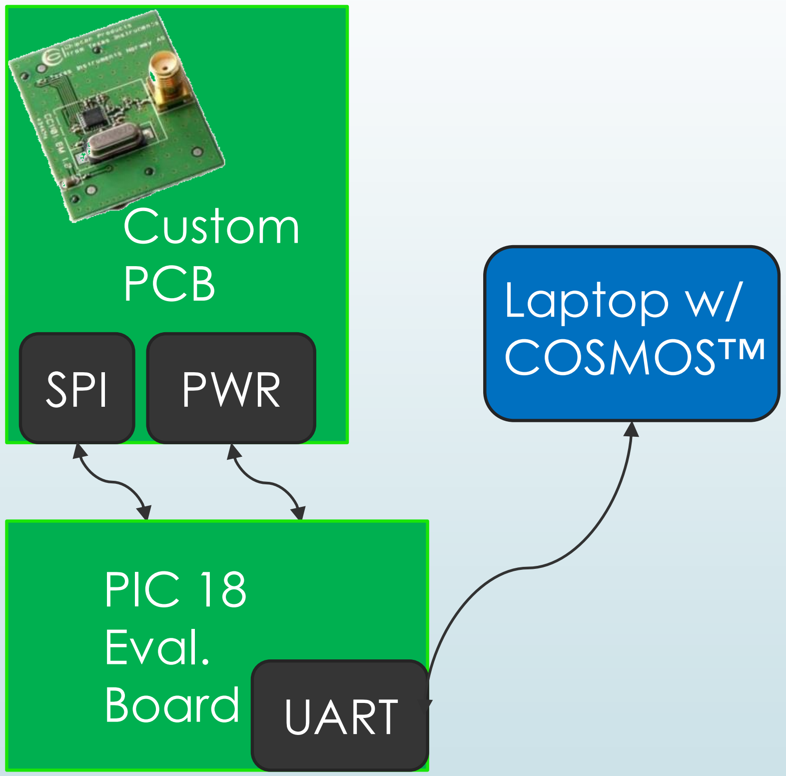
Cosmos



- 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

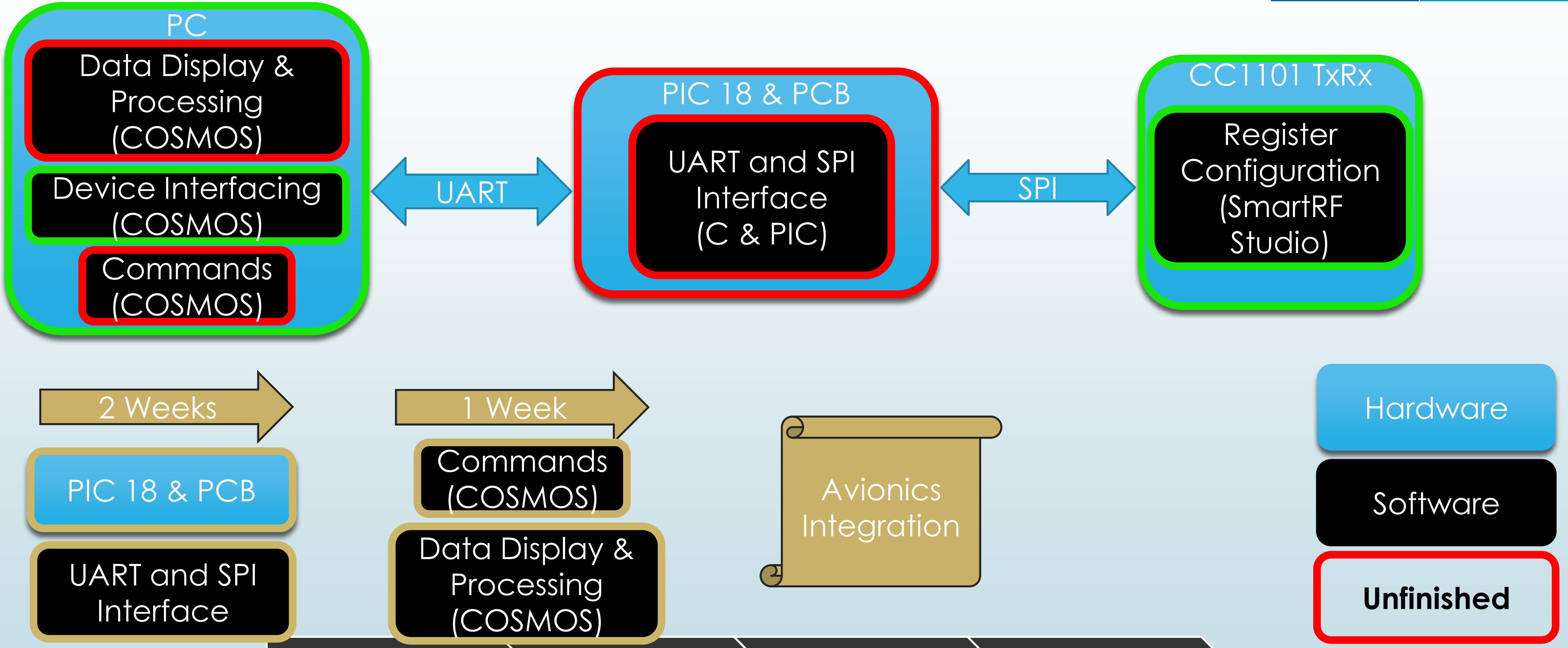
Alternative Ground Station

- 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



Project Overview | Schedule | Budget | Test Readiness

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

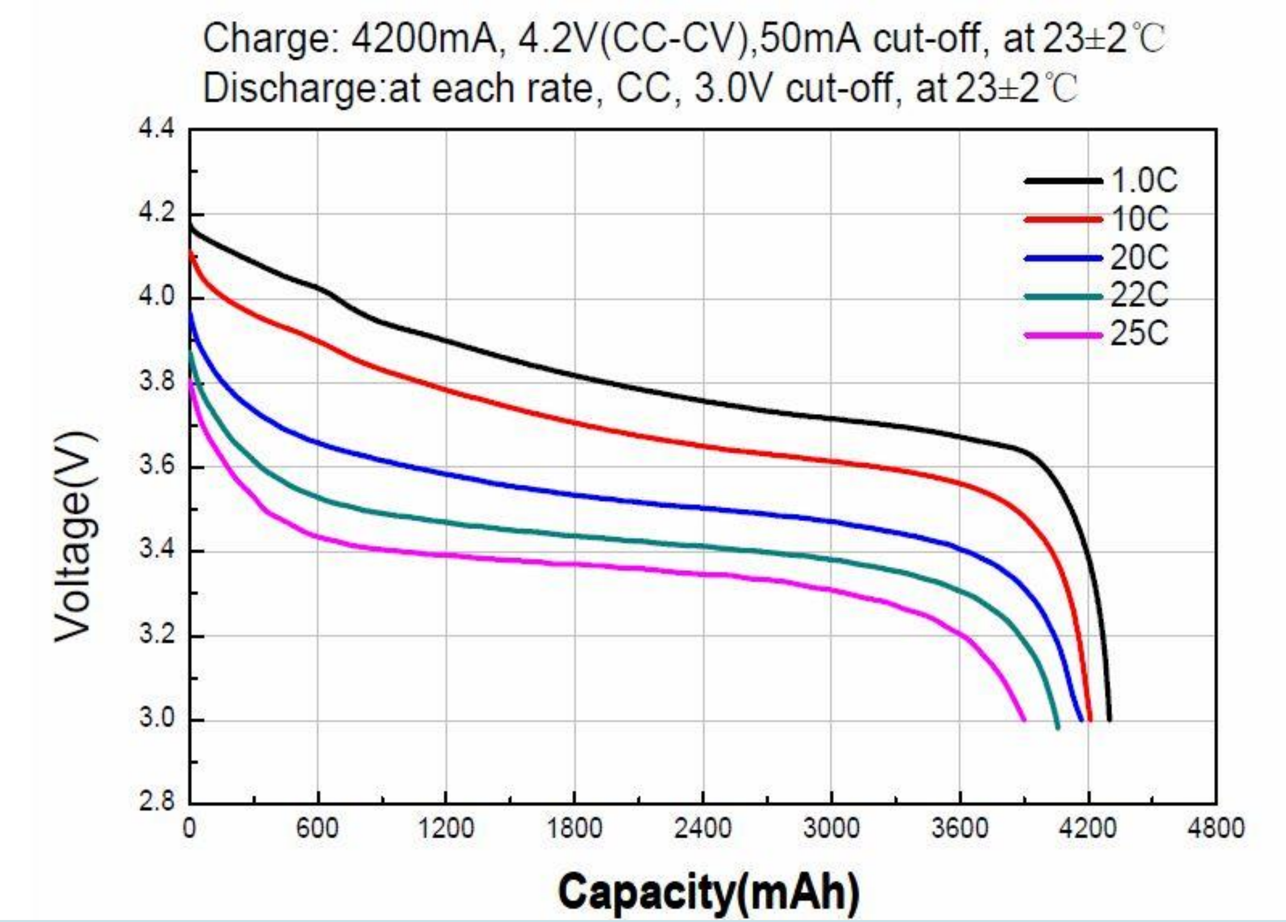
- Simple circuits designed to test each of the board components individually
- All components are operating within acceptable tolerances to meet requirements
  - LVC: Circuit broken at 10 V
  - Fuse: Circuit broken at 1.9 A
  - DC Converter: Output voltages of 5.04 V and 3.27 V (Req. 5±0.25 V and 3.3±0.3)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

