Project ELSA

Europa Lander for Science Acquisition

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Customer: Joe Hackel (Ball Aerospace)

Advisor: Dr. Robert Marshall

Agenda

- Project Overview
- Design Solution
- Requirements and Risk
- Testing and Verification
- Project Planning

Project Overview → Design Solution → Requirements and Risk → Testing and Verification → Project Planning

Project Overview

Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

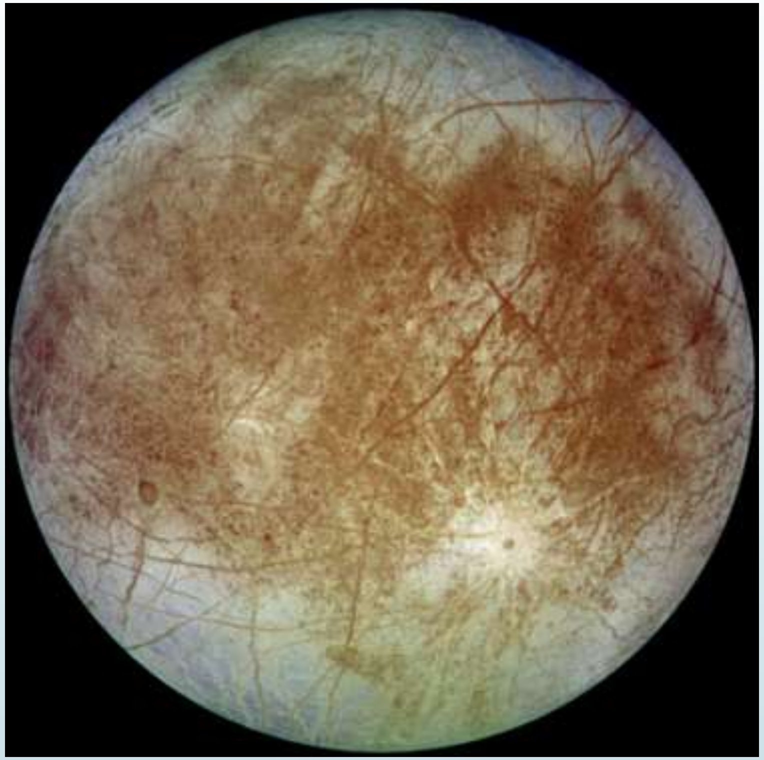
Project Statement

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 a 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 | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

ELSA Mission Objectives

- **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

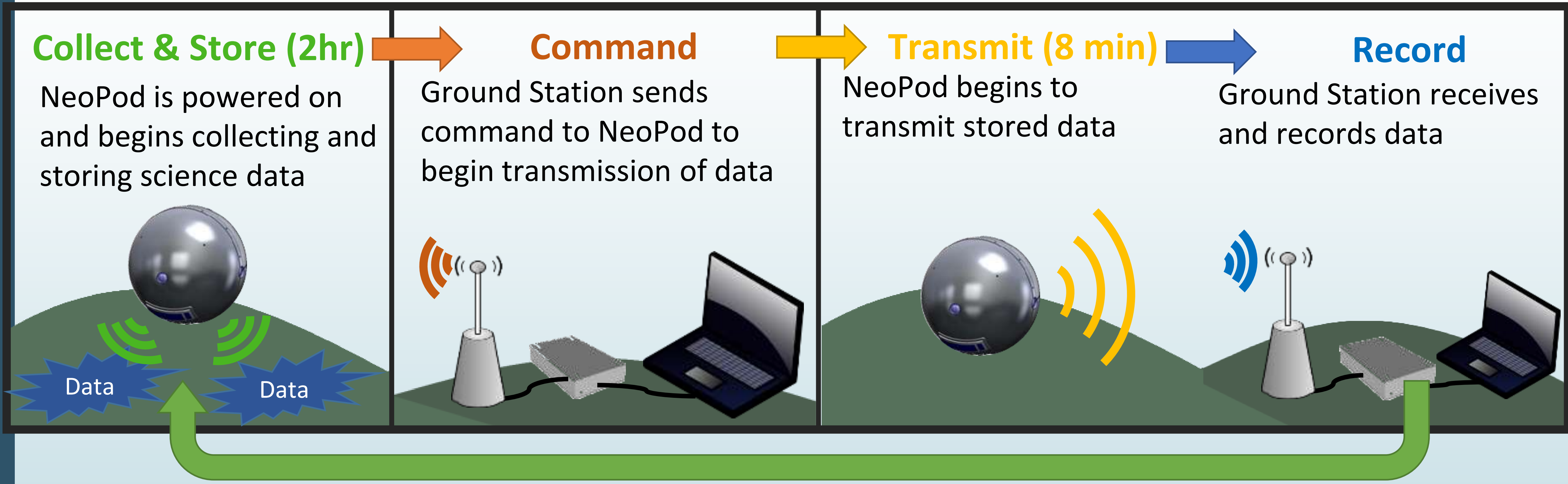
Ground Station sends command to NeoPod to begin transmission of data

Transmit (8 min)

NeoPod begins to transmit stored data

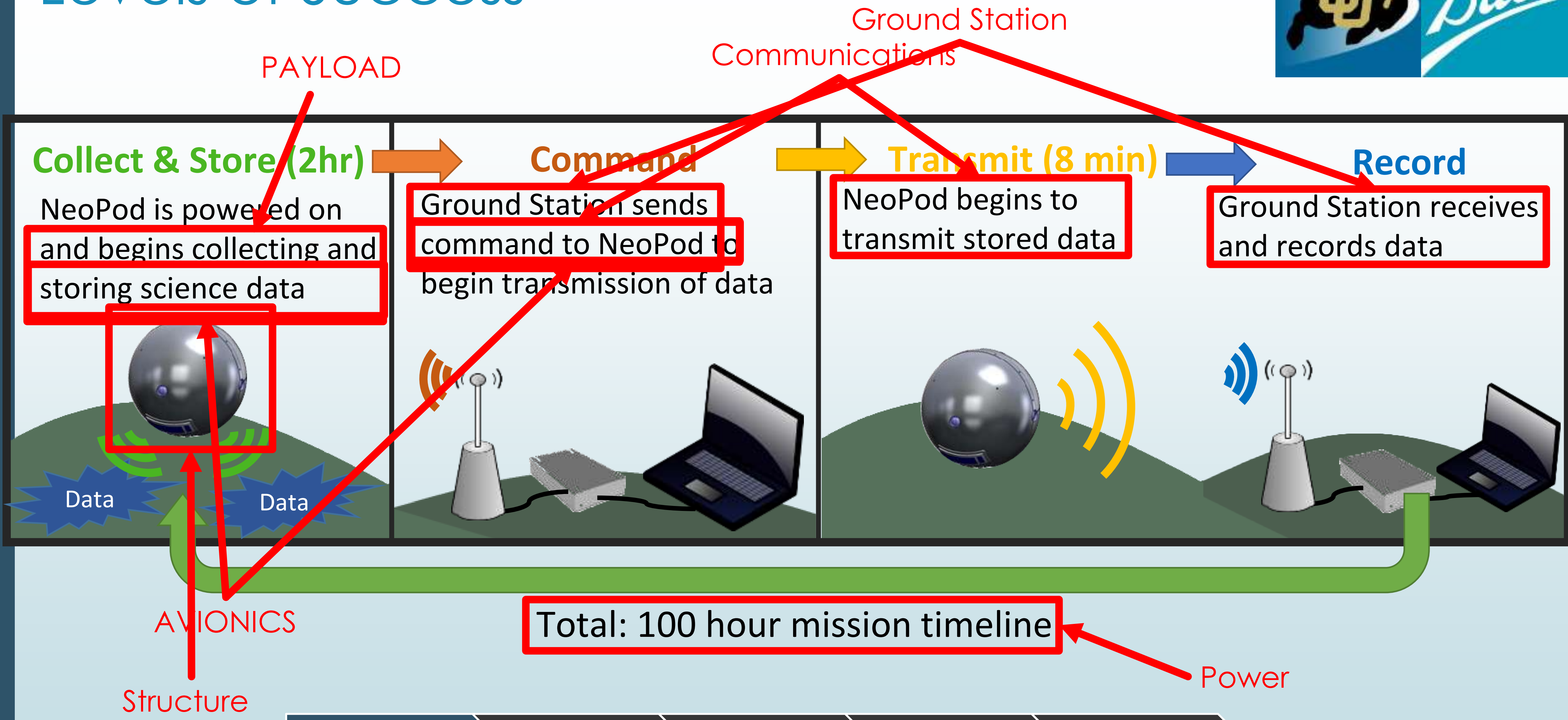
Record

Ground Station receives and records data

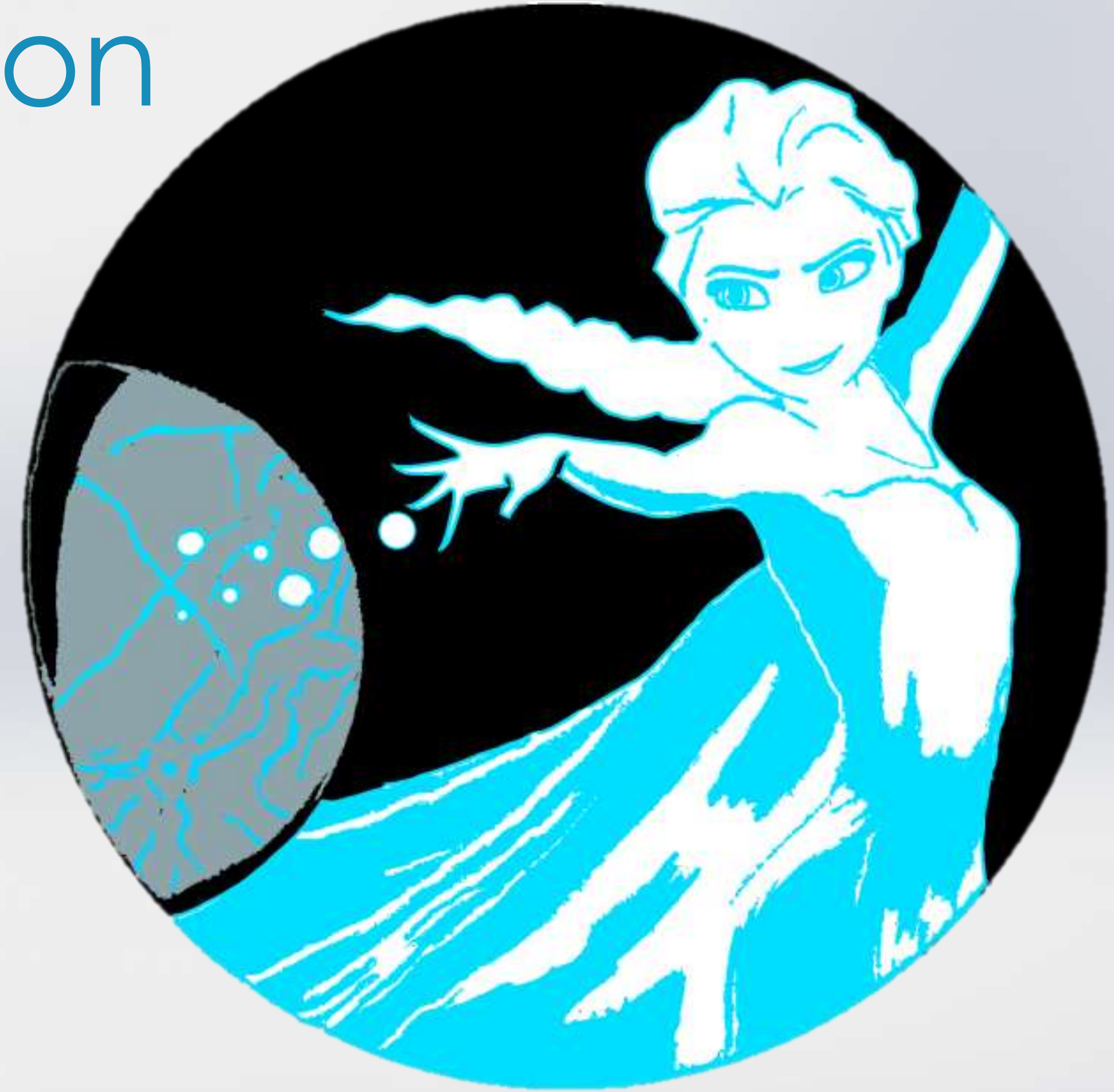


Total: 100 hour mission timeline

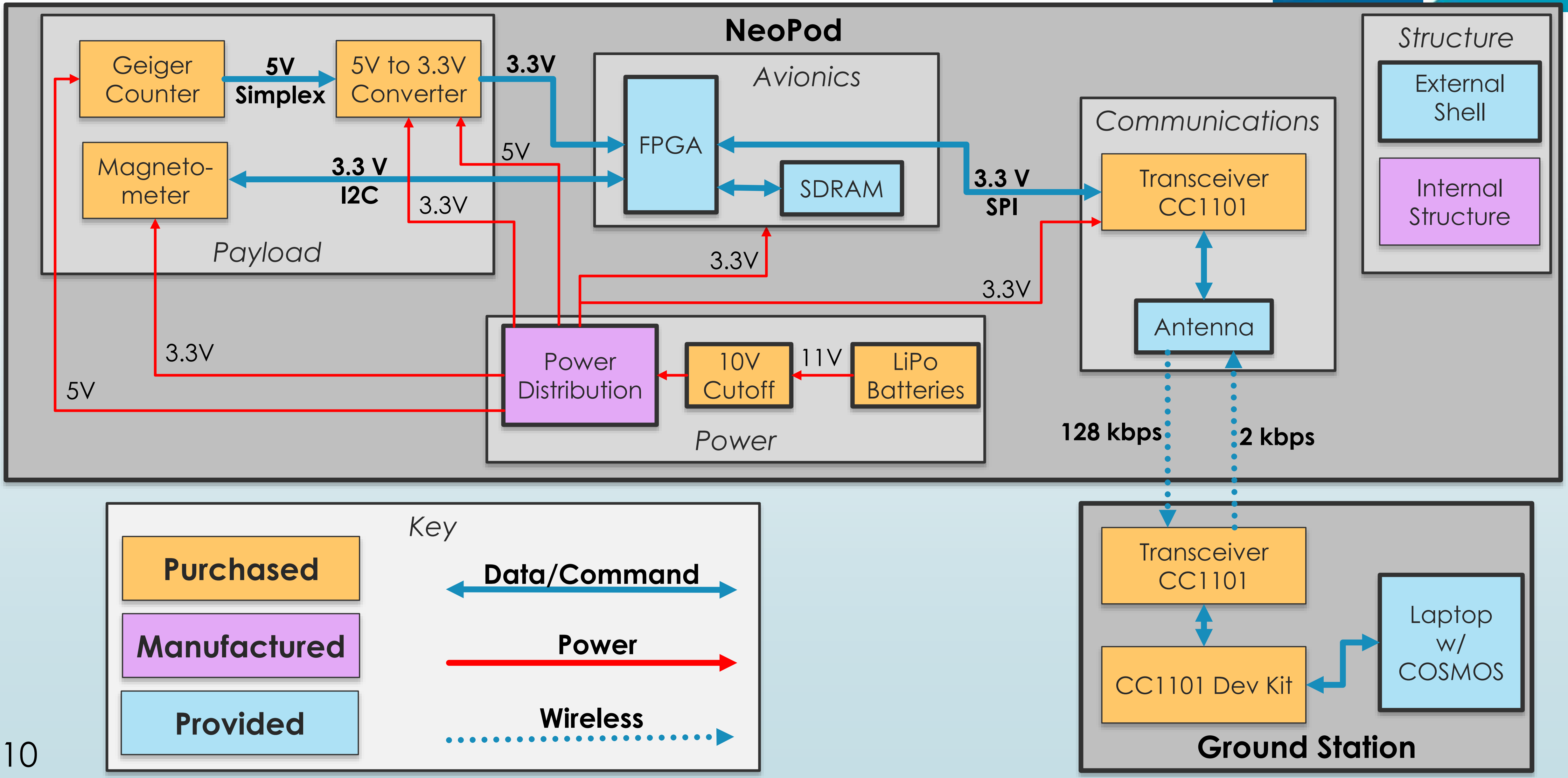
Levels of Success



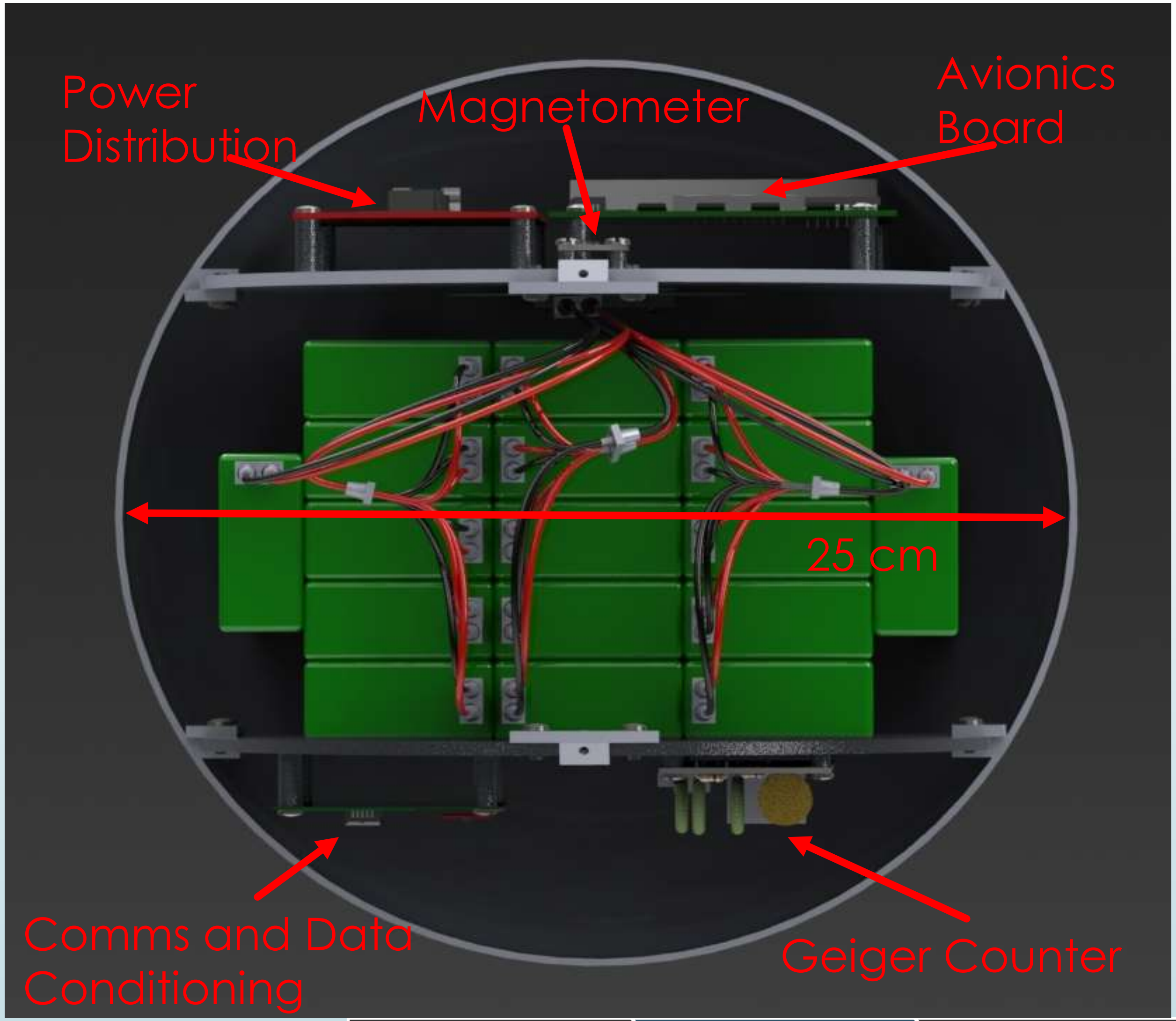
Design Solution



FBD of ELSA System



ELSA: Key Parameters



Key Parameter	Value
Mass	9 kg
Diameter	25 cm
Power Capacity	834 Wh
Maximum Data Rate	128 kbps
Total Data Transmission	52 MB

Requirements and Risk

Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

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**.

CPE-1: Requirements

Avionics Hardware Integration and FPGA Software

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

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

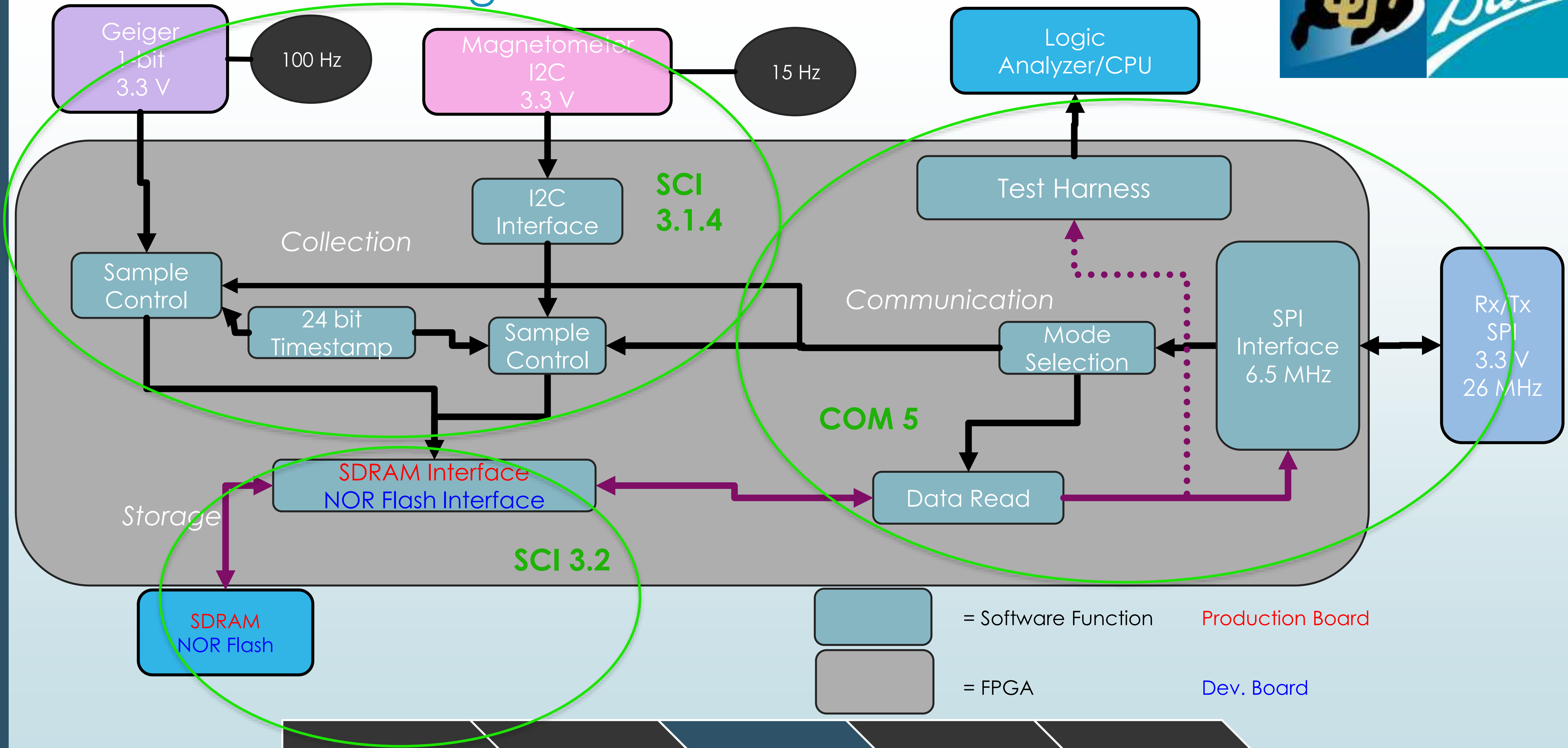
Geiger Counter:

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

SCI 1: NeoPod shall contain **two scientific instruments**

Radiation & Magnetic Field measurements would support further missions to Europa

FPGA Software Design



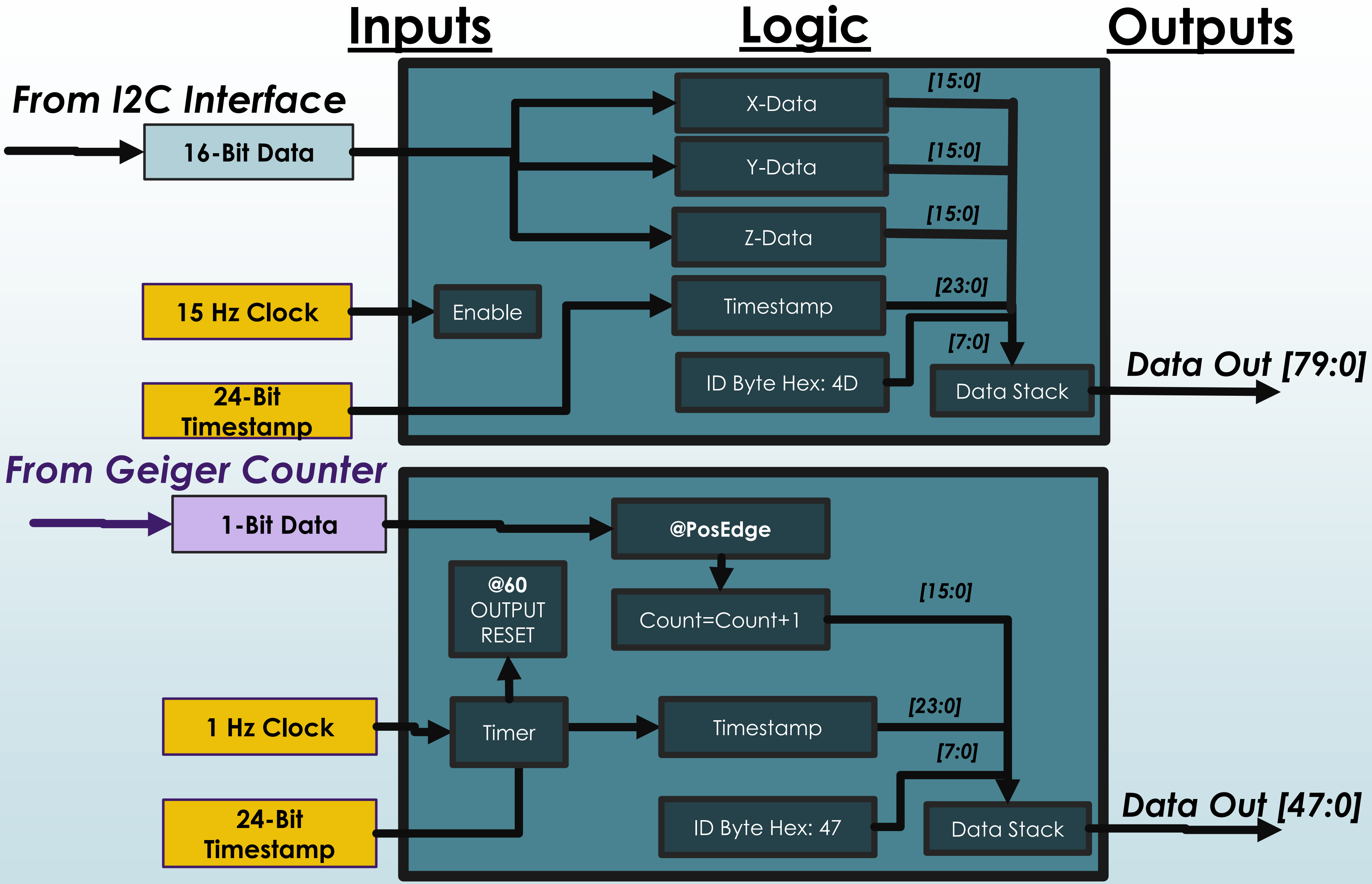
= Software Function

= FPGA

Production Board

Dev. Board

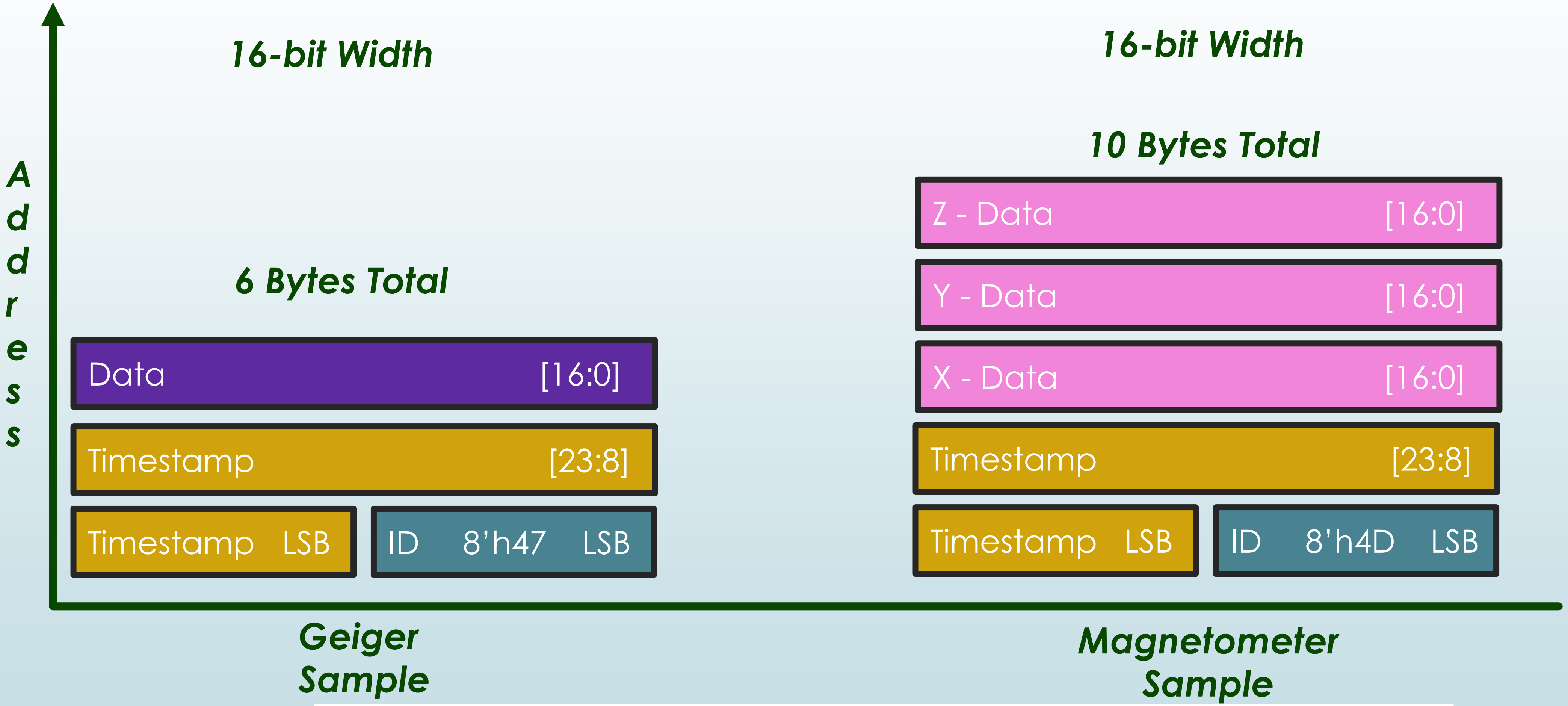
Control Data Flow From Sensors



Sensor:	Total Data:
Magnetometer	51.84 MB
Geiger Counter	35 kB
Total Data Collected:	**51.88 MB**

SCI 3.1.4: Avionics subsystem shall limit data collection to less than 353 MB

Data Storage: Memory Stack



Data Storage: SDRAM

- NAND Flash Storage not feasible

- Ball Avionics Board Alternate Storage:
  - 32 MB SDRAM
  - Simpler interface and control than Flash
  - Faster Performance: 20 ns Active to Command
  - Simple Addressing [Row:Column]

