Project ELSA

Europa Lander for Science Acquisition

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Customer: Joe Hackel (Ball Aerospace)

Advisor: Dr. Robert Marshall

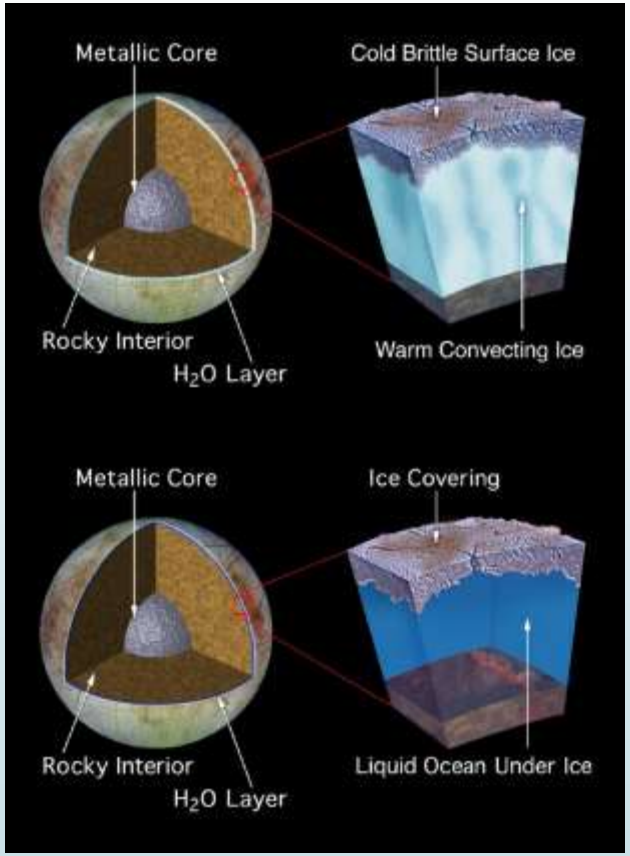
Project Overview

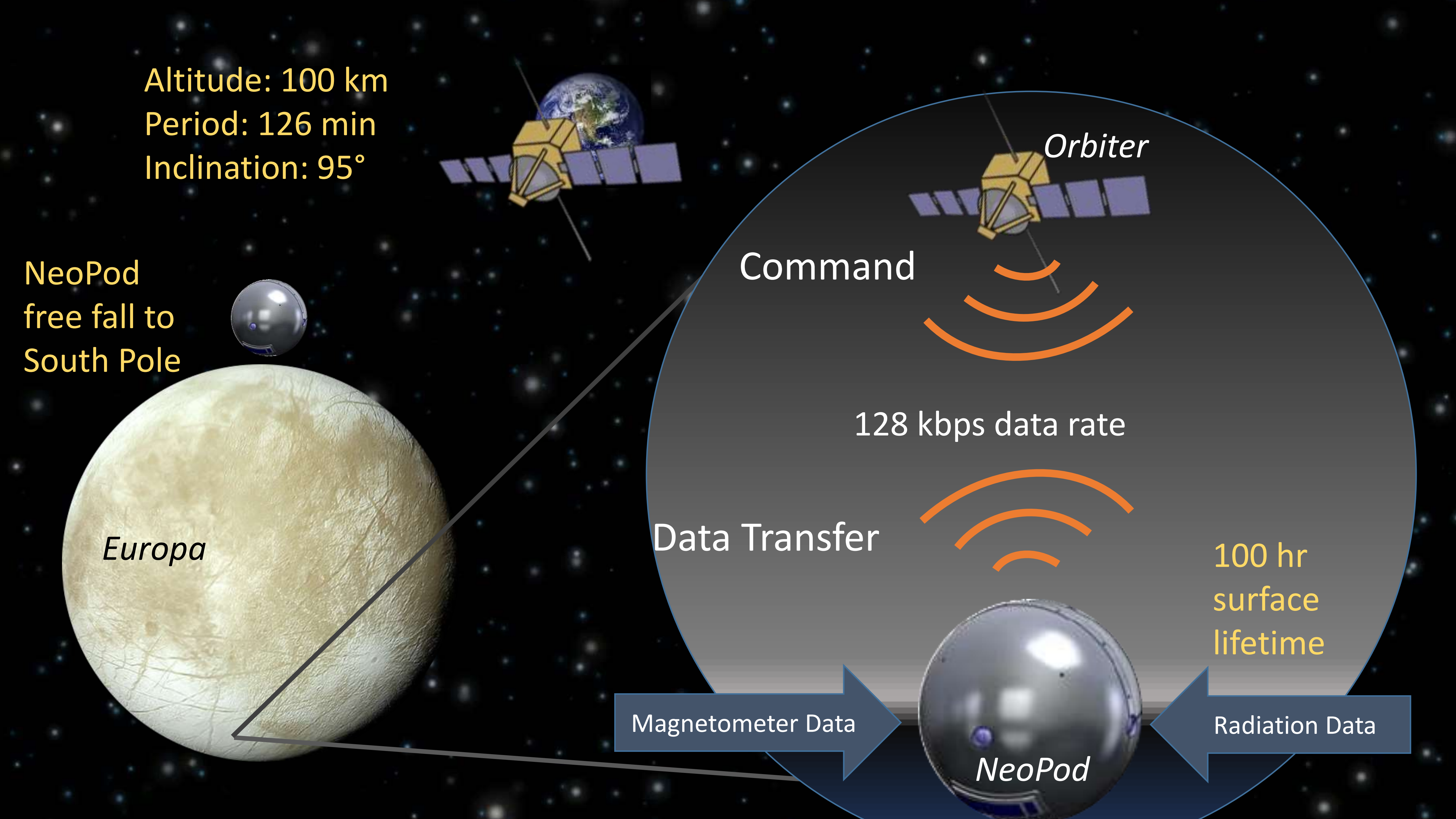
Project Statement

The ELSA team will build the Earth based, **“tabletop equivalent”**, of a spherical probe that would be sent to the surface of Europa. The goal of the ELSA project will be to **develop and integrate the communications and avionics systems with a scientific payload** chosen by the team. This project is motivated by the Europa mission concept developed by Ball Aerospace.

Motivation for Project: Europa

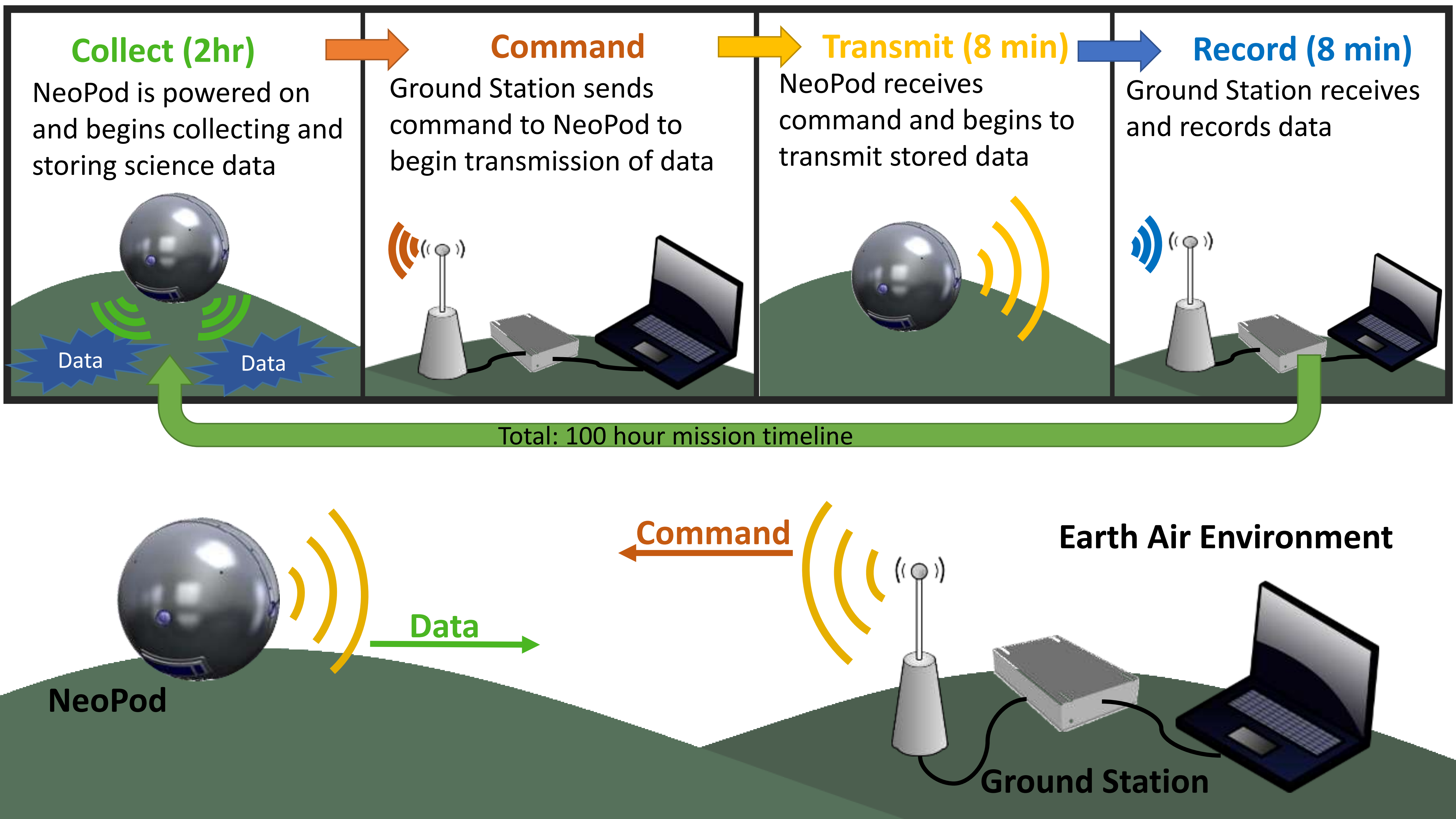
- Moon of Jupiter
- Icy surface with active geology
- Previous flybys suggest possibility of subsurface ocean
- **Identified by NASA as a “High Priority Target” for its potential to support life**




Altitude: 100 km
Period: 126 min
Inclination: 95°
NeoPod
free fall to
South Pole
Europa
Orbiter
Command
128 kbps data rate
Data Transfer
100 hr
surface
lifetime
Magnetometer Data
Radiation Data
NeoPod