- 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



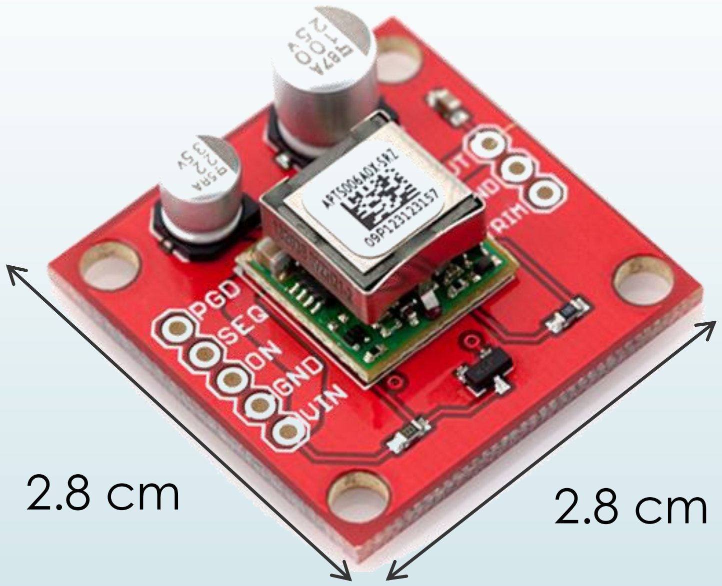
Project Overview | Schedule | Budget | Test Readiness

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

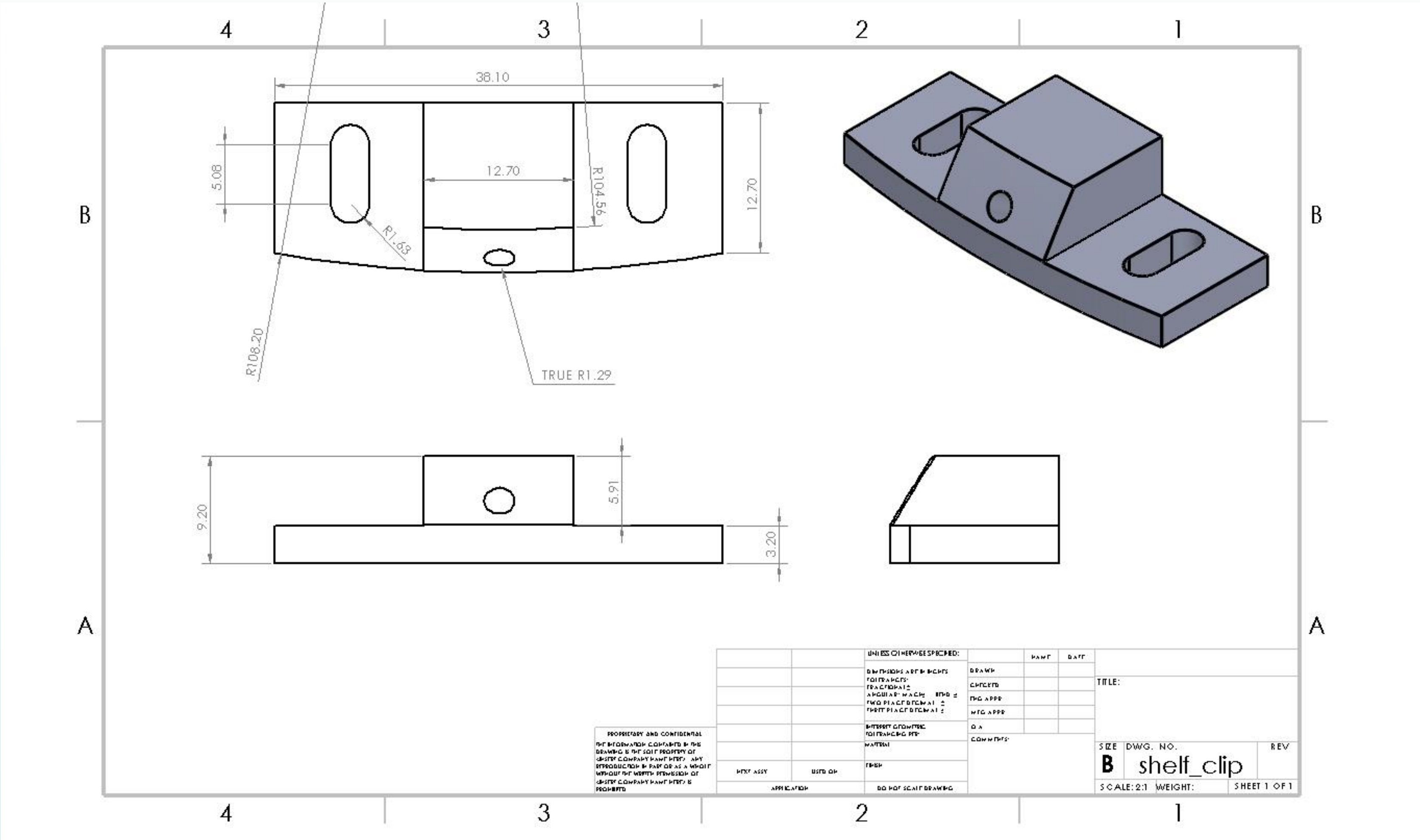
Structure Backup

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

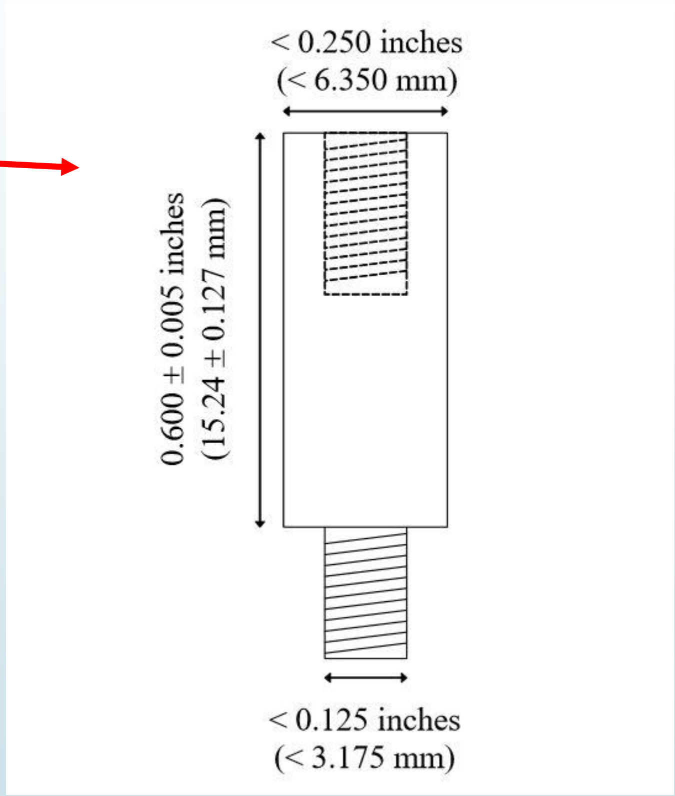
Backup Clip Drawing (dimensions in mm)