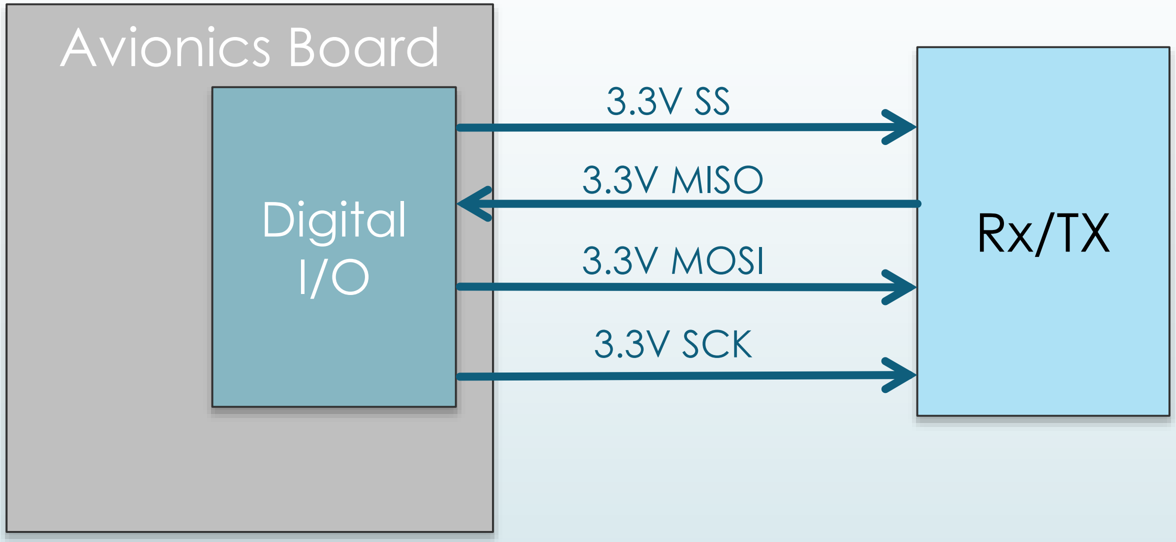
- Non-Volatile memory **NOT needed**
  - Overwriting stored data is OK

SCI 3.2: Avionics subsystem shall store data collected from sensors

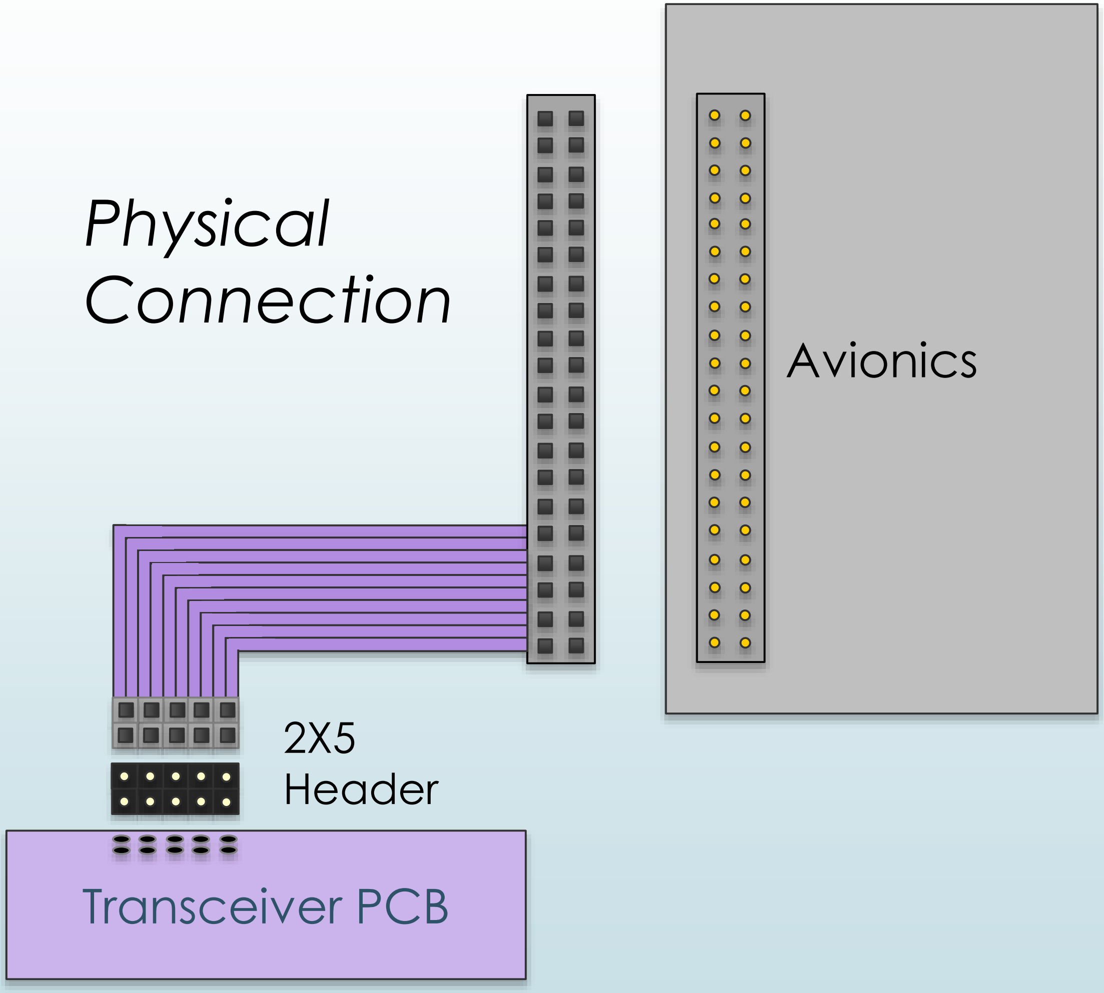
1.15 Mbytes
128 Min. Orbit
→
SDRAM
32 MBytes
→
27.8 Passes
Data Coverage

Communications Interface

SPI Interface



Physical Connection



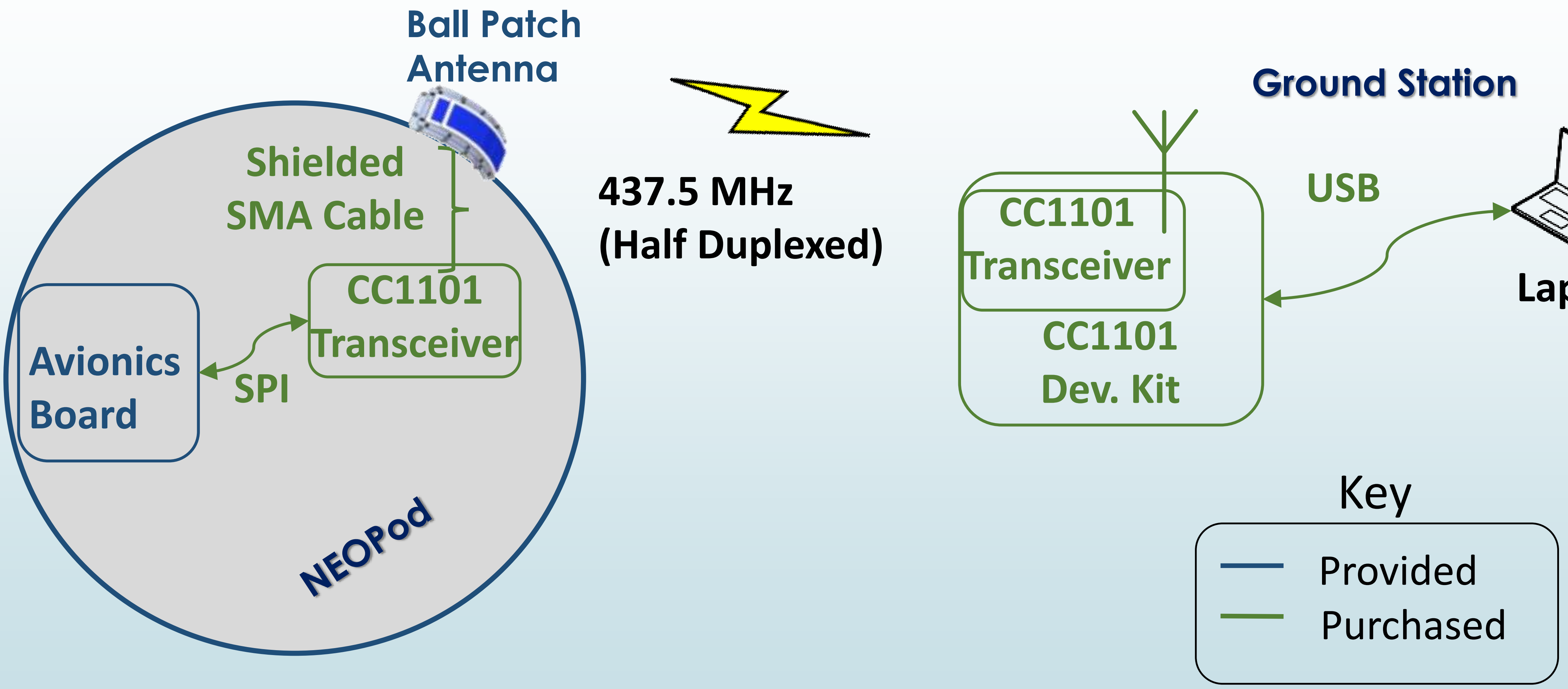
COM 5: Avionics subsystem shall interface with communications subsystem

CPE-2: Requirements

Communications System Design

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 Layout

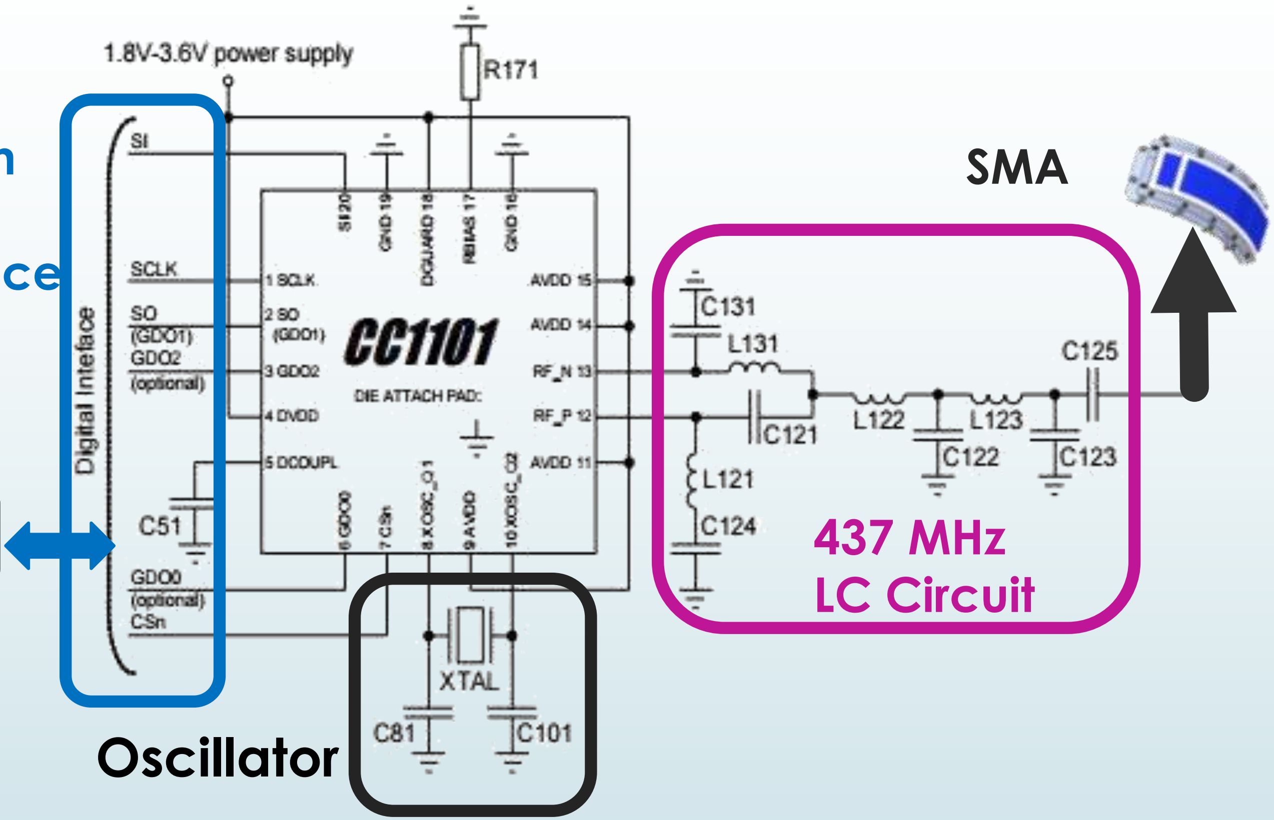


Communications Design (Hardware)

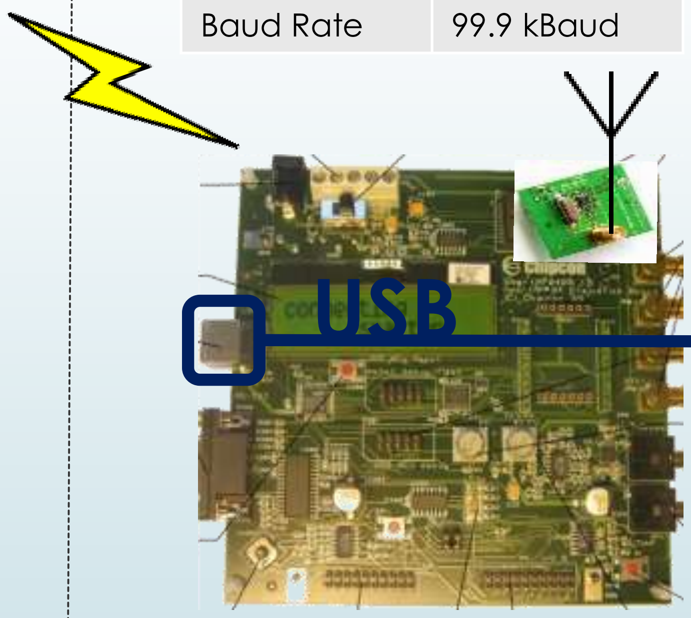
Parameter:	Value:
Frequency	437.5 MHz
Deviation	5.2 kHz
Modulation	GFSK
Baud Rate	99.9 kBaud

PCB & Ribbon Cable Interface

Avionics



Oscillator



Laptop w/ COSMOS™

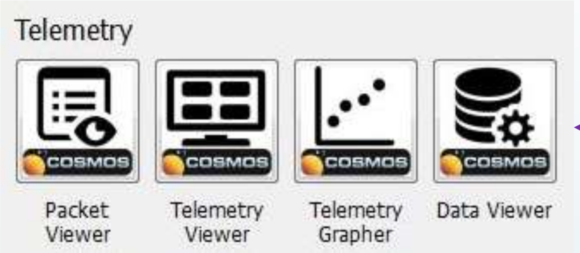
CC1101 Development Kit

NeoPod Comm. System

Ground Station

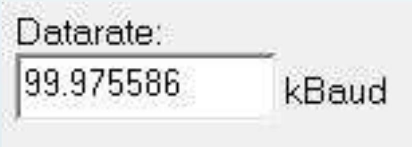
Ground Station Software: COSMOS and Packetization

- Scientific Data



IDs & Data (60 B)

CC1101



Science Telemetry Packet			
Preamble "10101010" (2B)	Sync Word "EL" (2B)	IDs & Sensor Data (60B)	CRC Checksum (2B)

- Commands

Command "T" (1B)

CC1101

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

COM 3: Ground Station shall **transmit commands** over RF

COM 4: Ground Station shall **receive data** over RF

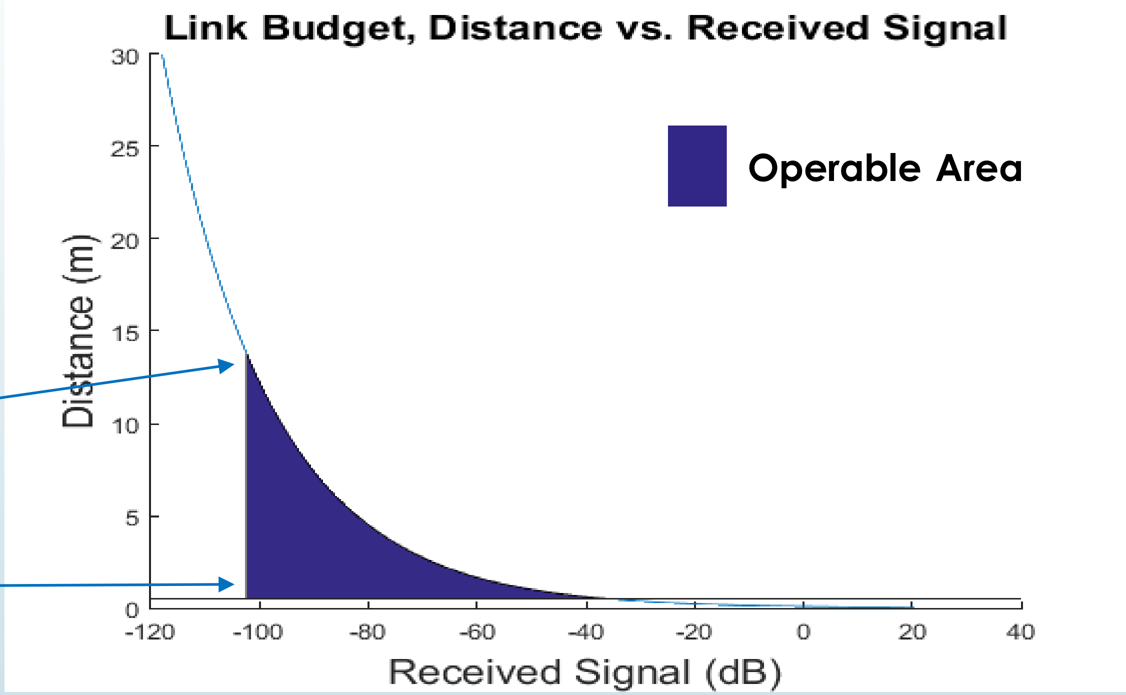
Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

Link Budget – Earth Testing Environment

Description:	Value:
Frequency:	437.5 MHz
Transceiver Transmit Power	+10 dBm
Total Antenna Gain	-40 dBi
Transceiver Receive Sensitivity	-108 dBm
Maximum Transmit Distance:	**13.8 meters**
Minimum Transmit Distance:	**0.5 meters**

COM 1: NeoPod shall **receive commands** over RF

COM 2: NeoPod shall **send data** over RF



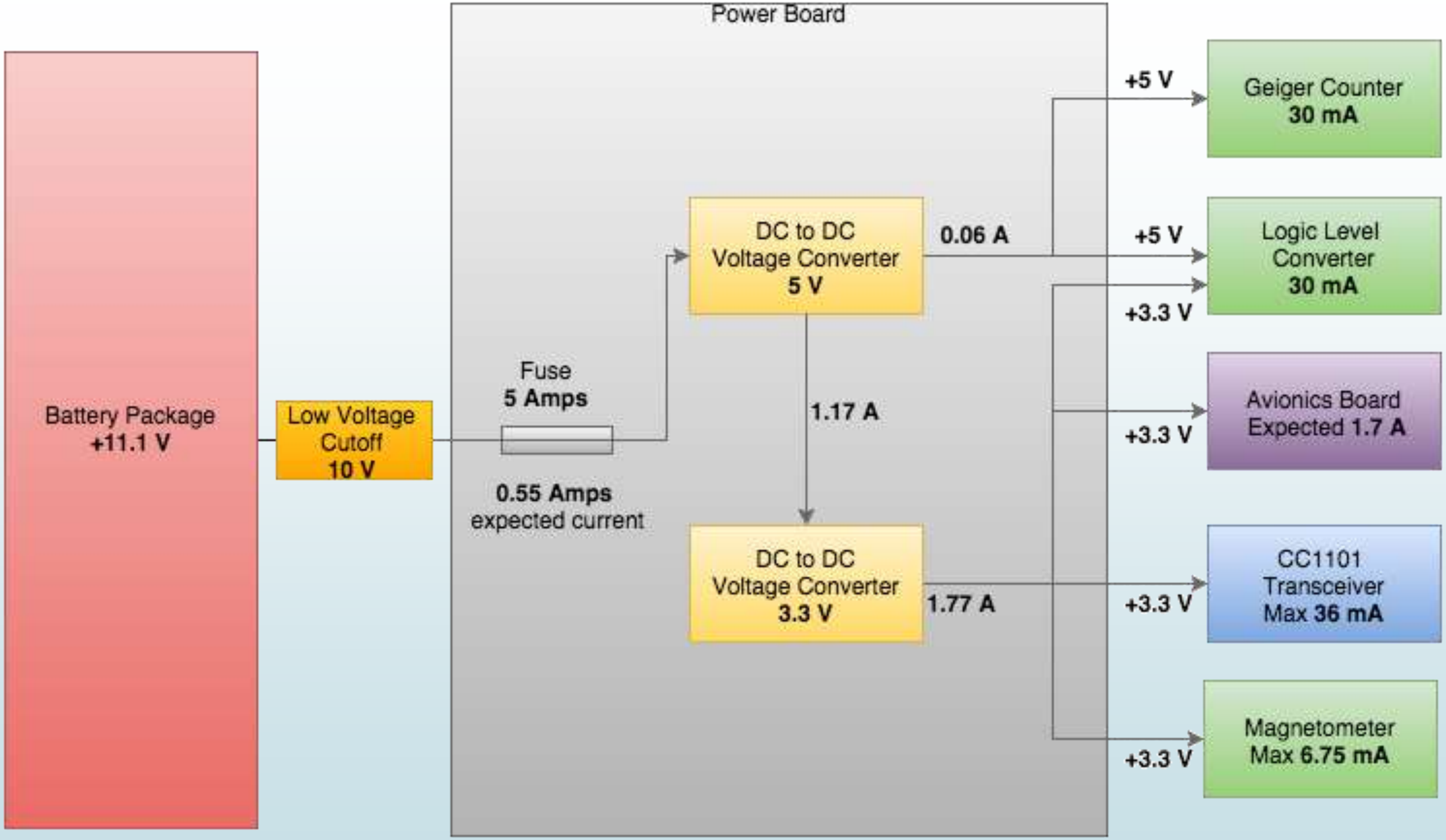
Note: Transmit distance on Europa (100 km) not in scope for this project, a more expensive, robust transceiver is needed on Europa

Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

CPE-3: Requirements

Powers System Design

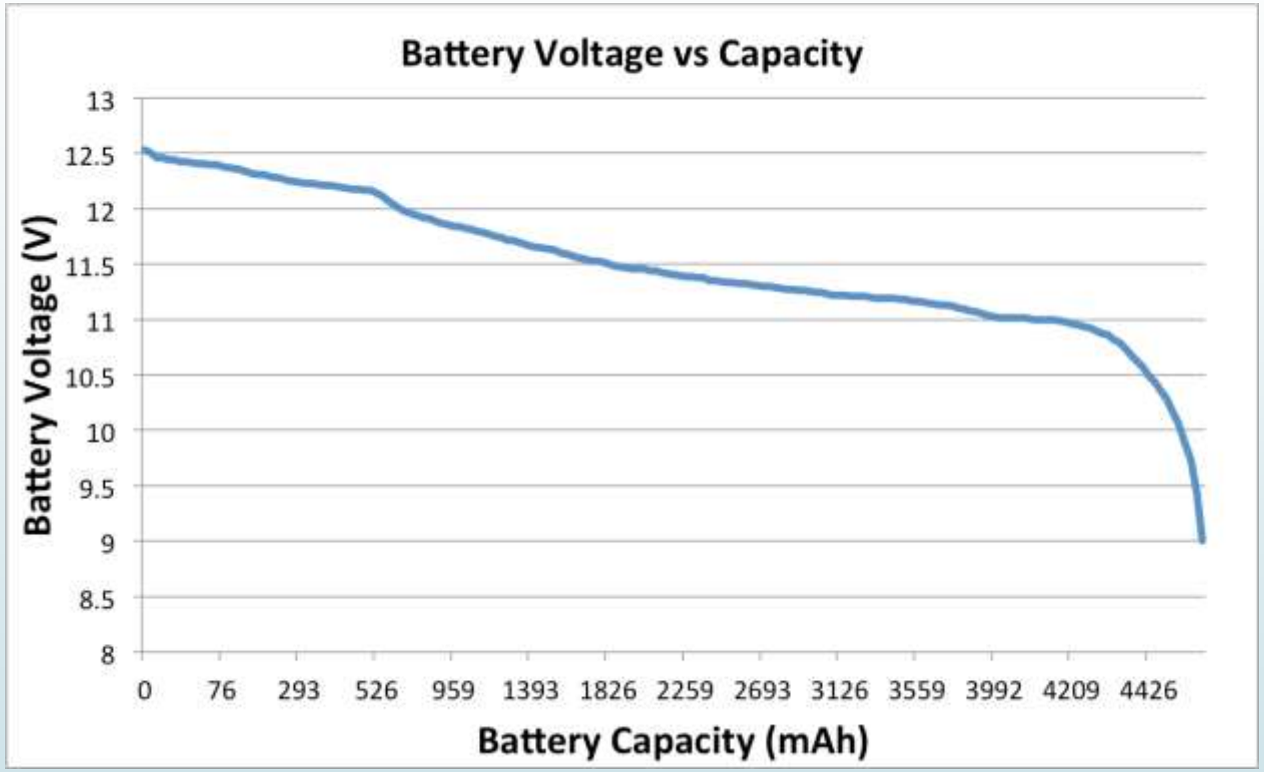
Requirement:	Description:	Motivation:
SCI 3.3.1, SCI 2.2.1, SCI 2.1.2, COM 6.1	Power subsystem shall provide **voltage** lines of **5 V, and 3.3 V**.	The power system must support the Geiger counter at 5±0.25 V, and the magnetometer, transceiver, and avionics board at 3.3±0.3 V.
SCI 2, SCI 3, COM 6	Power 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



Power Distribution Board Block Diagram

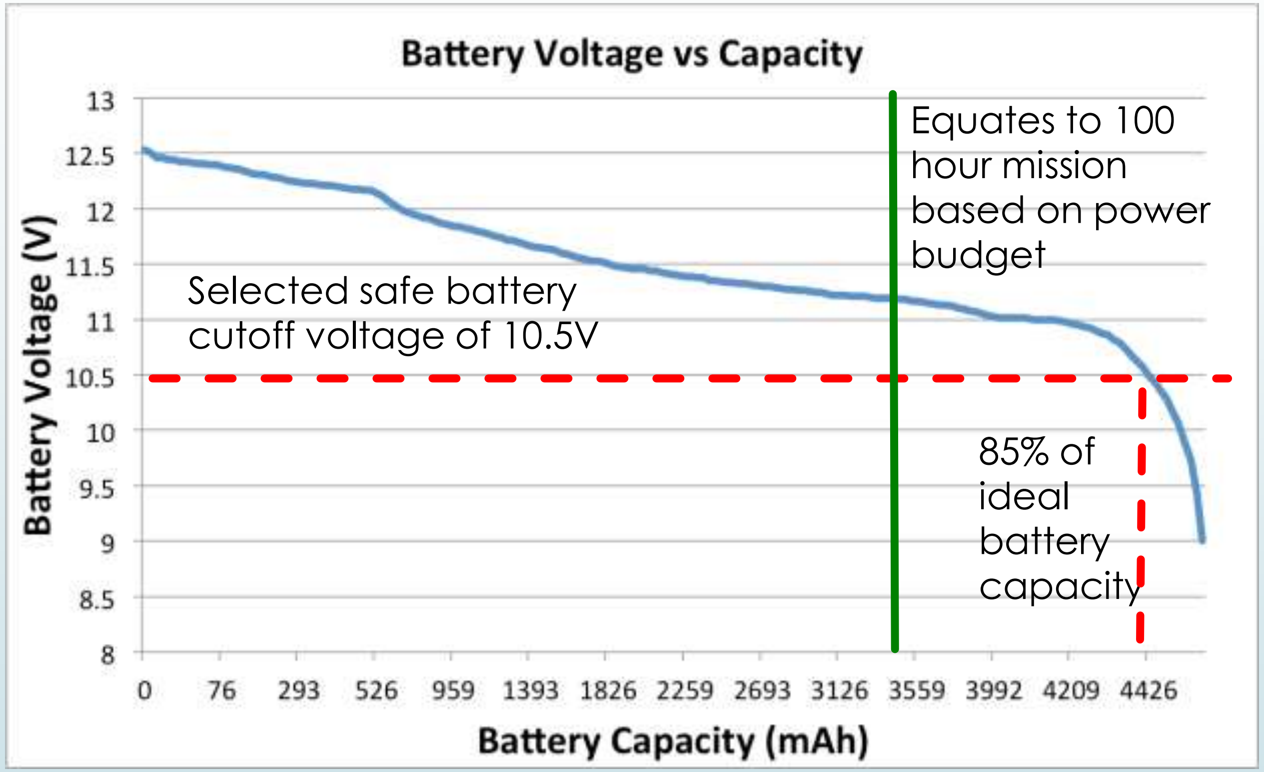
Battery Characterization Test

- Equipment:
  - TP 1430C Lipo Charger
  - TENMA EX354T Power Supply
  - 5200mAh Lipo Battery
- Description: Battery discharged at 2 A to 9 V (~2 hours)
  - Measurements recorded manually from charger display
  - Data recorded once every minute
  - Voltage resolution: 0.1 V
  - Capacity resolution: 1 mAH



Battery Power Available

	Solution:
Type:	LiPo Battery pack 11.1 V (3S) 5200 mAh
Ideal Battery Capacity:	57.72 Wh
Useable Battery Capacity (%85):	49.06 Wh
Number of Batteries:	17
Total Power Available:	**834.05 Wh**



Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

Power Budget

Component	Total Watt Hours over 100 hours (Wh)
Geiger Counter	15
Magnetometer	2.19
Avionics Board	547.6
Transceiver	5.27
DC-DC Converter	85.12
Total Power Needed:	**655.18 Wh**

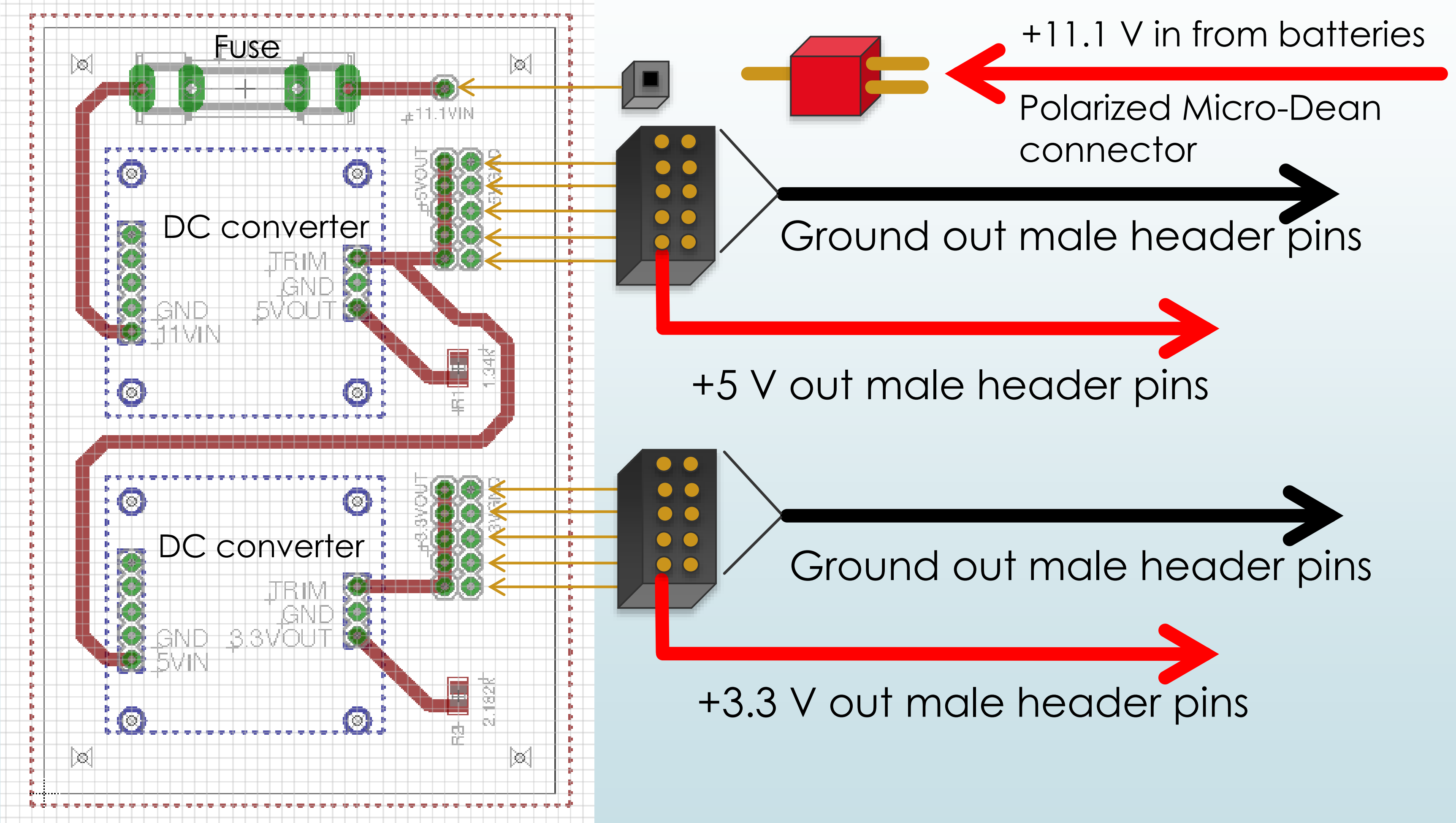
Power Budget:	Power (Wh)
Power Available:	**834.05 Wh**
Power Needed:	**655.18 Wh**
Margin:	**178.86 Wh** **27.3% Margin**

SCI 2, SCI 3, COM 6: Power subsystem shall **provide power** to subsystems for a total of **100 hours**

Printed Circuit Board Design

- 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
  - Can provide 5 ± 0.25 V and 3.3 ± 0.3 V

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**



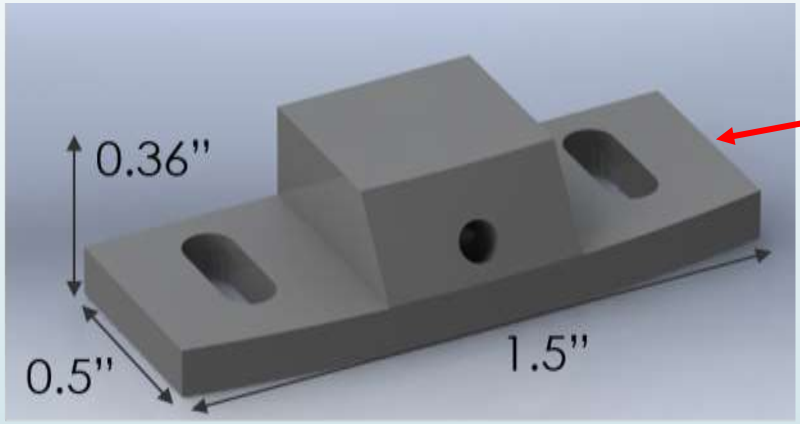
Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

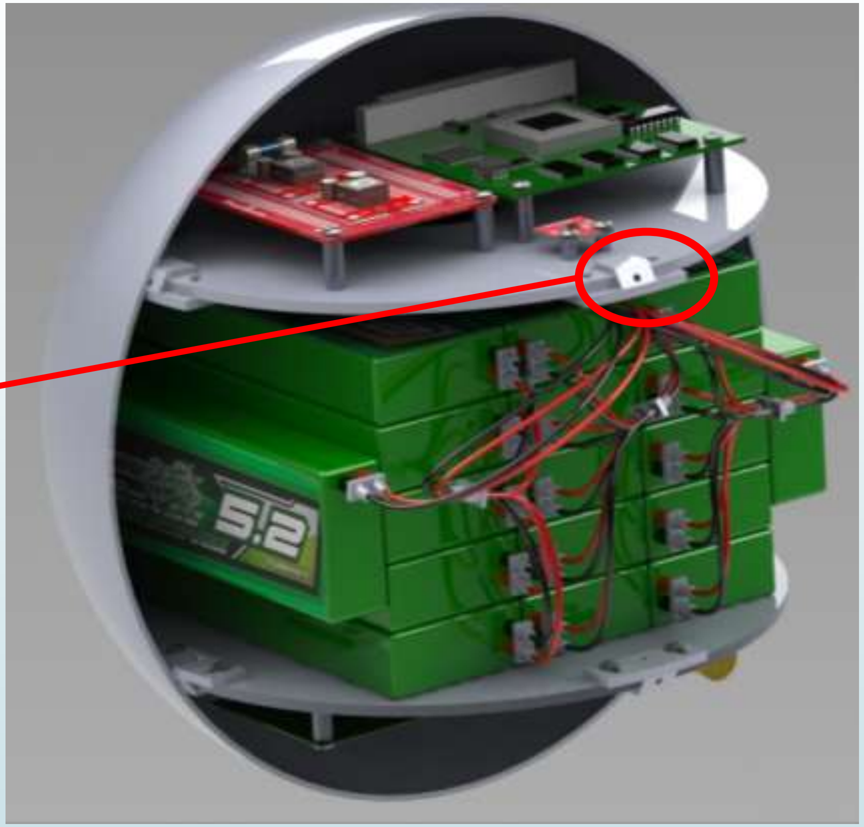
CPE-4: Requirements

Mechanical Integration

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.
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.