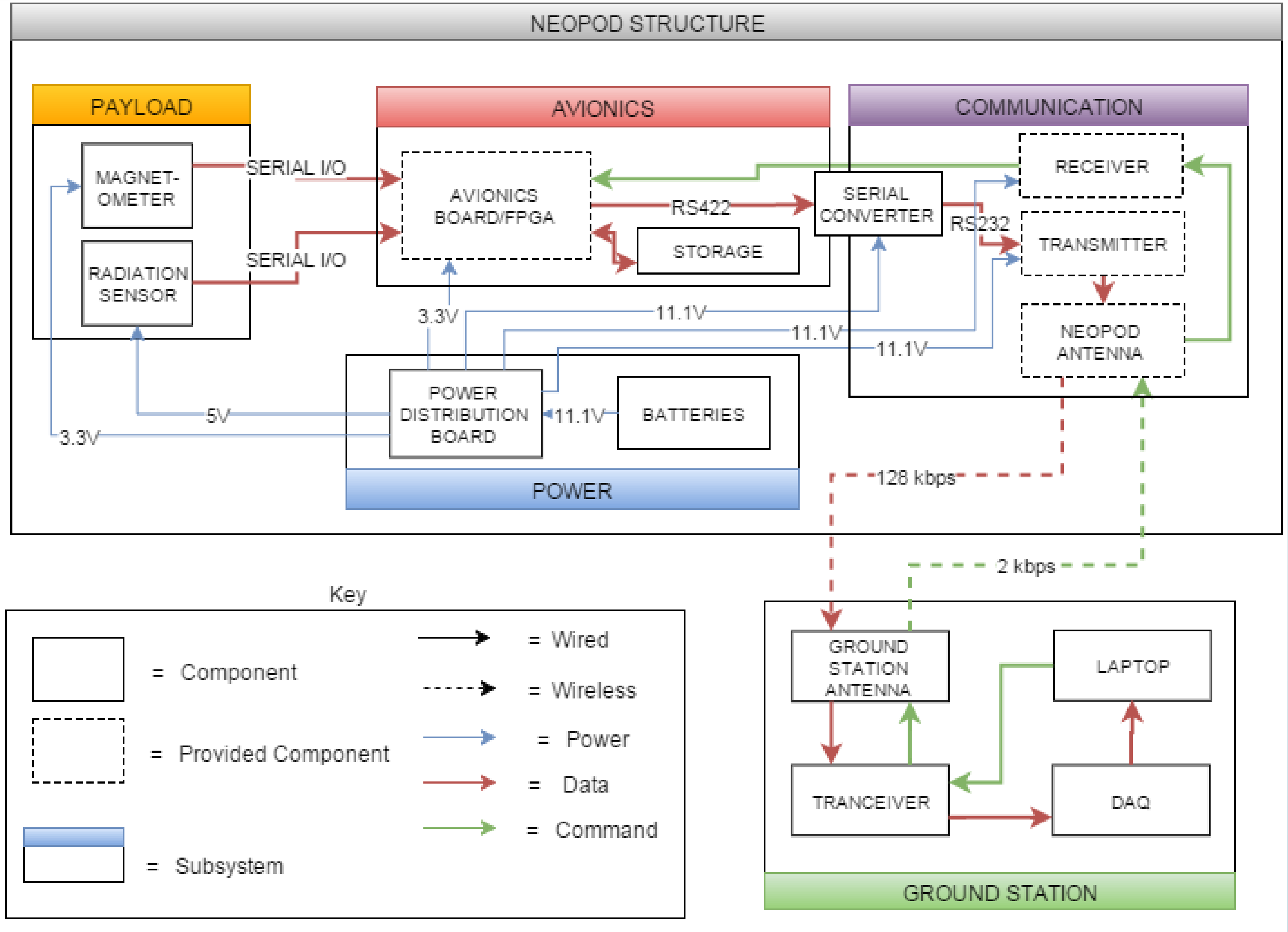
ELSA Mission Objectives

- **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*



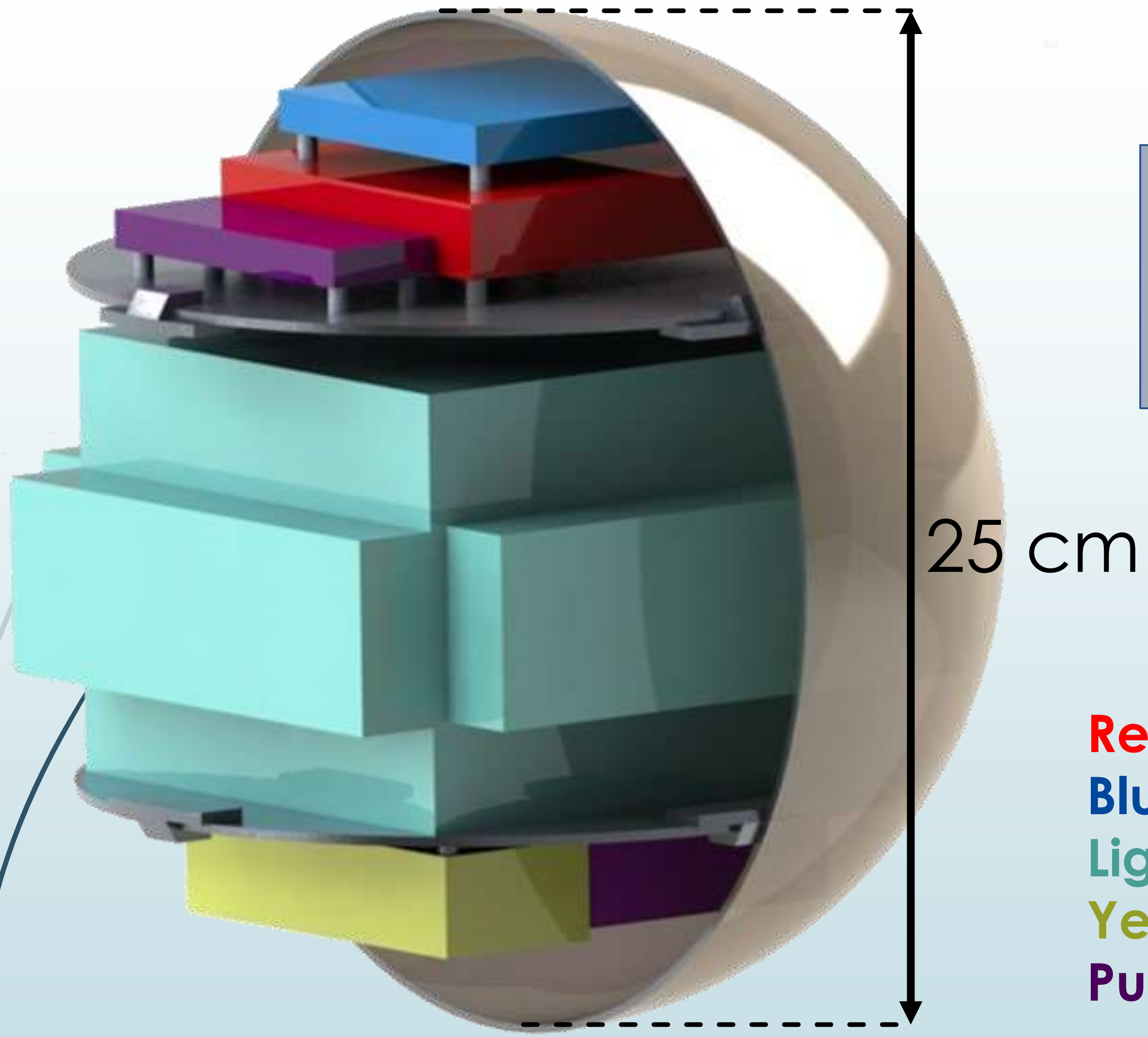
Collect (2hr)
NeoPod is powered on and begins collecting and storing science data
Data
Data
Command
Ground Station sends command to NeoPod to begin transmission of data
Transmit (8 min)
NeoPod receives command and begins to transmit stored data
Record (8 min)
Ground Station receives and records data
Total: 100 hour mission timeline
Command
Earth Air Environment
Data
NeoPod
Ground Station

Functional Block Diagram



Baseline Design

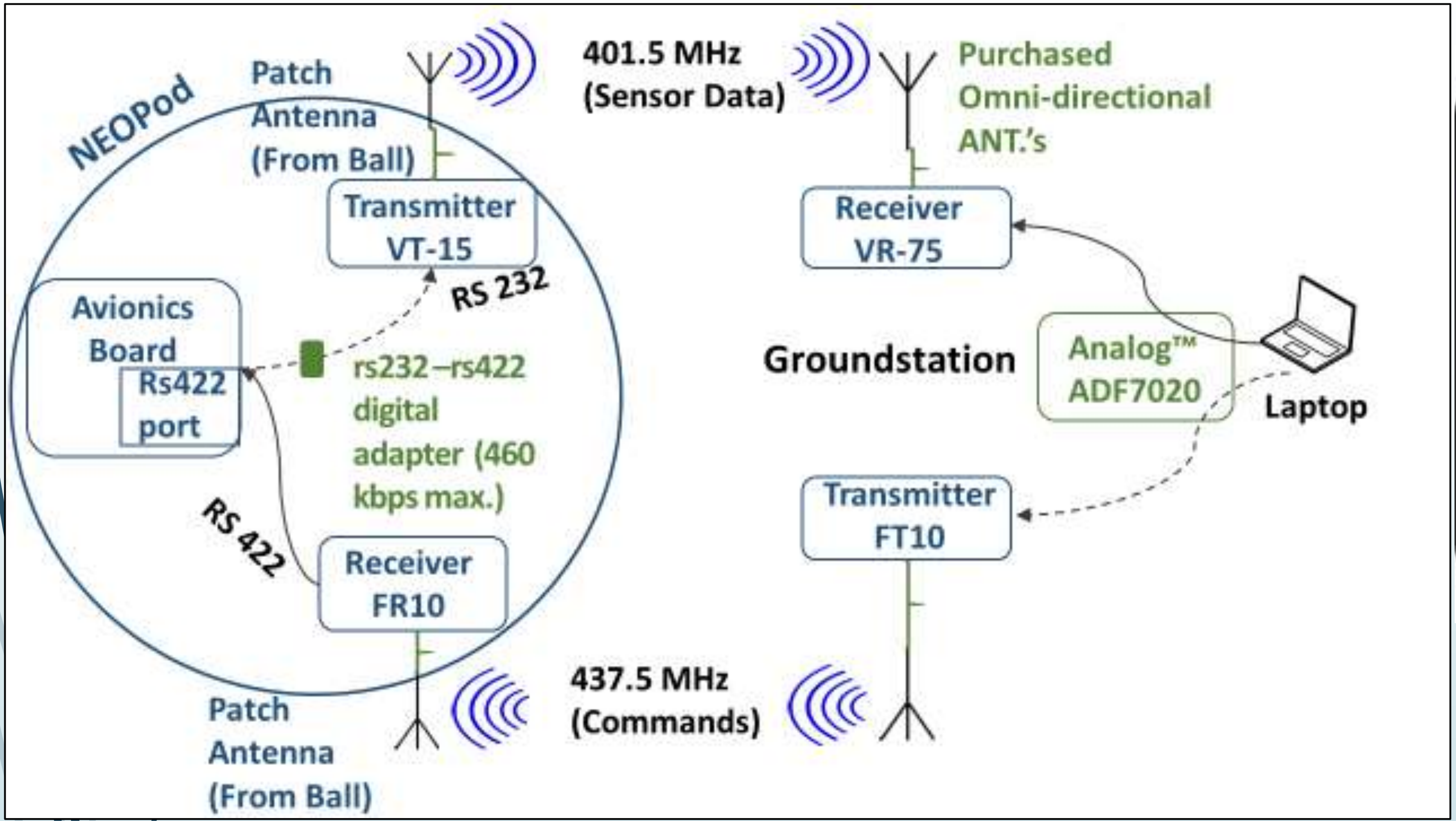
Structures Baseline Design

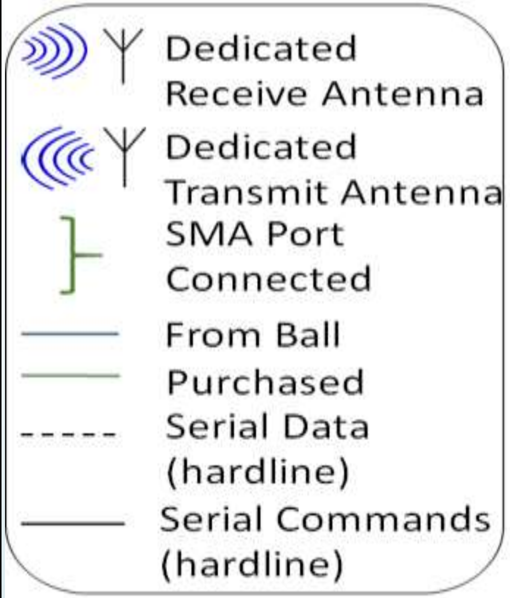


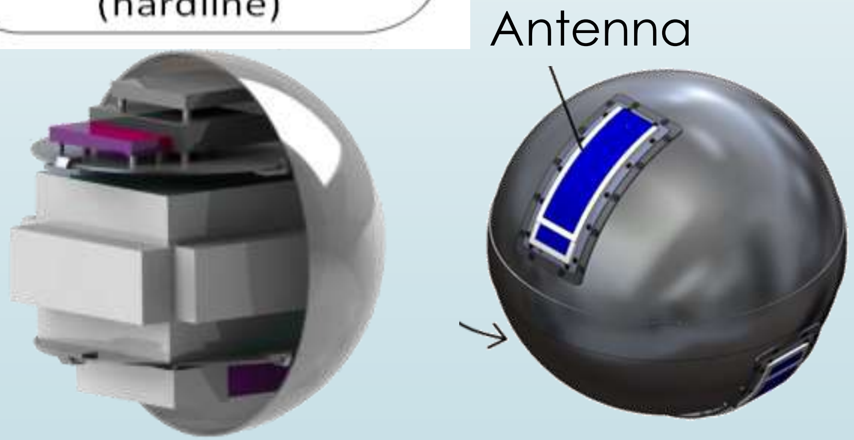
- **Critical Elements:**
  - Housing all components within sphere
  - Mounting internal structure to sphere

Red – Avionics Board
Blue – Power Board
Light Blue – Batteries
Yellow – Science Payloads
Purple – Communications