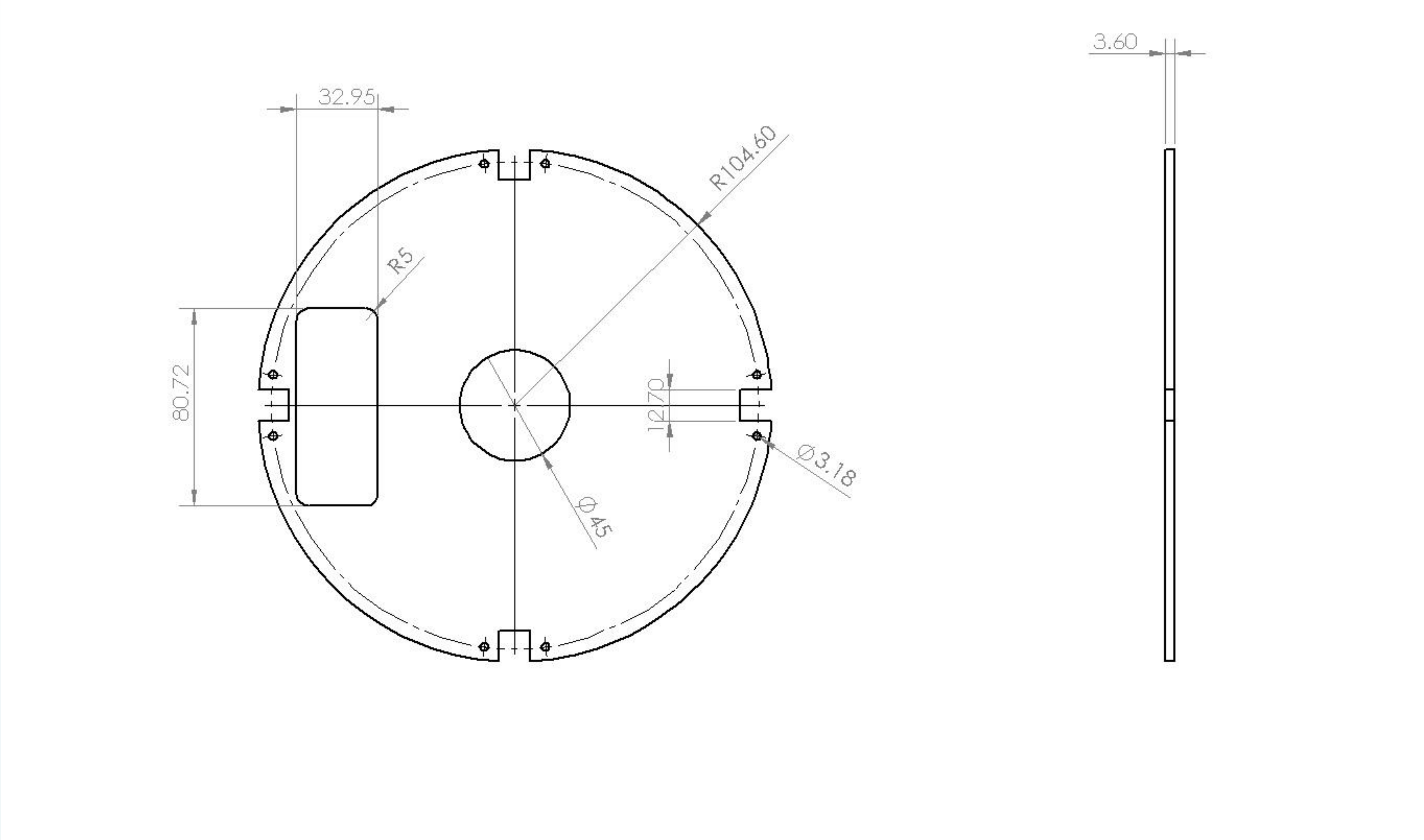
Project Overview | Schedule | Budget | Test Readiness

Standoffs and Battery Connectors

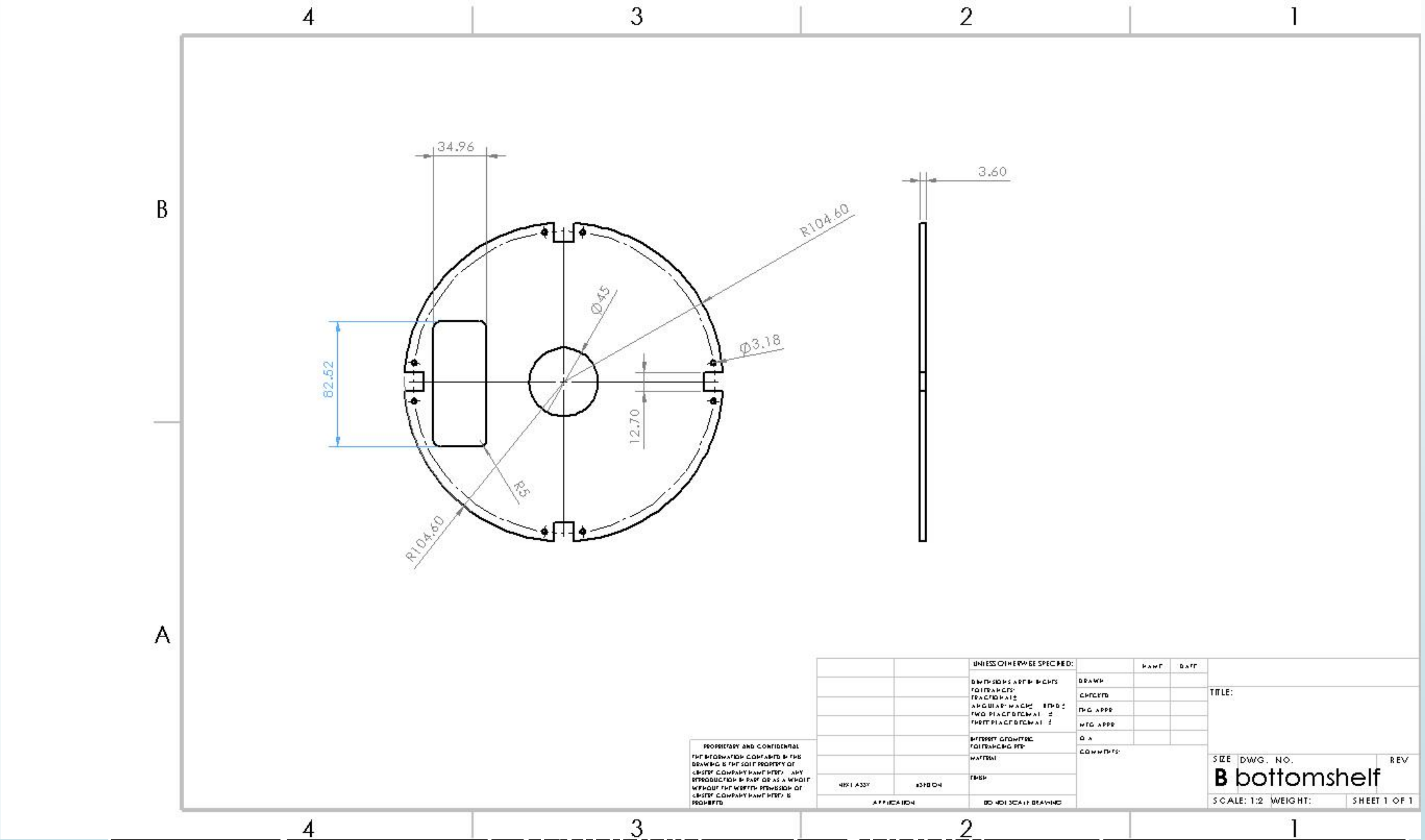
- Avionics/Power/Comms Board Standoff
- Sparkfun science instruments come with Standoffs