Structural Design Solution





Key Specifications:

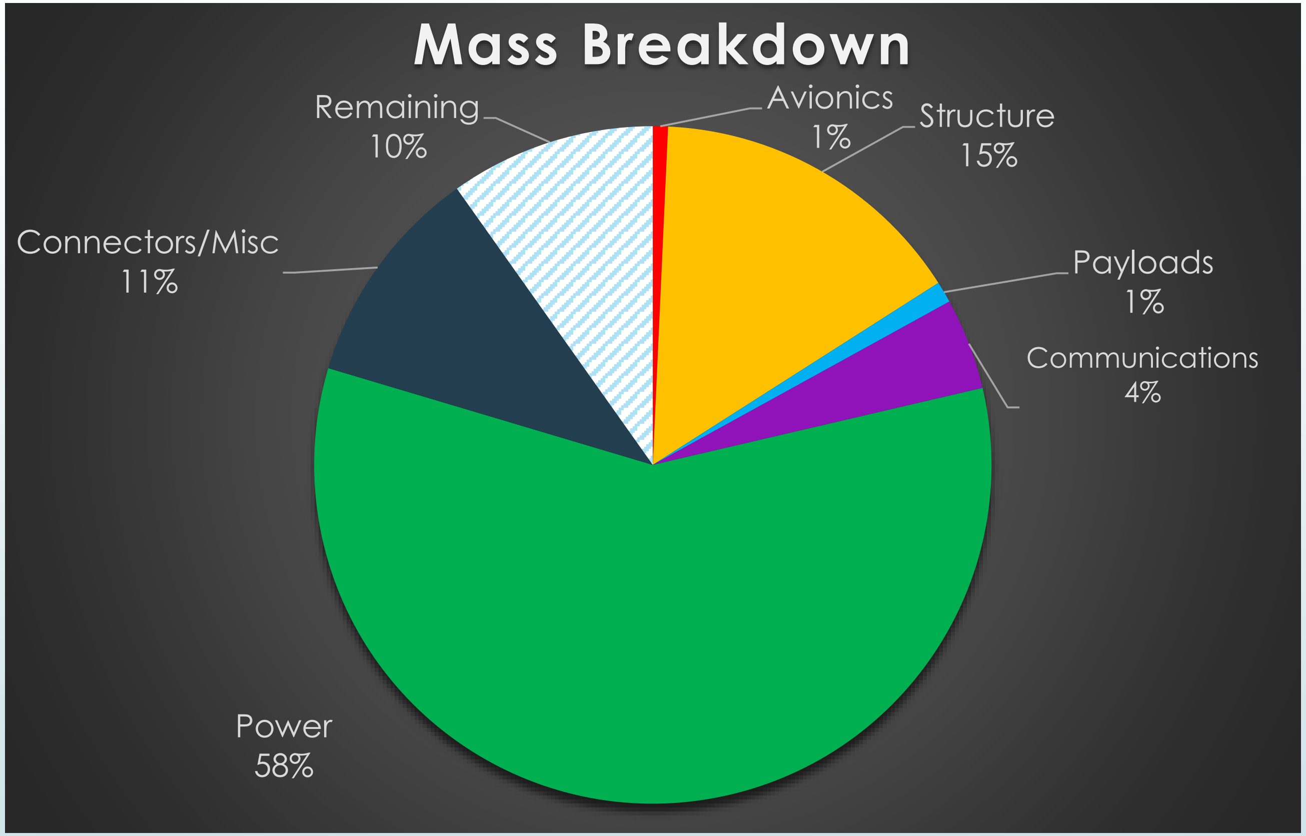
Subsystems will be mounted to **two circular shelves** using **standoffs/straps**

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

All components **fit within closed sphere** with a mass of **9 kg**

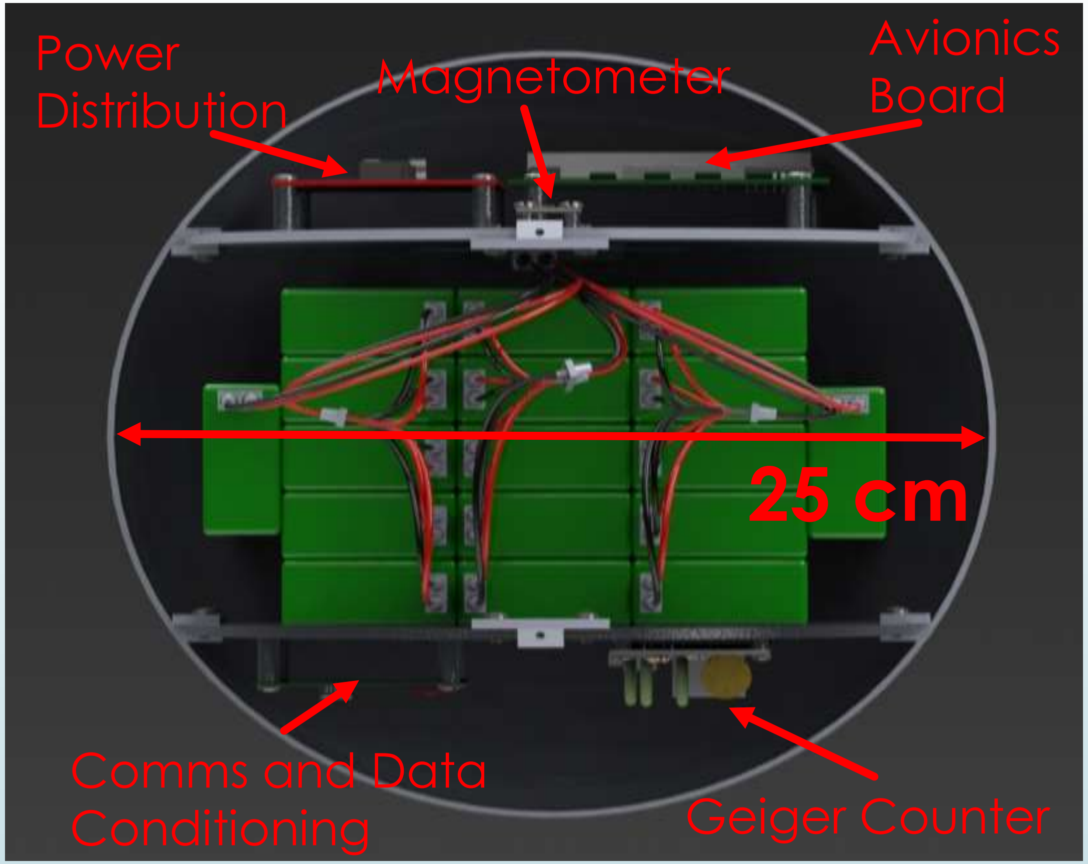
Mass Breakdown

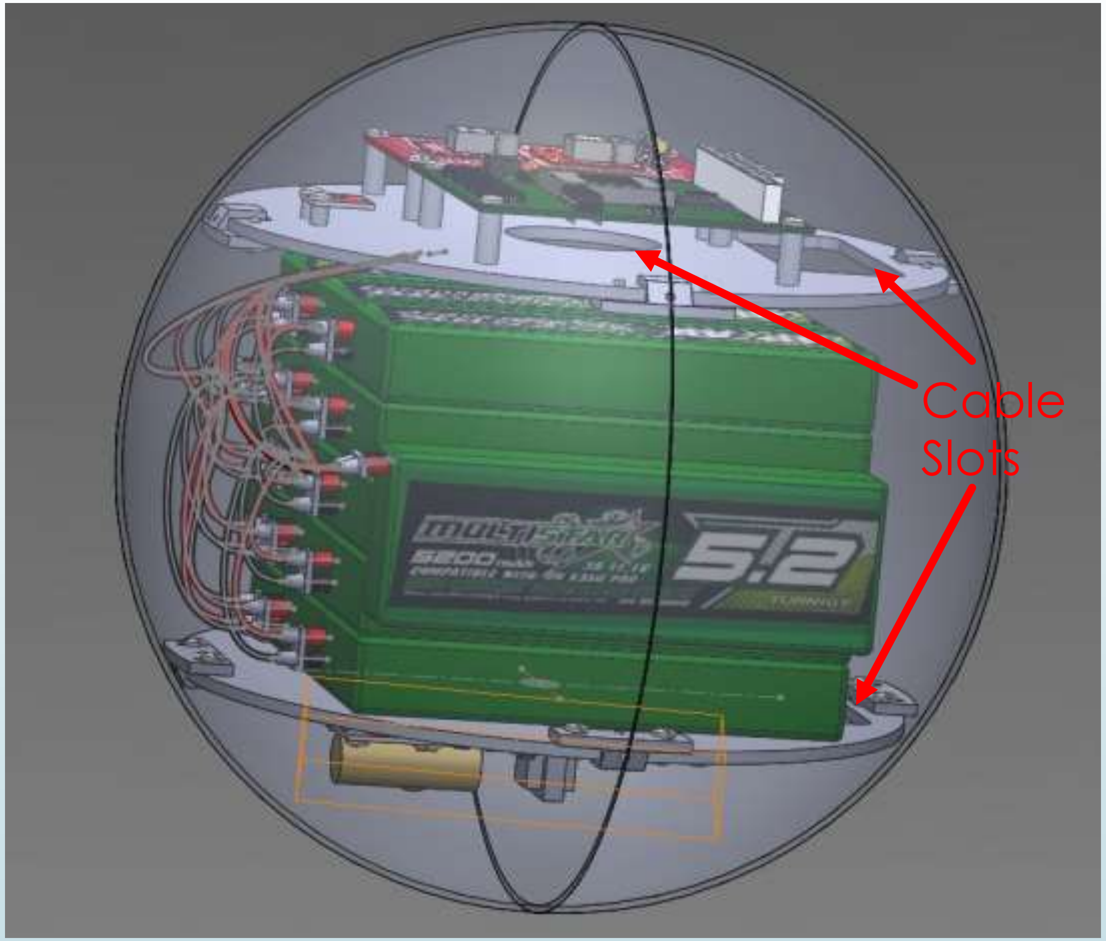
Subsystem	Mass with Margin (g)	Margin:
Available	10000	
Avionics	72	20%
Structure	1525	10%
Payloads	102	20%
Communications	436	10%
Power	5826	2%
Connectors/Misc.	1057	15%
Total Mass:	**9017 g**	**411 g**
Remaining:	**10% or 983 g**	



INT 1: NeoPod shall have a **mass less** than **10 kg**

NeoPod Structural Layout



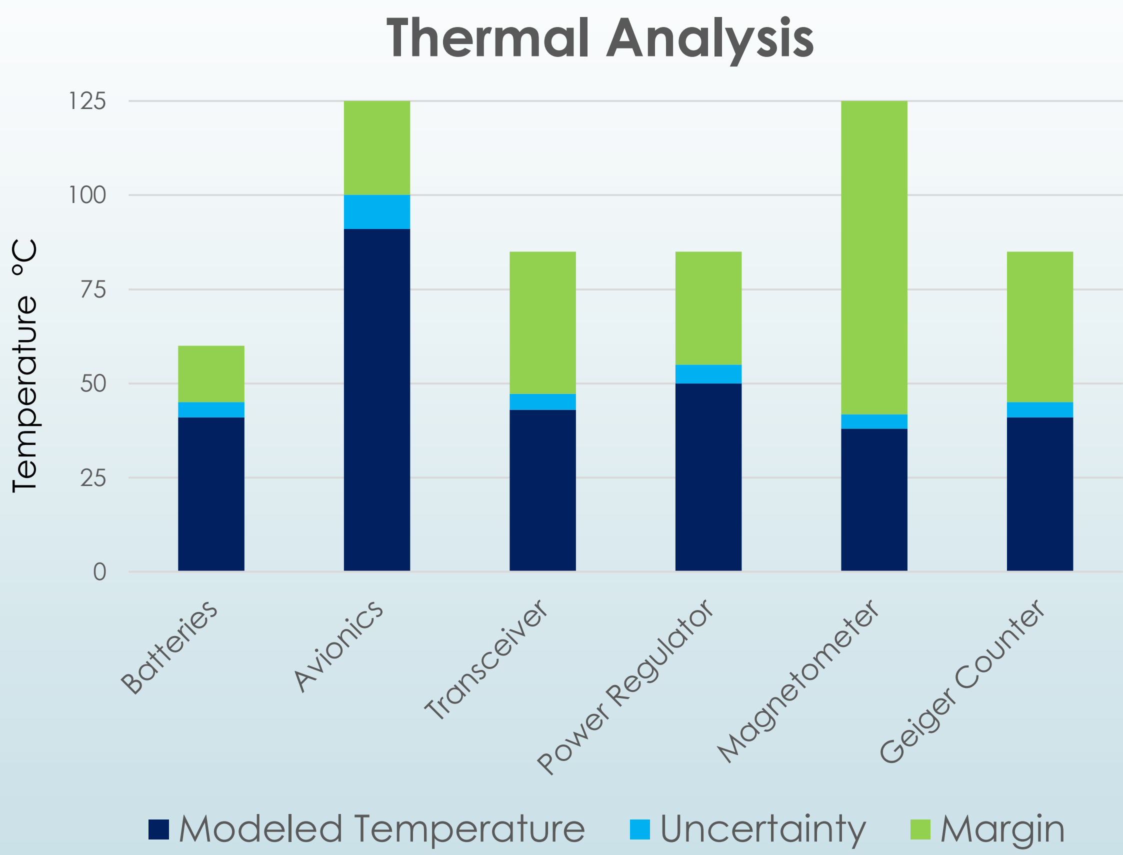


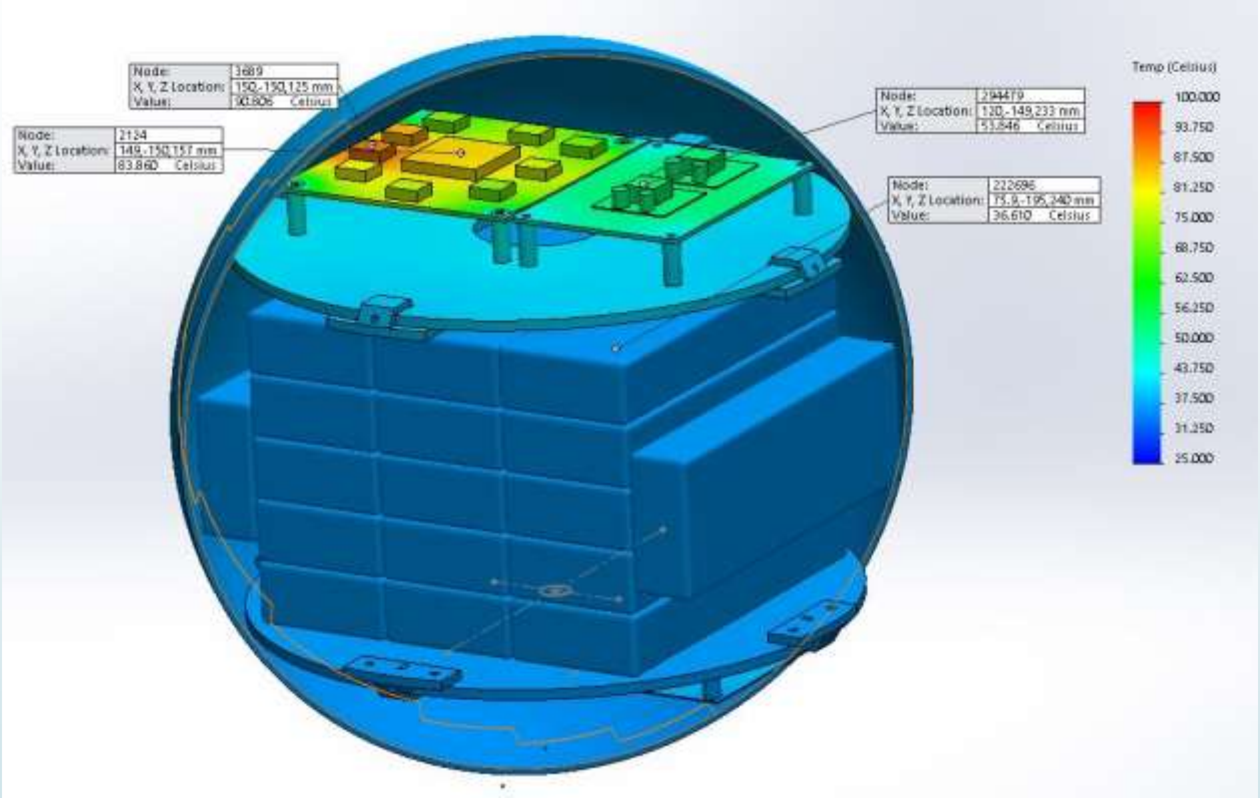
INT 2: NeoPod shall have a maximum diameter of 30cm

Thermal Model Assumptions:

- Done in SolidWorks
- Assumed all Chip Components made from silicon material
- All boards are FR-4 material
- Applied **maximum expected operating loads** to each component
- Thermal model run with **ball closed**
- Free convection on outside of the ball
- Thermal model predicts **steady state temperatures**
- Ambient Temperature: 25 °C

Temperatures within Operating Conditions



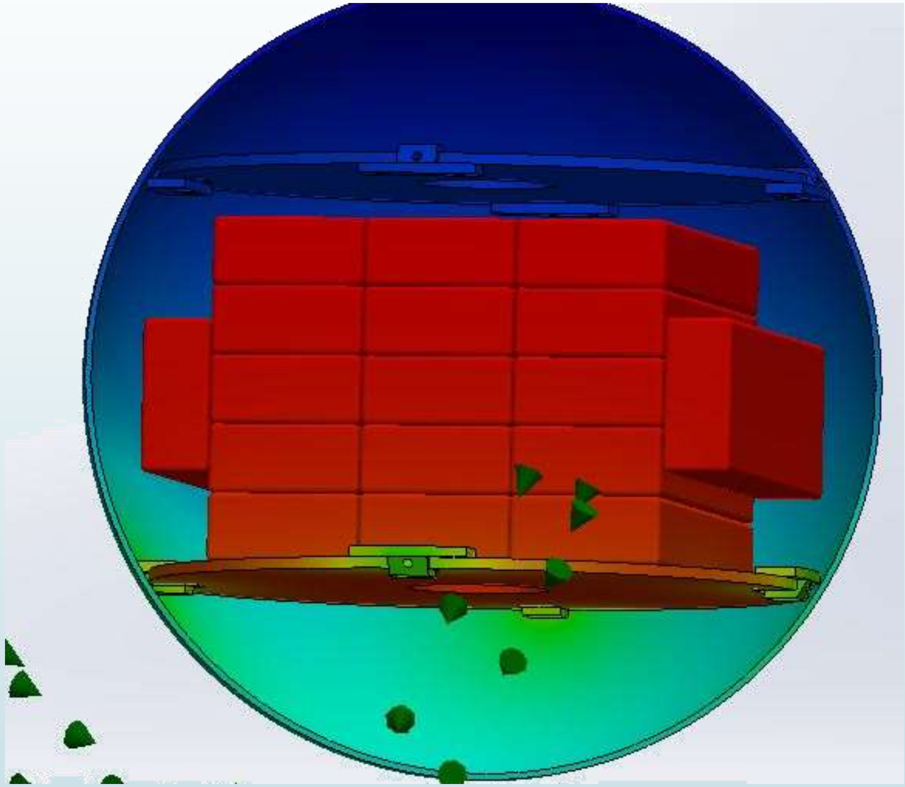


INT 6: All temperatures are within acceptable range of onboard components

Will be refining models through component testing

Worst Case Battery Thermal Model

- All power generated by batteries **assumed** to be heat
- 8.7 Watts/17 batteries = 0.51 Watts per battery
- Steady State Temperature: 48 °C
  - Maximum allowable battery temperature: 60 °C



INT 6.1: Batteries shall not exceed 60°C

Risk Analysis

Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

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

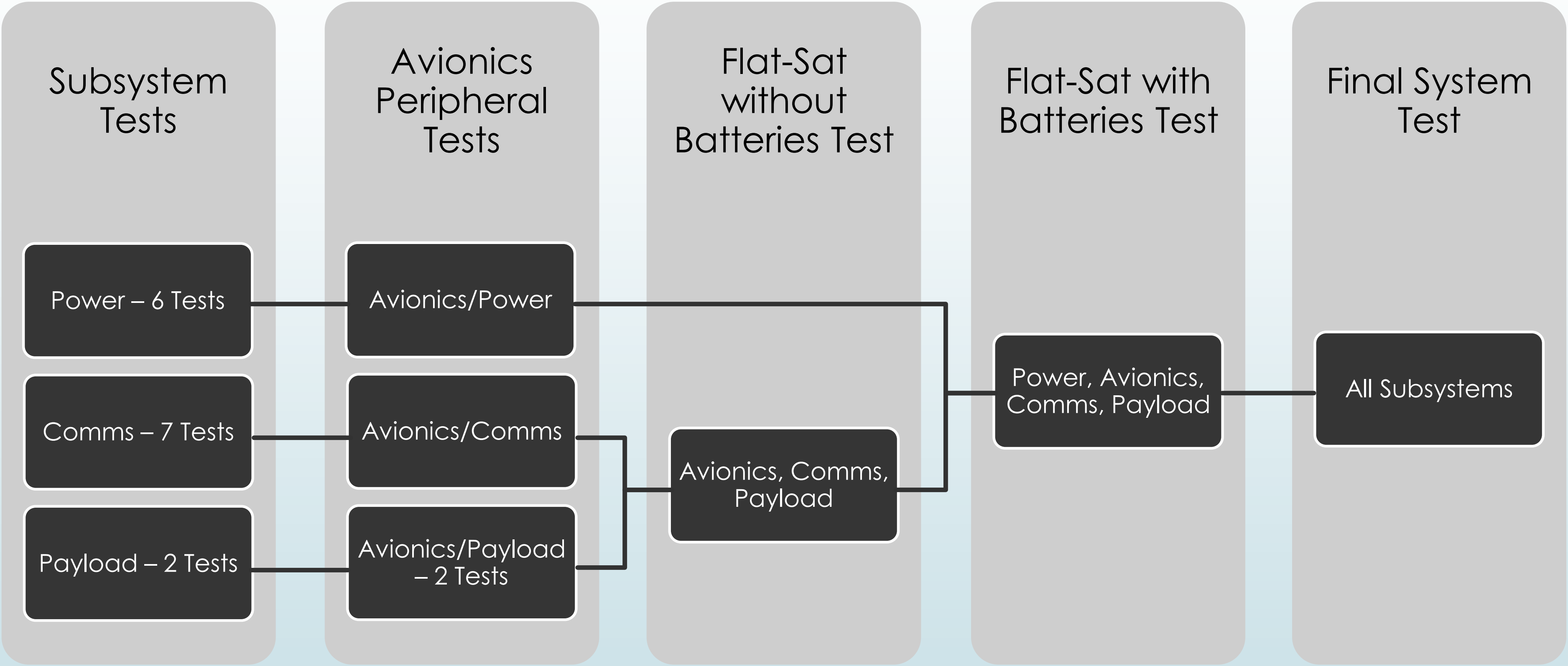
	1	2	3	4	5
5 (Very High)					
4 (High)				RP3	RP1 RP2
3 (Moderate)				RP4 RP5	
2 (Low)					
1 (Very Low)					

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

Testing and Verification

Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

Test Plan Overview



Testing Design Requirements, Levels of Success, and Models

Subsystem Tests	Avionics Peripherals Tests	Flat-Sat without Batteries Test	Flat-Sat with Batteries Test	Final System Test
Payload L1 – L2, L4	Payload L3	–	–	Power L3
Power L1 – L2	Communication L1 – L4	–	–	Structure L1 – L4
Ground Station L1 – L3	Avionics L1 – L4	Ground Station L4	–	–
SCI 1	SCI 3	–	–	SCI 2
COM 1 – 4	COM 5	–	–	COM 6
INT 3	–	INT 6, 9	INT 5 – 6, 9	INT 1 – 2, 4 – 9
RF Link	–	*RF Link	*RF Link	*RF Link
–	–	–	Battery Discharge	*Battery Discharge
–	–	–	–	Thermal Model

Key
Levels of Success
Functional Requirements
Models

* Redundant test for statistics

Battery Discharge Model Validation

Objective: Validate Battery Discharge Model

Test: Flat-Sat with Batteries Test → by March 17th

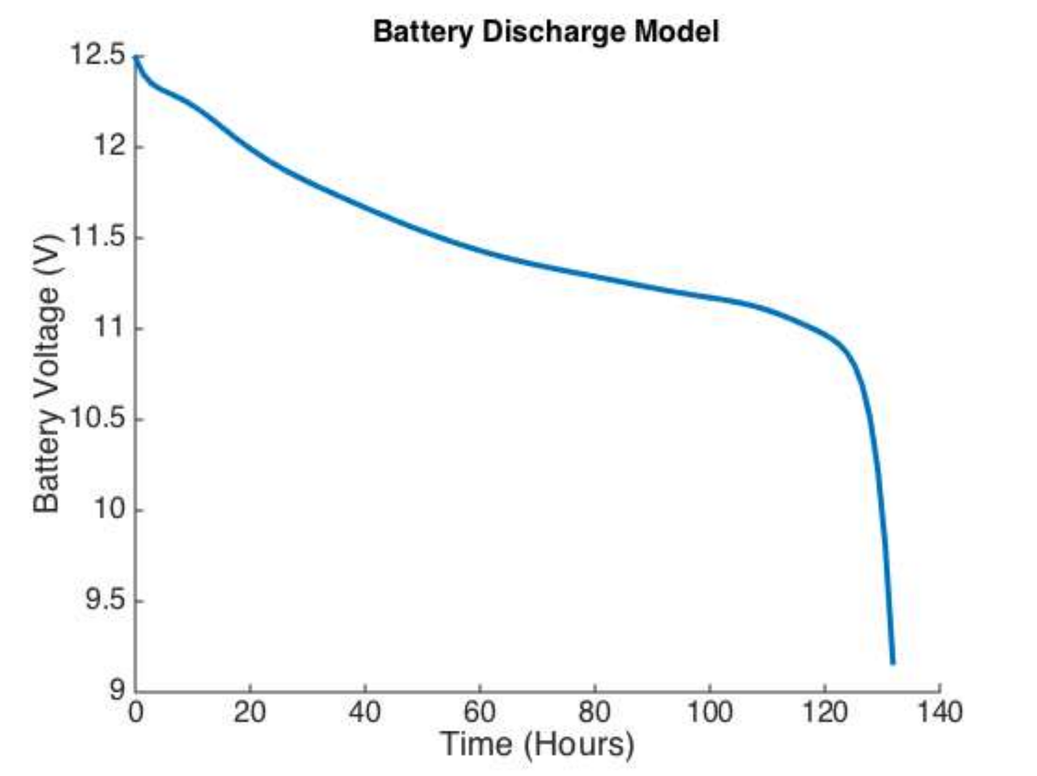
Duration: 8.5 hr w/ 2hr shifts

Location: Trudy's Lab

Data Needed*	Resolution Needed	Sampling Rate
Voltage	.1 Volts	Once every 15 minutes
Time	1 minute	

Equipment*	Resolution	Procurement
Agilent 34410A Multimeter	.06 Volts	Trudy's Lab
Laptop (clock)	> 1second	Trudy's Lab
(17) 5200mAh Lipo Batteries	-	Purchased

***additional information included in backup slide (Flat-Sat Test Logistics)**



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RF Link Model Validation

Objective: Validate RF Link Model

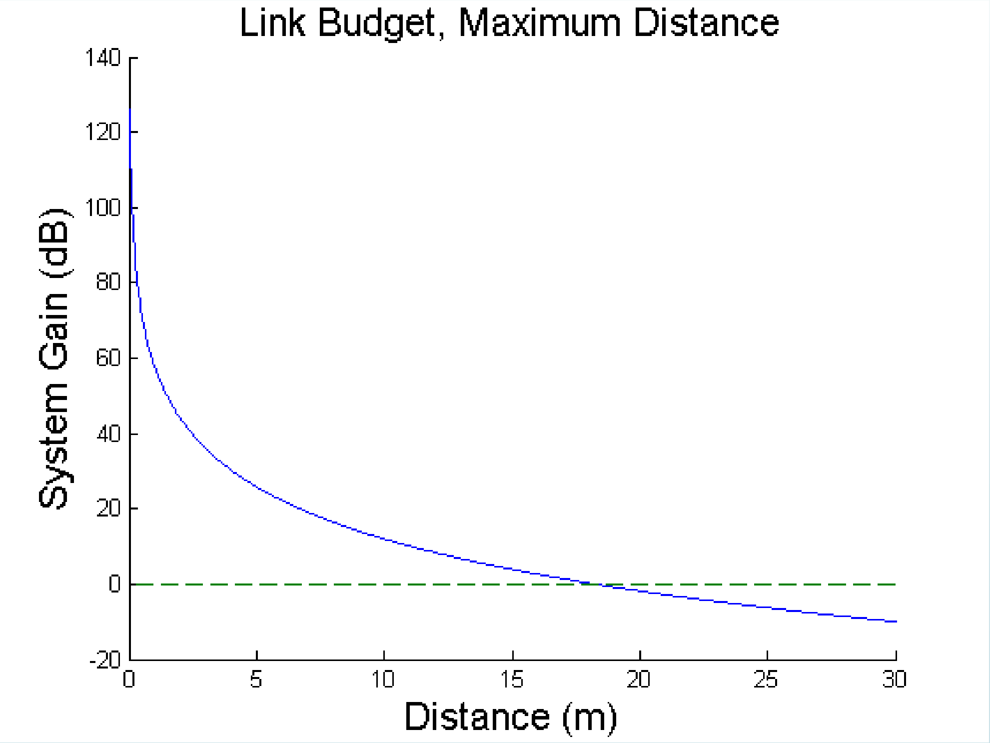
Test: Signal Strength Test with Patch Antenna ➔ by January 31st