Communications Baseline Design

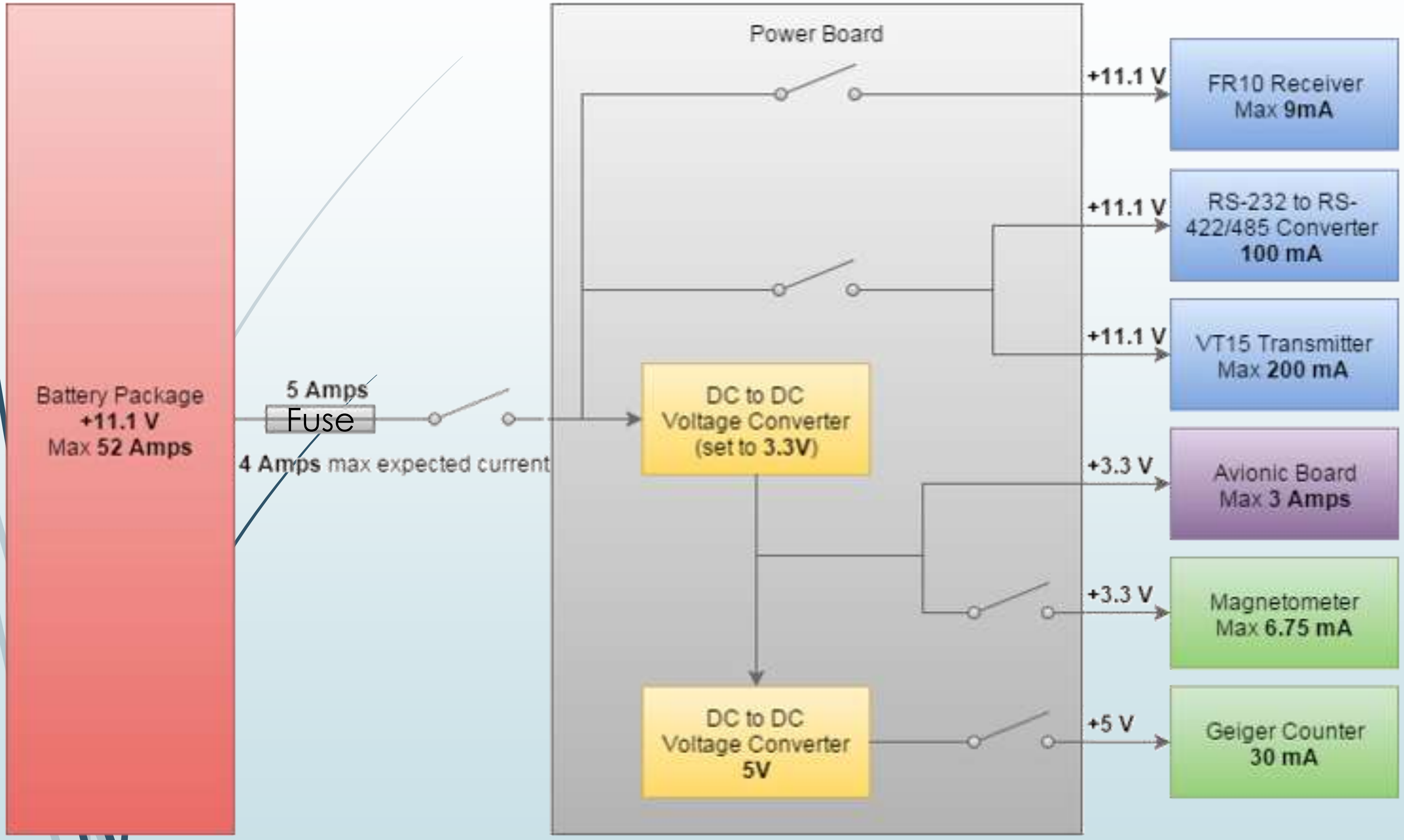


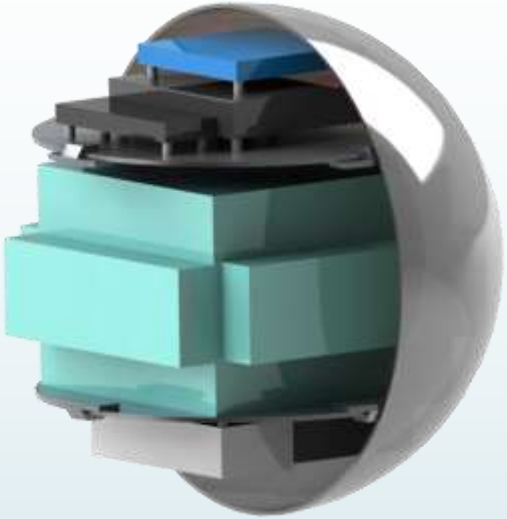




- **Critical Element:**
  - Transmitting data / command wirelessly

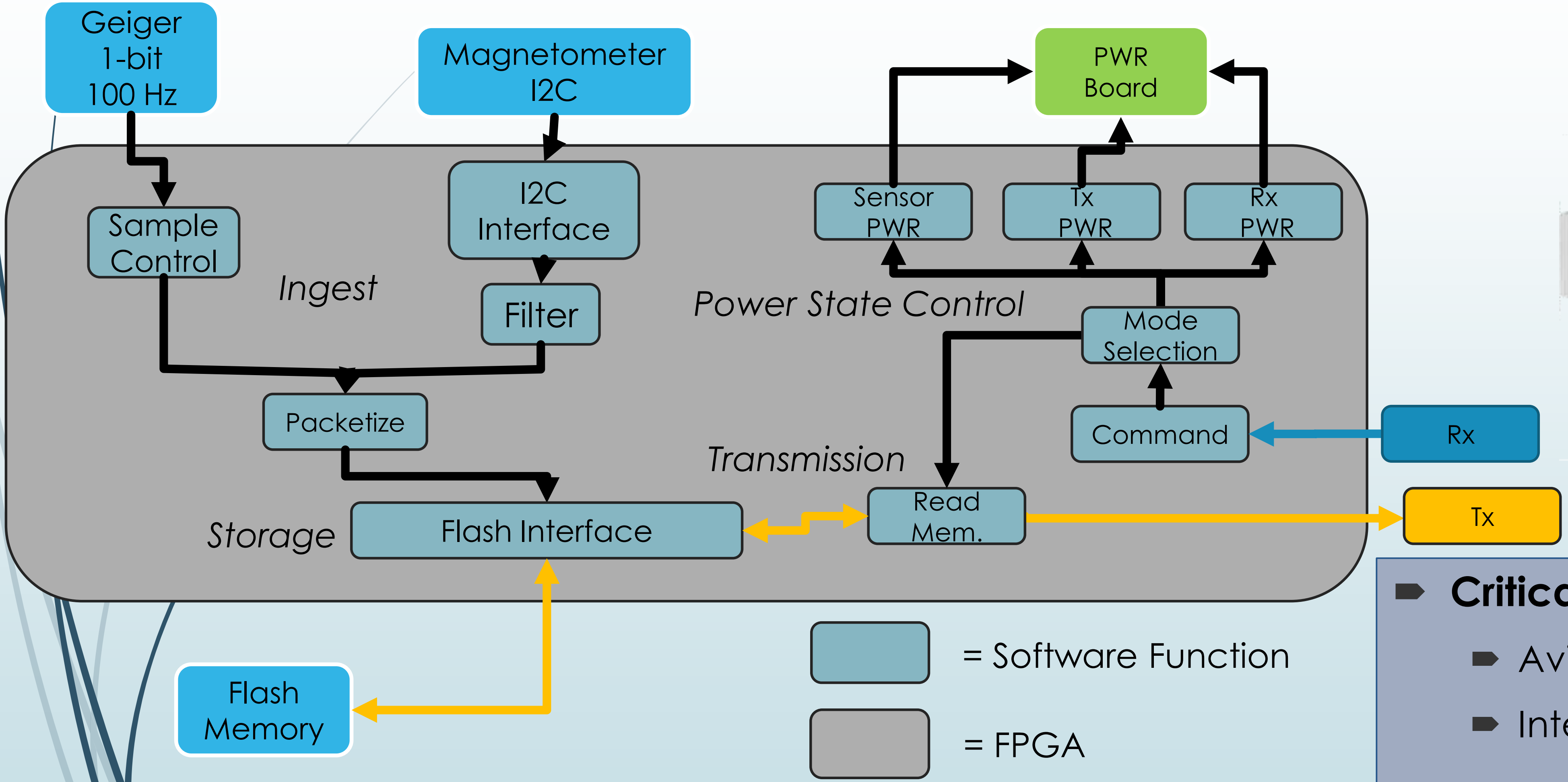
Power Baseline Design

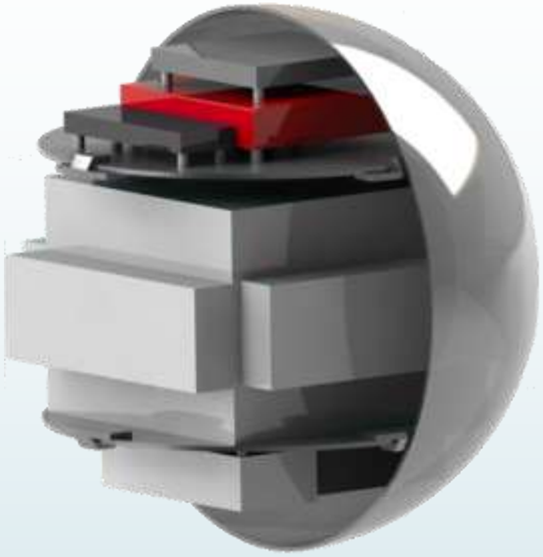




- **Critical Elements:**
  - 100 hour power requirement with a limited amount of volume
  - Developing accurate power budget

Avionics Baseline Design





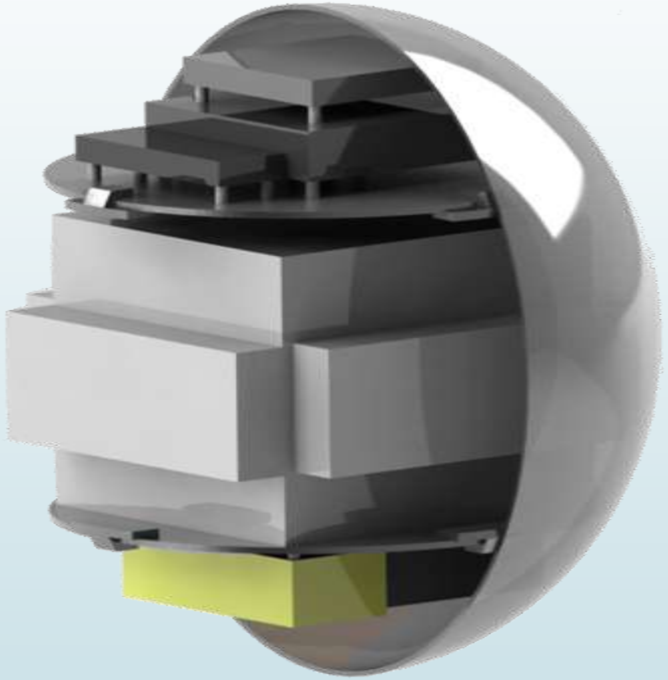
- **Critical Elements:**
  - Avionics board delivery
  - Internal skill development

Payload Selection

Results of trade study of 9 different science options

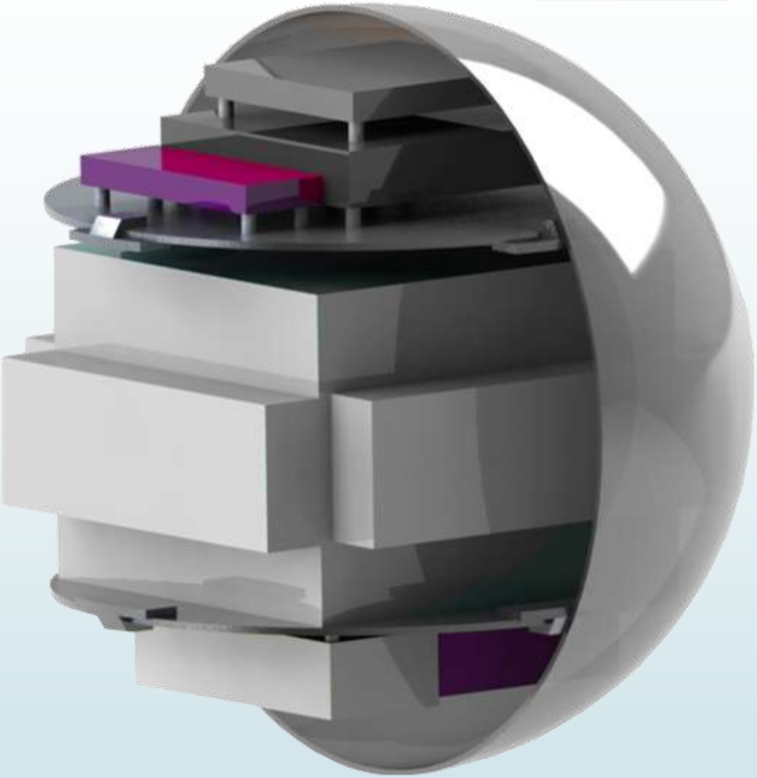
Selected Sensors

- **Vector Magnetometer**
  - Measure 3-D changes in magnetic field to study evidence of subsurface ocean
  - Large variety of instruments to choose from
  - Widely used on satellite missions
- **Geiger Counter**
  - A Geiger counter would measure the radiation experienced on the surface of Europa
  - High levels of radiation on the surface would have an effect on potential life there, as well as any instruments or people sent from Earth



Subsystem Feasibility Studies

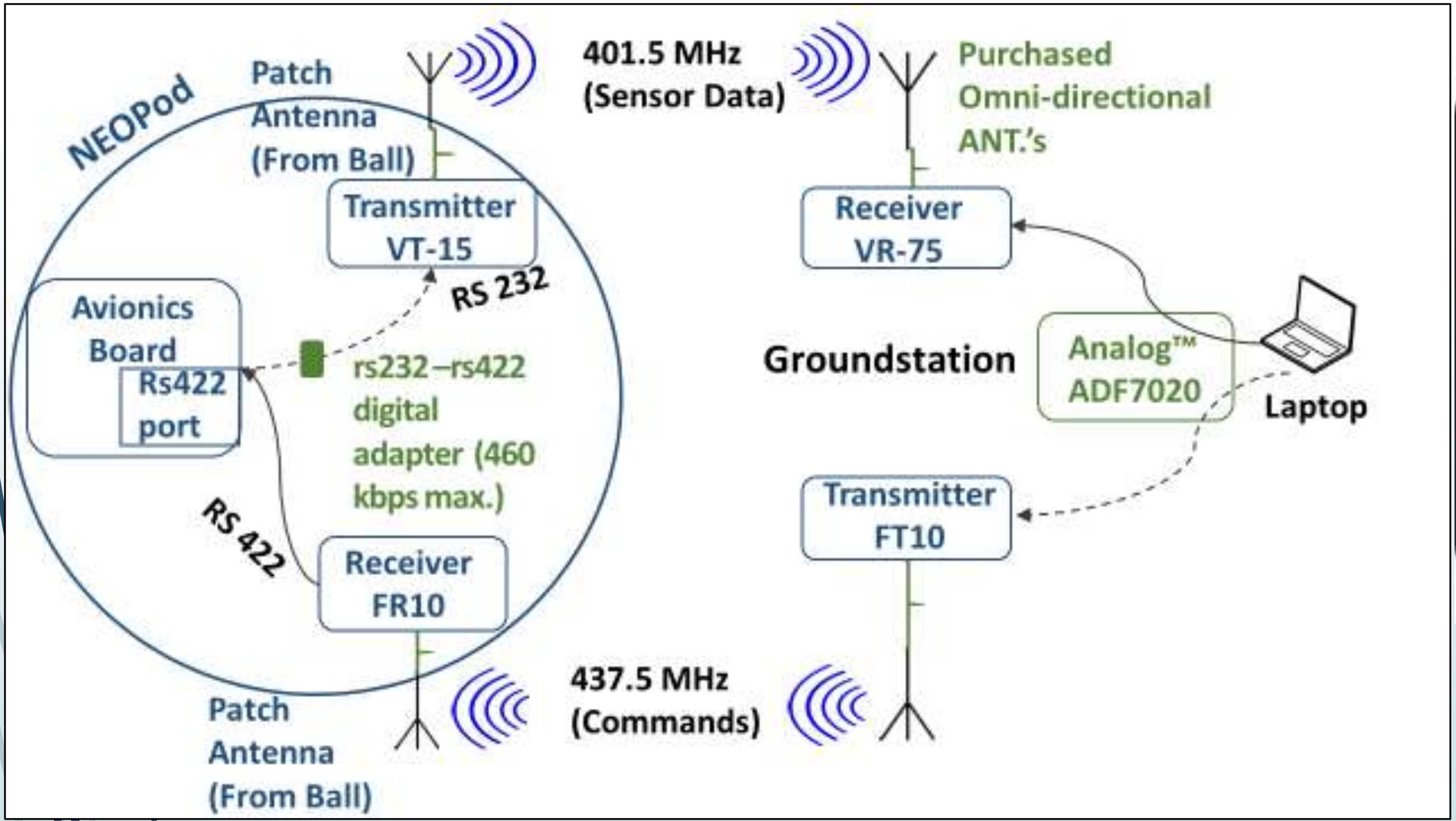
Communications Subsystem

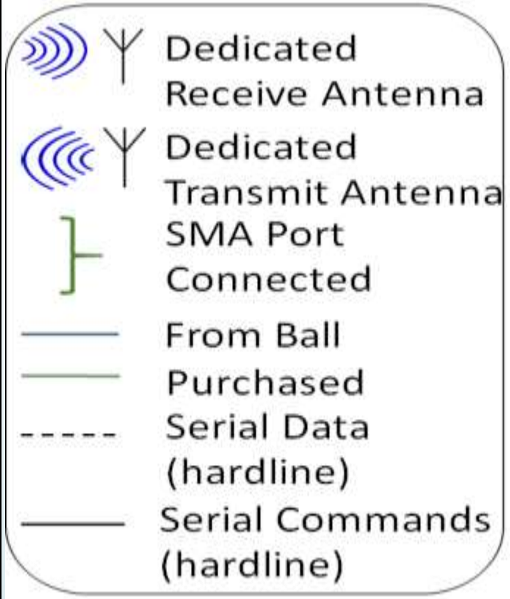


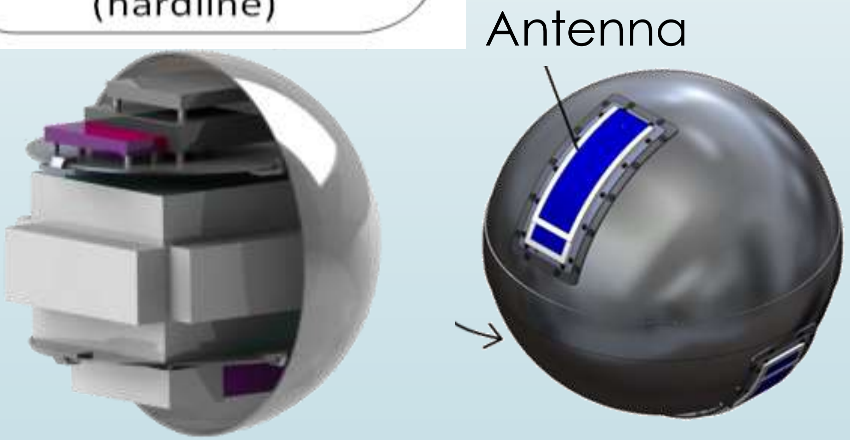
Communications Requirements

Requirement	Description	Motivation
COM 1	The NeoPod shall **wirelessly accept commands**	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 **wirelessly transmit data**	NeoPod must be able to transmit data in order to successfully complete its mission
COM 3	NeoPod shall **employ antennas** supplied by Ball Aerospace (x2)	Antennas conform to the external spherical shape of NeoPod
COM 4	The Ground Station shall **wirelessly send commands**	Mimics the activity of an orbiter
COM 5	The Ground Station shall **wirelessly receive data**	Used for verification of data collection and transmission