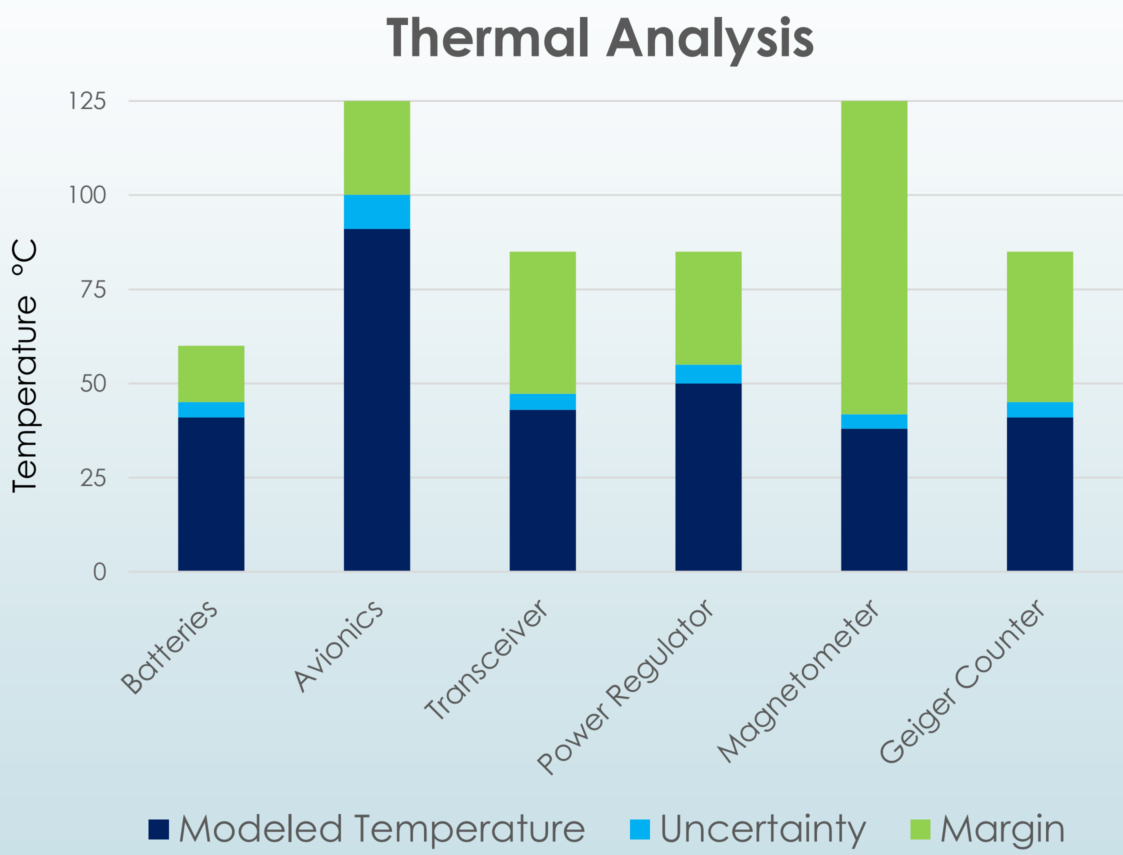
Top Shelf Drawing (dimensions in mm)

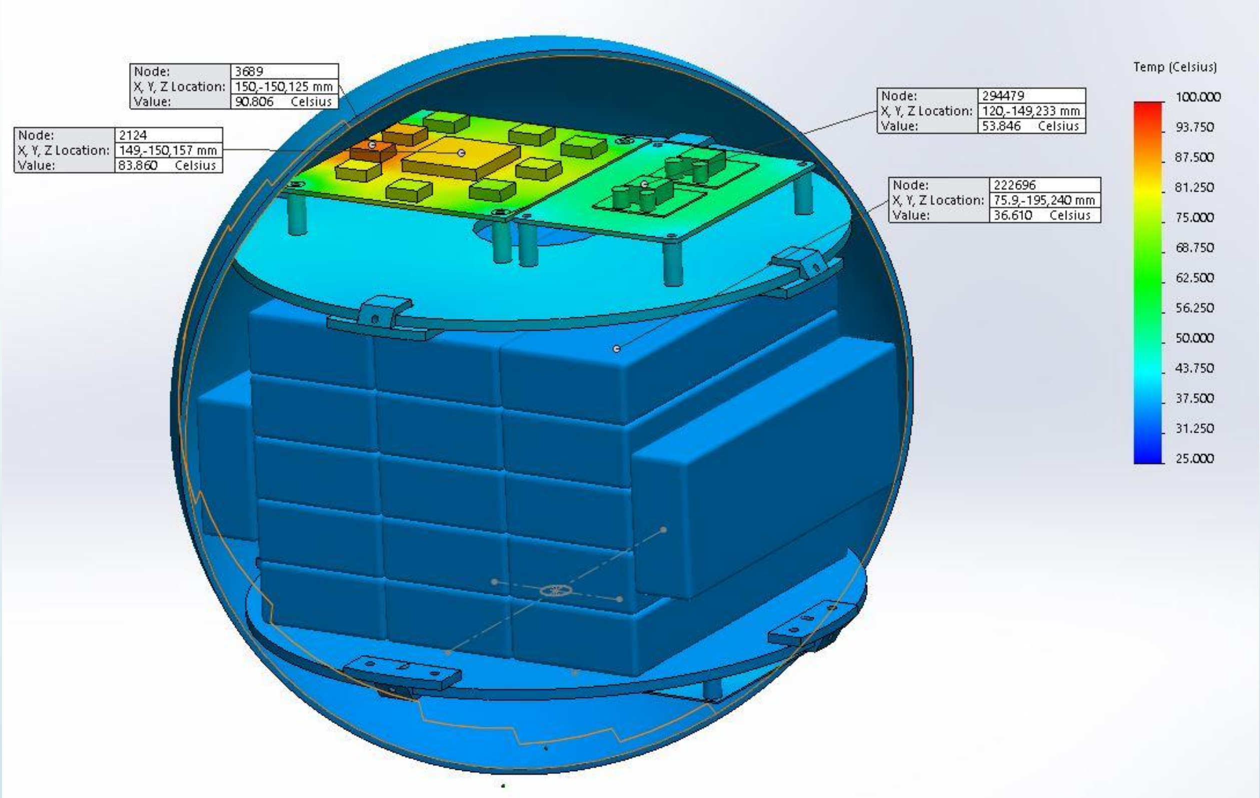


Top Shelf Drawing (dimensions in mm)



Temperatures within Operating Conditions





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

Will be refining models through component testing

Payload

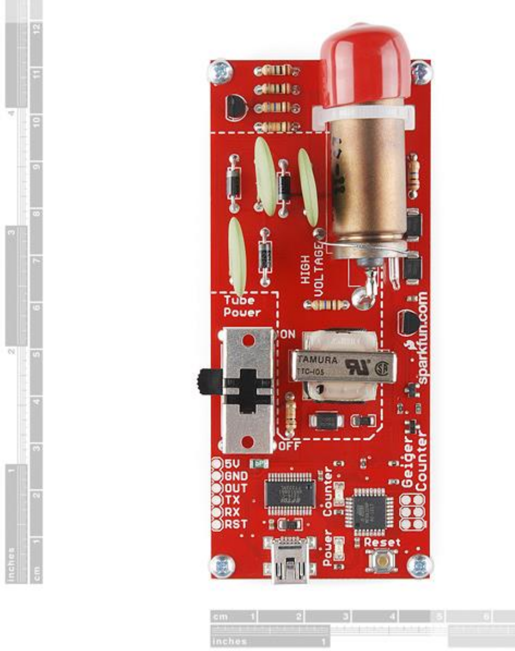
Project Overview | Schedule | Budget | Test Readiness

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

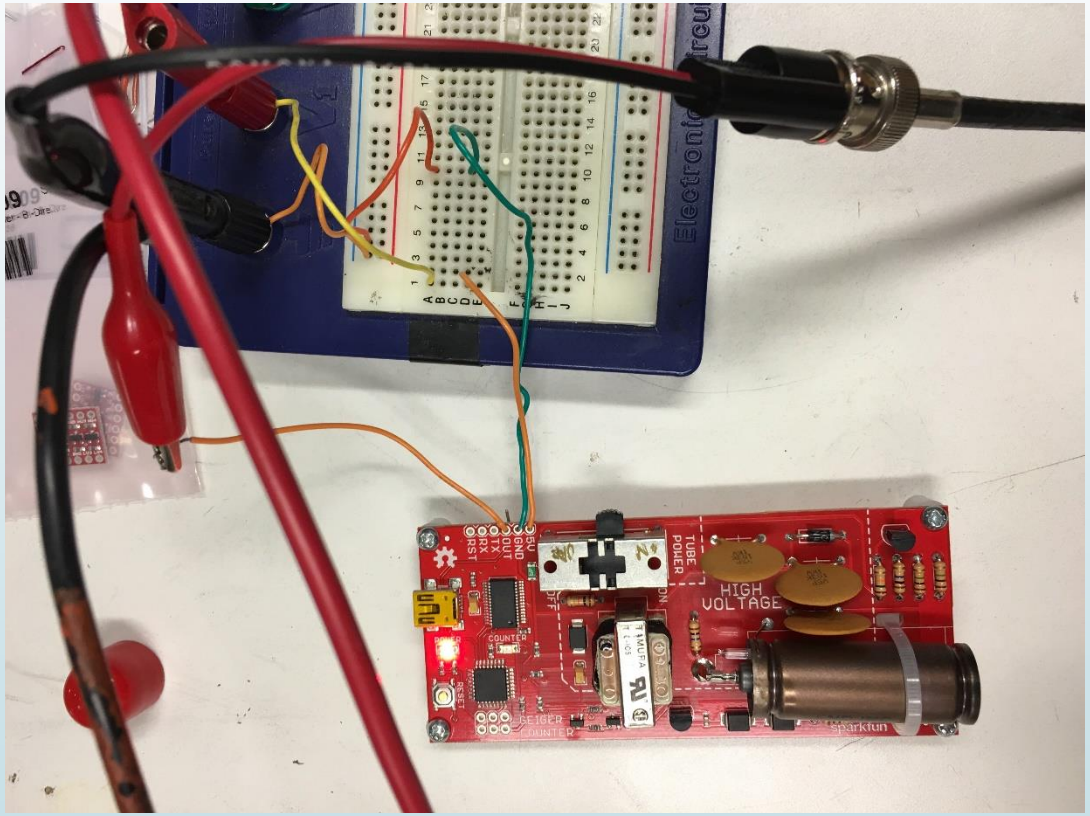
Highest Payload Level of Success: Samples data and relays it to Avionics Board for onboard storage