Duration: 1 hr

Location: Trudy's Lab

Data Needed	Resolution Needed	Sampling Rate
Distance	0.1 m	1 Hz
RSSI	0.1 dBm	

Equipment	Resolution	Procurement
CC1101 Dev. Kit & Attenuators	0.01 dBm	Purchased/ Borrowed
2 Laptops	0.01 dBm	Owned
Measuring Tape	0.001 m	ITLL



Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

Thermal Model Validation

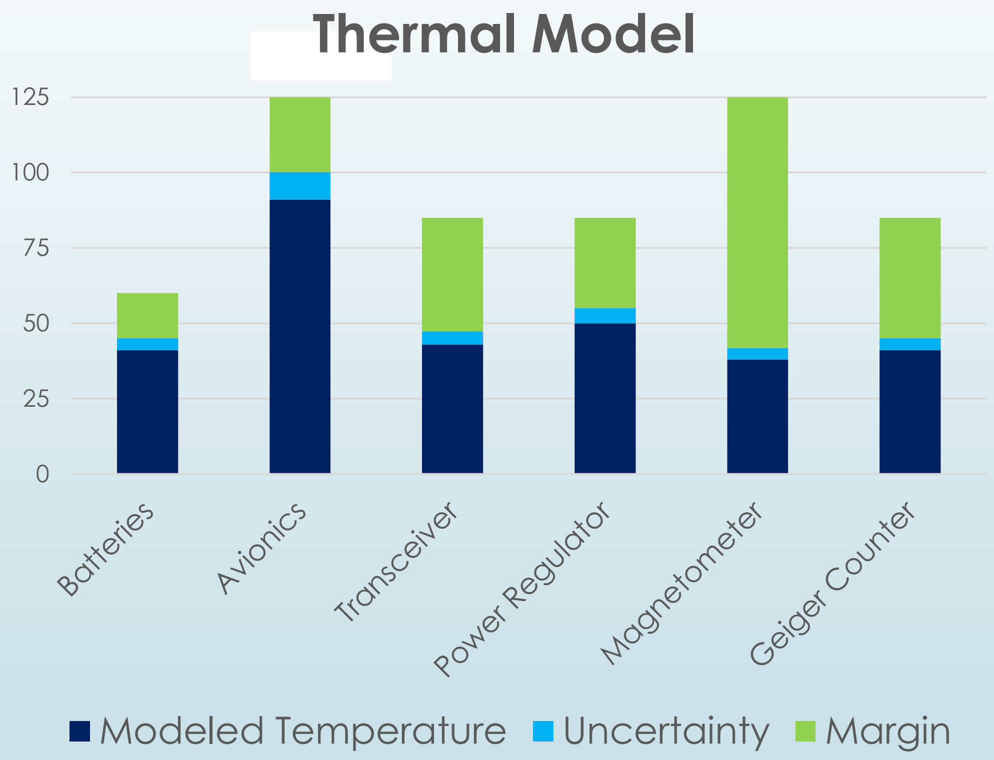
Objective: Validate Thermal Model

Test: Final System Test ➔ by April 17th

***additional information included in backup slide (Final System Test Logistics)**

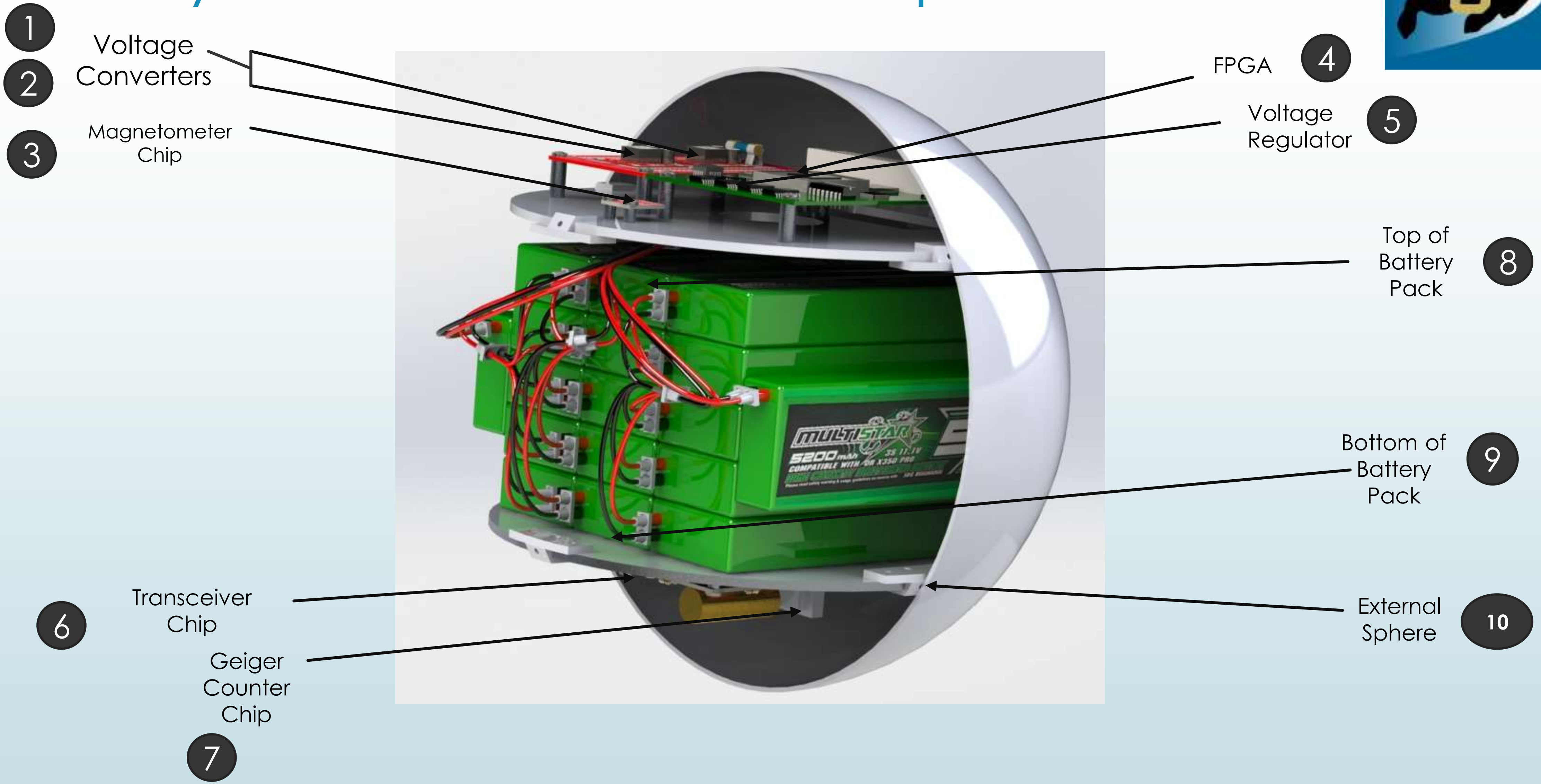
Duration	Data Needed*	Resolution Needed	Sampling Rate
100 hrs. ~4 hr. shifts	Temperature	2 °C	Once every 15 minutes
	Time	1 minute	

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



Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

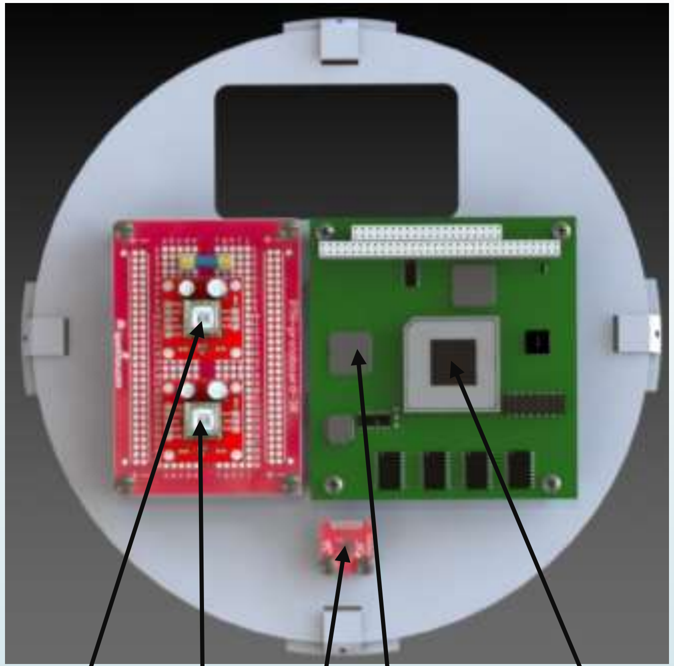
Final System Test: Thermocouple Locations



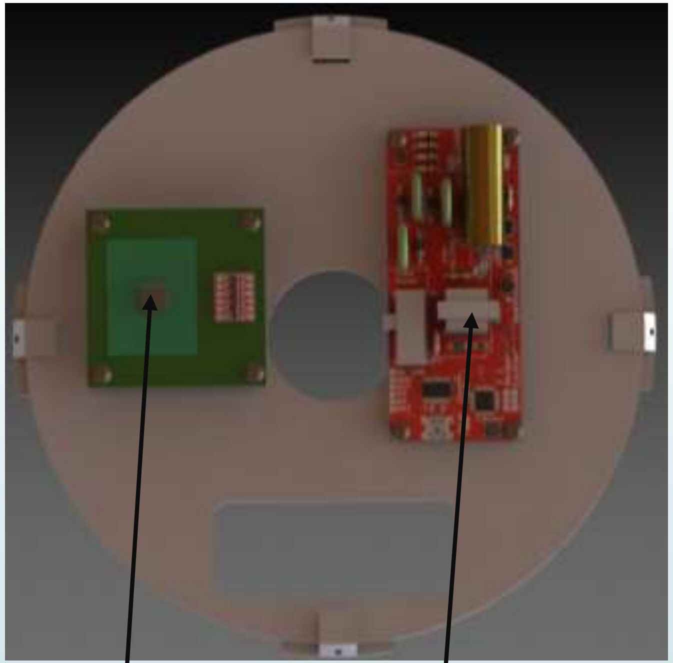
Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

Thermocouple Setup: Exploded View

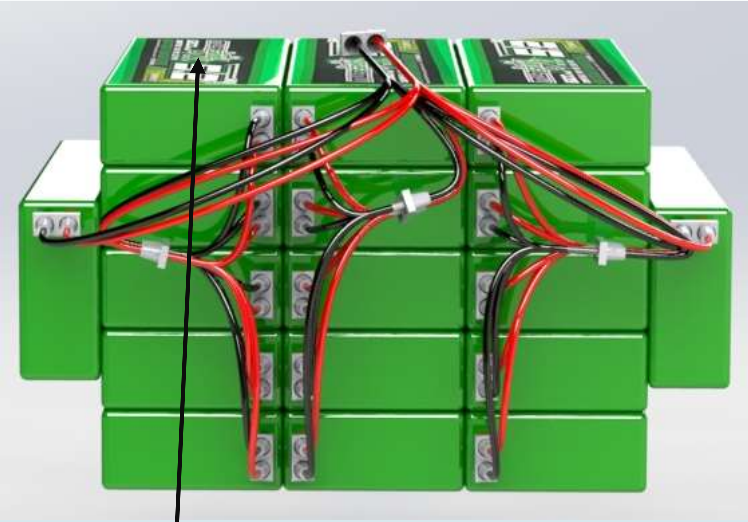
Top Shelf



Bottom Shelf



Battery Stack



Voltage Converters
1 2

Magnetometer Chip
3

Voltage Regulator
4

FPGA
5

Transceiver Chip
6

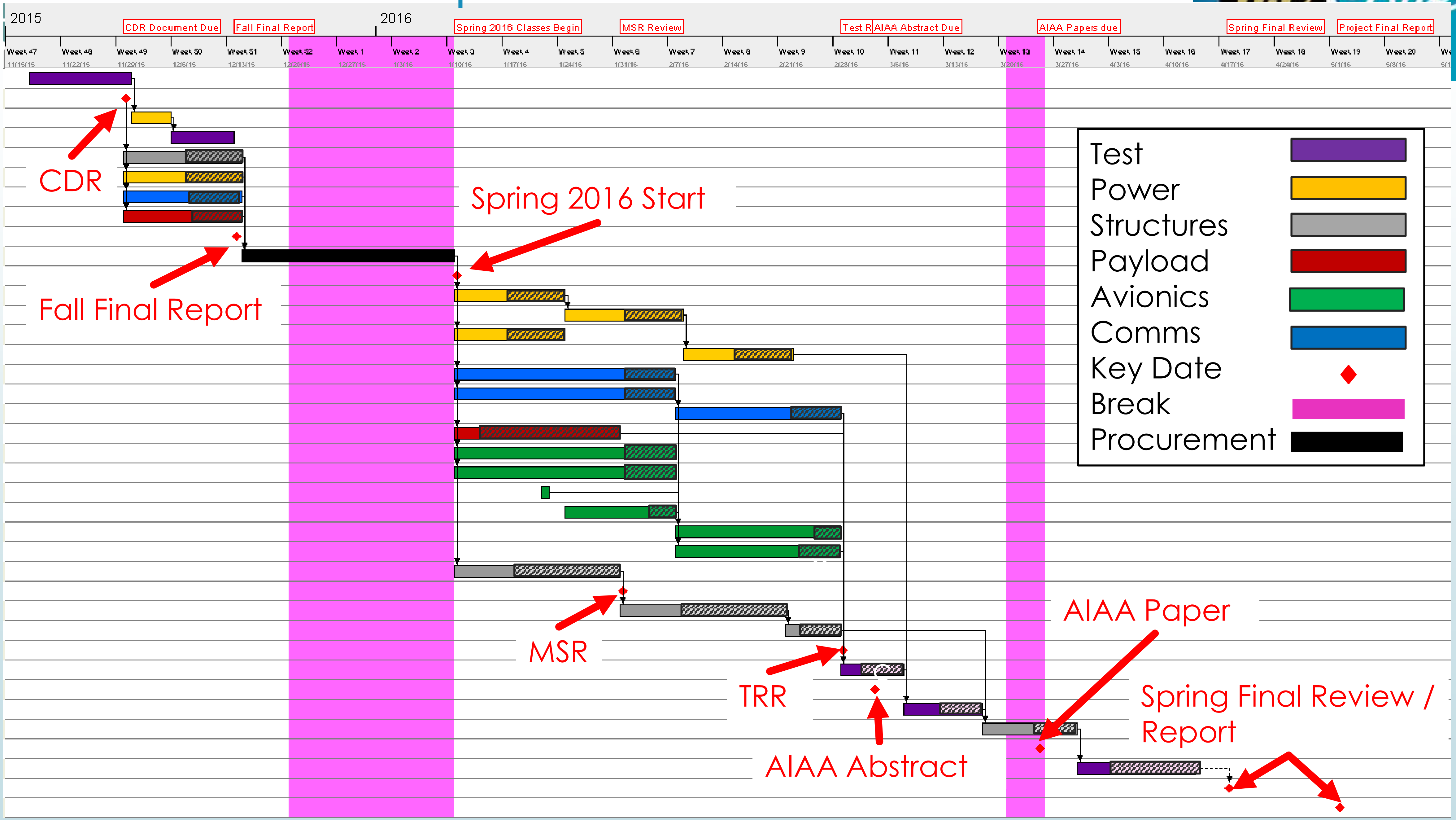
Geiger Counter Chip
7

Top of Battery Pack
8

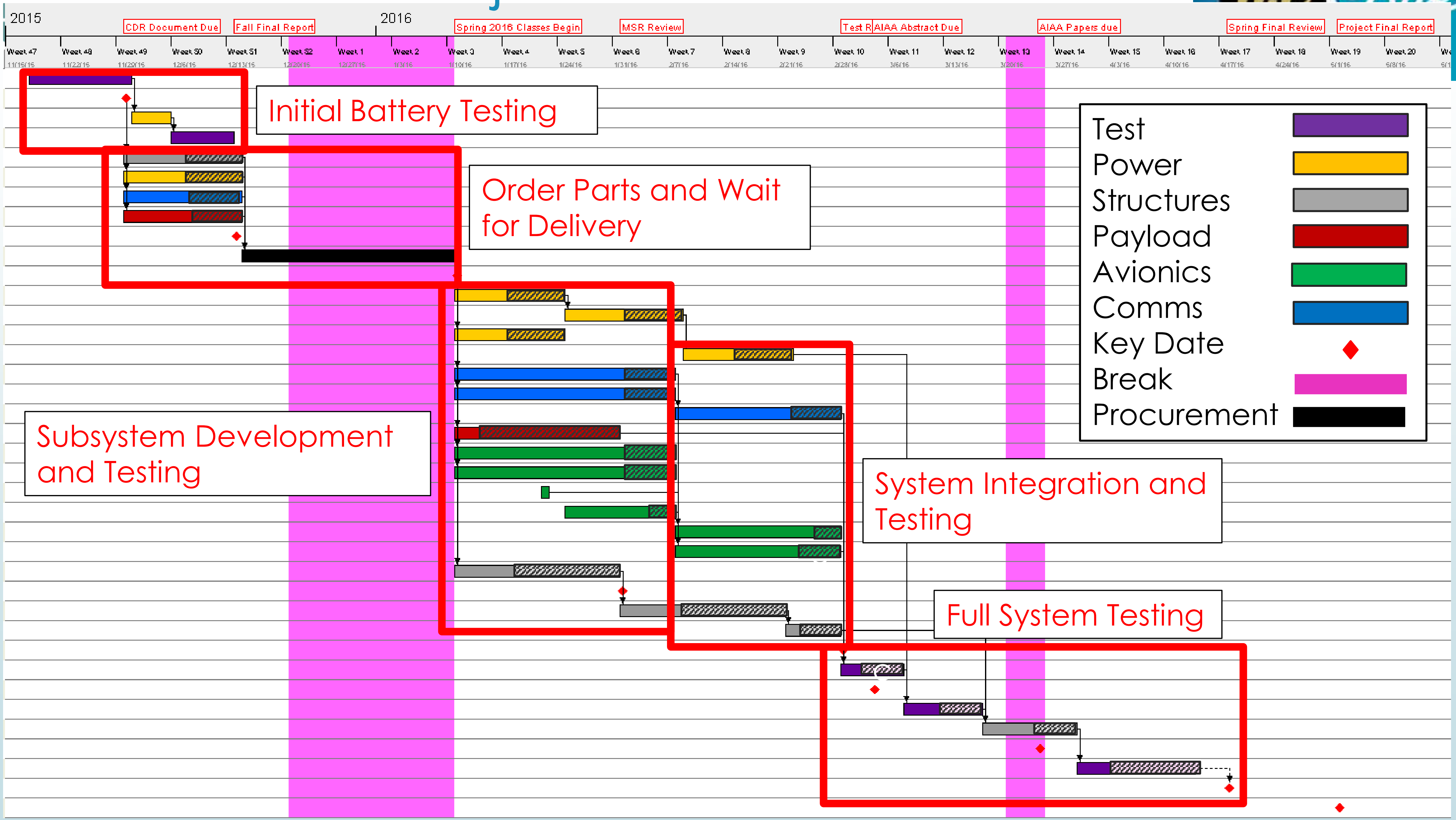
Project Planning

Project Overview
Design Solution
Requirements and Risk
Testing and Verification
Project Planning

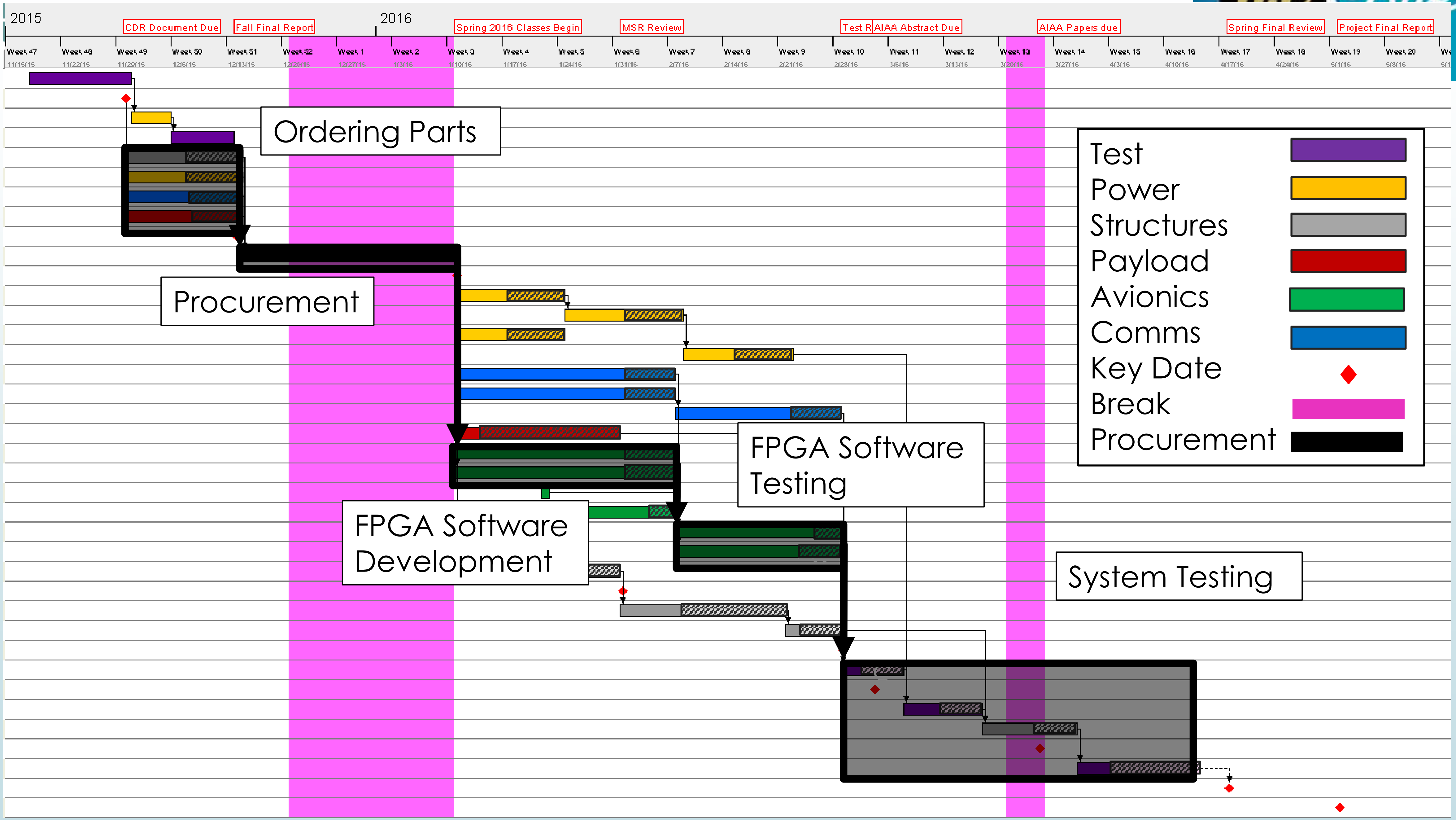
Semester Plan: Important Dates



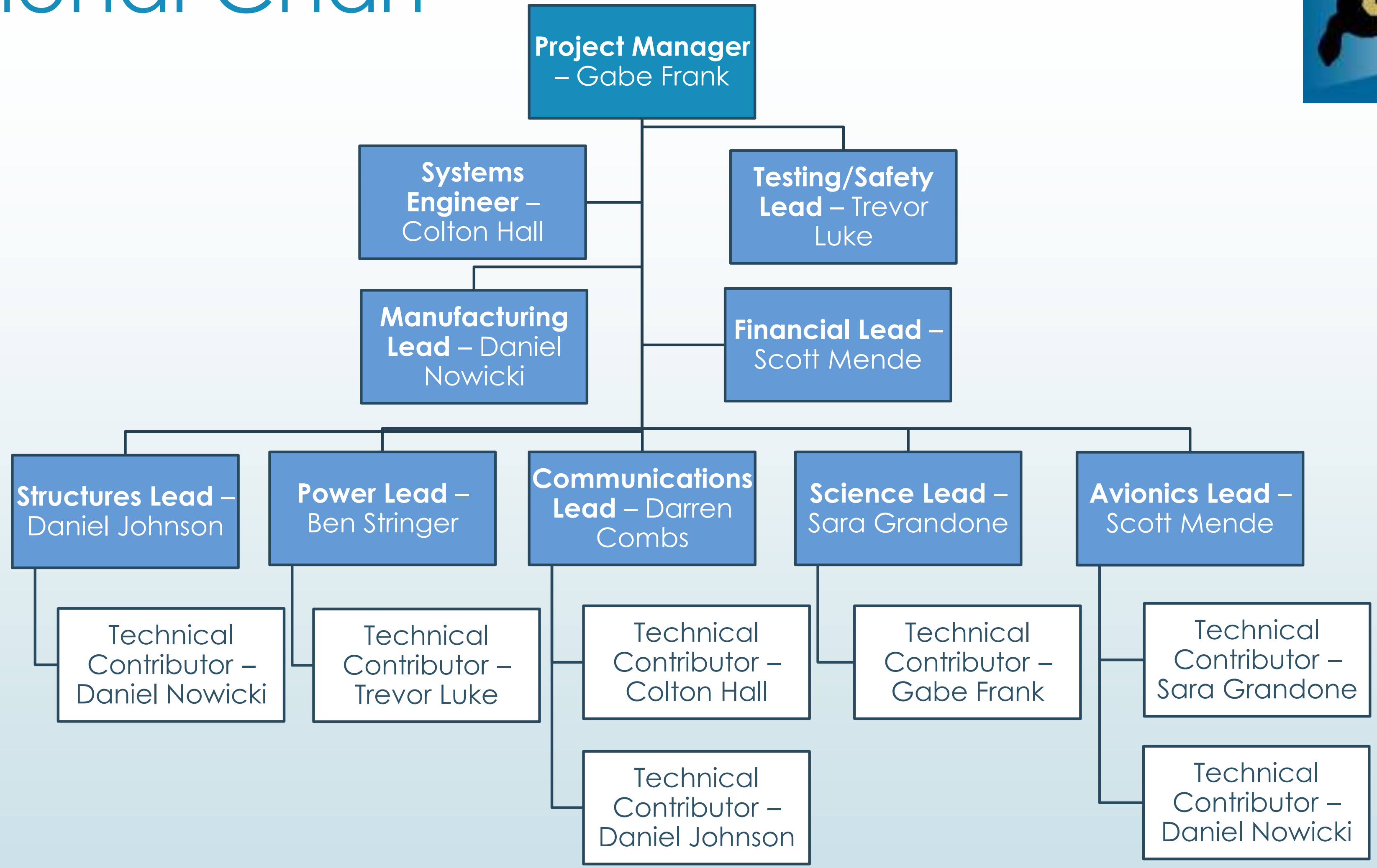
Semester Plan: “Project Phases”



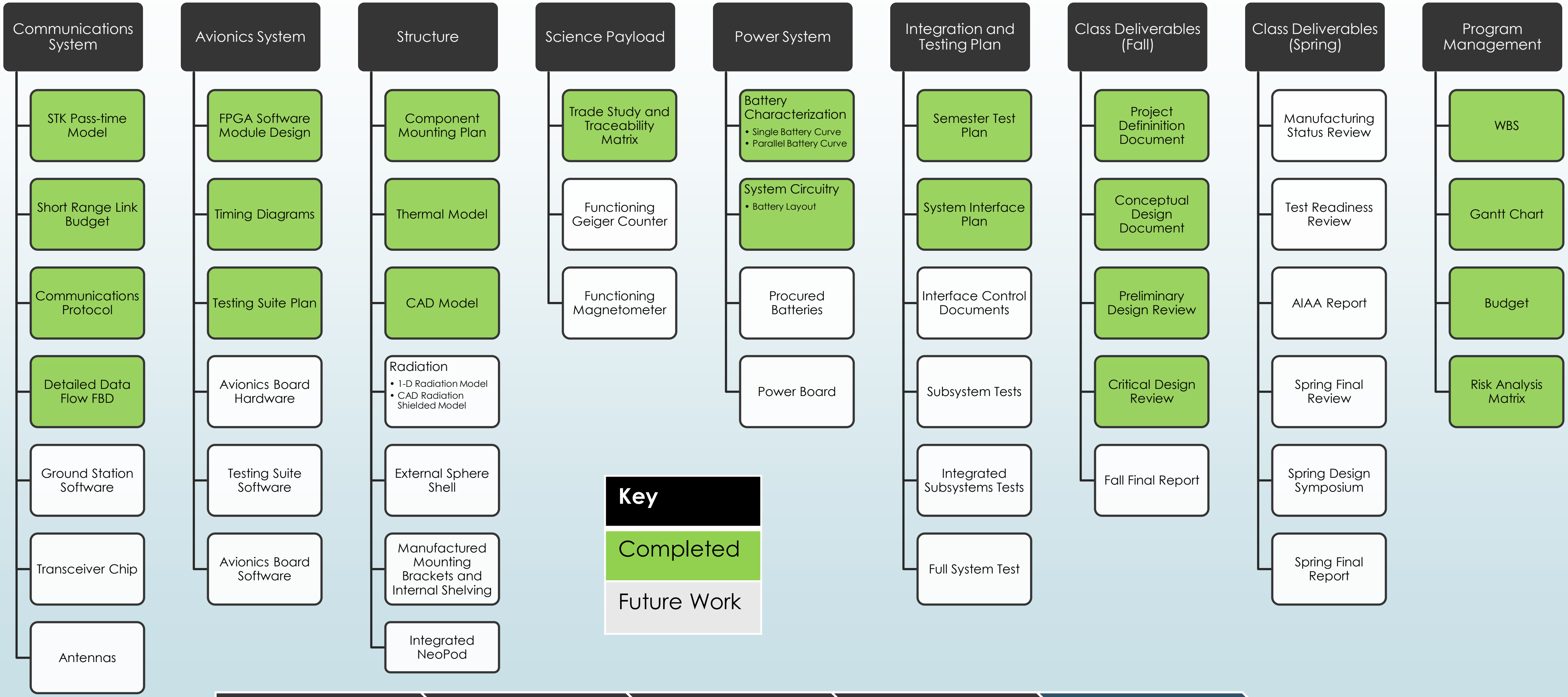
Semester Plan: Critical Path



Organizational Chart



Work Breakdown Structure



Cost Plan

Part	Cost	Contingency	Total ($):
Batteries (x17)	$544.00	$128.00 (4 batteries)	$672.00
CC1101 Transceiver Kit	$500.00	$500.00 (100%)	$1000.00
Metals and Fasteners	$177.00	$354.00 (200%)	$531.00
DC/DC and Logic Converters	$35.00	$35.00 (100%)	$70.00
Wires, Connectors, Cables	$400.00	$800 (200%)	$1200.00
Printed Circuit Boards	$100.00	$300.00 (300%)	$400.00
Power Safety Devices	$20.00	$60.00 (300%)	$80.00
Sensors	$165.00	$165.00 (100%)	$330.00
Testing Equipment	$240.00	$25.00 (~10%)	$265.00
Total:	**$2181**	**$2367**	**$4548**

Questions?

Project Overview → Design Solution → Requirements and Risk → Testing and Verification → Project Planning

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

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.