Communications Baseline Design



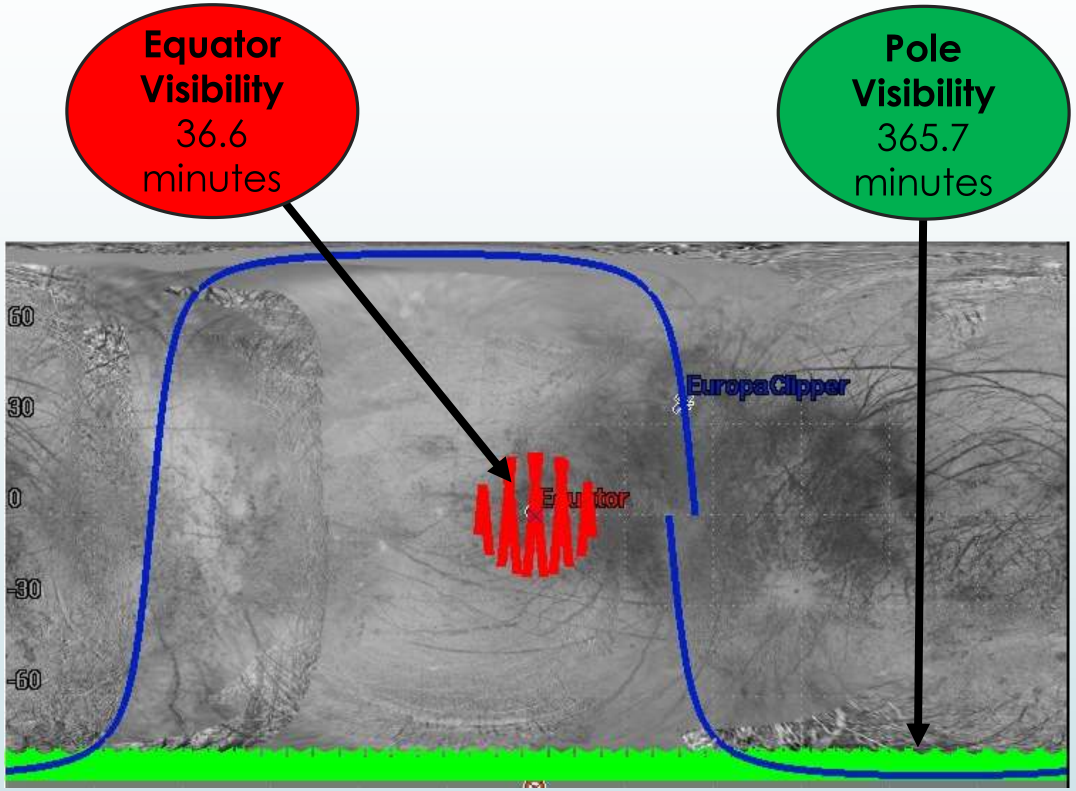




- Requirements Met
  - COM 1, 2, 3, 4, 5

STK Model

- **Mission lifetime 100 hours**
  - 96 hours of data collection
  - 4 additional hours for additional link time
- **Europa Orbiter Parameters**
  - Inclination 95°
  - 126 minute period
  - Eccentricity = 0
- **NeoPod Probe**
  - 12 degree mask angle
  - Ideal 90°S latitude location (Assumed)



STK Ground Track: South Pole vs. Equator Pass Area

Data Transmission at Each Latitude

Transmitted Mission Data at Different Latitudes Over 100 Hour Period*				
Latitude Location (deg South)	Total Pass Time (s)	Transmit Rate(kbps)	Maximum Data (MB)	**Total Data Including 25% Margin (MB)**
0	2198	128	40	**30**
20	2094	128	38	**29**
45	3010	128	55	**41**
60	4146	128	76	**57**
75	10149	128	186	**139**
90	21942	128	401	**301**

*Scenario time frame from 1 Oct. 2015, 00:00.00 UTC -> 5 Oct. 2015 04:00.00 UTC
*All longitude values set to 0°

Maximized Data at Pole-> Assume Pole Location for Mission Timeline

Link Budget - RF

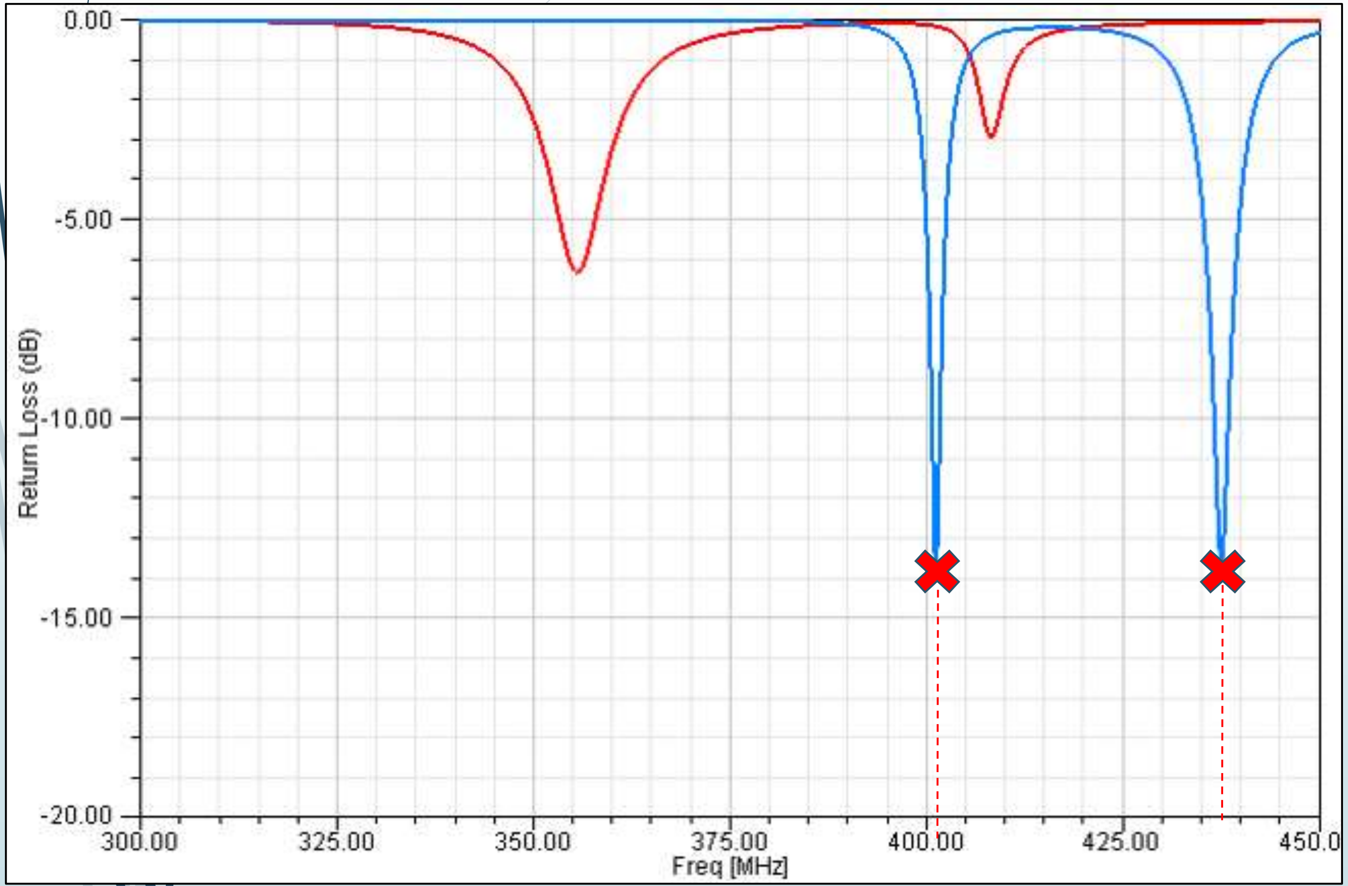
Parameter	Uplink (Data from NeoPod)	Downlink (Command to NeoPod)
Frequency	401.5 MHz	437.5 MHz
Range	100 km	100 km
Bit Error Rate	10E-6	10E-6
Data Rate	128 kbps	2 kbps
TX Power Output	2 W	200 mW
Link Margin	8.49 dB	32.15 dB
Design Margin	-6 dB	-6 dB
Total Link Margin	**2.49 dB**	**26.15 dB**

Assumptions:
1) For long range test, orbiter antenna must be 25 dbi gain.

2) Europa Environment: **Negligible** atmospheric loss

- Requirements Met
  - COM 1, 2, 3, 4, 5

Provided Antennas: Perceived Issue

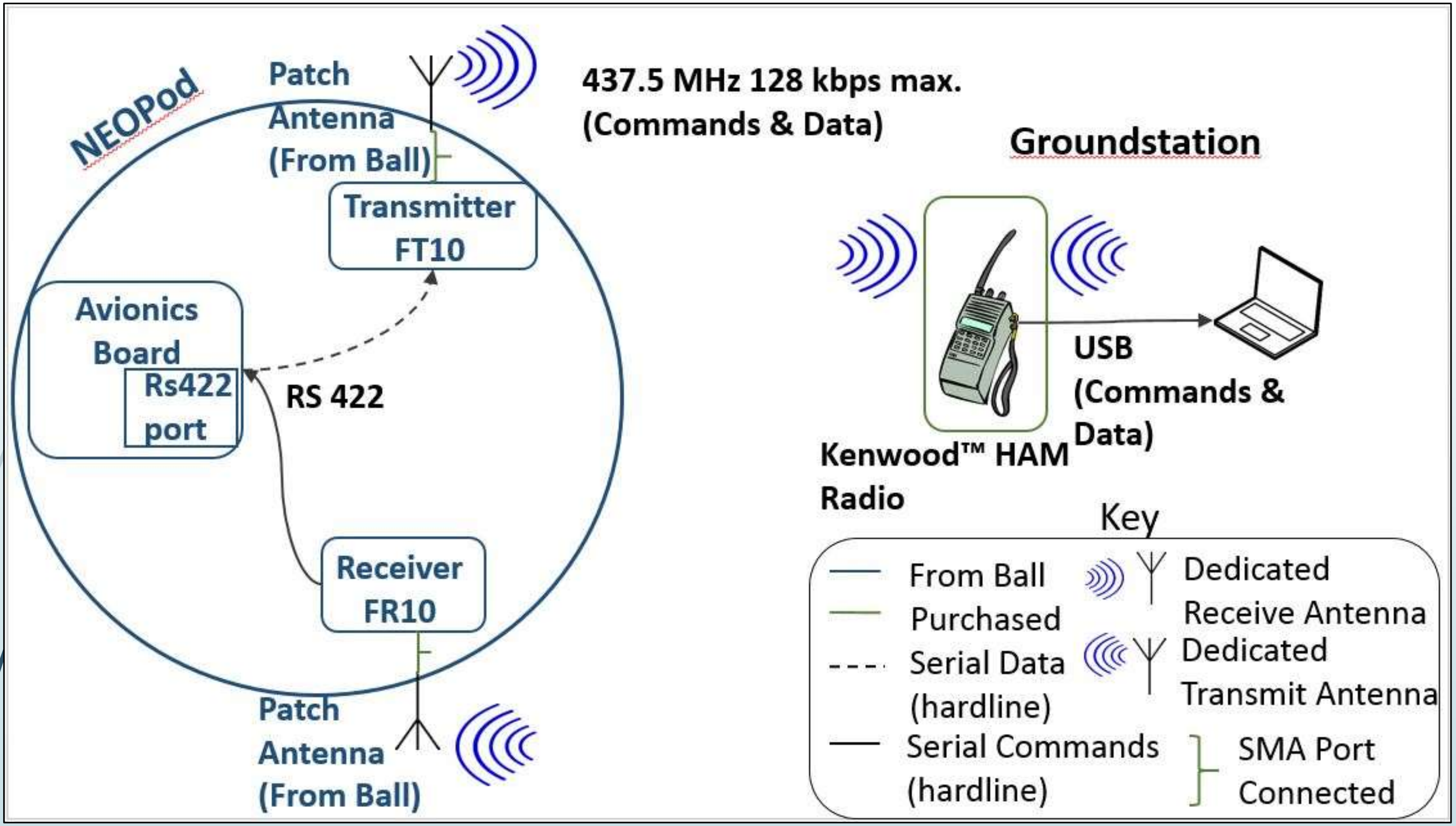


- Appropriate Antenna Frequencies:
  - **401 MHz**
  - **437.5 MHz**
- Transmitter Receiver Frequencies:
  - TR10/TR15: **433.0 - 434.8 MHz**
  - VR15/VT75: **340.0 - 399.9 MHz**

90% Success Confidence

- Custom made for Ball
- Customer Assurance
  - Pending future data points from Ball

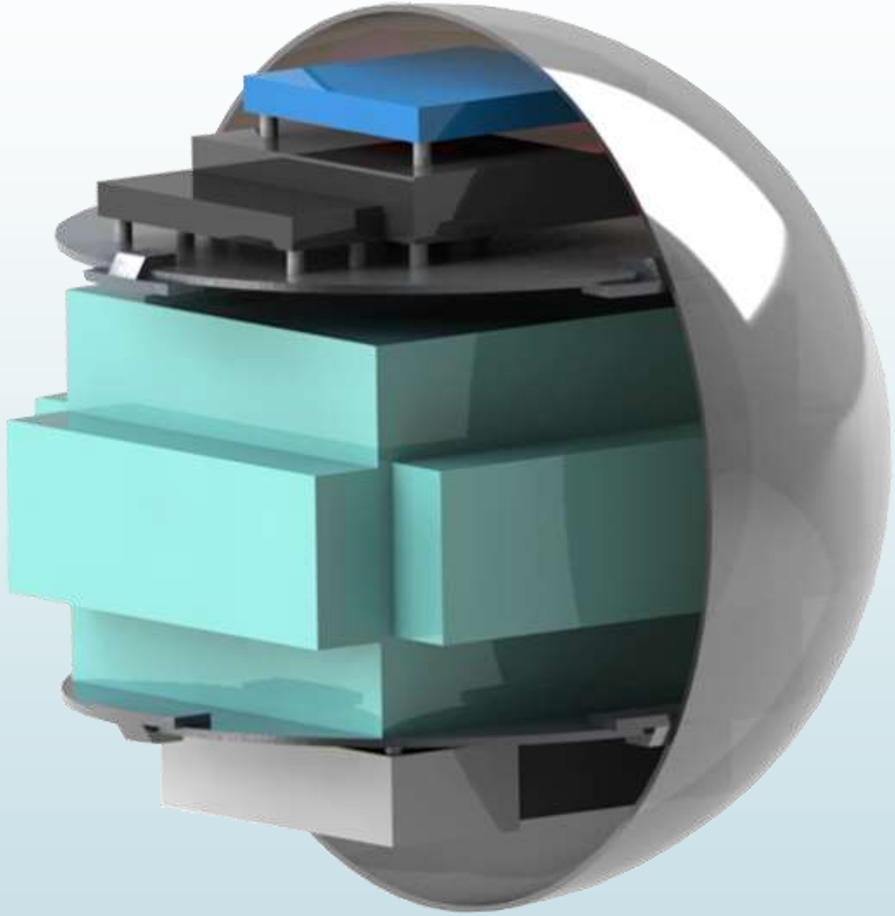
Simplified Ground Station



Communications Requirements

Requirement	Description	Feasible
COM 1	The NeoPod shall **wirelessly accept commands**	✓
COM 2	NeoPod shall **wirelessly transmit data**	✓
COM 3	NeoPod shall **employ antennas** supplied by Ball Aerospace (x2)	✓
COM 4	The Ground Station shall **wirelessly send commands**	✓
COM 5	The Ground Station shall **wirelessly receive data**	✓