Payload Acquisition and Status

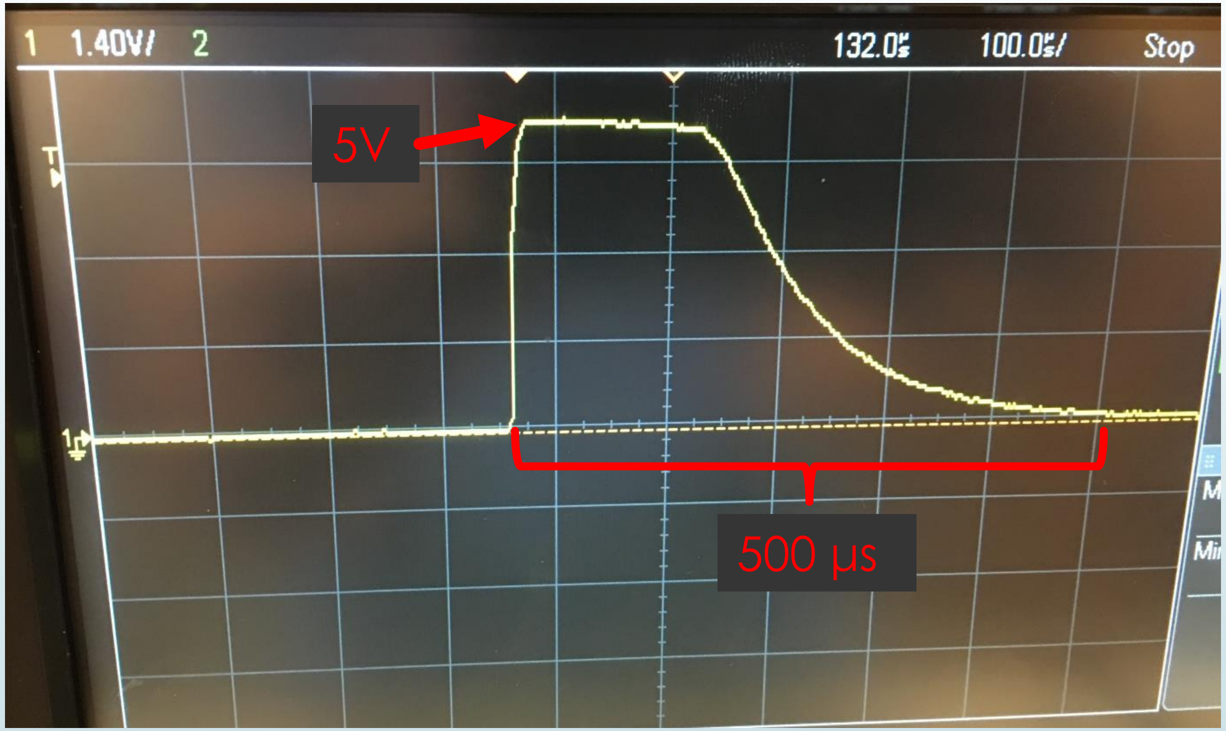
Hardware Component	Acquisition Method	Status
Magnetometer	Purchased	Received/ Successfully tested
Geiger Counter	Purchased	Received/ Successfully tested
Geiger Counter Logic Converter	Purchased	Received/ Unsuccessful testing → New revision
Geiger Counter Voltage Divider	Purchased	Design In Progress

Geiger Counter Testing

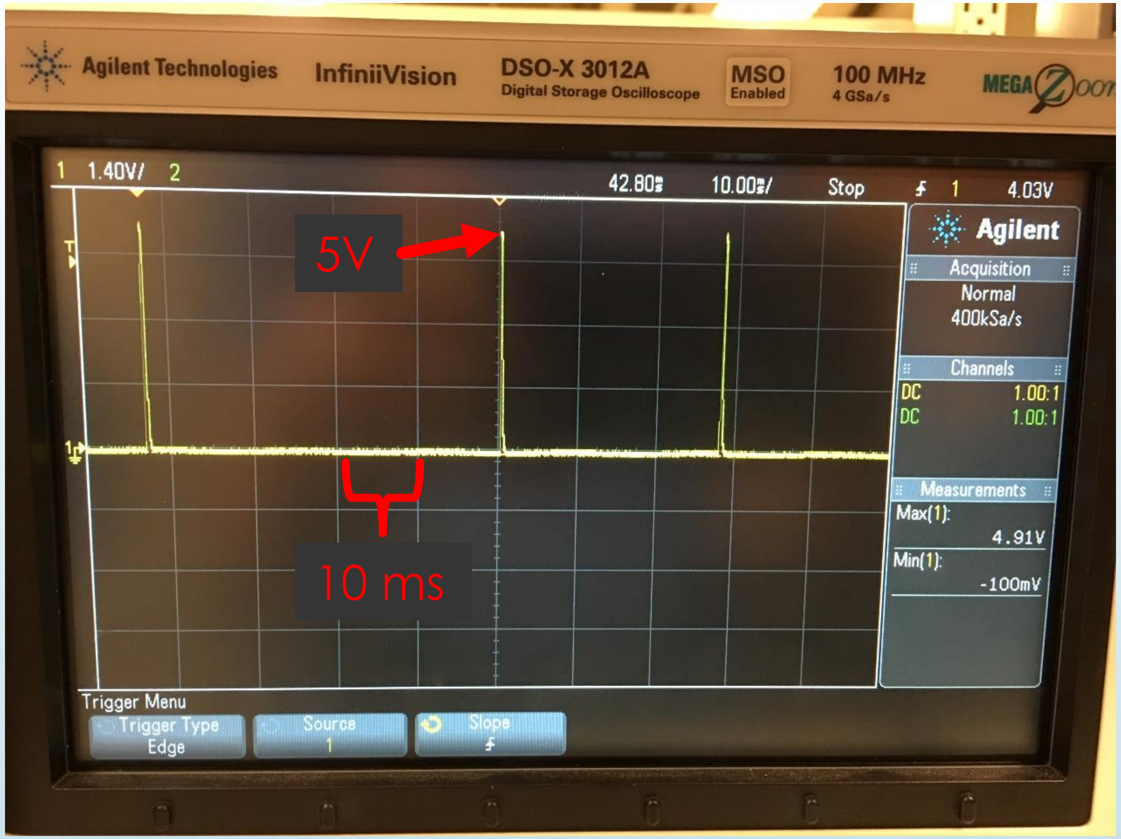
- Connected to Power Supply and Oscilloscope to confirm output
- Plan to test with Americium (from smoke detector) to induce higher count rates this week (Feb 4)



Results:



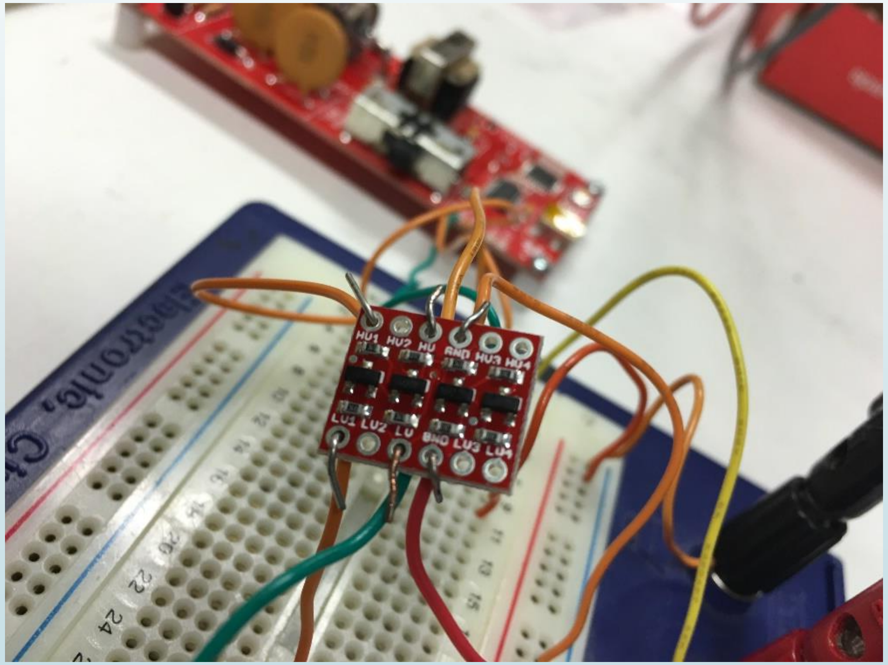
1 1.40V/ 2
132.0
100.0
Stop
5V
500 µs



Agilent Technologies
InfiniiVision
DSO-X 3012A
Digital Storage Oscilloscope
MSO
Enabled
100 MHz
4 GSa/s
1 1.40V/ 2
42.80
10.00
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
5V
10 ms
Trigger Menu
Trigger Type
Edge
Source
1
Slope