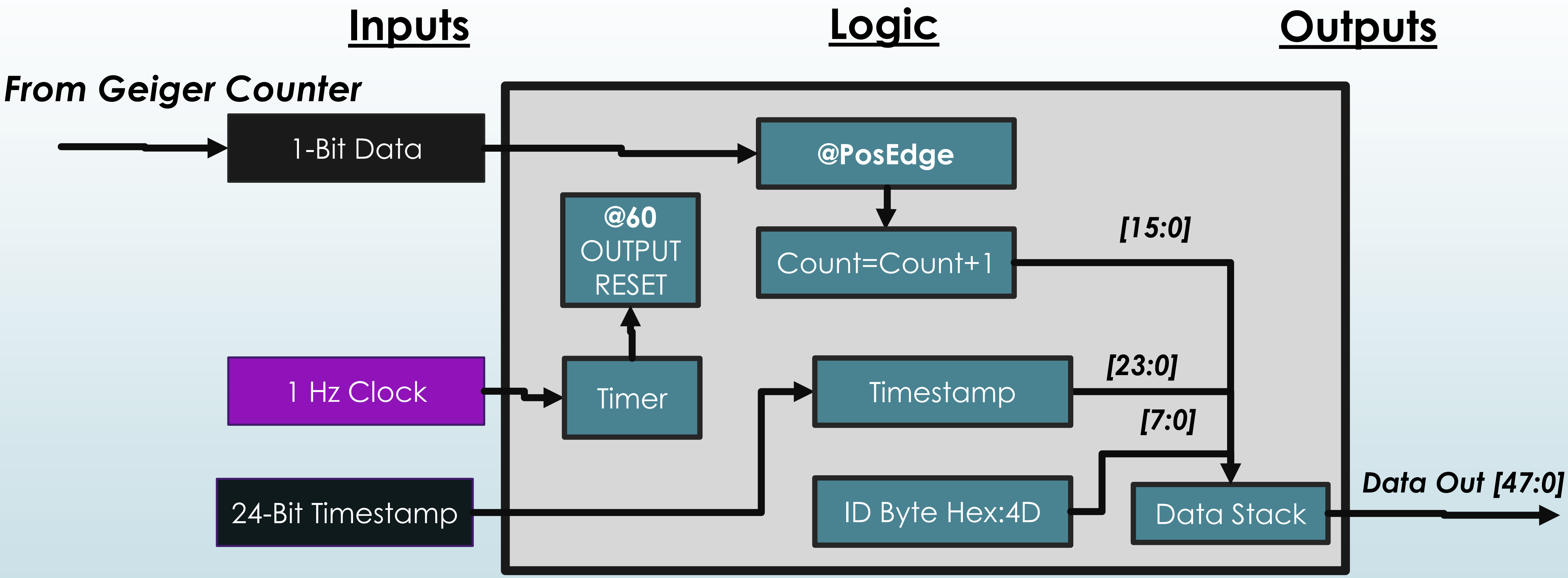
Metric	Weight	Imager Zoom	Spectrometer	Radiation	Temperature	Pressure
Science Value	15%	3	5	5	1	1
Cost	15%	3	1	4	5	5
Availability	16%	4	1	4	5	5
Complexity	20%	2	1	4	3	3
Size	22%	3	2	2	5	5
Mass	12%	3	2	4	5	5
Total	100%	2.96	1.94	3.71	4.00	4.00

Science Traceability

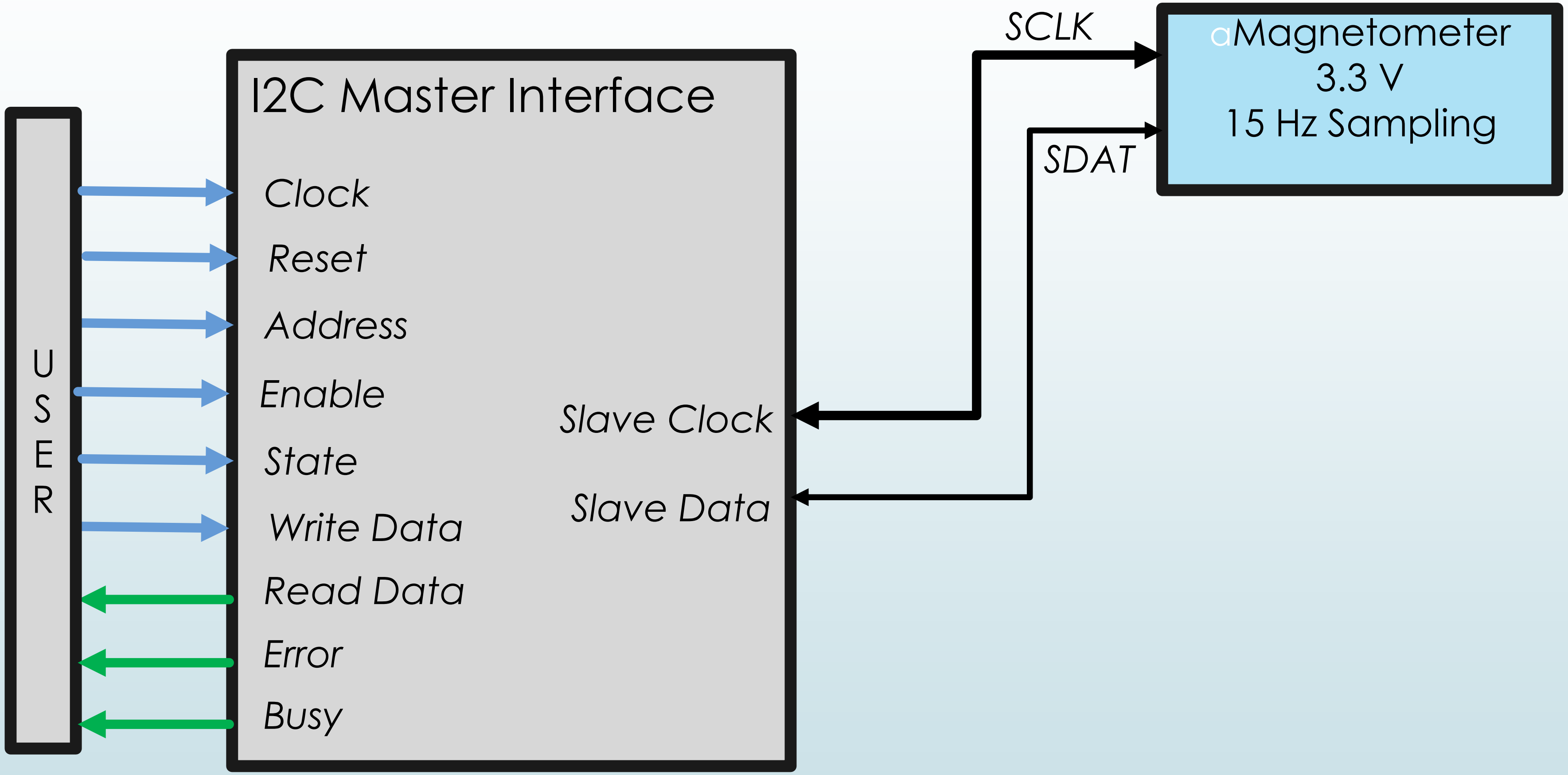
Requirement ID	Magnetometer	Seismometer	Imager Visual	Imager IR	Imager Micro
SCI 0: Neopod shall collect scientific data relevant to Europa	✓ Ice shell characterization	✓ Surface geology characterization	✓ Surface geology characterization	✗ Stationary probe leads to static and not unique results	✓ Surface 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

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

Geiger Counter Sample Control

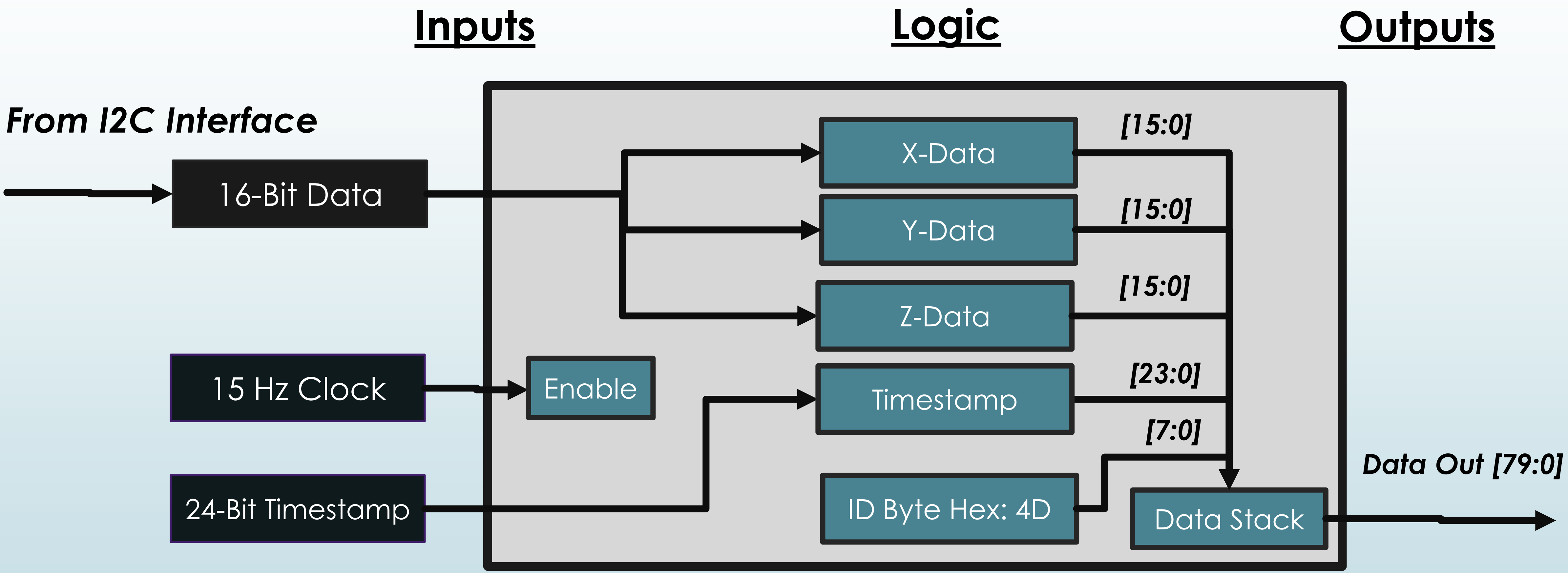


I²C Interface

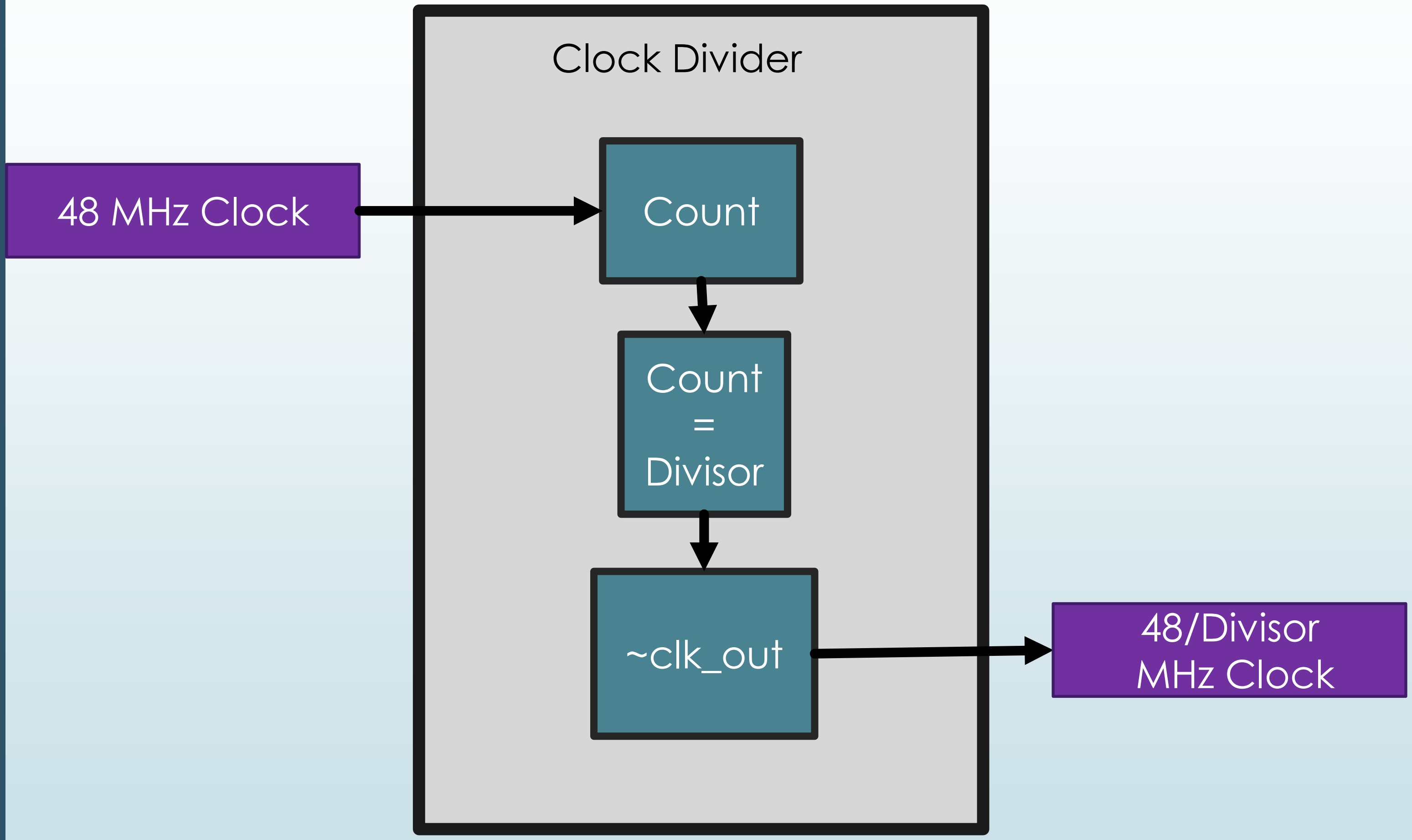


Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

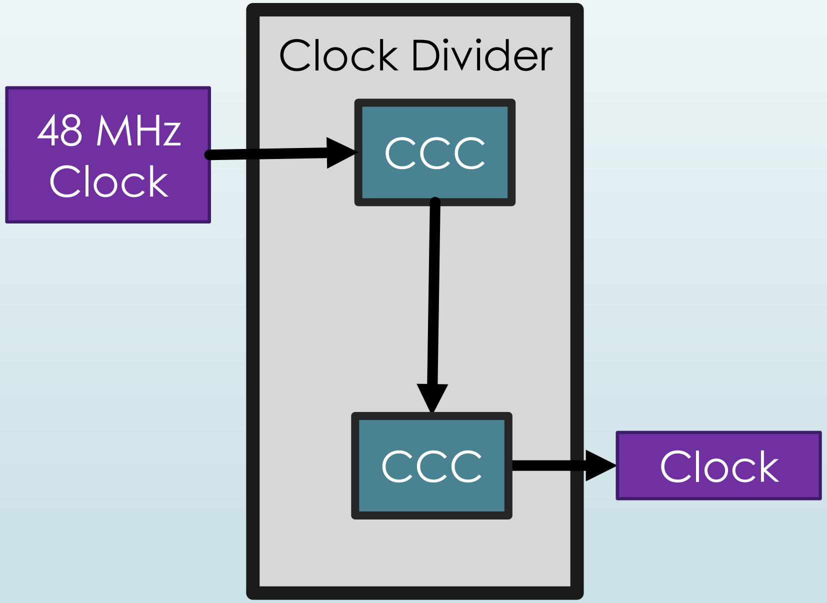
Magnetometer Sample Control



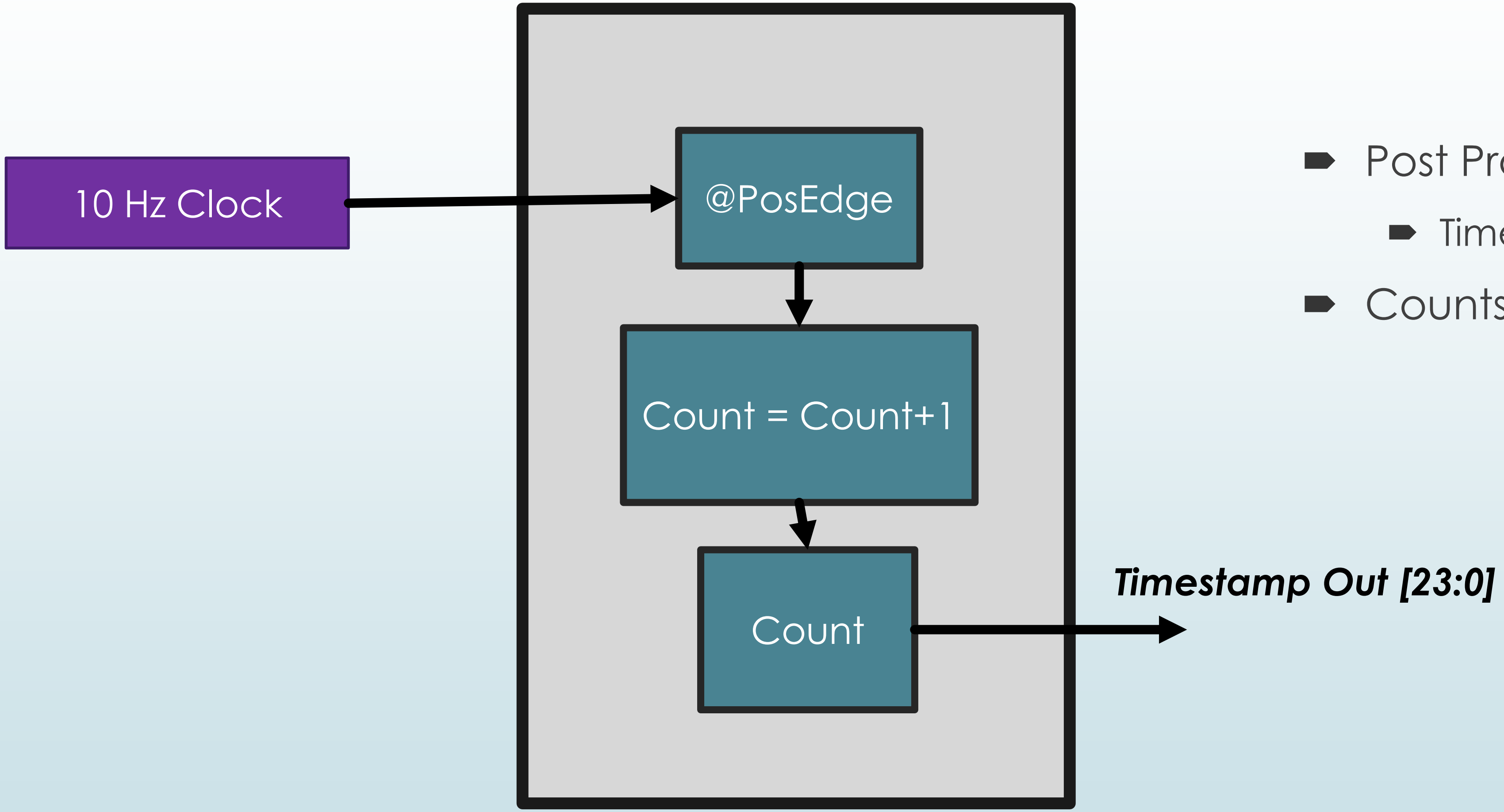
Basic Clock Division



- Microsemi provided Clock Conditioning Circuit (CCC) used for higher accuracy.

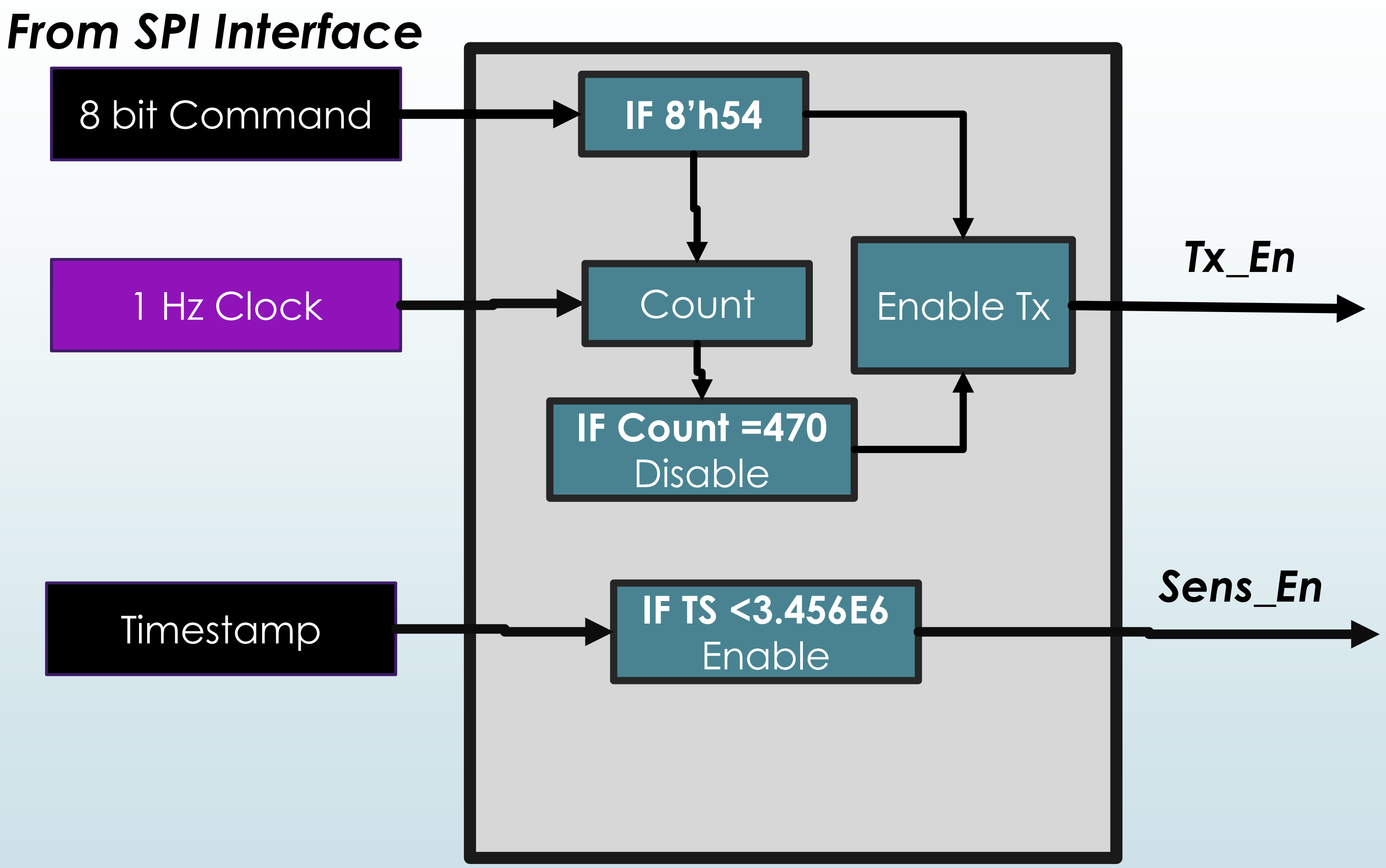


Time Stamping



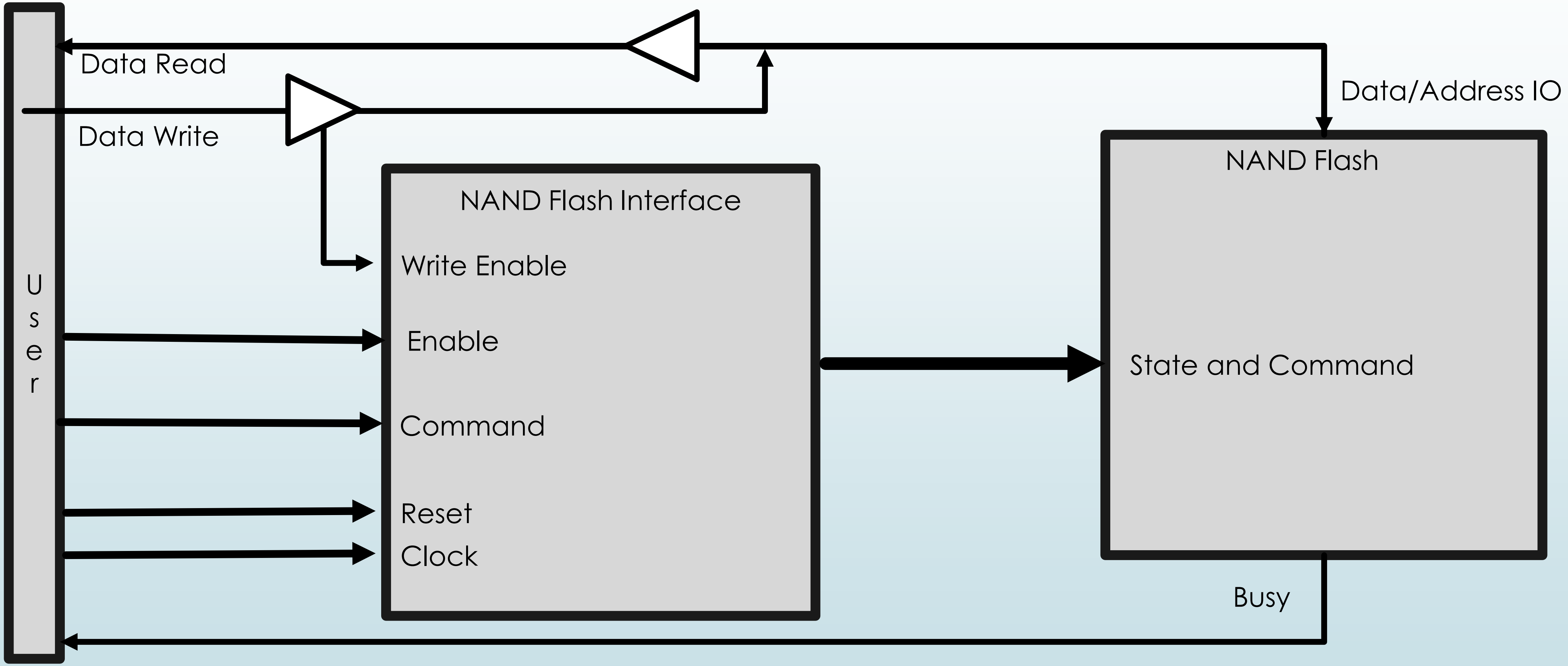
- Post Processing
  - Timestamp/10 = Time (seconds)
- Counts from 0 at device startup

Command Handling & Mode Control



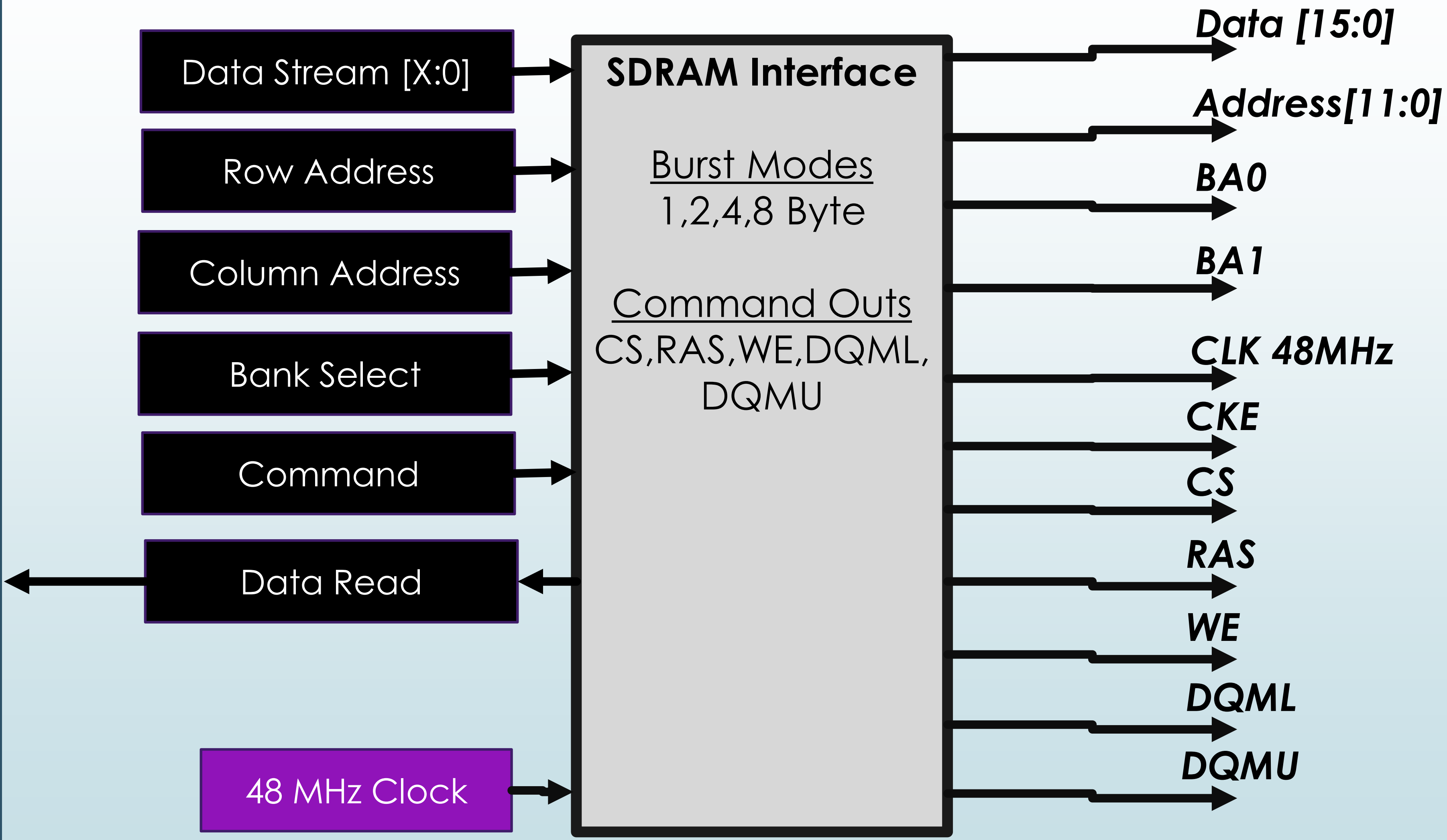
- Command
  - ASCII “T”: Transmit for 470 seconds
- Mode
  - Time > 96 Hours: Don’t save data

NAND Flash Interface



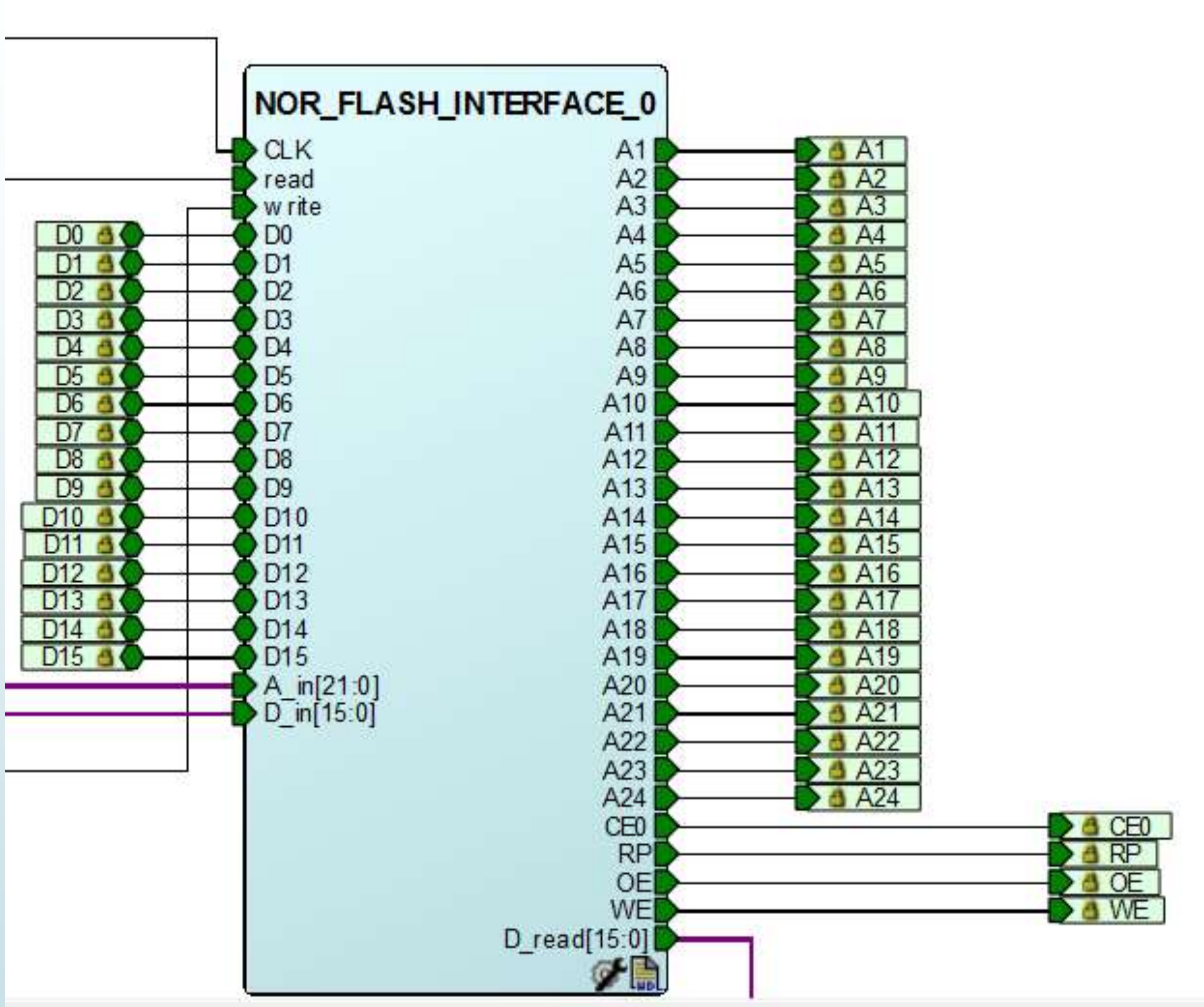
Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