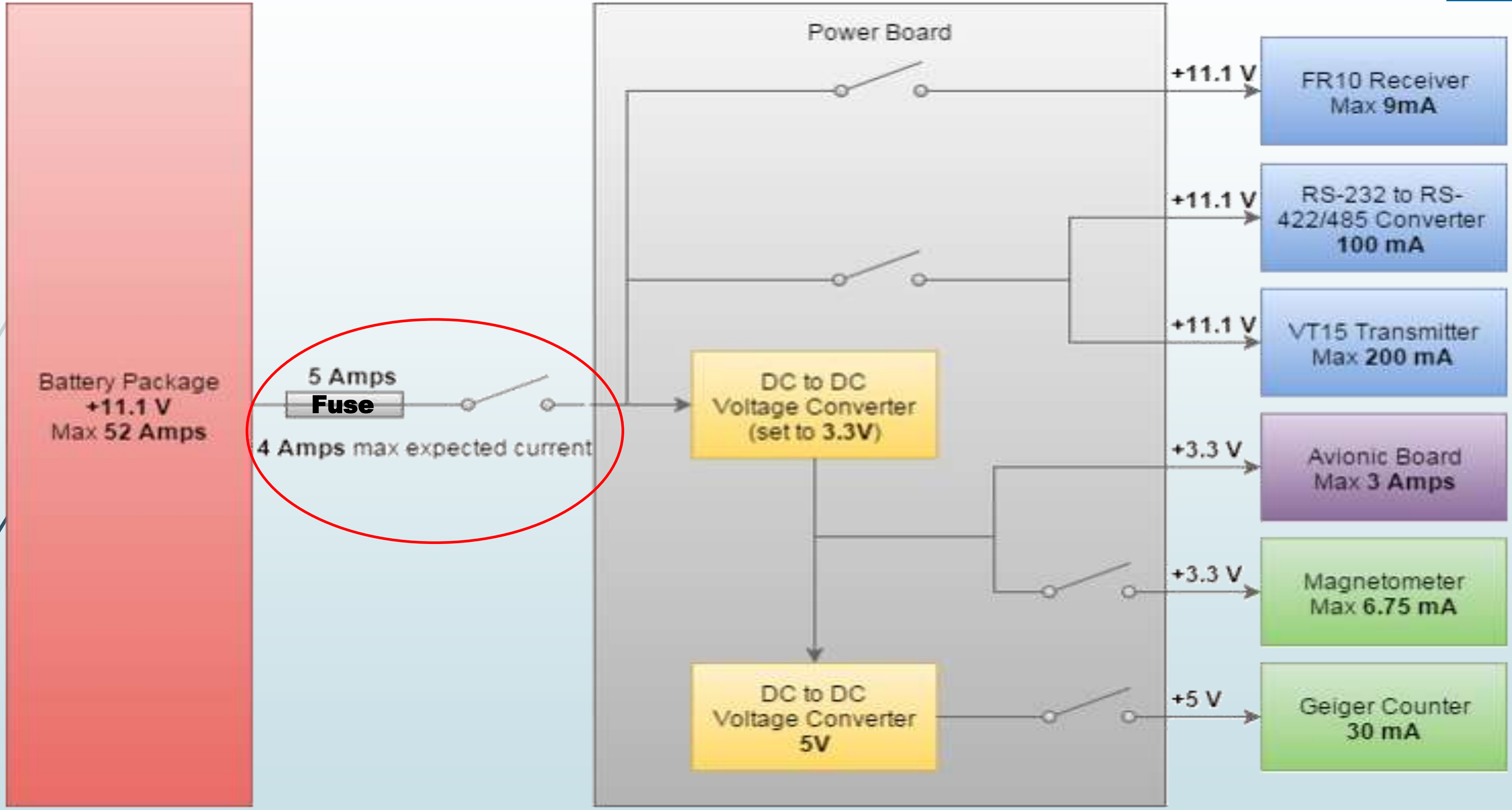
Power Subsystem



Power Requirements

Requirement	Description	Motivation
SCI 2.1	NeoPod power subsystem shall sustain the **scientific instruments** for a **96 hour period**	Europa orbits Jupiter every 3.5 Earth days. The 96 hour period will capture data from the entire orbit.
COM 6	NeoPod **communications** system shall be powered by **onboard power system**	Derived. NeoPod must be self-sufficient.
INT 6.2	Power subsystem will **provide power** to the **avionics** subsystem	Derived. Power system must be able to power the avionics subsystem.

Power Distribution Board



Battery Selection

	Lithium-ion Polymer (3 Cell)	Lithium Iron Disulfide (AA)
Voltage (V)	11.1	1.5
Capacity (Ah)	5.2	3
Mass (g)	331	24
Volume (cm^3)	154	22
Total Energy (Wh)	58	4.5
Specific Energy (Wh/kg)	**175.2**	**189.5**
Energy Density (Wh/cm^3)	**0.376**	**0.206**
Rechargeable	**Yes**	**No**

Lithium-Ion Polymer Feasibility

Structural Limit: 19 batteries

Parameter:	Each Battery:	Total (19 batteries in parallel)
Power Capacity:	57 Wh	1083 Wh
Mass:	0.35 kg	6.3 kg
Volume:	154 cm^3	2926 cm^3
Cost:	$32.00	$610.00

- **Contingency Plan:**
  - Expand spherical structure from 25 cm to **30 cm diameter**
    - Allows for 29 batteries
    - Power Capacity: **1847 Wh**

- Verified With Customer

Power Budget

Component	Max Power Draw [Wh]	15% Power Margin [Wh]
Lithium polymer 5200mAh	+1083	-163
Sparkfun DC/DC Converters	-59	-9
Geiger Counter	-15	-3
9 DOF Sensor Stick	-2	-0.5
Avionics Board	-572	-86
FR10 Receiver	-111	-17
VT15 Transmitter	-12	-2
RS-232 to RS-422/485 Converter	-7	-1

Calculation Assumptions:

1. *Probe is placed on South Pole*
2. *DC-DC 90% Efficiency*
3. ***All components at maximum operating conditions***

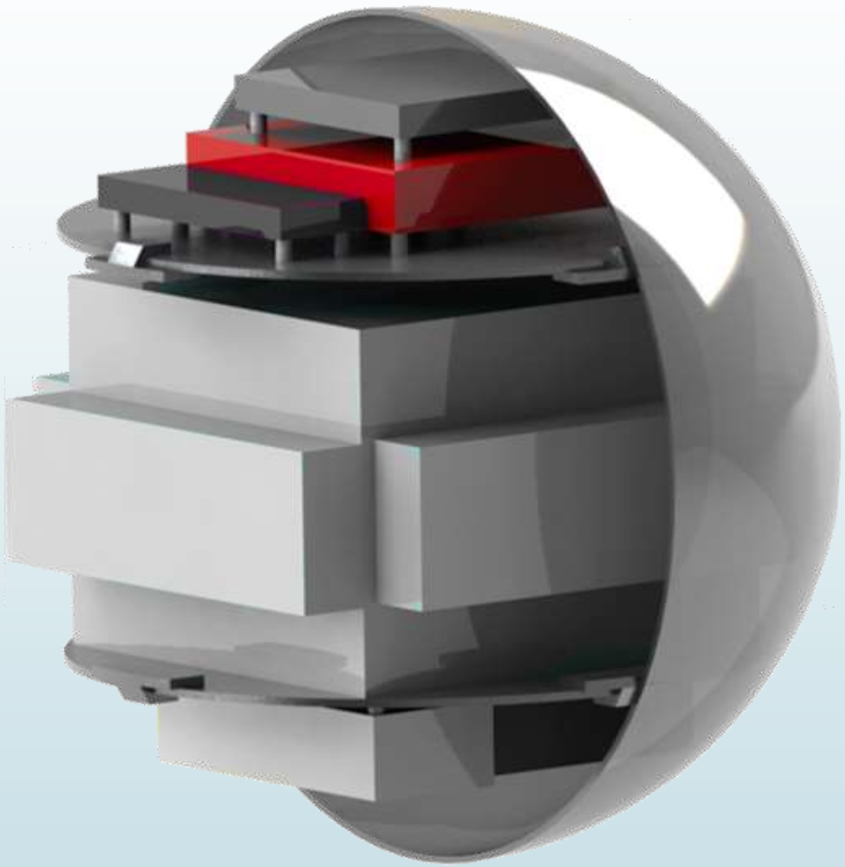
Totals	[Wh]
Available + Margin	1083 -163
Needed + Margin	-776 -118.5
Remaining Power	25 Wh

- Requirements Met
  - COM 6, SCI 2.1, INT 6.2

Power Requirements

Requirement	Description	Feasible
SCI 2.1	NeoPod power subsystem shall sustain the **scientific instruments** for a **96 hour period**	✓
COM 6	NeoPod **communications system** shall be powered by **onboard power system**	✓
INT 6.2	Power subsystem will **provide power** to the **avionics subsystem**	✓

Avionics Subsystem



Avionics Requirements

Requirement	Description	Motivation
SCI 2.2	NeoPod **sensors** shall **integrate** with **avionics** subsystem	The avionics system must process data from the payloads for transmission
INT 6	NeoPod shall have an **avionics board** that will **store data** from sensors and **relay data** to communication system	Avionics board is a component provided by Ball Aerospace for integration in the system.
COM 1	The NeoPod shall **wirelessly** accept **commands**	The avionics system must responds to commands sent from ground station
COM 2.3	NeoPod shall **transmit data** at as near as possible to a maximum of **128kbps**	Avionics subsystem must meet data throughput requirements

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

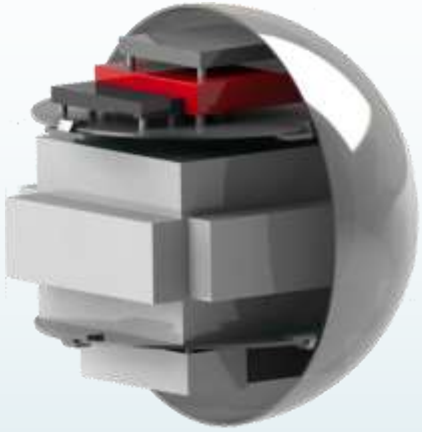
LVDS Driver
>400 Mbps

RS-422 Receiver
100kbps-10Mbps

RS-422 Driver
100kbps-10Mbps

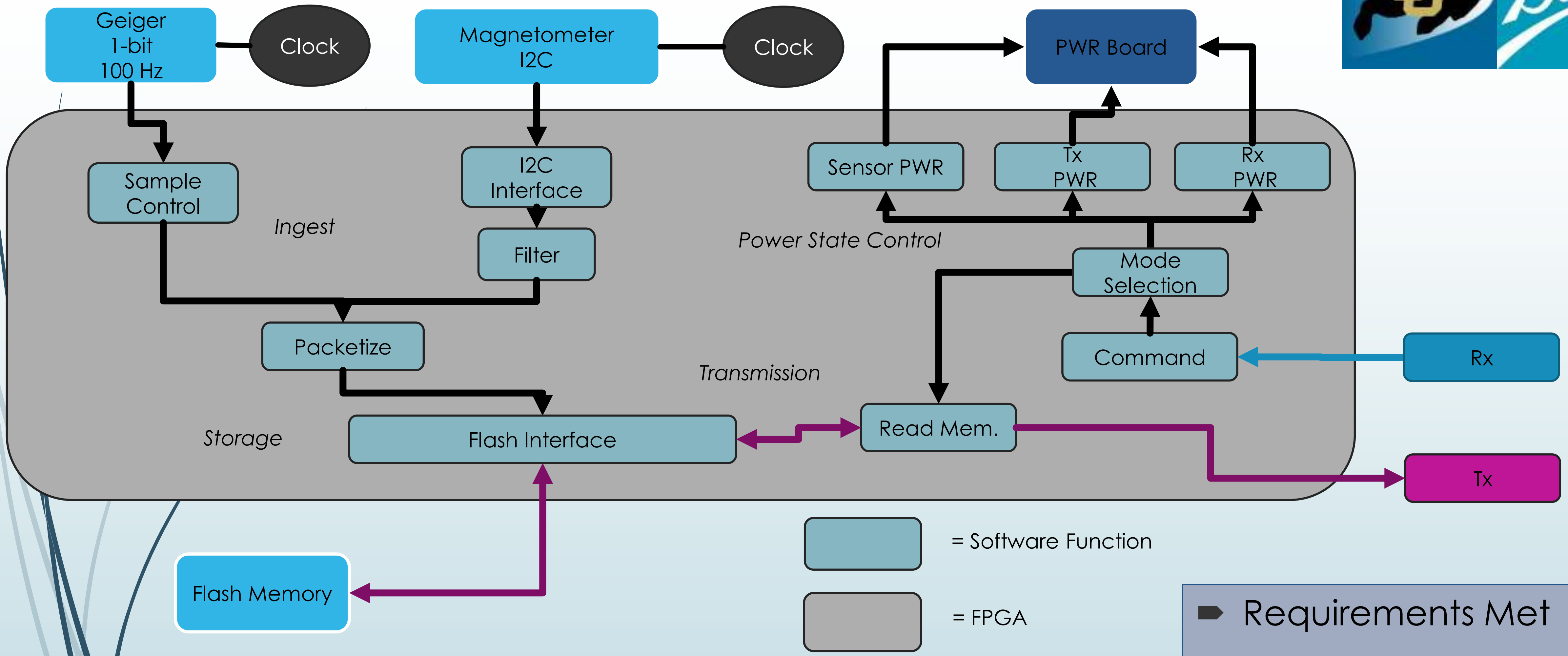
96 mm

90 mm



- Requirements Met
  - COM 2.3

FPGA Software Design

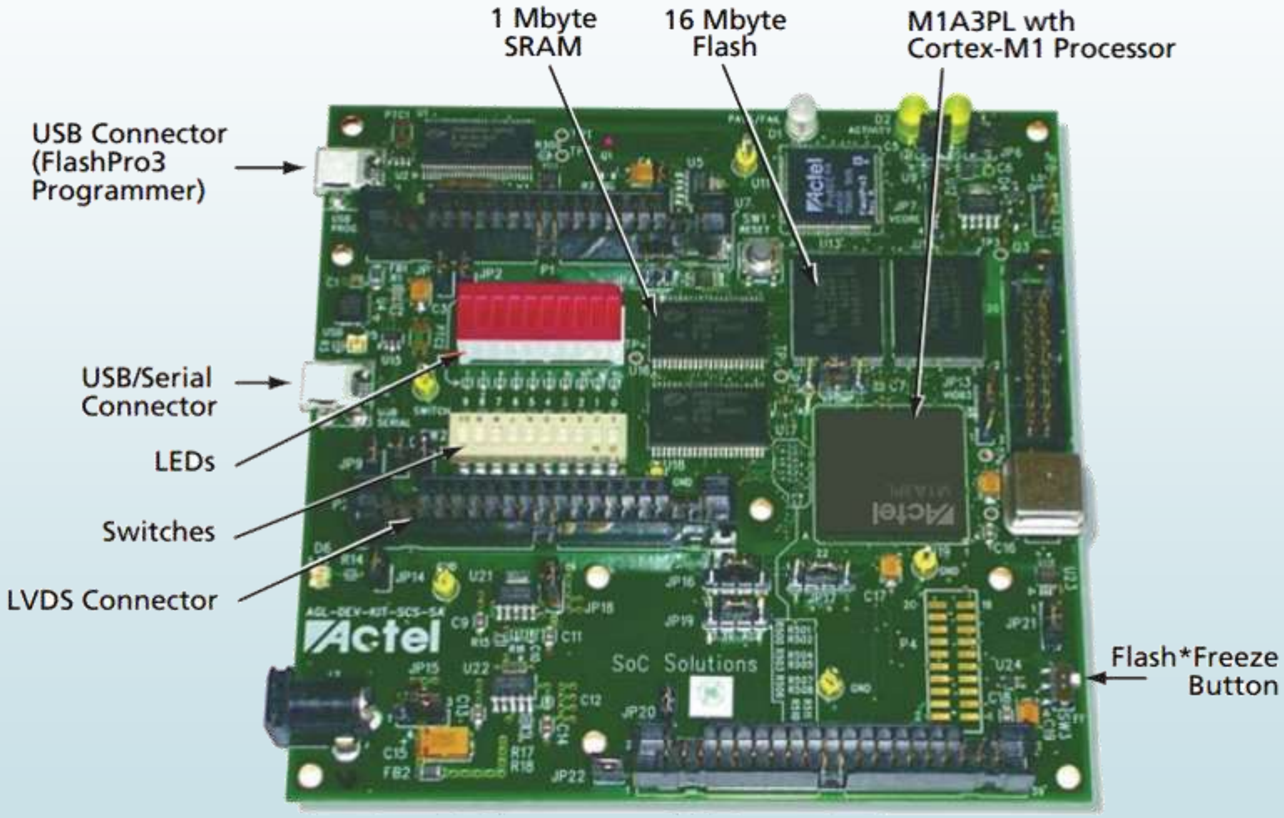


- Requirements Met
  - SCI 2.2, INT 6, COM 1

Current Status – Software Development

- ProASIC3L Development Kit ($600)
  - Provided at **no charge** by Microsemi
  - Received **10/6/2015**
- Software: Libero SoC Platinum
  - Awaiting response for licensing
- Ball Aerospace Avionics Board
  - Expected delivery **1/22/2016**