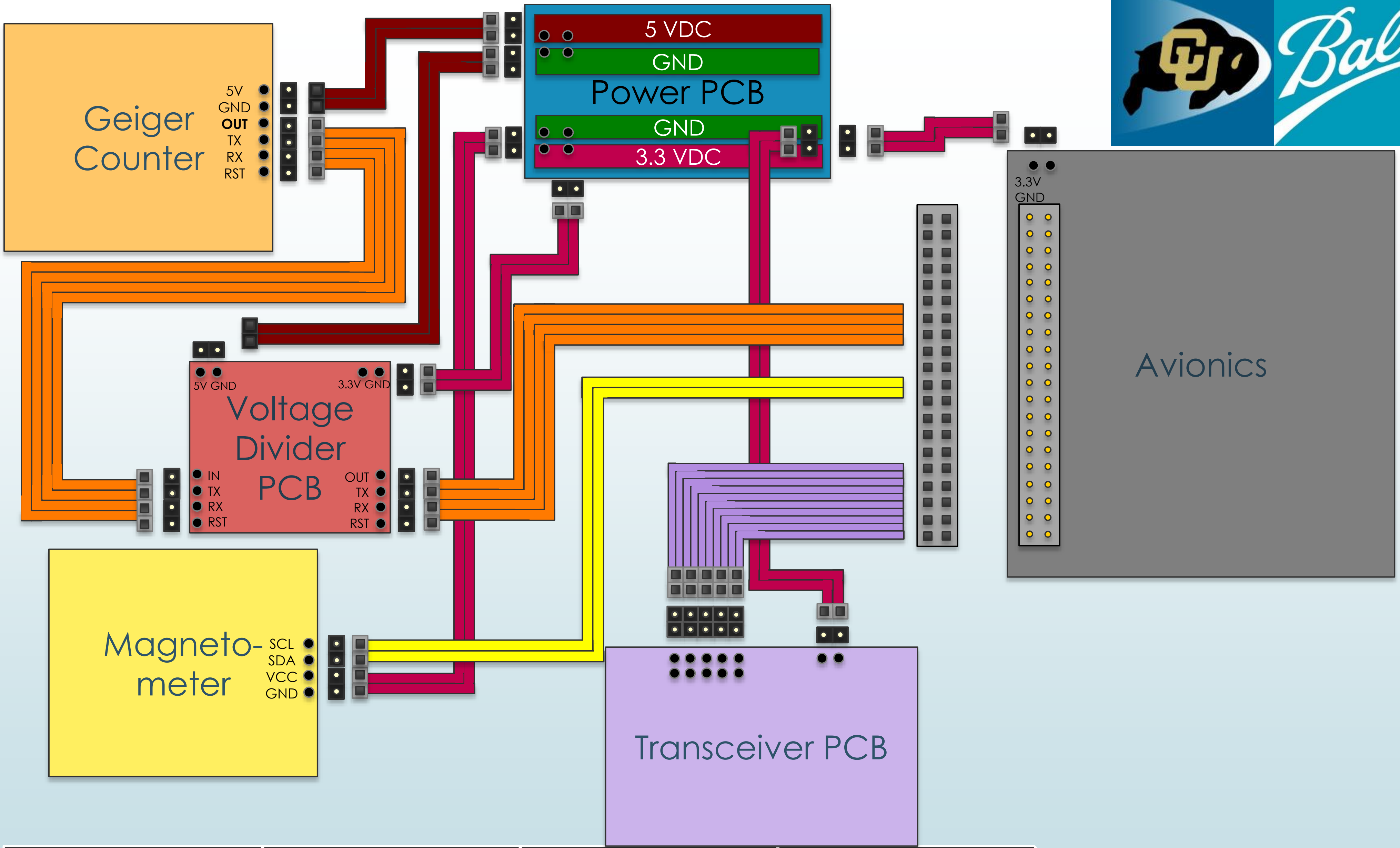
Change to Design:

- 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



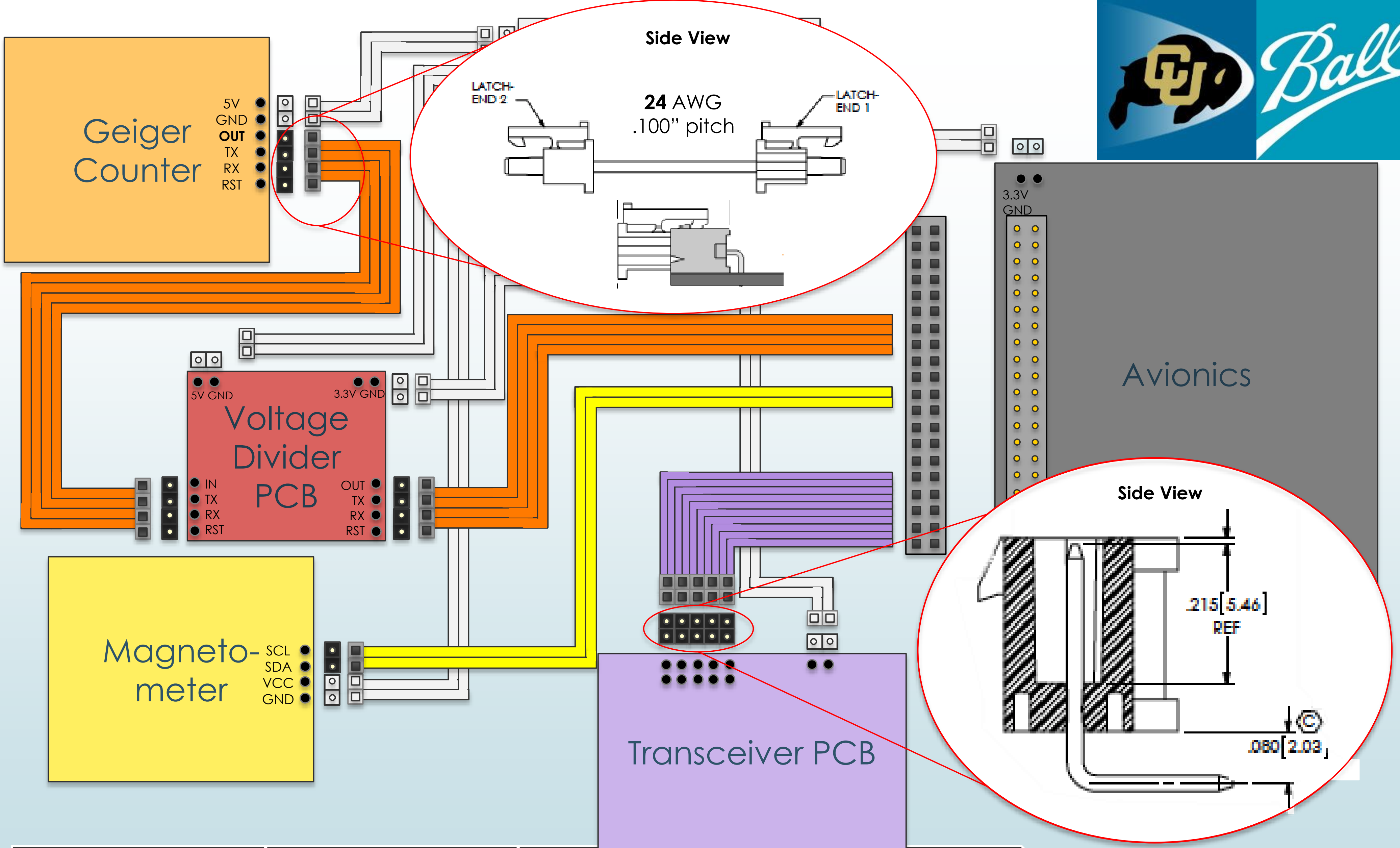
Systems Backup Slides

Wiring



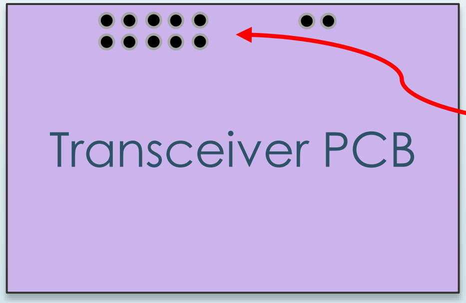
Project Overview | Schedule | Budget | Test Readiness