SDRAM Interface

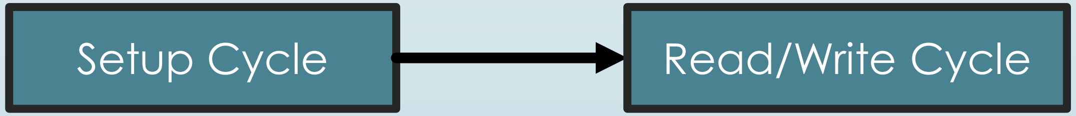


- Use Self-Refresh Idle
- Read/Write Cycle
  - Activate
    - Bank Select
    - Row Address
  - Read/Write
    - Read/Write CMD
    - Data In/Out
- Active to CMD
  - 20 ns minimum

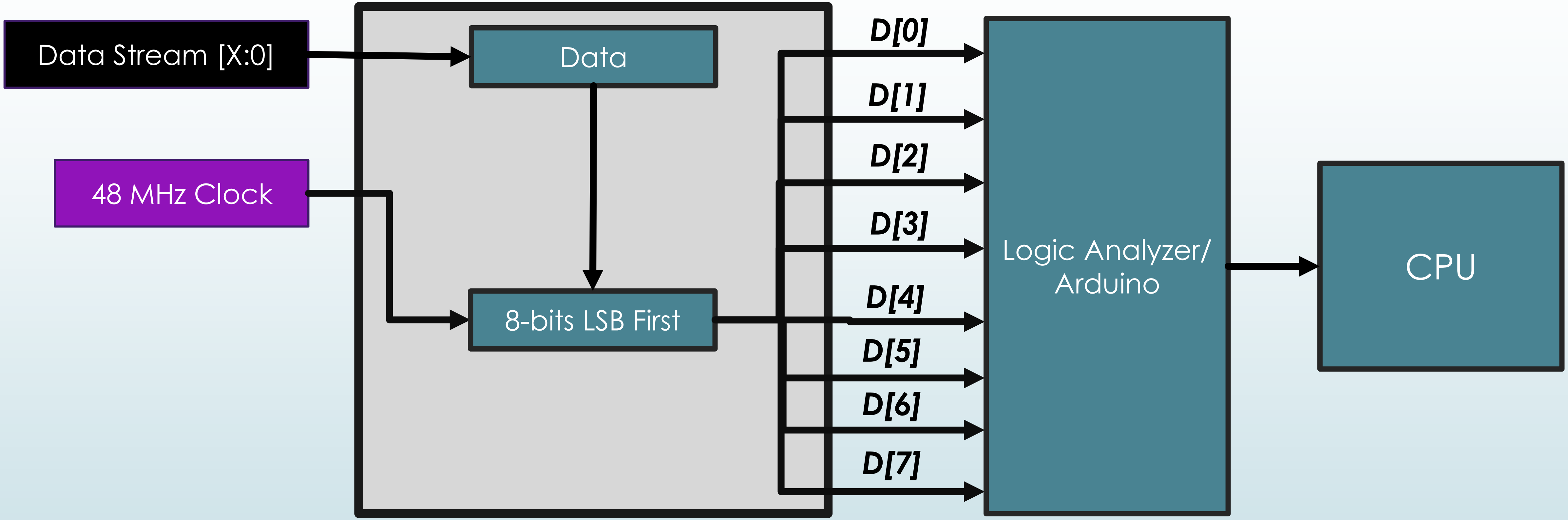
NOR Flash Interface



- Setup/Write Cycle:
  - Hex: 10
  - Minimum: 55 ns
- Read Cycle:
  - Command Hex: FF
  - Minimum 75 ns

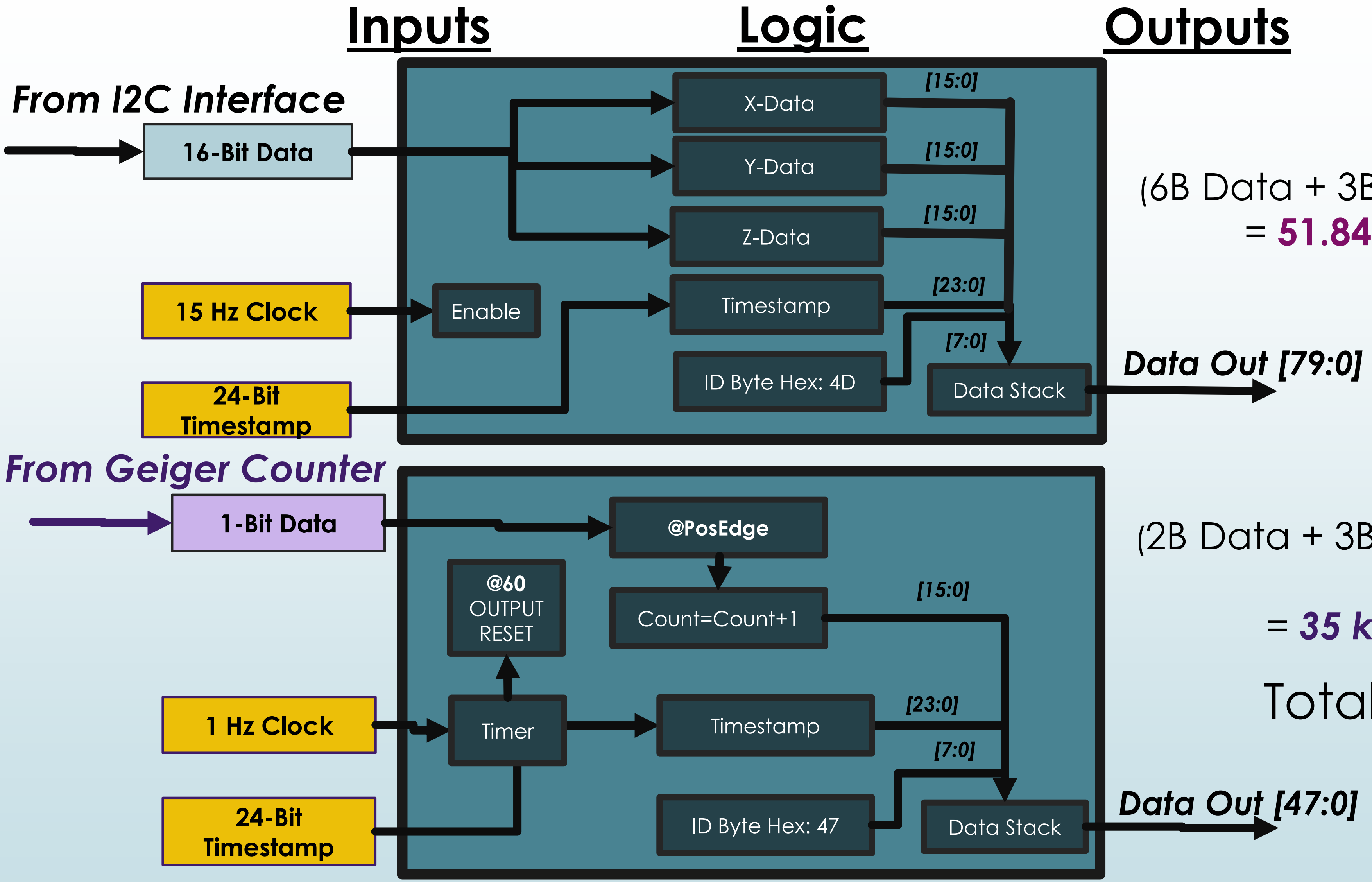


Avionics Test Harness



Data compared with data sent through communication system.

Avionics - Control Data Flow From Sensors



(6B Data + 3B T-stamp + 1B ID) x 15 Hz x 96 hr
= **51.84 MB** Magnetometer Data

(2B Data + 3B T-stamp + 1B ID) x 1/60 Hz x 96 hr
= ***35 kB*** *Geiger Counter Data*

Total Data to Transmit:
51. 875 MB

SCI 3.1.4: Avionics subsystem shall limit data collection to less than 353 MB
✓

Avionics Board Overview

Ball Aerospace Avionics Board

NAND Flash Mem
8 Gb

SDRAM
256 Mb, 100 MHz

Voltage Regulator
1.5 V

Oscillator
48 MHz

Reset / Watchdog
3.3 V

FPGA

1.5 V
48 MHz
504 kbits RAM
3 Million Gates
66 MHz, 66-Bit PCI

Reprogrammable

CMOS XCVR

LVDS Receiver
>400 Mbps

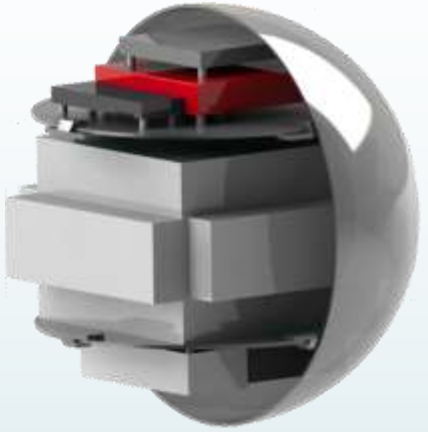
LVDS Driver
>400 Mbps

RS-422 Receiver
100kbps-10Mbps

RS-422 Driver
100kbps-10Mbps

90 mm

96 mm

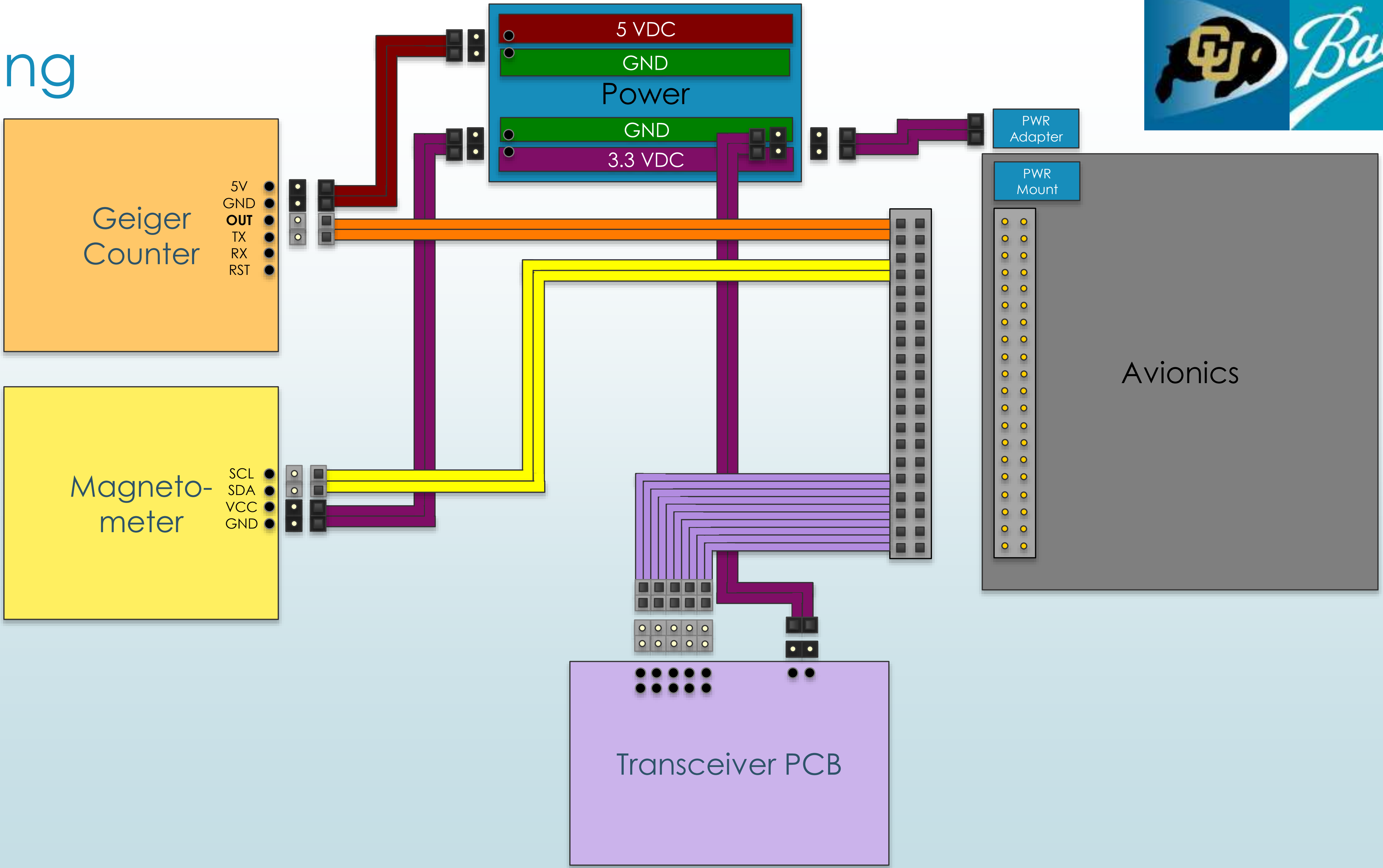


- Requirements Met
  - COM 2.3

Digital Wiring Component List

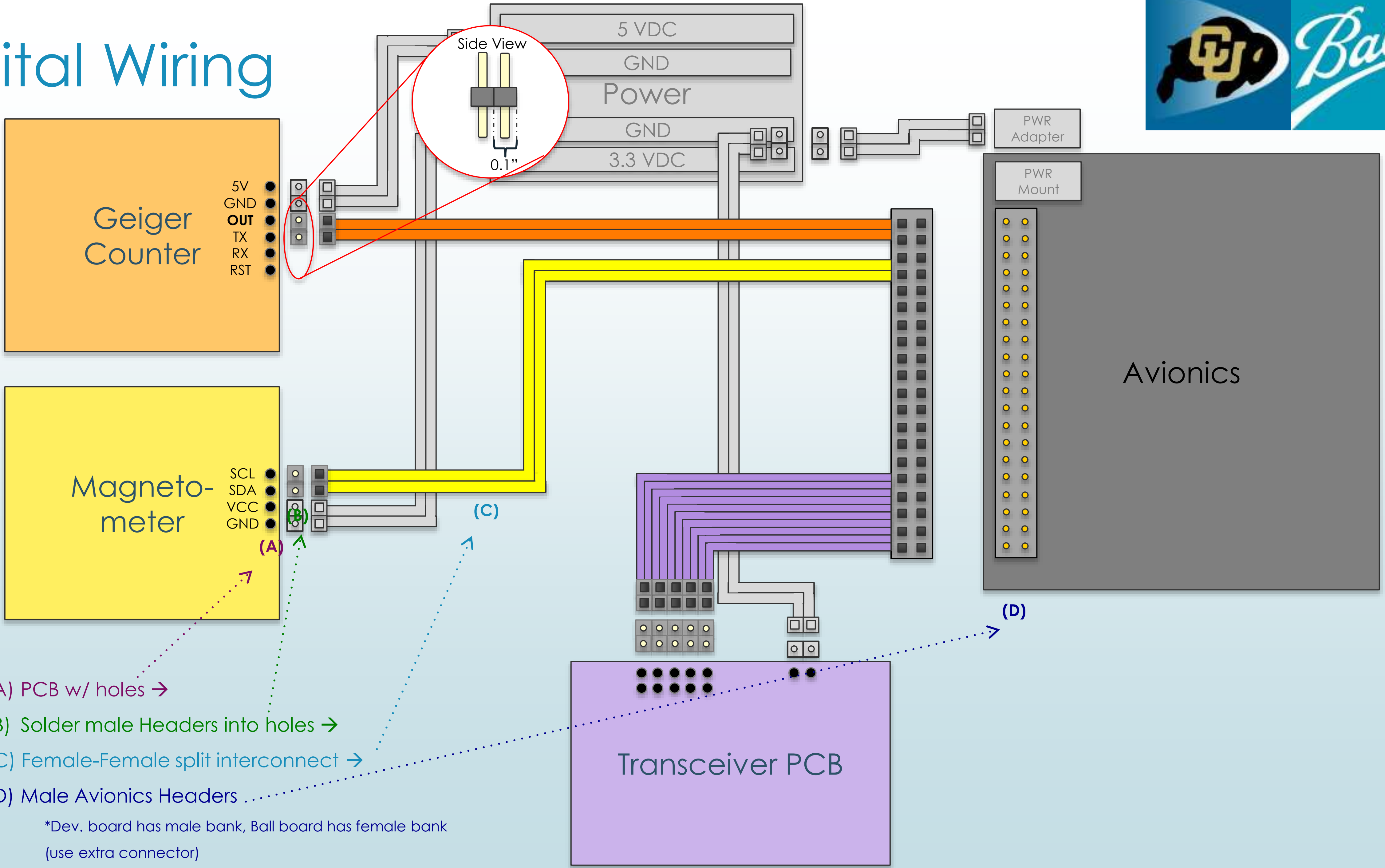
- Avionics
  - 1- 2 x 20, 0.1" Single-ended discrete wire socket cable (SMSD-20-24C-F-24.00-S)
  - 1- 2 x 20, 0.1" Elevated PC/104 Socket (ESQ-120-XX-T-D-LL-XXX)
  - 1- 2 x 20, 0.1" Square Post Header (TSW-120-XX-T-D-XXX)
- Sensors
  - 2- 1 x 2, 0.1" Right Angle Square Post Header (TSW-102-XX-T-S-RA)
  - 2- 1 x 2, 0.1" Discrete Wire Socket Housing (ISSM-02)
- Transceiver
  - 1- 2 x 5, 0.1" Square Post Header (TSW-105-XX-T-D-RA)
  - 1- 2 x 5, 0.1" Discrete Wire Socket Housing (ISDM-05)

Wiring



5 VDC
GND
Power
GND
3.3 VDC
PWR Adapter
PWR Mount
Avionics
Geiger Counter
5V
GND
OUT
TX
RX
RST
Magneto-meter
SCL
SDA
VCC
GND
Transceiver PCB

Digital Wiring



(A) PCB w/ holes →

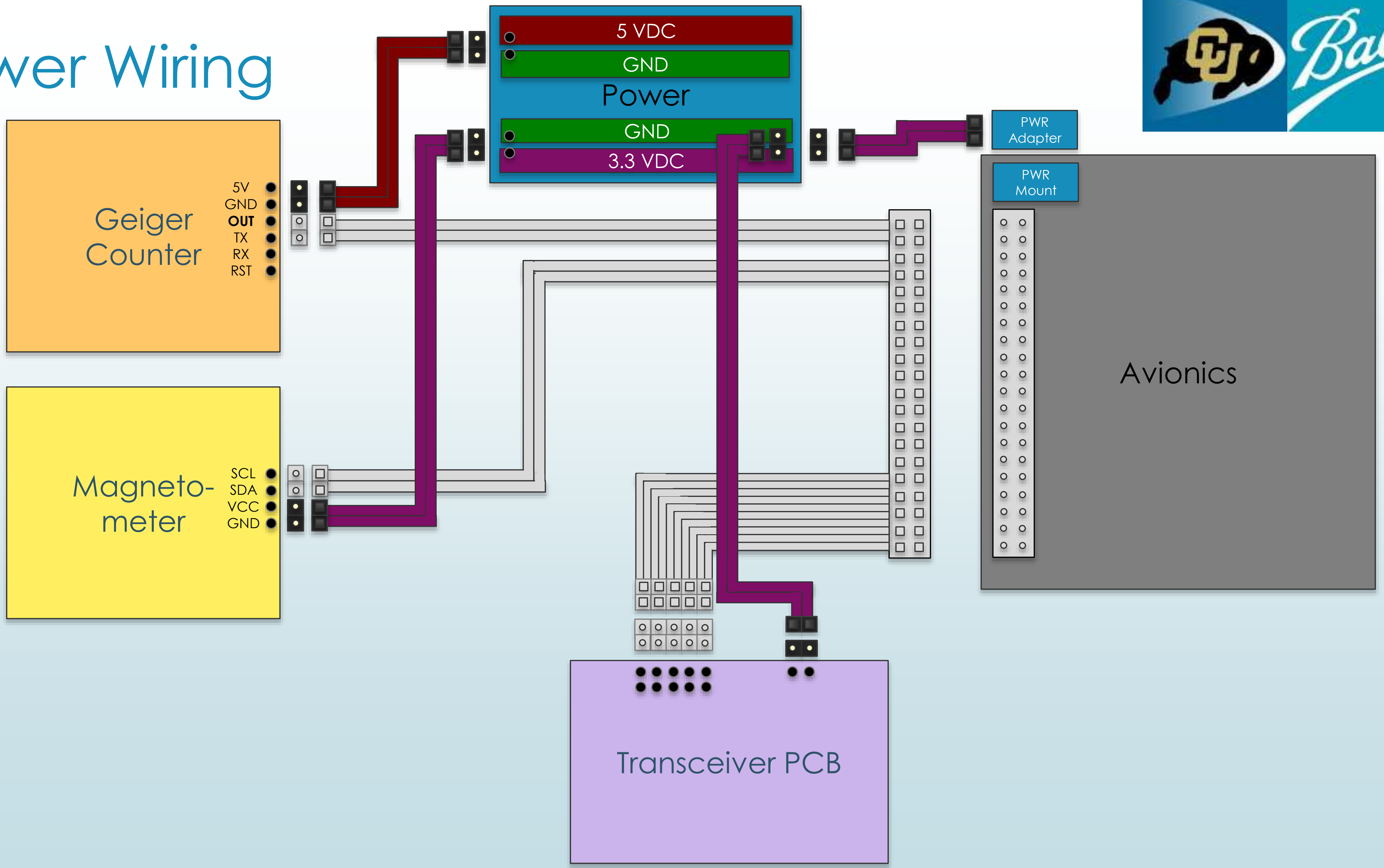
(B) Solder male Headers into holes →

(C) Female-Female split interconnect →

(D) Male Avionics Headers

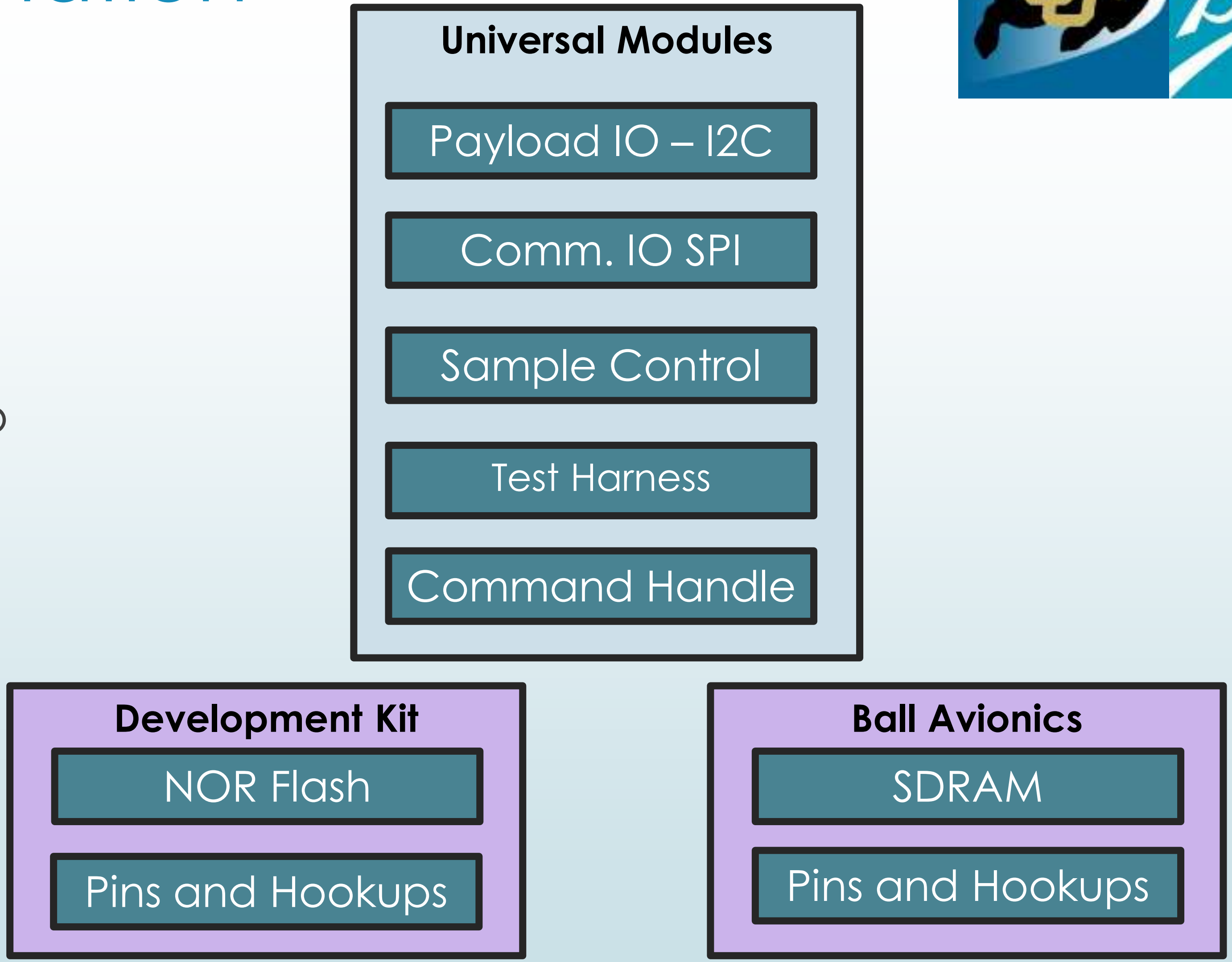
*Dev. board has male bank, Ball board has female bank (use extra connector)

Power Wiring



Software Design Deviation

- Memory Interface
  - SDRAM and NOR Flash are similar, however would require a specific interface to be written
- Pins and Hookups
  - Power
    - Development Kit: 5 V
    - Ball Avionics: 3.3 V
  - Unique Pin Assignments



Instructional Milestones

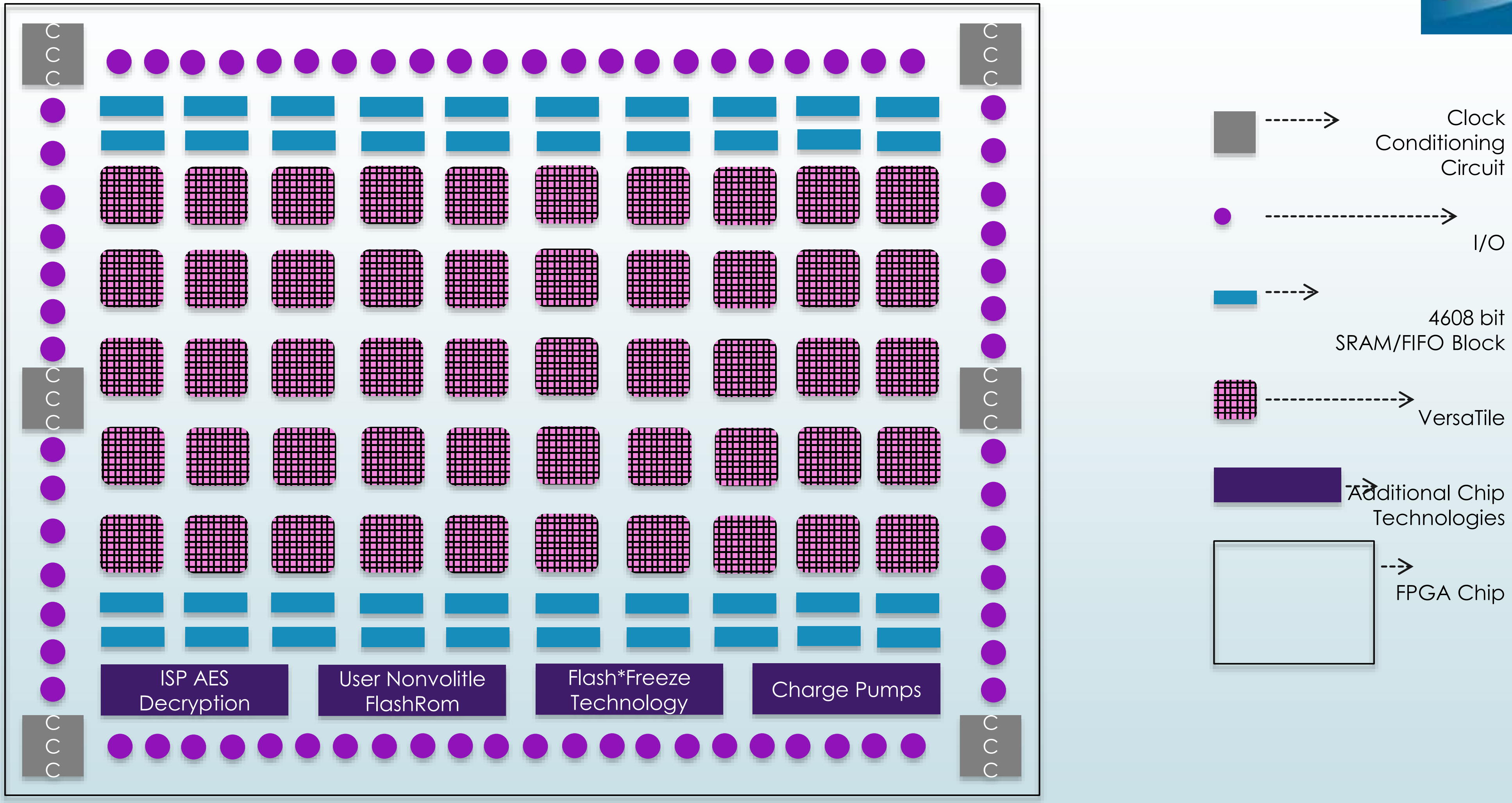
Level	Task
0	Understand dev environment/tools and FPGA development
1	FPGA flashes a light
2	Inputs logic value, blinks light according to true or false
3	Inputs 2 logic values, flash separate lights according to true or false
4	Inputs logic values, stores values in FIFO or RAM, outputs logic value
5	Inputs logic values, stores values in flash memory
6	Inputs sinusoidal signal, stores values in flash memory, reads from memory, outputs to serial port
7	Repeat 6, add a logical input that turns output on or off

Contingency Plan

- **Cutoff Dates**
  - Board Design and Documentation Delivery **10/30/2015**
    - Complete avionics design documentation delivered from Ball
  - Internal Knowledge Evaluation **11/9/2015**
    - Feasibility based on knowledge progress rate
  - Avionics Board Delivery **1/22/2016**
    - Delivery of hardware from Ball
- **Contingency Plan**
  - Default to ProASIC3L Development Kit as primary avionics package