Microsemi ProASIC3L **Development** Board



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 (Goal: **10/26/2015**)
6	Inputs sinusoidal signal, stores values in flash memory, reads from memory, outputs to serial port (Goal: **11/9/2015**)
7	Repeat 6, add a logical input that turns output on or off (Goal: **CDR**)

Contingency Plan

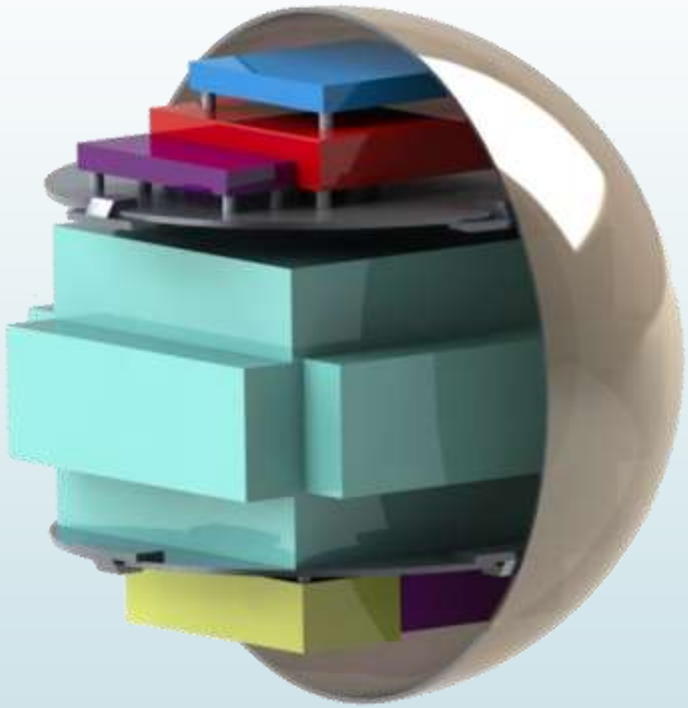
- **Cutoff Dates**
  - Board Design and Documentation Delivery **10/30/2015**
    - Complete avionics design documentation delivered from Ball
  - Internal Knowledge Evaluation **11/9/2015**
    - Feasibility based on knowledge progress rate
  - Avionics Board Delivery **1/22/2016**
    - Delivery of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

- Verified With Customer

Avionics Requirements

Requirement	Description	Feasible
SCI 2.2	NeoPod **sensors** shall **integrate** with **avionics** subsystem	✓
INT 6	NeoPod shall have an **avionics board** that will **store data** from sensors and **relay data** to communication system	✓
COM 1	The NeoPod shall **wirelessly** accept **commands**	✓
COM 2.3	NeoPod shall **transmit data** at as near as possible to a maximum of **128kbps**	✓

Structure Subsystem

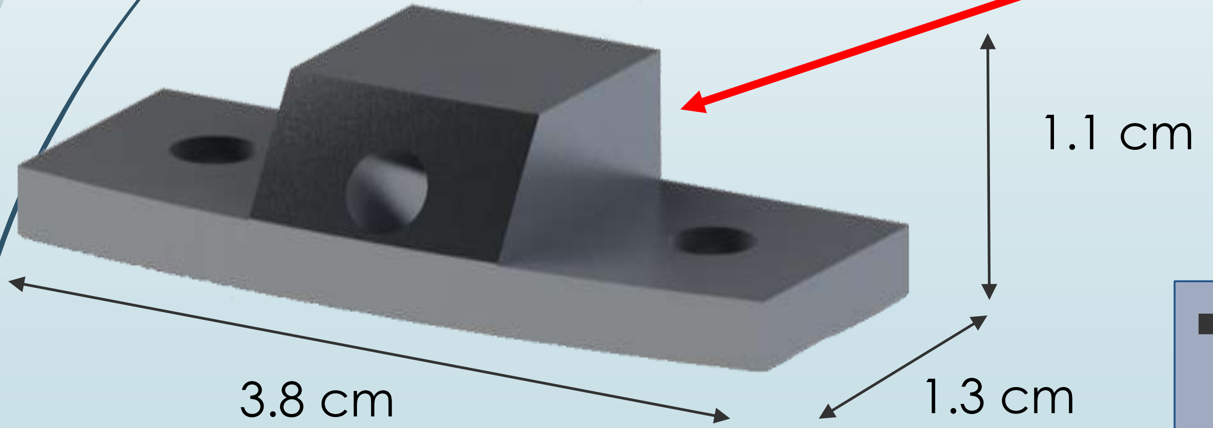


Structure Requirements

Requirements	Description	Motivation
INT 1	NeoPod shall have an **internal structure** that **attaches** the components to the **external shell**	The NeoPod is required to be fully integrated with all essential components mounted within the structure.
INT 2	NeoPod shall have a **mass less than 10 kg**	Mass limitation based on orbiter. This does not apply to the CAD model of the NeoPod with extra shell thickness for radiation shielding.
INT 3	NeoPod shall have a **maximum diameter of 30 cm**	Limited by space on orbiter.

Basic Structure

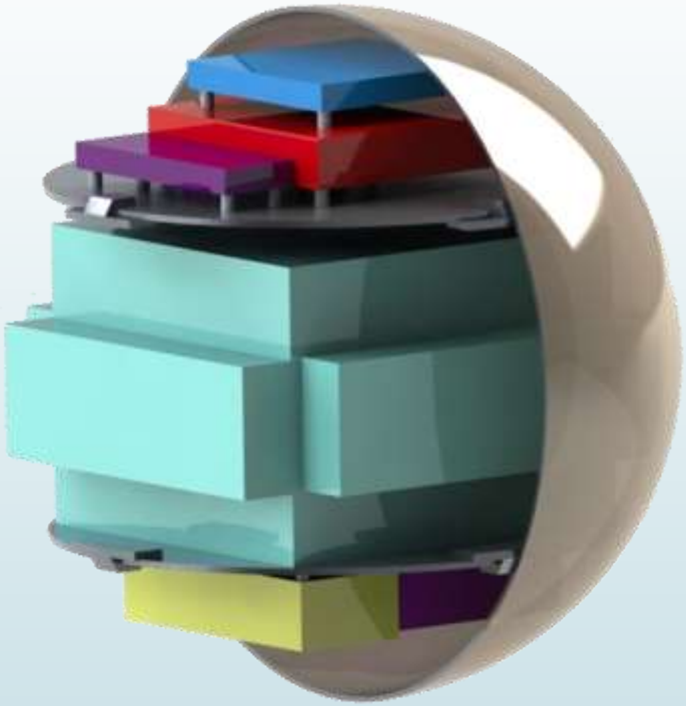
- Two hemispherical shells (**25 cm internal diameter**)
- Two circular shelves (**20.9 cm diameter**)
- Metal clips attach shelves to shell
  - (**1.3cm x 3.8cm x 1.1cm**)

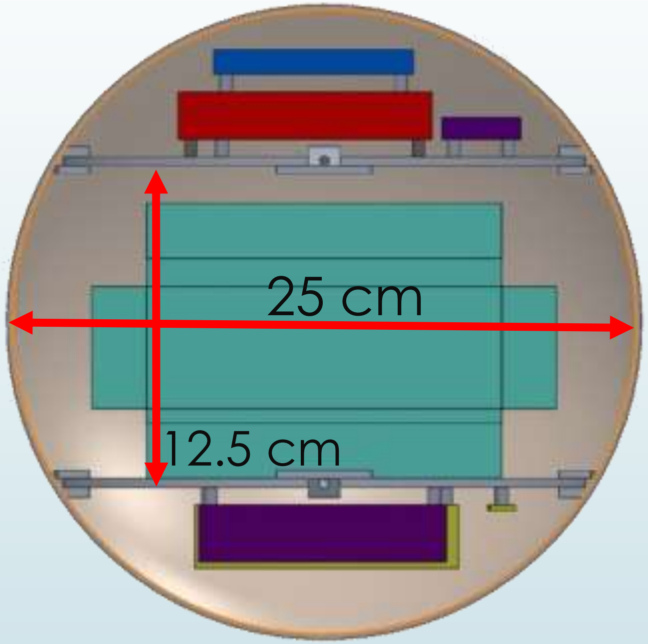


- Requirements Met
  - INT 1

Fitting Hardware

- Contains all hardware
  - Red – Avionics Board
  - Blue – Power Board
  - Light Blue – Batteries
  - Yellow – Science Payloads
  - Purple – Communications



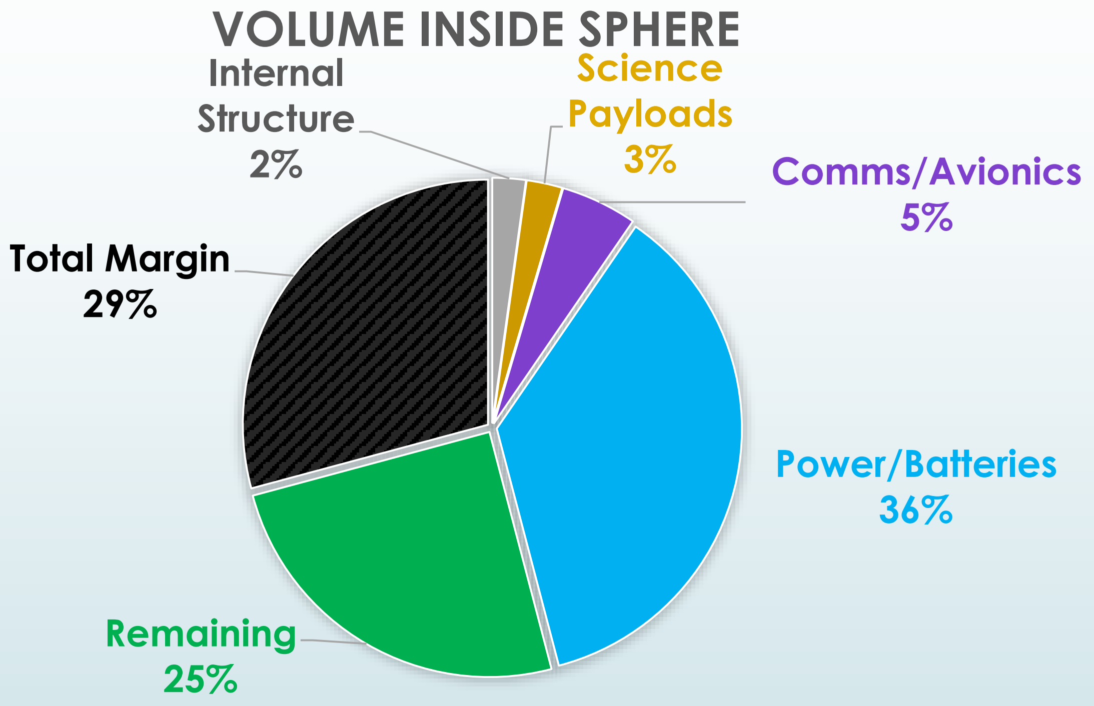


- Requirements Met
  - INT 1

Volume Budget

Component	Volume [cm^3]	20% Margin [cm^3]
Total Volume	+8181	-1637
Internal Structure	-180	-36
Science Payload	-193	-39
Comm. and Avionics	-411	-83
Power Board and Batteries	-2973	-595
Remaining	4424 cm^3 (w/o margin)	-2390 cm^3 (margin)

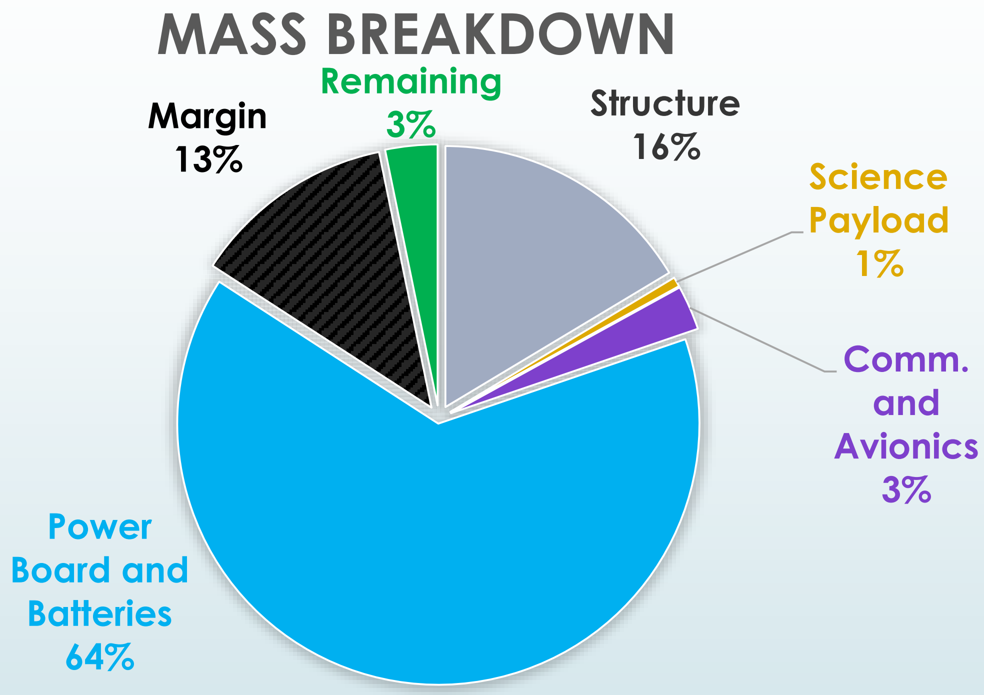
2036 cm^3 (w/ margin)