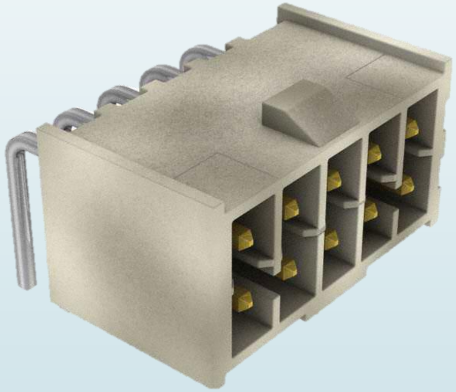
Digital Wiring

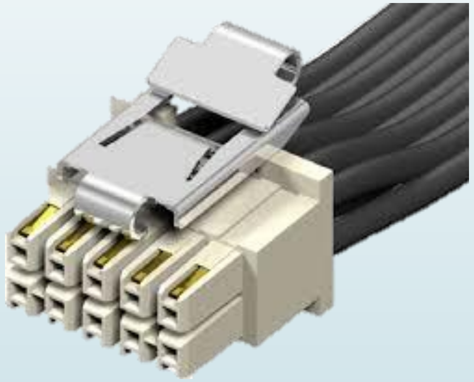


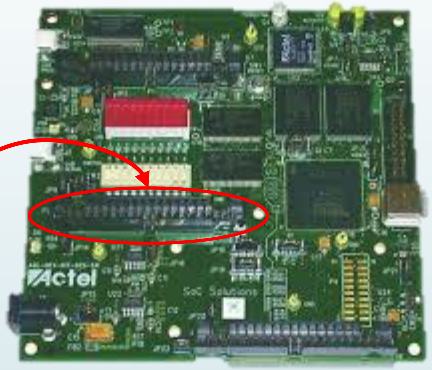
Digital Connectors

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



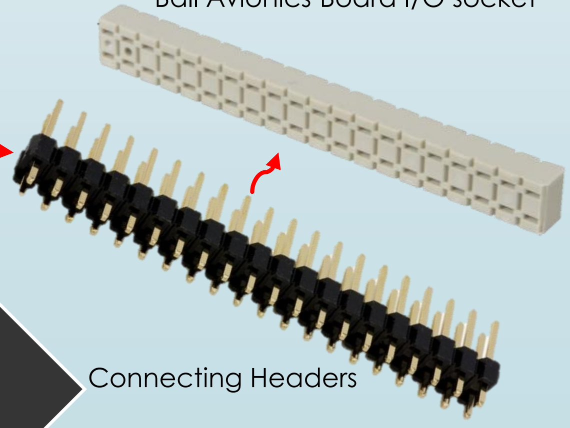






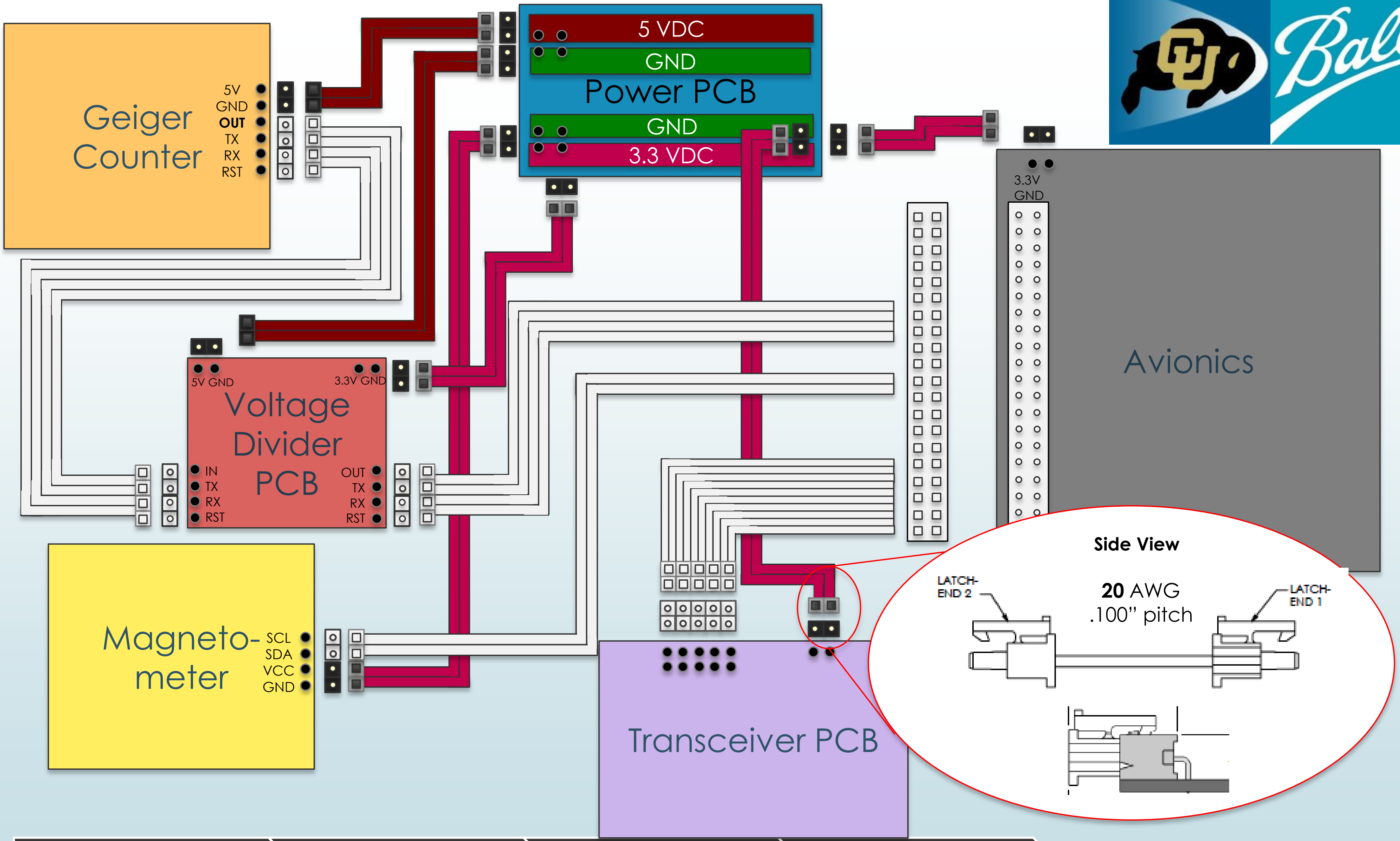
Microsemi Development Kit

Ball Avionics Board I/O socket



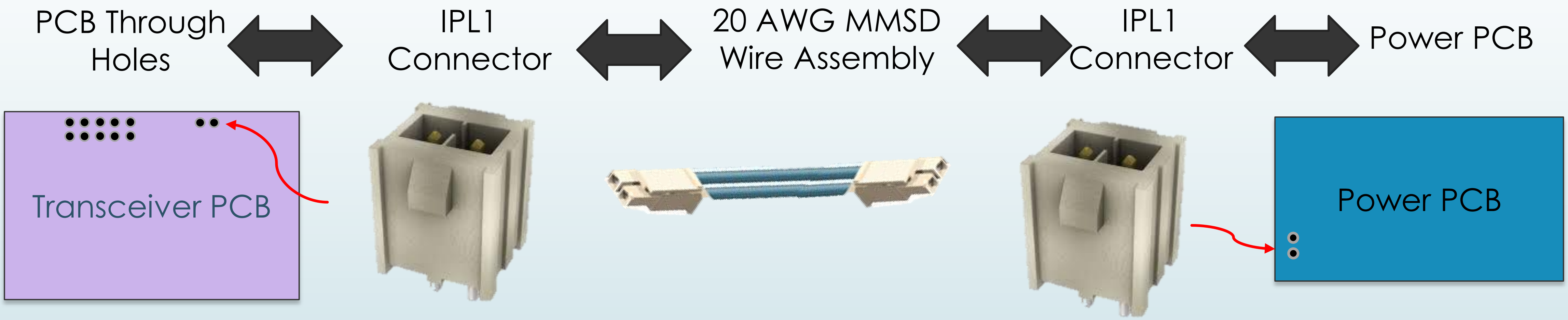
Connecting Headers

Power Wiring

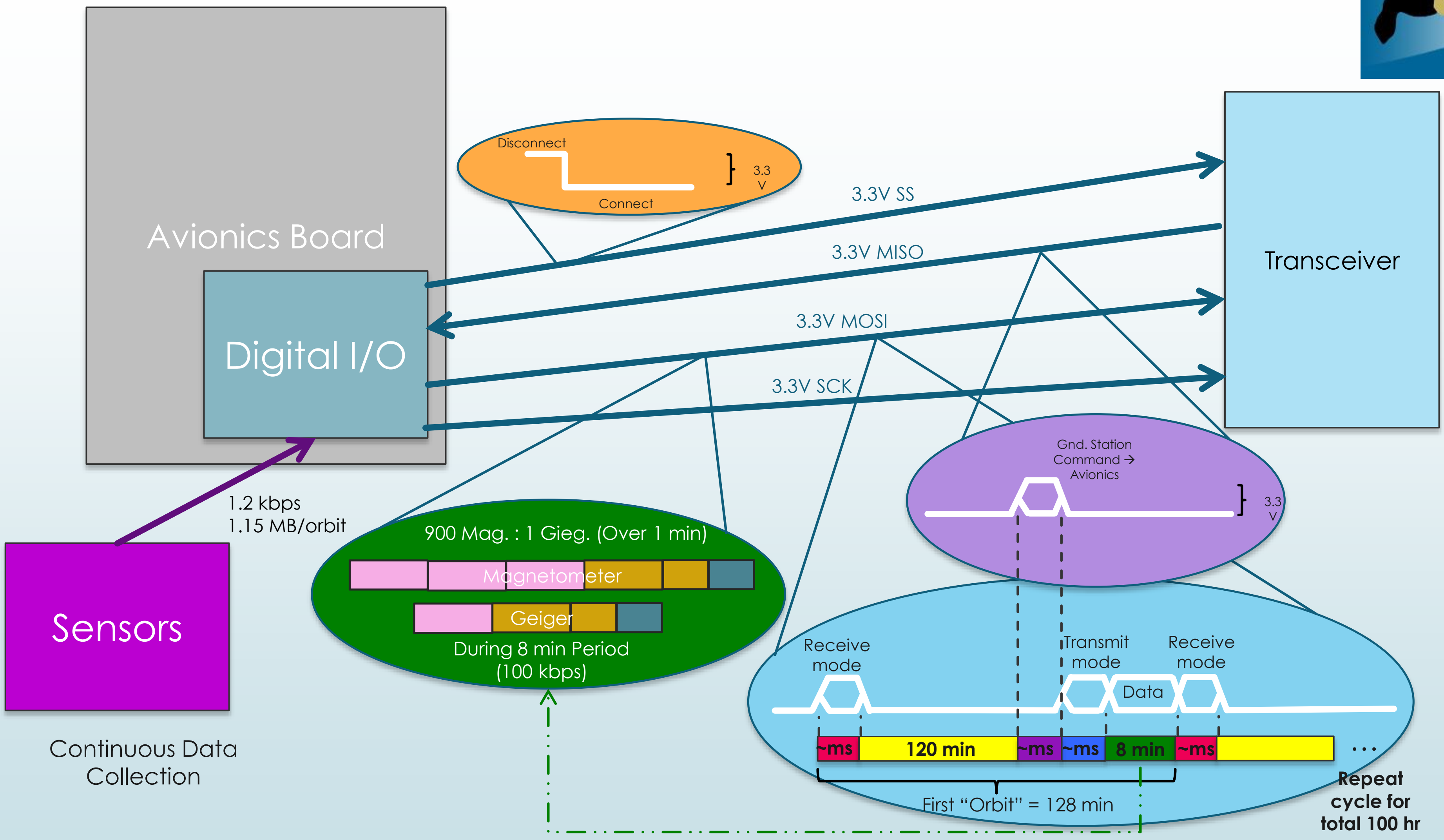


Project Overview | Schedule | Budget | Test Readiness

Power Connectors



Timing



Project Overview | Schedule | Budget | Test Readiness

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

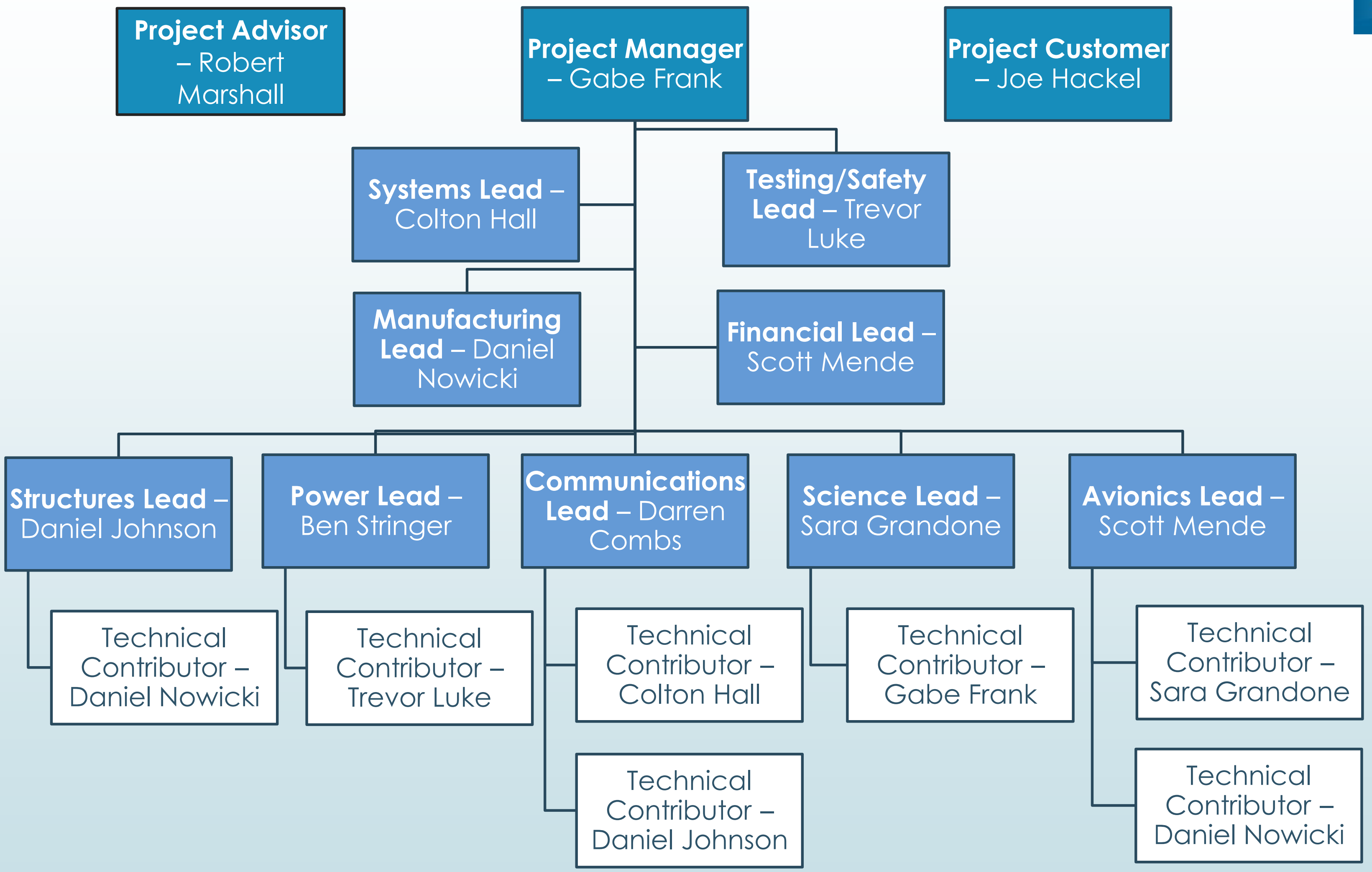
Likelihood

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

(red)	Unacceptable
(yellow)	Acceptable with Mitigation
(green)	Acceptable

Project Management Backup

Organizational Chart



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

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 Overview | Schedule | Budget | Test Readiness

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

Project Overview
Schedule
Budget
Test Readiness

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

Project Overview | Schedule | Budget | Test Readiness

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

Primary Backup

Power Backup

Systems Backup

Avionics Backup

Payload Backup

Project Management Backup

Communications Backup

Structure Backup

Science Traceability Backup

Project Overview | Schedule | Budget | Test Readiness