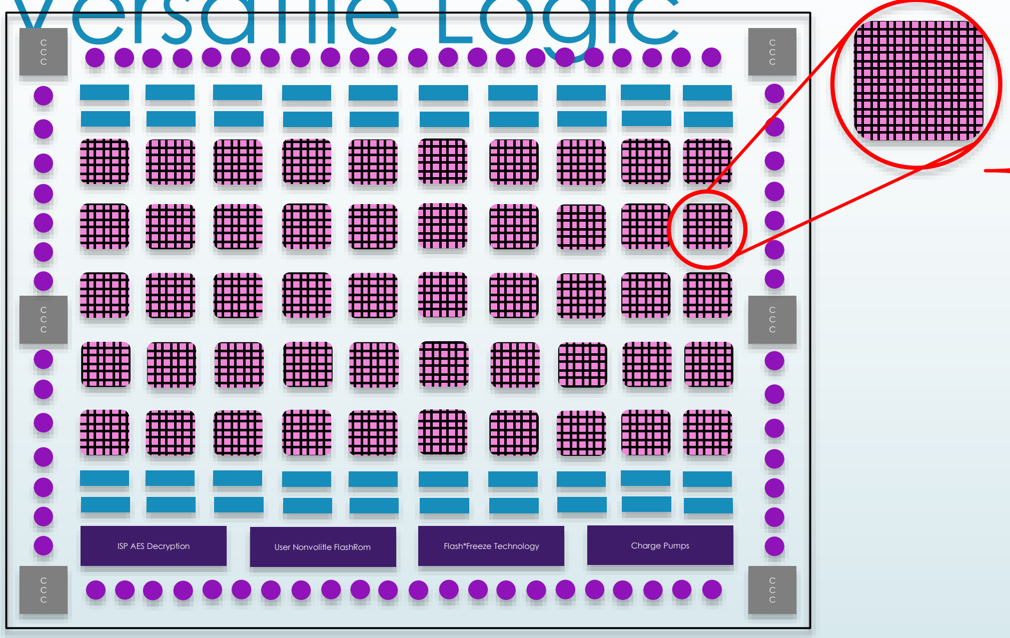
- Verified With Customer

FPGA Layout

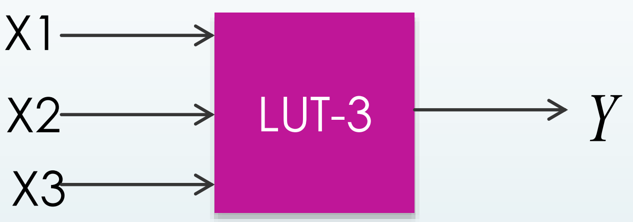


Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

VersaTile Logic

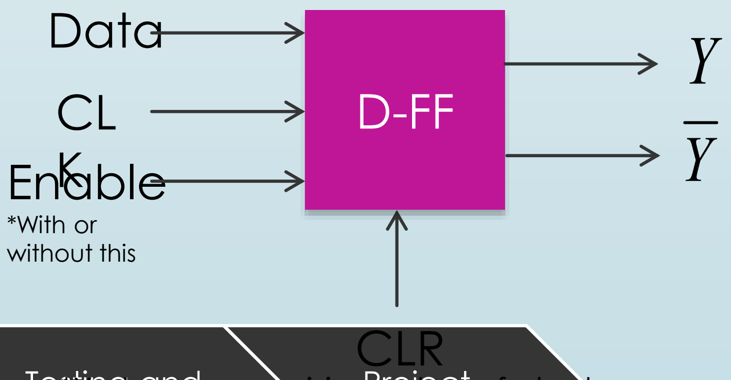


3-input Logic



*Can be programmed to std. logic combinations
ex. (X1 & X2) | X3

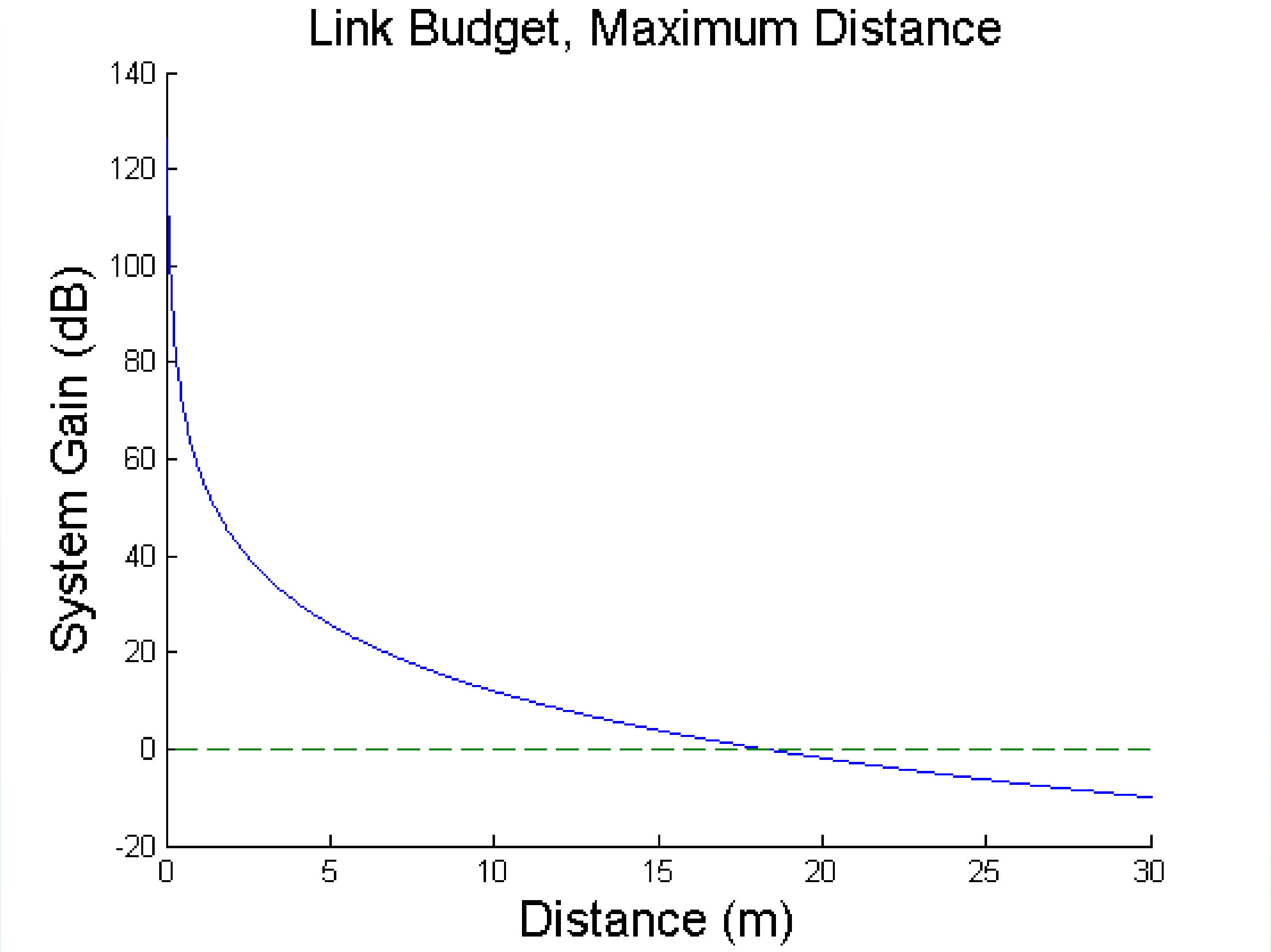
D-flip-flop Logic



*With or without this

*Y changes on rising edge of clock

System Link Budget

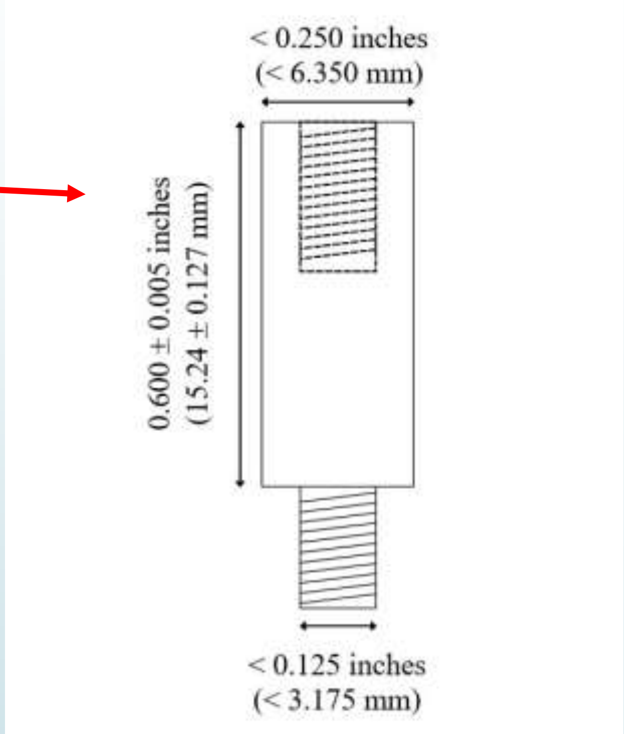


Link Budget Parameter:	**Value:**
System Gain*	-32 dBm
Free Space Path Loss at 10 meter test	-61.95 dBm
Receiver Sensitivity	-108 dBm
Link Margin:	**+14.05 dBm**
Maximum Possible Distance:	**18.2 m**

*Assumes 4dB cable loss and -20 dB antenna gain

Standoffs and Battery Connectors

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



Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

Communications and Ground Station

NeoPod

FPGA ⟷

SMA Cable

Ground Station

USB (to COSMOS)

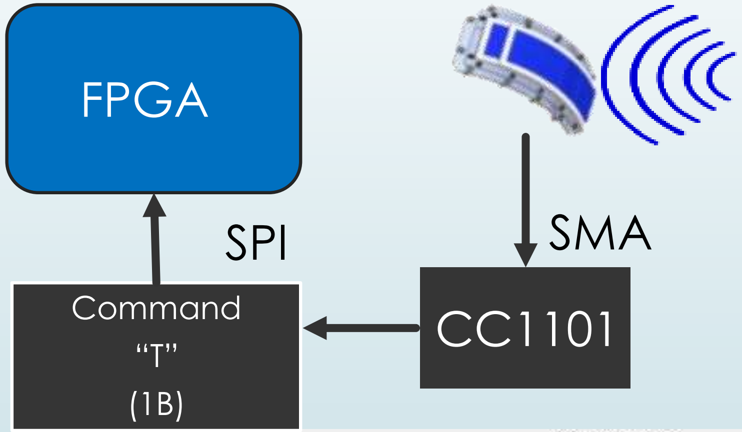
COSMOS™

Transceiver Key Specifications
Model: CC1101 Texas Instruments Transceiver Kit and Chip
Maximum Data Rate: 500 kbps
Frequency: 387-464 MHz
Power and Logic: 3.3VDC and 3.3V Logic
Receive Sensitivity: -108 dbm
Transmit Power: +10 dbm

Satisfies highest level of success: Capable of 128 kbps data transmission and command transmission from Ground Station. Capable of integrating with 437 MHz antennas

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



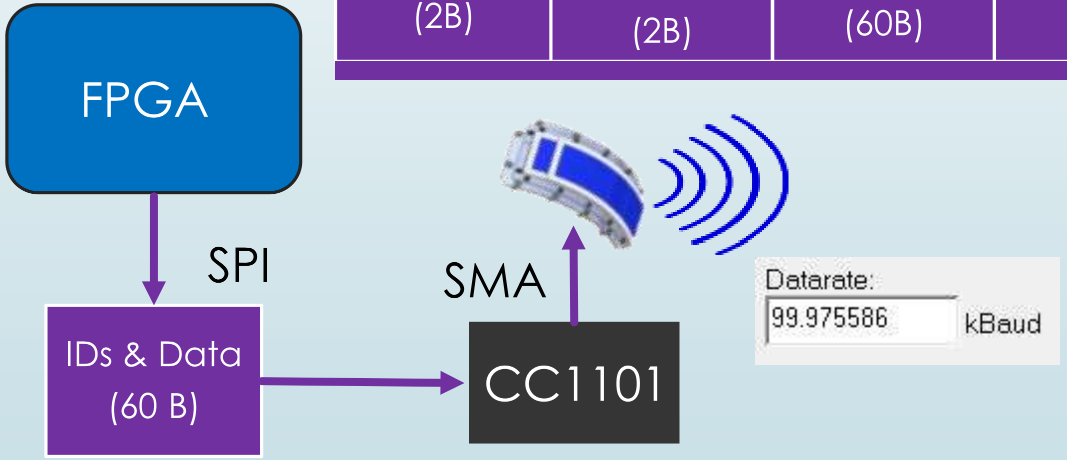
"Begin Telemetry Transmission" Command		
Sync Word "SA" (2B)	Command "T" (1B)	CRC Checksum (2B)

- 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)

Command "T" (1B)

USB

Cosmos

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

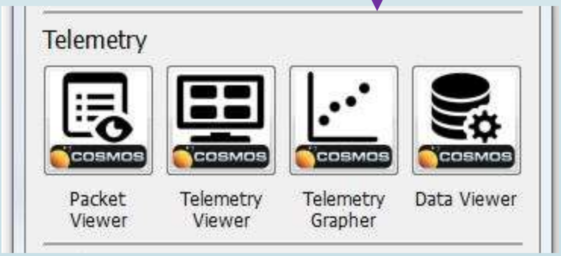
Comm: Ground Station shall receive data over RF

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)

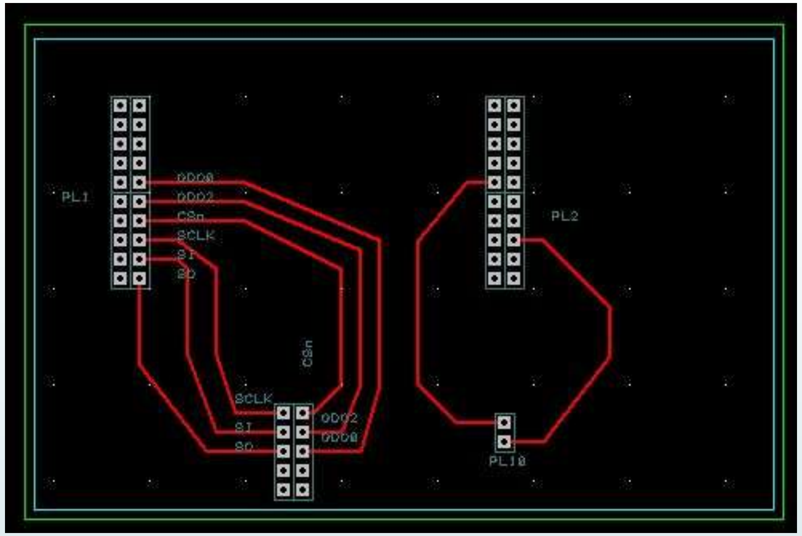
IDs & Data (60 B)

Cosmos

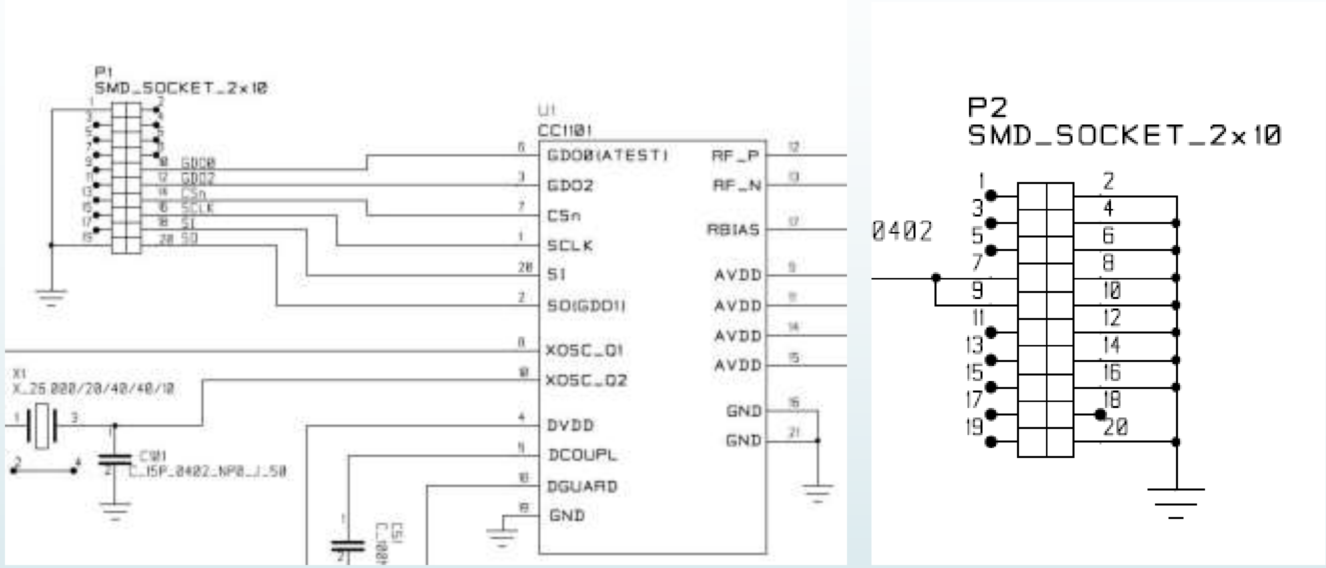


- CC1101 will de-packetize data
- Cosmos will identify separate data files using the 1 Byte ID attached to each data point
- Smart RF will be used to Debug CC1101 and display RSSI and LQI

PCB Design

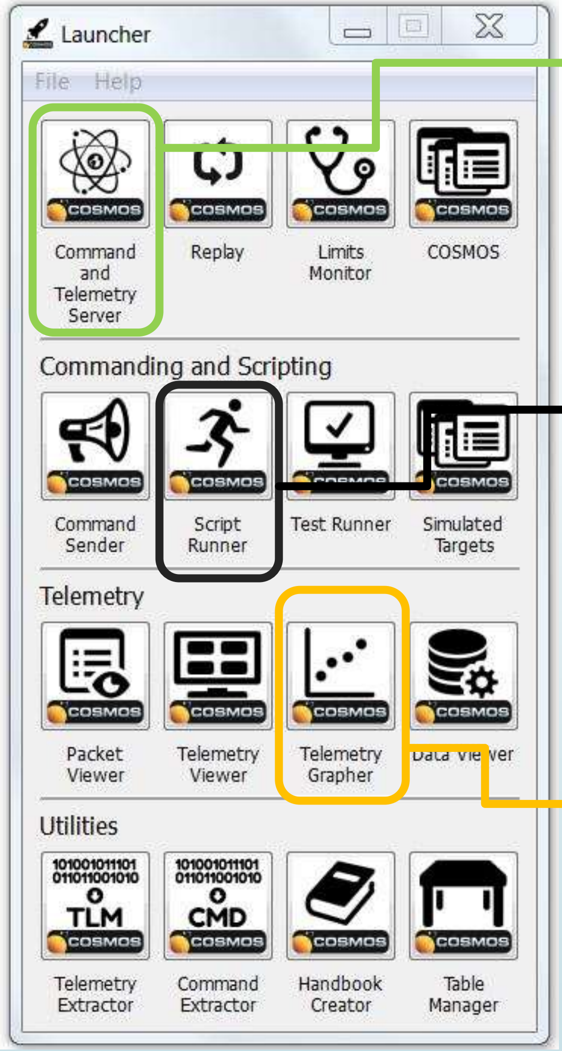


Preliminary PCB Design



CC1101 Schematic

COSMOS



Will serve as the dashboard for the mission

Interface	Connect/Disconnect	Connected?	Clients	Tx Q Size	Rx Q Size	Bytes Tx	Bytes Rx	Cmd Pkts	Tlm Pkts
INST_INT	Disconnect	true	0	0	0	292	555394	20	7292
INST2_INT	Disconnect	true	0	0	0	0	555394	0	7292
EXAMPLE_INT	Connect	false	0	0	0	0	0	0	0
TEMPLATED_INT	Connect	false	0	0	0	0	0	0	0
COSMOS_INT	Disconnect	true	0	0	0	0	0	0	351

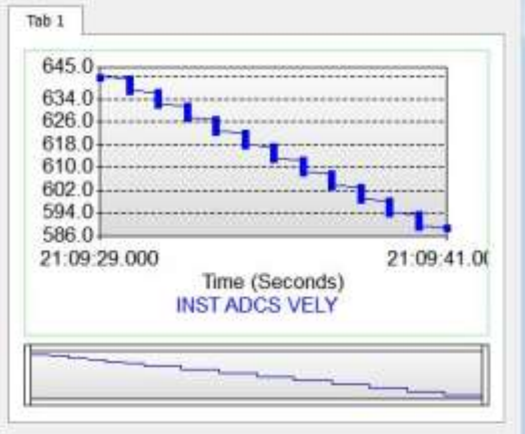
Will automate mission by sending “Begin Data Transmission” command every two hours

```
prompt("Press Ok to start NORMAL Collect")
collect('NORMAL', 1)
prompt("Press Ok to start SPECIAL Collect")
collect('SPECIAL', 2, true)
clear()

wait_check("INST HEALTH_STATUS COLLECTS == 0", 10)
```

Script Output:

Can Be Used for real time and post-collection data display

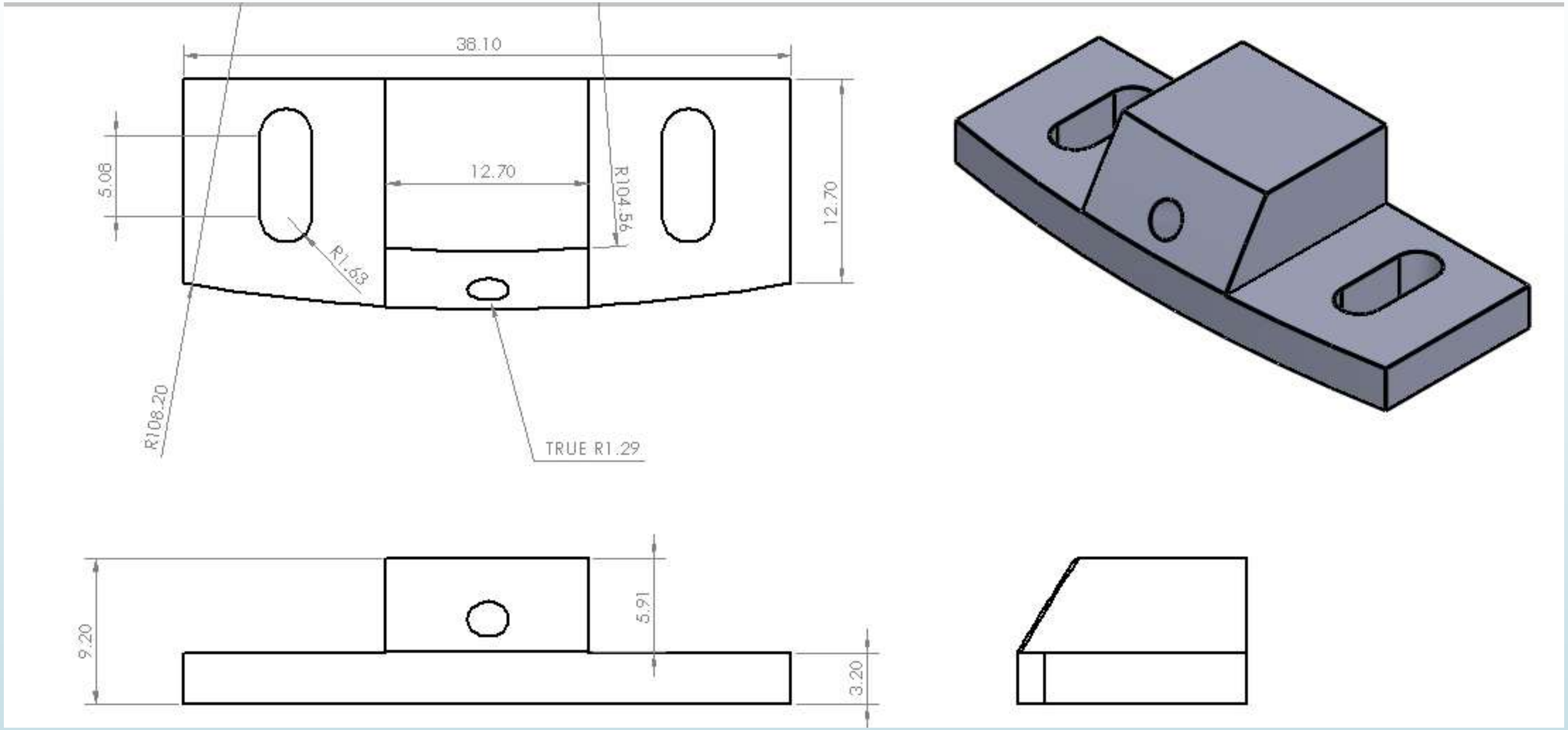


Mass Budget Backup Slide

Subsystem	Component	Raw Mass	Uncertainty Category	Budgeted Mass
Total mass Available		10000		10000
Avionics				
	Avionics Board	60	E	72
Structure				
	Top Shelf	284	C	341
	Bottom Shelf	286	C	343
	Ball	766	M	774
	8 Clips	56	C	67
Payloads				
	Magnetometer	10	E	12
	Geiger Counter	70	E	84
	Converter for Geiger	5	E	6
Comms				
	SMA cable	18	D	19
	Patch Antennas	234.8	M	237
	Tranceiver and Boards	150	E	180
Power				
	Batteries	5582.8	M	5639
	Board	100	E	120
	2 Converters	40	E	48
	Fuse	18	E	19
Connectors				
	Voltage Regulator	50	E	60
	Power Cable Connectors	330	D	347
	52 screws	45.5	C	50
	Misc Wires	500	E	600
Used Mass				**9017**
Margin				**10%**

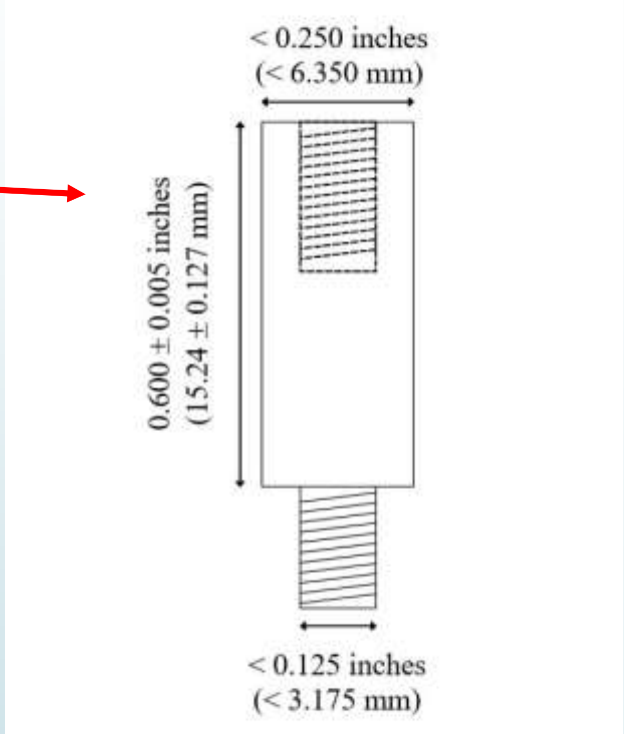
1E	**Estimated**	**20%**	**Best Guess**
2C	**Calculated**	**10%**	**SolidWorks Model**
3A	**Datasheet**	**5%**	**Datasheet**
4M	**Measured**	**1%**	**Weighed on Scale**

Backup Clip Drawing (dimensions in mm)



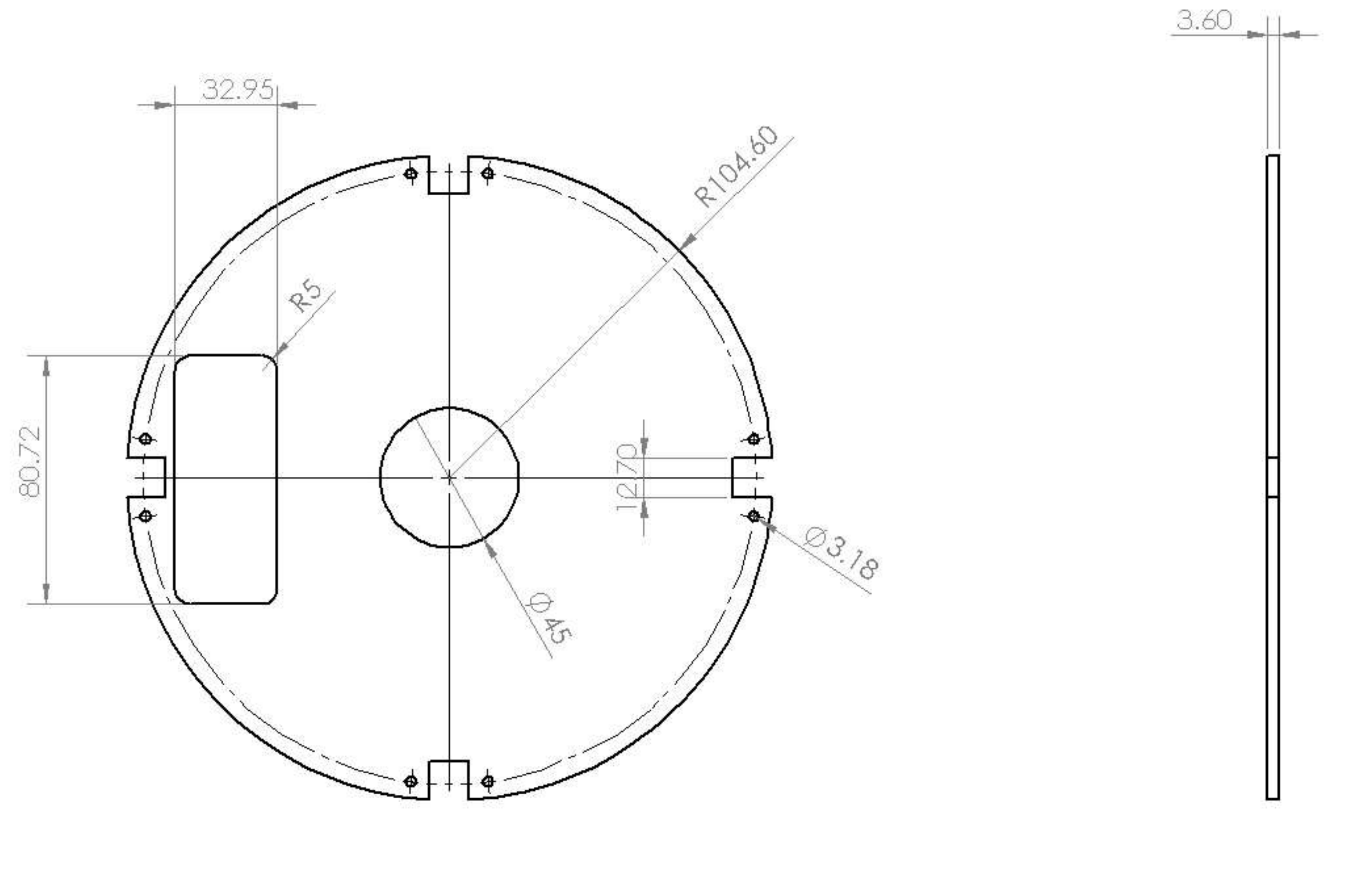
Standoffs and Battery Connectors

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

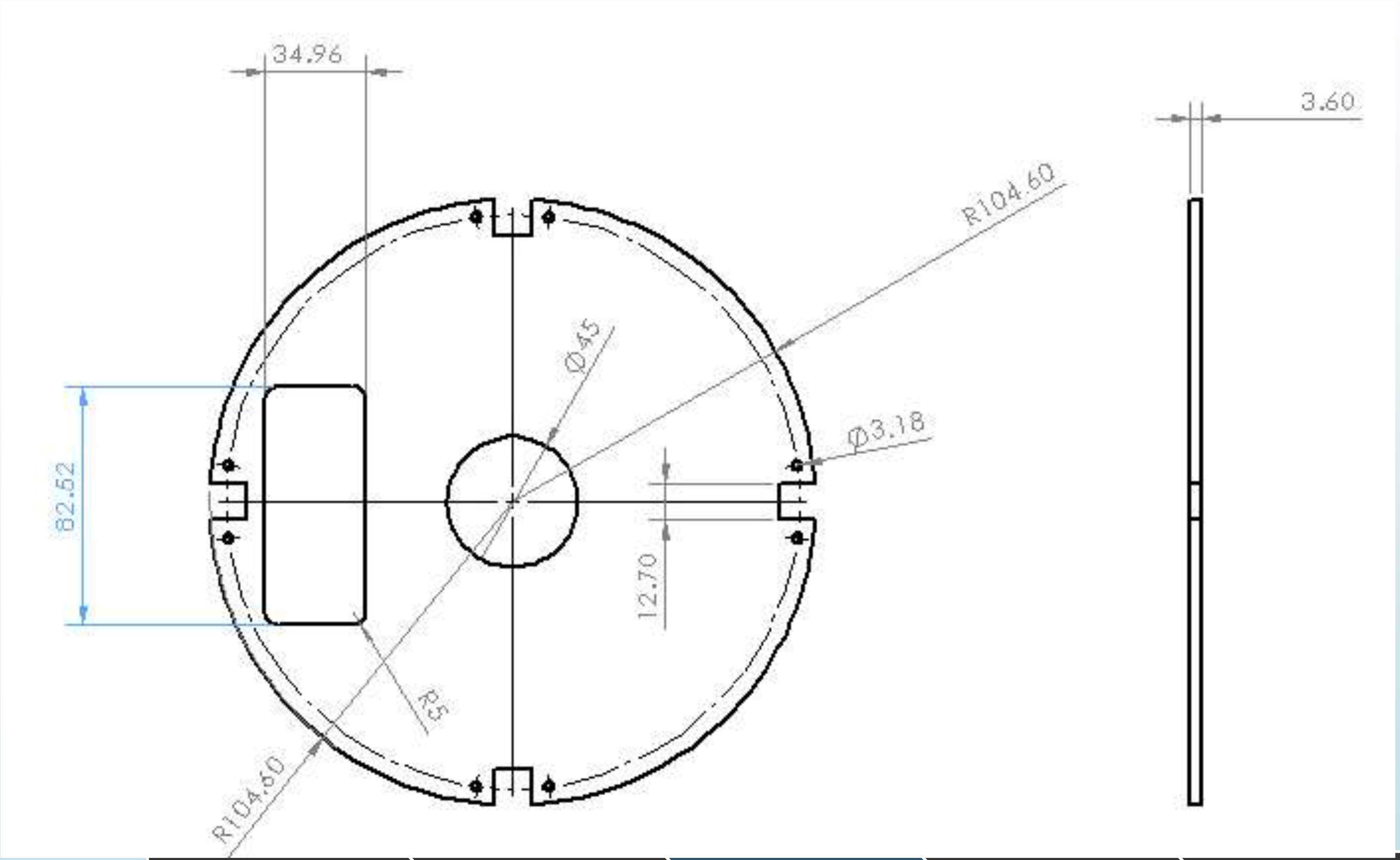


Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

Top Shelf Drawing (dimensions in mm)



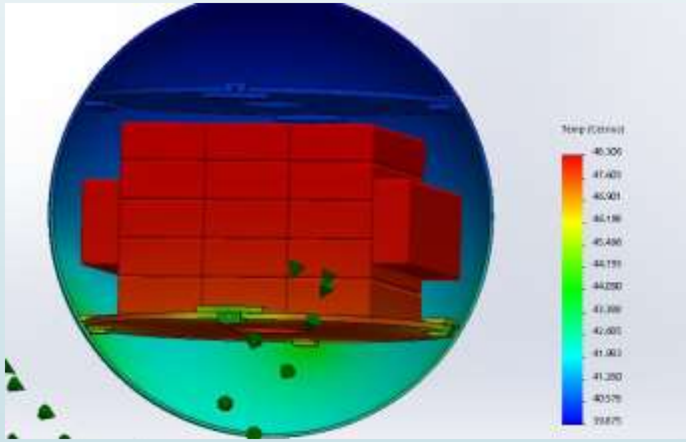
Top Shelf Drawing (dimensions in mm)



Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

Thermal Study Backup

- Applied 8.7 Watts load total on batteries assuming that all power went to heat *only*.
  - Batteries reached max temp of 48 °C
  - This is unrealistic since most all of that power is transferred to components
  - Actual Wattage used = current draw^2 * internal Resistance (P = I^2*R)



Thermal Study Backup

- Thermal Properties of Lipo Batteries
- Not much info found online. Took weighted average of all materials inside to find thermal conductivity and specific heat

Material	Percent Weight Low	Percent Weight High	Used Percent	Used Mass	Density (g/cm^3)	Gross Volume (cm^3)	Volume ratio	Thermal Coductiviy (W/mK)	Weighted Thermal Conductiviy (W/mK)	Specific Heat Capacity (J/g-C)	Weighted Specific Heat Capacity
Aluminum	2	10	10	33.1	2.7	1.24966965	0.092997626	205	19.0645133	0.896	0.08332587
Aluminum Foil	5	15	5	16.55	2.7	0.62483482	0.046498813	205	9.53225666	0.896	0.04166294
Carbon	10	30	15	49.65	2.26	2.23945225	0.166655038	1.7	0.28331356	0.71	0.11832508
Copper	5	15	10	33.1	8.96	0.37657456	0.028023838	401	11.2375591	0.39	0.0109293
Lithium Cobalt Oxide	20	40	25	82.75	2.3	3.66750875	0.272927815	5	1.36463908	1.8105	0.49413581
Lithium Salts copper chloride	1	5	3	9.93	2.07	0.48900117	0.036390375	5	0.18195188	0.39	0.01419225
Nickel	0.5	5	2	6.62	8.908	0.07575456	0.005637485	91	0.51301115	0.461	0.00259888
Organic Carbonate (calcium carbonate)	10	25	24	79.44	2.7	2.99920716	0.223194302	5.526	1.23337171	0.81994	0.18300594
Polymer	3	10	6	19.86	1.18	1.71564816	0.127674707	0.2	0.02553494	1.47	0.18768182
SUMS			100			13.4376511			43.4361514	7.84344	1.13585788
AVG									**43.4361514**		**1.13585788**

Thermal Model Temperatures Backup

	Modeled Temperature	Uncertainty	Margin	Uncertainty Percentage	Maximum Temperature
Batteries	41	4.1	14.9	10%	60
Avionics	91	9.1	24.9	10%	125
Transceiver	43	4.3	37.7	10%	85
Power Regulator	50	5	30	10%	85
Magnetometer	38	3.8	83.2	10%	125
Geiger Counter	41	4.1	39.9	10%	85

Power System Design Solution

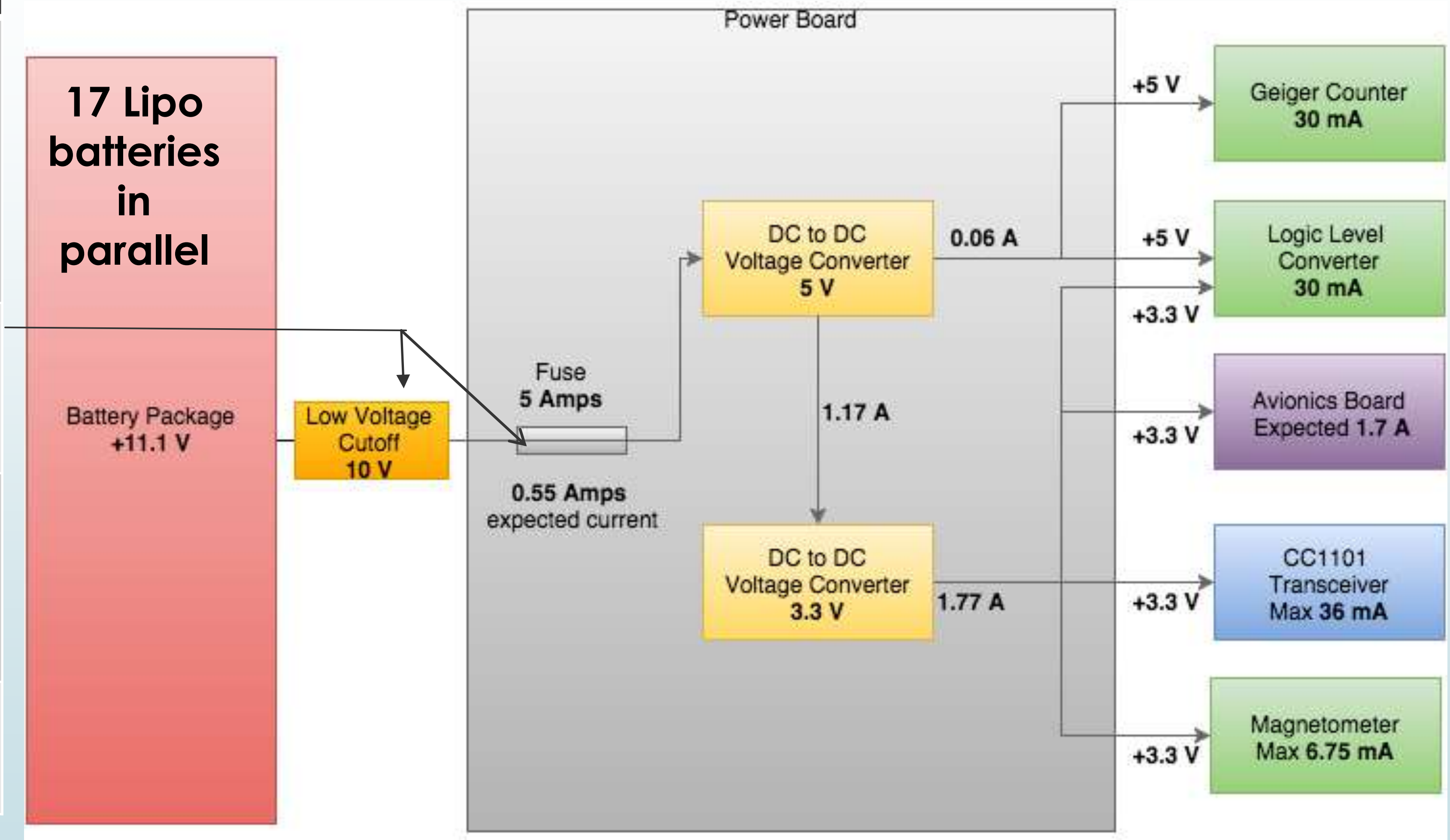
Power Key Specifications:

Voltage will **range from 12.6 V to 10.5 V** over the course of the 4 day test, with an **average voltage of 11.1 V**

Will include **voltage cutoff circuit** and **fuse** for **protection**

Two DC/DC voltage regulators to step down to **5 V** and **3.3 V**

Power is conserved up to **95% efficiency**



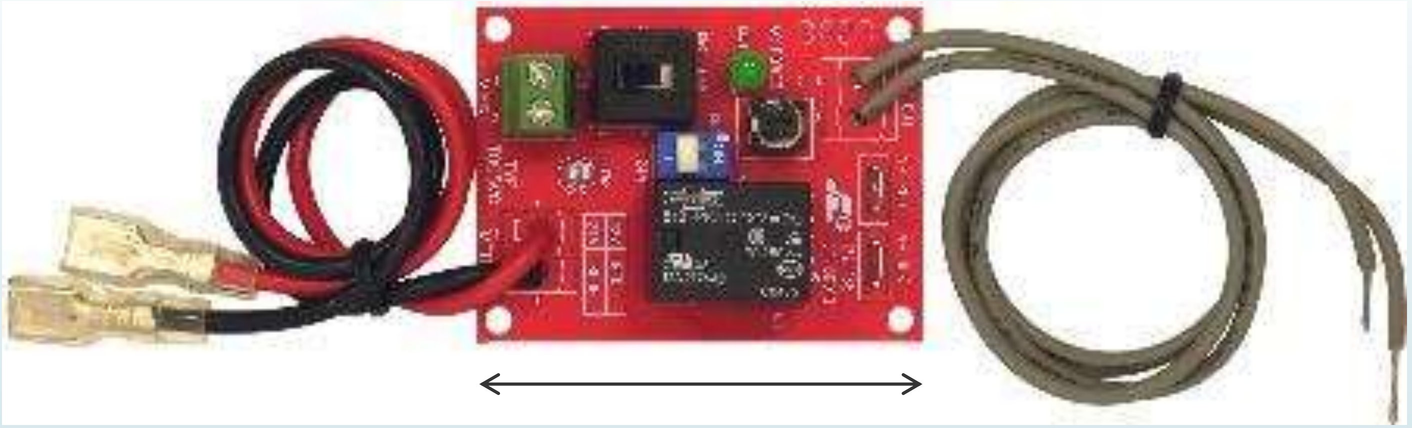
Satisfies highest level of success: Power system is capable of provided **100 hours of power** to system and provides **protection** against damaging system

Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

Safe Power System

Drivers:
- **INT 5.2: Power system shall cut power if battery voltage is under 9 Volts**
- **INT 5.3: Power system shall not allow more than 5 Amps into system**

Solution:
- **Include a fuse rated up to 5 A, 125 V**
- **Maximum expected current 0.55 A**
- **Design margin of 5.25**
- **A Low Voltage Cutoff device set at 10 V**
- **Minimum safe battery voltage is 9 V**
- **Design margin of 11.1%**



45 mm

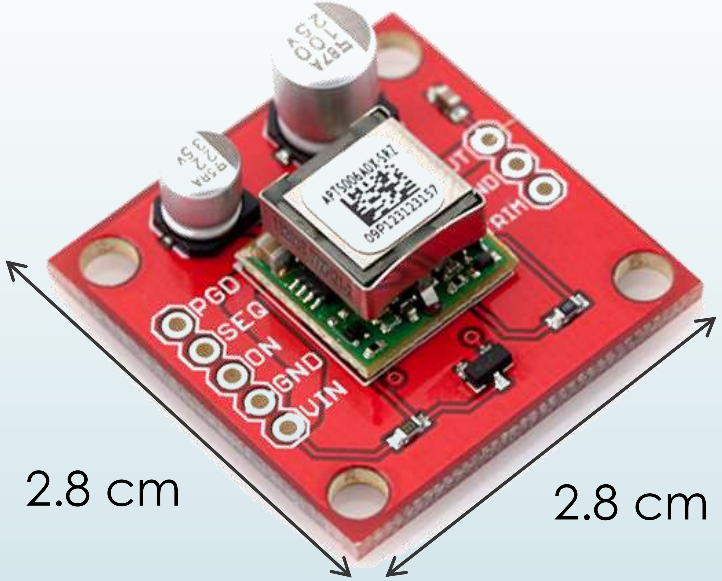
60 mm

Low Voltage Cutoff Device

Devices selected to ensure the batteries will operate within safe current and voltage parameters. Requirements INT 5.2 and 5.3 satisfied.

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

Payload Subsystem Tests

Test	Requirement/Level of Success
Magnetometer Test - compare to earth's magnetic field	SCI 1, Payload L1 – L2, L4, Power L1
Geiger Counter Test- compare to expected radiation	SCI 1, Payload L1 – L2, L4, Power L1

Comms Subsystem Tests

Test	Requirement/Level of Success/Model
Test signal strength using chip to chip with dev. kits	COM 2, Ground Station L1
Test signal strength using chip to chip with patch antenna	COM 2, Link Budget
Configure chip using 8051 before FPGA hookup	N/A
Configure chip with FPGA via SPI and check with smartRF	N/A
Use RF commands to program N.P. chip via FPGA	COM 1, COM 3, Ground Station L2
Cycle commands to data and wake to idle representing a full mission	COM 1, COM 3
Test ground station to save and display 2 separate sets of data from 1 stream	COM 4, Ground Station L3

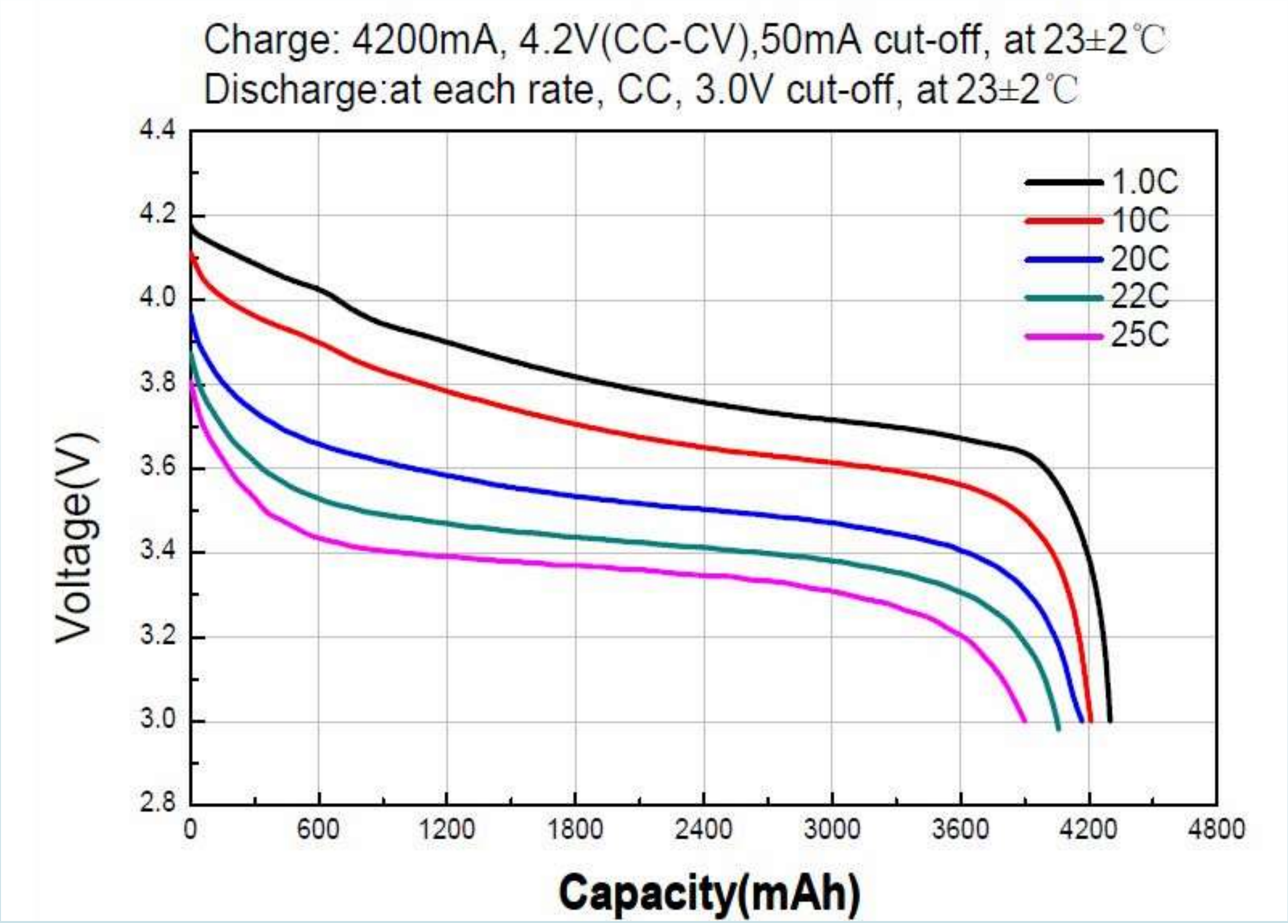
Avionics Subsystem Tests

Test	Requirement/Level of Success
Validate individual module outputs via testbench simulation	N/A
Validate total system outputs via testbench simulation	N/A
Validate individual module outputs via testbench simulation	N/A
Validate total system outputs via testbench simulation	N/A
Test functionality of simulated peripherals via O-Scope/Logic analyzer.	N/A
Validate data throughput requirements.	N/A
Validate power consumption.	N/A

Avionics Peripheral Tests

Test	Requirement/Level of Success
Test connection to power Avionics via powerboard	N/A
Test Magnetometer → Avionics connection	N/A
Test Geiger Counter→ Avionics connection	N/A
Test Avionics/Memory <--> Transceiver connection	N/A

Similar Lipo Battery Discharge Curves



Test Plans

- We are developing test procedures for all tests
- Before performing tests, we will review test plans with Trudy/Matt to make sure all safety concerns have been accounted for

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	Power L1	–	–
Test power board with TENMA EX354T Power Supply	Power L1	–	–
Test power board with single battery	Power L2	–	–
Test power board with battery pack	Power L2	–	–

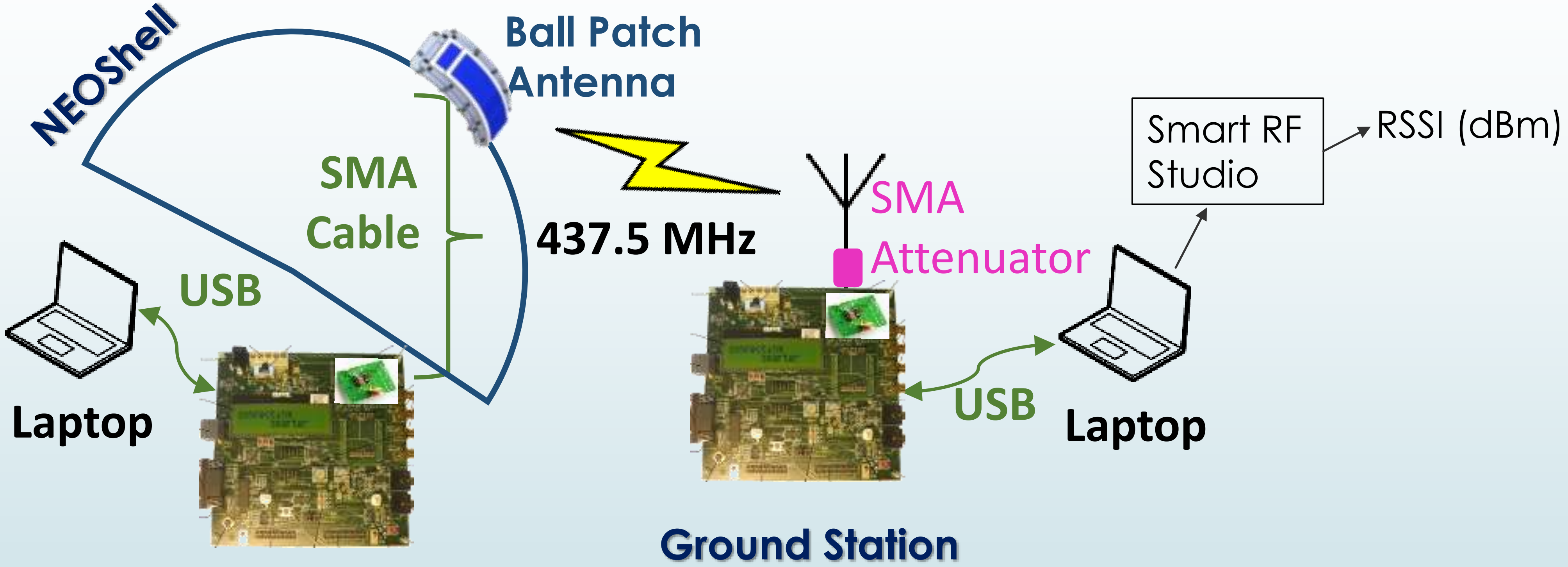
Payload Subsystem Tests

Test	Levels of Success	Functional Requirements	Models
Magnetometer Test - compare to earth's magnetic field	Payload L1 – L2, L4 Power L1	SCI 1	–
Geiger Counter Test - compare to expected radiation	Payload L1 – L2, L4 Power L1	SCI 1	–

Comms Subsystem Tests

Test	Levels of Success	Functional Requirements	Models
Test signal strength using chip to chip with dev. kits	Ground Station L1	COM 2	–
Test signal strength using chip to chip with patch antenna	–	COM 2	RF Link Model
Configure chip using 8051 before FPGA hookup	–	–	–
Configure chip with FPGA via SPI and check with smartRF	–	–	–
Use RF commands to program N.P. chip via FPGA	Ground Station L2	COM 1, COM 3	–
Cycle commands to data and wake to idle representing a full mission	–	COM 1, COM 3	–
Test ground station to save and display 2 separate sets of data from 1 stream	Ground Station L3	COM 4	–

Link Budget Validation Schematic



Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

Avionics Subsystem Tests

Test	Levels of Success	Functional Requirements	Models
Validate individual module outputs via testbench simulation	–	–	–
Validate total system outputs via testbench simulation	–	–	–
Validate individual module outputs via testbench simulation	–	–	–
Validate total system outputs via testbench simulation	–	–	–
Test functionality of simulated peripherals via O-Scope/Logic analyzer	–	–	–
Validate data throughput requirements	–	–	–
Validate power consumption	–	–	–

Avionics Subsystem Tests

Test	Levels of Success	Functional Requirements	Models
Test Powerboard → Avionics connection	–	–	–
Test Magnetometer → Avionics connection	–	–	–
Test Geiger Counter → Avionics connection	–	–	–
Test Transceiver → Avionics/Memory connection	–	–	–

Moving Forward with Test Plans & Safety

- We are developing detailed test procedures for all tests, including steps to mitigate component safety hazards/concerns
- Before performing tests, we will review test plans with PAB members to make sure all safety concerns have been considered and addressed properly

- Some Component Safety Concerns:
  - Use ESD safe protocol to protect avionics board
  - Connect all tools, peripherals, hardware, and operators to a common ground during avionics board operation
  - Not shorting the leads to the batteries
  - Lipo batteries must be discharged within 48 hours being fully charged
  - Batteries should always be kept between 0°C and 60°C
  - Lipo batteries should be charged in Lipo-safe bag
  - Lipo battery assembly must not be discharged below 10V → voltage cutoff circuit

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	Power L1	–	–
Test power board with TENMA EX354T Power Supply	Power L1	–	–
Test power board with single battery	Power L2	–	–
Test power board with battery pack	Power L2	–	–

Payload Subsystem Tests

Test	Levels of Success	Functional Requirements	Models
Magnetometer Test **- compare to earth's magnetic field**	Payload L1 – L2, L4 Power L1	SCI 1	–
Geiger Counter Test **- compare to expected radiation**	Payload L1 – L2, L4 Power L1	SCI 1	–

Comms Subsystem Tests

Test	Levels of Success	Functional Requirements	Models
Test signal strength using chip to chip with dev. kits	Ground Station L1	COM 2	–
Test signal strength using chip to chip with patch antenna	–	COM 2	RF Link Model
Configure chip using 8051 before FPGA hookup	–	–	–
Configure chip with FPGA via SPI and check with smartRF	–	–	–
Use RF commands to program N.P. chip via FPGA	Ground Station L2	COM 1, COM 3	–
Cycle commands to data and wake to idle representing a full mission	–	COM 1, COM 3	–
Test ground station to save and display 2 separate sets of data from 1 stream	Ground Station L3	COM 4	–

Avionics Subsystem Tests

Test	Levels of Success	Functional Requirements	Models
Validate individual module outputs via testbench simulation	–	–	–
Validate total system outputs via testbench simulation	–	–	–
Validate individual module outputs via testbench simulation	–	–	–
Validate total system outputs via testbench simulation	–	–	–
Test functionality of simulated peripherals via O-Scope/Logic analyzer	–	–	–
Validate data throughput requirements	–	–	–
Validate power consumption	–	–	–

Avionics Periferals Tests

Test	Levels of Success	Functional Requirements	Models
Test Powerboard → Avionics connection	–	–	–
Test Magnetometer → Avionics connection	–	–	–
Test Geiger Counter → Avionics connection	–	–	–
Test Transceiver → Avionics/Memory connection	–	–	–

Thermal Model Validation

Objective: Validate Thermal Model

Test: Final System Test ➔ by April 17th

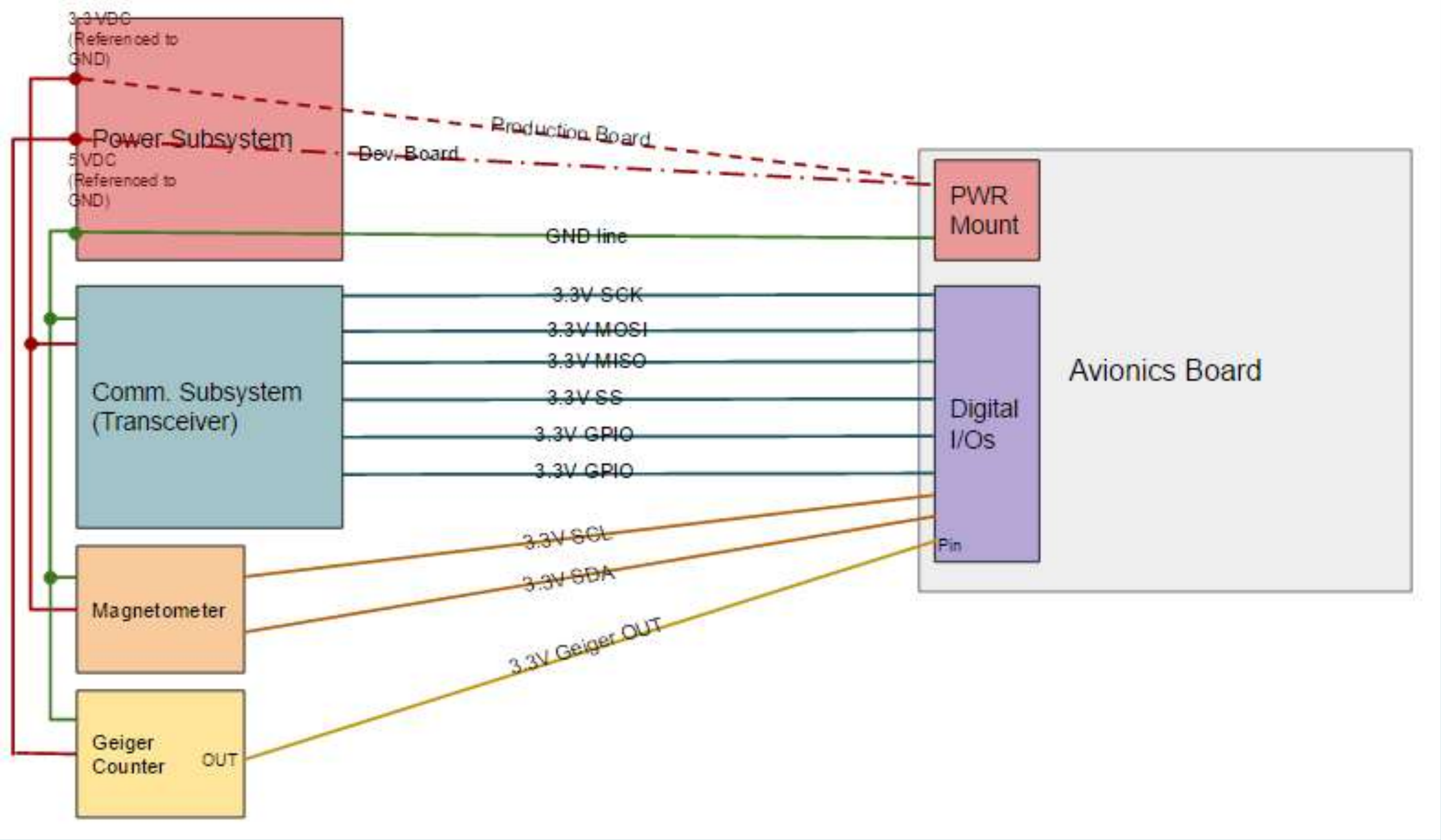
Duration	Data Needed*	Resolution Needed	Sampling Rate
100 hrs. ~4 hr. shifts	Temperature	2 °C	Once every 15 minutes
	Time	1 minute	

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

***additional information included in backup slide (Final System Test Logistics)**

Component	Maximum Temperature (°C)	Modeled Temperature (°C)	Margin (°C)
Batteries	60	41	+19
Avionics	125	91	+34
Transceiver	85	42	+42
Power Regulator	85	50	+35
Magnetometer	125	38	+87
Geiger Counter	85	41	+44

Subsystem Integration Setup



Project Overview | Design Solution | Requirements and Risk | Testing and Verification | Project Planning

Flat-Sat Test Logistics

- Test Schedule: (2) 8.5 hour tests ➔ February 29th – March 17th
- Location: Trudy's Lab
- Data Needed: Radiation data
  Magnetometer data
  Time of ground station reception
  Component temperature at least once per minute➔ nearest 2 °C
- Key Equipment: Neopod assembly
  (7-8) K-type thermocouples (available in Trudy's Lab)
  ➔ accurate to 1.1 °C
  NI9213 Thermocouple DAQ (Needs to be checked out from ITLL)
  ➔sampling rate: 1200 Samples/second
  ➔resolution: 0.02 °C for up to 16 thermocouples

Final System Test Logistics

- Model Validation: Power Budget, Mass Budget, Thermal Model
- Test Schedule: 100 hours between March 30th - April 17^{th}
  - ➔ 4 hour shifts, 2 people each shift
- Location: Trudy's Lab
- Data Needed: Radiation data
  - Magnetometer data
  - Time
  - Component temperature at least every 30 minutes ➔ nearest 2 °C
- Key Equipment: Neopod assembly
  - (10) K-type thermocouples (available in Trudy's Lab) ➔ accurate to 1.1 °C
  - NI9213 Thermocouple DAQ (Needs to be checked out from ITLL)
    - ➔ sampling rate: 1200 Samples/second
    - ➔ resolution: 0.02 °C for up to 16 thermocouples

Structural Risk Assessment

Risks	Description	Mitigation
RP1: Tolerance Stack up	The clips may not mate properly to the internals of the sphere due to tolerances	Clip design modified to allow **adjustment**
RP2: Mistake in Machining	Designed toolpaths can behave unexpected	**SolidCAM and CNC mill simulation** tools will be used extensively
RP3: Unable to Dissipate Heat	Structure unable to dissipate the heat in an earth environment	**Sphere will be opened** and fan will be added if deemed necessary

Severity

Likelihood	1	2	3	4	5
5					
4					
3					
2		**RP1**		**RP3**	
1				**RP2**	

Red	**Unacceptable**
Yellow	**Acceptable with Mitigation**
Green	**Acceptable**

Sensor Risk Assessment

Risk	Description	Mitigation
RA1	Geiger Counter is Improperly Handled	For any test using the Geiger Counter, there will be specific procedures to avoid improper use. There will also be a requirement to **use ESD safe equipment** when handling the sensors.
RA2	Hardware failure in sensors	Quick **initial testing and calibration of sensors** with pre-developed software will detect if this is a problem and **allow enough time to purchase another device.**

Severity

Likelihood

	1	**2**	**3**	**4**	**5**
5					
4					
3			**RA1**		
2		**RA2**			
1					

	Unacceptable
	Acceptable with Mitigation
	Acceptable

Avionics Risk Assessment

Risk	Description	Mitigation
RA1	Ball Avionics Delivery	Constant **customer feedback** will allow for **early warning** and preparation. Microsemi Dev Kit is valid offramp.
RA2	ESD Failure	Proper team **ESD training**. Always use ESD safe **work** and **storage environments** for all avionics and interfacing activities.
RA3	FPGA Software Development	Attend Microsemi **trainings** and **webinars**. Use professional resources. Follow learning **curriculum**.

Severity

Likelihood

	1	2	3	4	5
5					
4					
3	RA1				
2					RA3
1				RA2	

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

Communications Risk Assessment

Risk	Description	Mitigation
RP1	Front-end of communications equipment is damaged	Will use **appropriate safety precautions** when operating equipment. Use of transceiver instead of transmitter/receiver
RP2	Noise within NeoPod significantly disrupts communications system	Will buy **shielded SMA cable** Early integration test will allow us to characterize noise
RP3	Interference within 437.5 MHz band disrupts demonstration	Capability to **switch to 401 MHz range if needed.**

Severity

Likelihood

	1	2	3	4	5
5					
4					
3	**RP3**		**RP2**		
2					
1					**RP1**

	Unacceptable
	Acceptable with Mitigation
	Acceptable

Power Risk Assessment

Risk	Description	Mitigation
RP1	Project runs out of power while testing	Developing an **accurate power budget** and **characterizing the battery capacity.**
RP2	Batteries discharge unevenly while testing	The **batteries will be tested individually for defects**. We have plans to do testing with batteries in parallel
RP3	Batteries are damaged	Have included both **a 5 A fuse** as well as a **voltage cutoff circuit**. This should prevent damaging the batteries during tests. Safety precautions during charging.

Severity

Likelihood

	1	2	3	4	5
5					
4					
3				RP2	
2					RP3
1				RP1	

Red	**Unacceptable**
Yellow	**Acceptable with Mitigation**
Green	**Acceptable**

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