- Requirements Met
  - INT 3

Mass Budget

Component	Mass [g]	15% Margin [g]	
Total Mass	+10,000		
Structure	-1640	-246	
Science Payload	-60	-9	
Comm. and Avionics	-276	-42	
Power Board and Batteries	-6439	-966	
Remaining	1585 g (w/o margin)	-1263 g (margin)	322 g (w/ margin)



- Requirements Met
  - INT 2

Structures Requirements

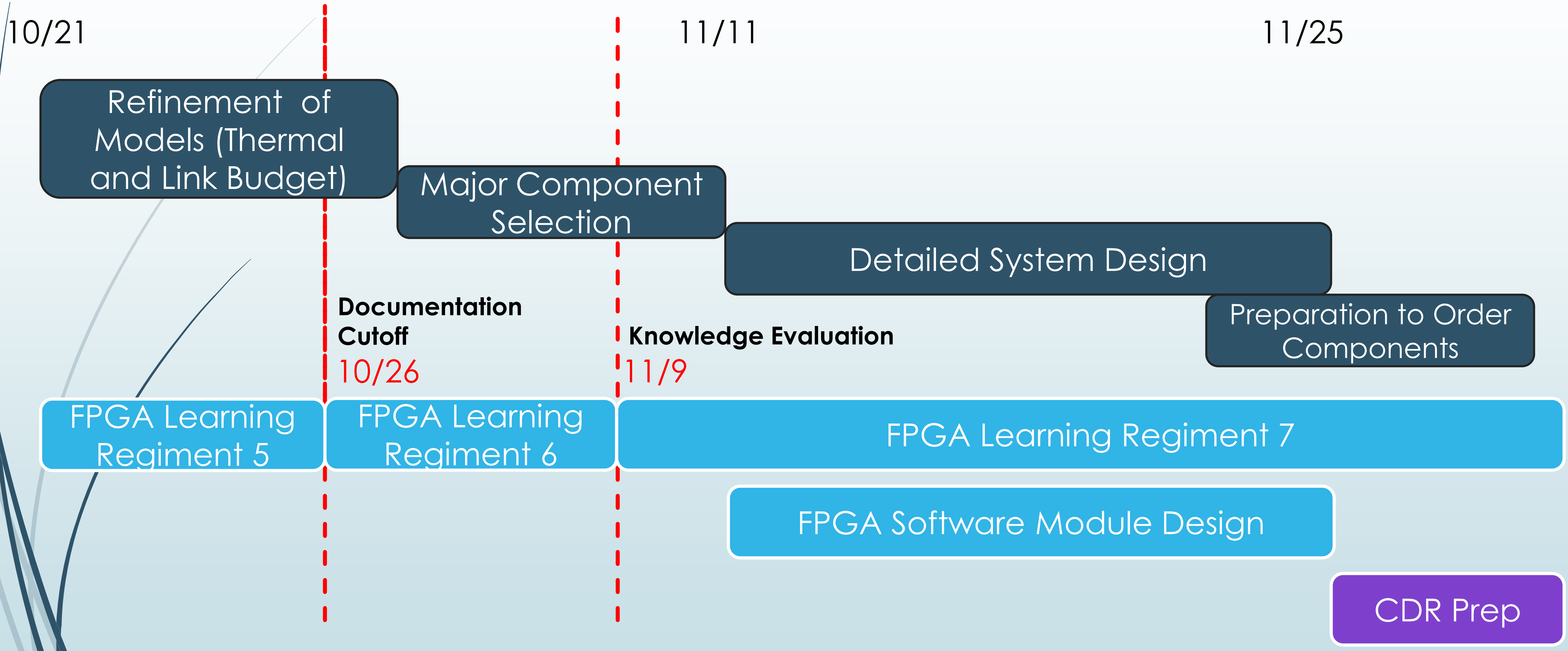
Requirements	Description	Feasible
INT 1	NeoPod shall have an **internal structure** that **attaches** the components to the **external shell**	✓
INT 2	NeoPod shall have a **mass less than 10 kg**	✓
INT 3	NeoPod shall have a **maximum diameter of 30 cm**	✓

Logistics

Budget

Subsystem	Low Estimate	High Estimate
Communications	$110	$1110
Power	$750	$815
Avionics	$52	$750
Structure	$180	$250
Payload	$200	$500
Margin	$1000	$1000
TOTAL	$2292 ($2708 left)	$4425 ($575 left)

Schedule



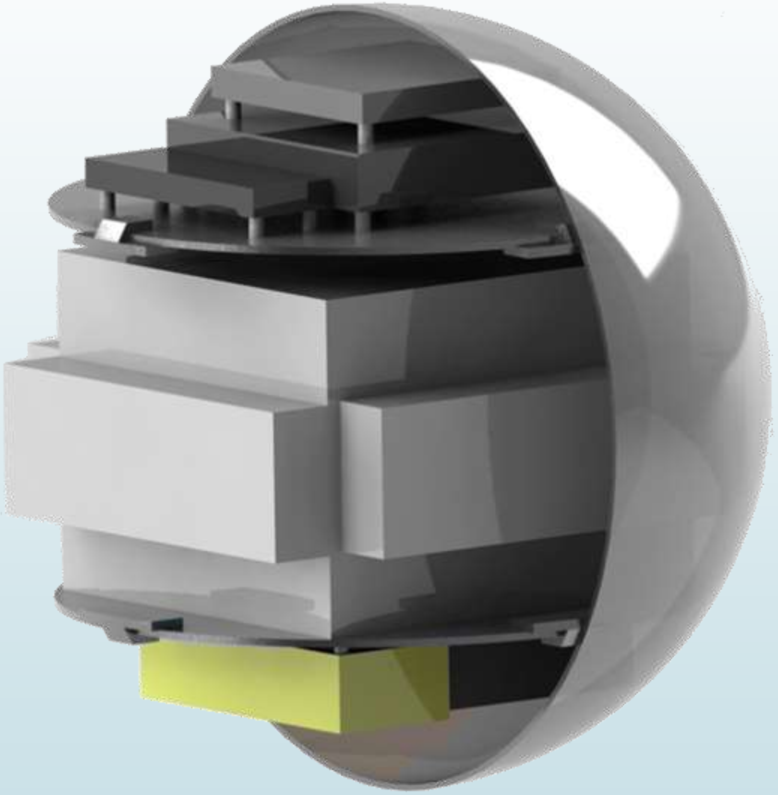
10/21
11/11
11/25
Refinement of Models (Thermal and Link Budget)
Major Component Selection
Detailed System Design
Preparation to Order Components
Documentation Cutoff
10/26
Knowledge Evaluation
11/9
FPGA Learning Regiment 5
FPGA Learning Regiment 6
FPGA Learning Regiment 7
FPGA Software Module Design
CDR Prep

Summary

Summary of Feasibility

Payload:

- Instruments will collect **relevant** science **data**
- Can **integrate** with **avionics board**

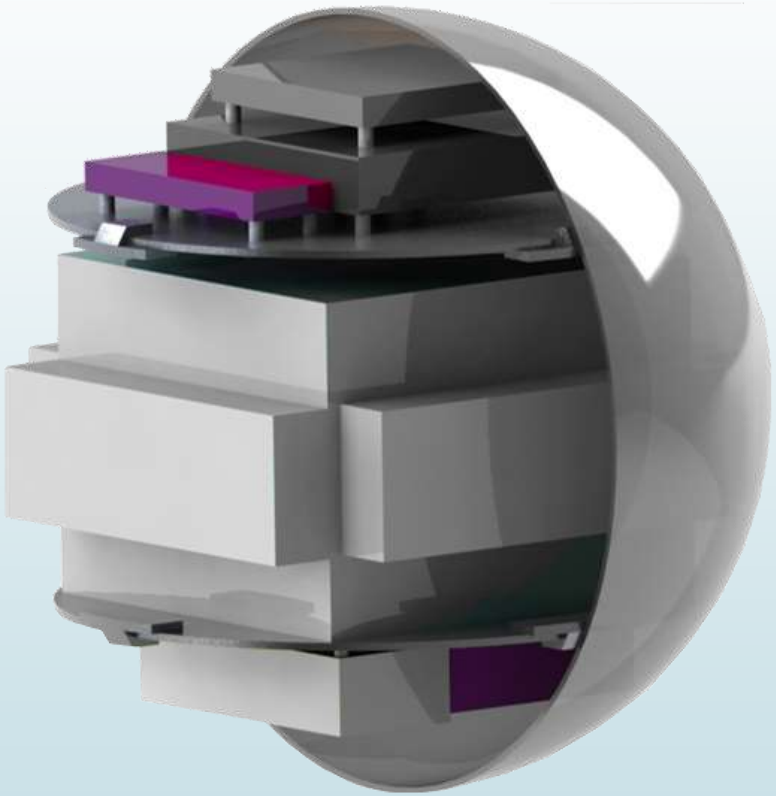


Payload	**Feasible**
Communications	
Power	
Avionics	
Structure	
Logistics	

Summary of Feasibility

Communications:

- Communications systems have some **heritage**
- Antenna mismatch risk mitigated by **alternative designs** and **customer data**

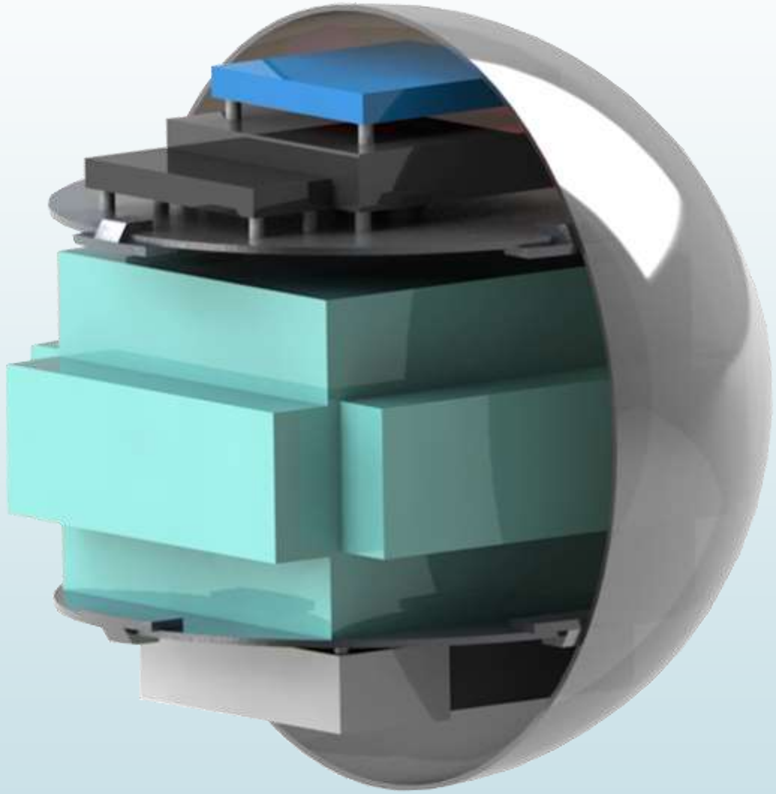


Payload	**Feasible**
Communications	**Feasible**
Power	
Avionics	
Structure	
Logistics	

Summary of Feasibility

Power:

- **Power budget** shows positive power remaining with **design margin**
- Power risk mitigated by **spherical shell expansion** contingency plan

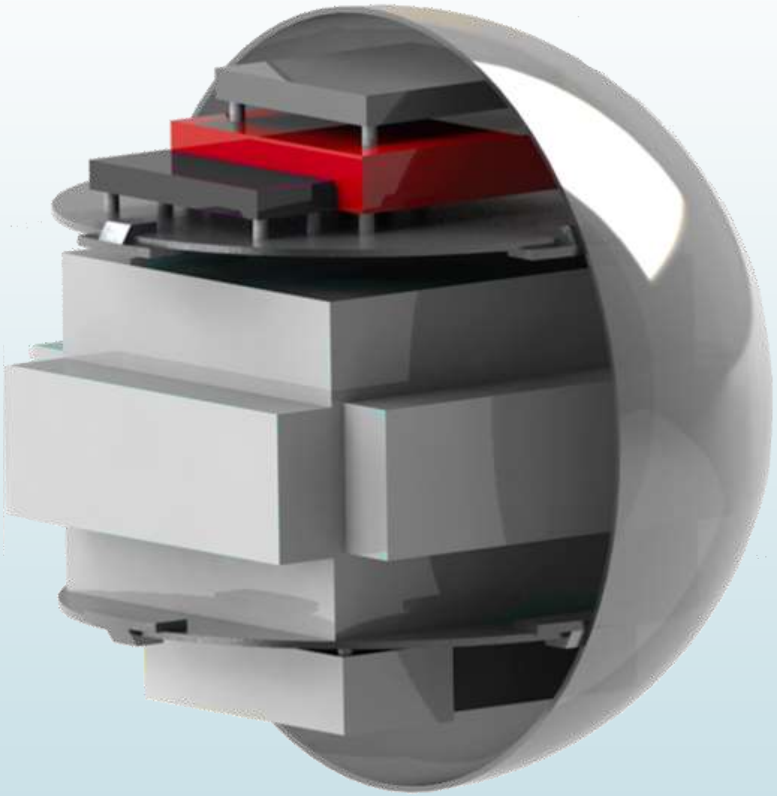


Payload	Feasible
Communications	Feasible
Power	Feasible
Avionics	
Structure	
Logistics	

Summary of Feasibility

Avionics:

- **Learning Curriculum** with Development Board provides team with necessary skillset
- Avionics delivery risk mitigated by **Development Board** contingency plan

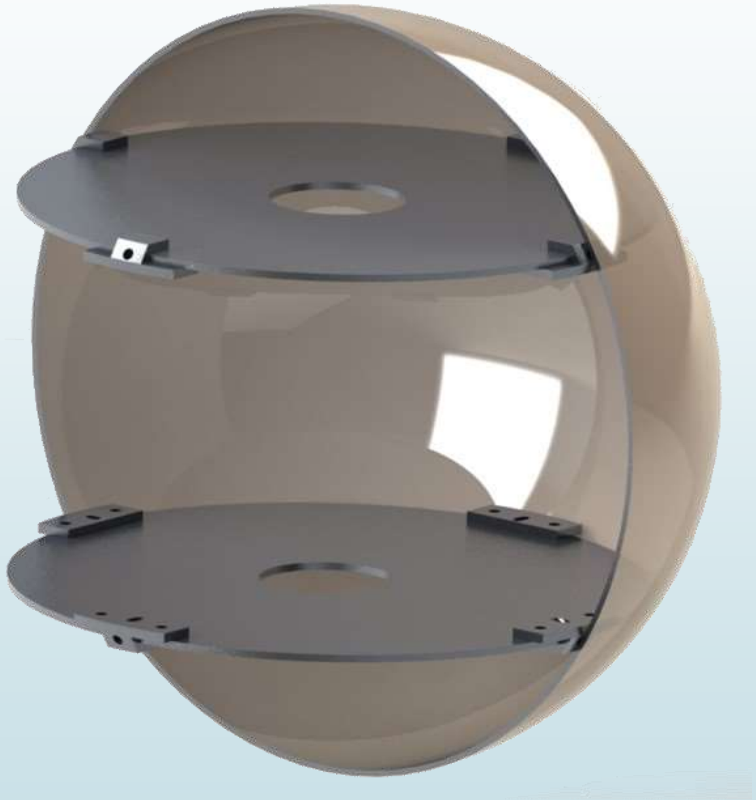


Payload	**Feasible**
Communications	**Feasible**
Power	**Feasible**
Avionics	**Feasible**
Structure	
Logistics	

Summary of Feasibility

Structure:

- Volume and mass with **design margin** meet requirements
- Use of modified **heritage components**

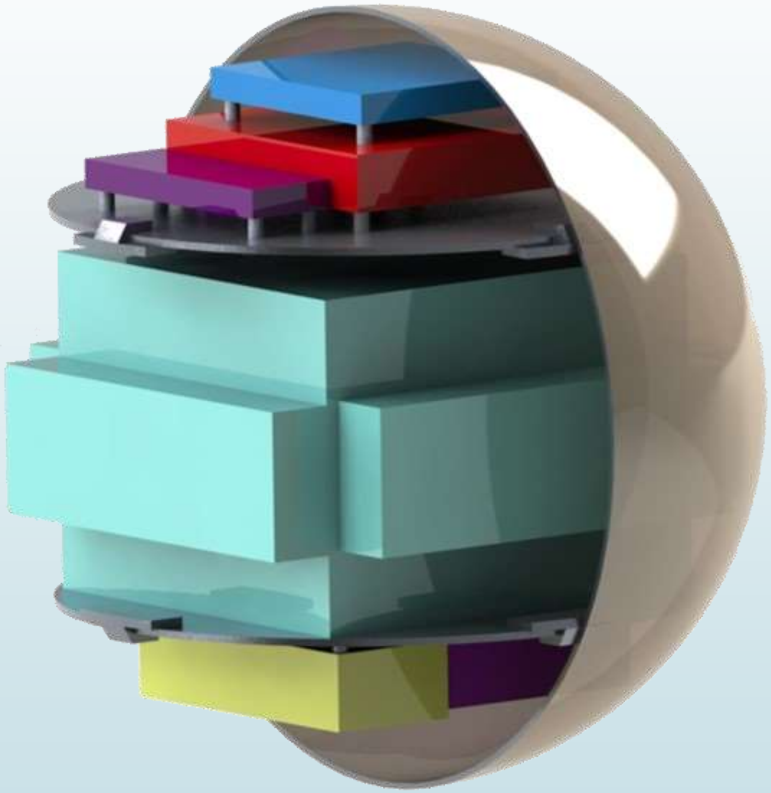


Payload	**Feasible**
Communications	**Feasible**
Power	**Feasible**
Avionics	**Feasible**
Structure	**Feasible**
Logistics	

Summary of Feasibility

Logistics:

- Current budget indicates that there will be **extra funds** in case of emergency
- Avionics **delivery** and **cutoff dates** have been **coordinated with Ball Aerospace**



Payload	Feasible
Communications	Feasible
Power	Feasible
Avionics	Feasible
Structure	Feasible
Logistics	Feasible

Questions?

Project Overview | Communications | Power | Avionics | Structure | Logistics | Summary | Backup Slides

Backup Slides

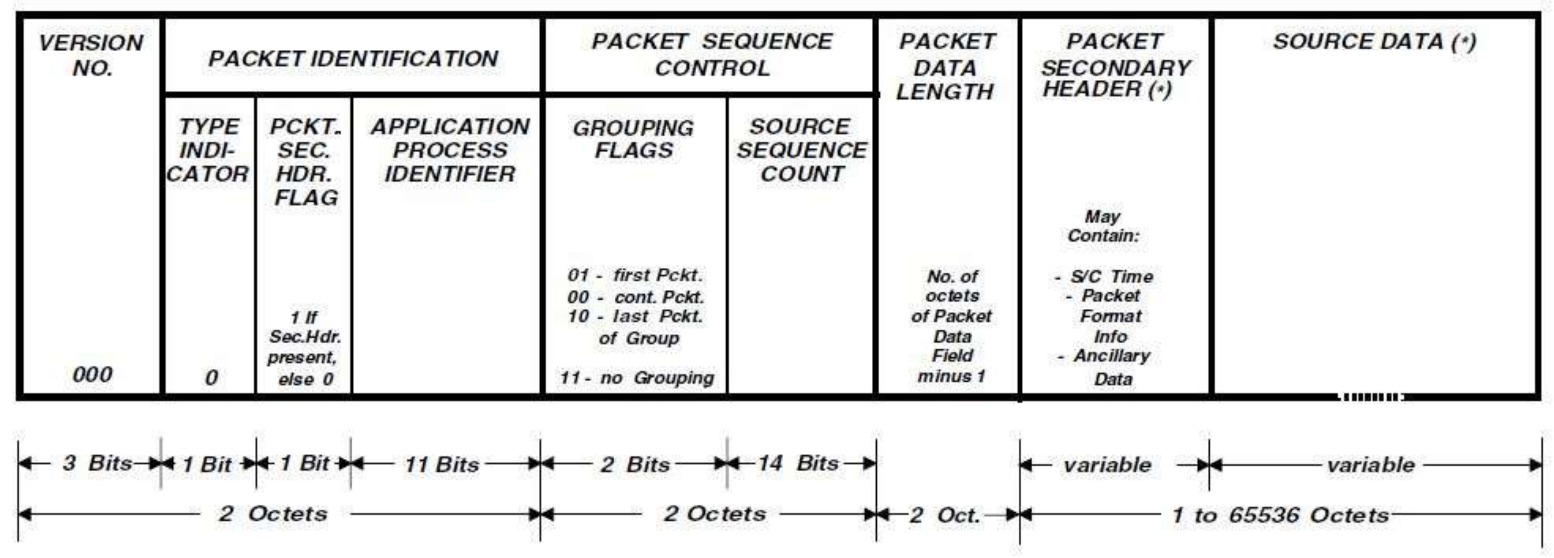
RS232-RS422/485 Digital Converter

- 460.8 kbps max.
- 0.15 kg
- Requires 10-30 VDC
- Modbus ASCII/RTU

- http://www.bb-elec.com/Products/Datasheets/SCPx11_3713ds.pdf

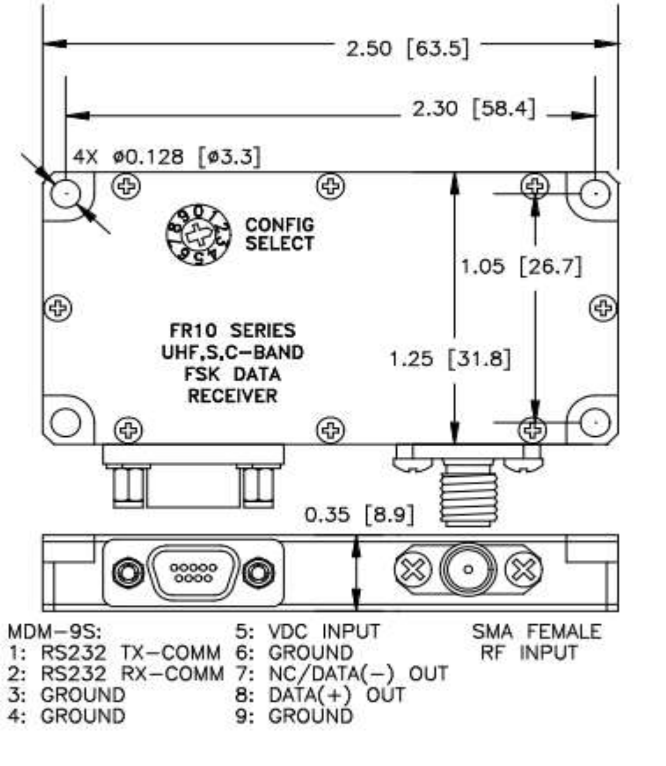
CCSDS Source Packet Design

- 6 bytes max of overhead in each packet
- 60 bytes of data per packet equates to 10% overhead



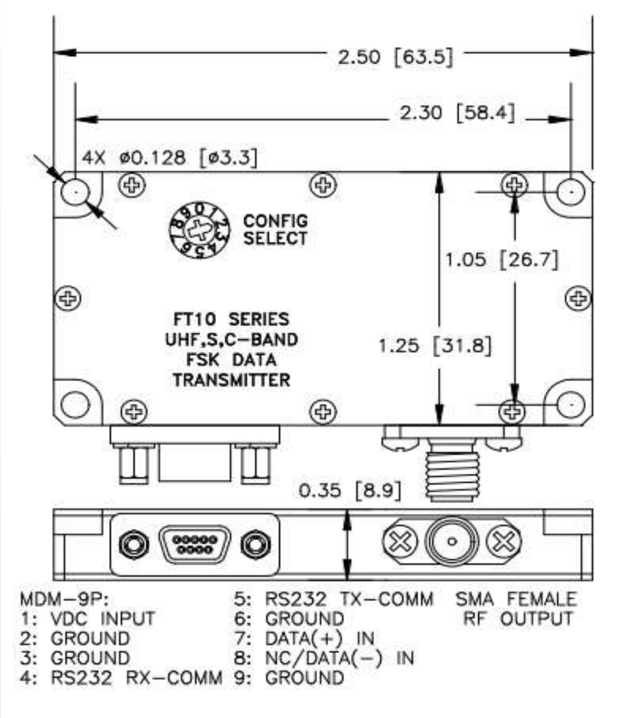
Receiver: FR-10

- **Specifications:**
  - **Frequency Range**: 433.0 - 434.8 MHz
  - **Modulation**: Binary Frequency Shift Keying (BFSK)
  - **Output Impedance**: 50 Ohms
  - **Data Format**: RS 422
  - **Volume**: 1.1 Cubic Inches (1.25”x2.50”x0.35”)
  - **Weight**: < 1.00 oz



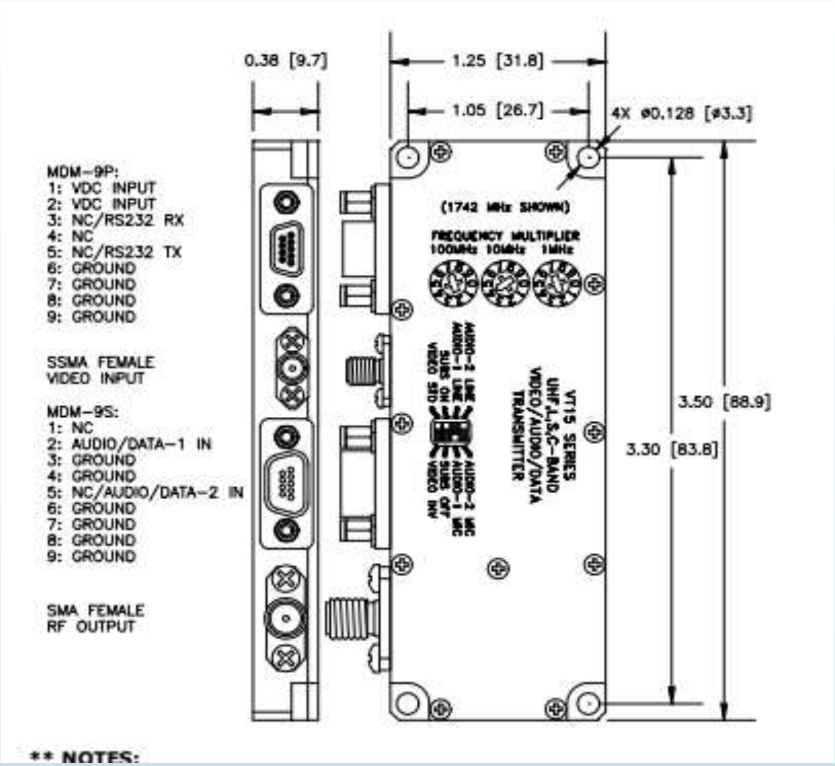
Transmitter: FT-10

- **Specifications:**
  - **Frequency Range**: 433.0 - 434.8 MHz
  - **Modulation**: Binary Frequency Shift Keying (BFSK)
  - **Output Impedance**: 50 Ohms
  - **Data Format**: RS 422
  - **Volume**: 1.1 Cubic Inches (1.25”x2.50”x0.35”)
  - **Weight**: < 1.00 oz



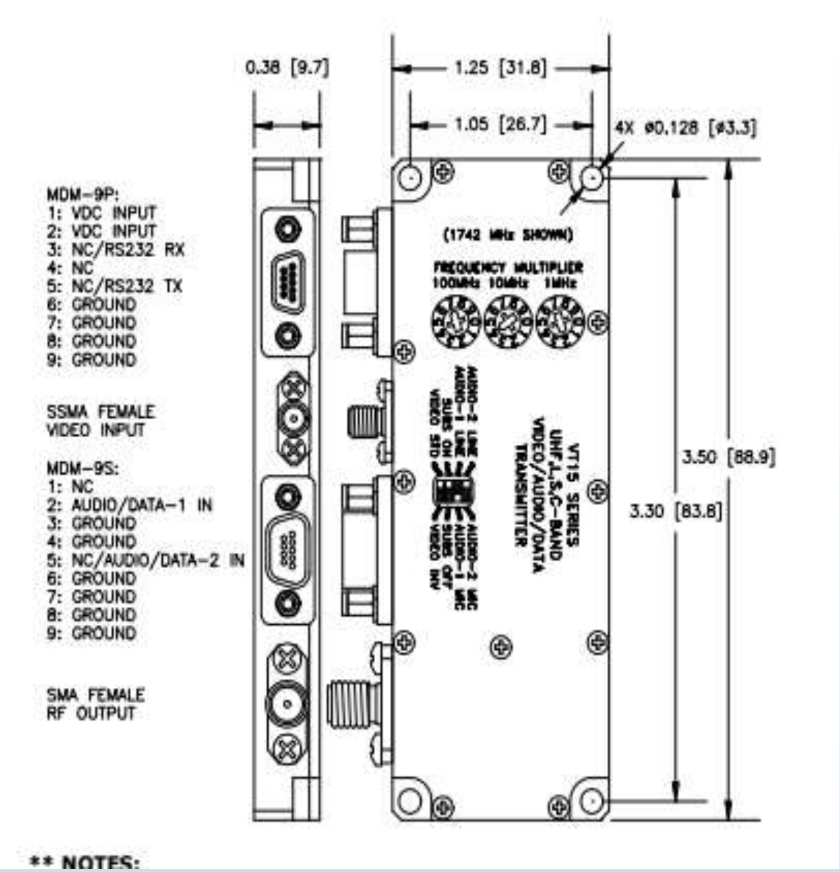
Transmitter: VT-15

- **Specifications:**
  - **Frequency Range**: 340.0 - 399.9 MHz
  - **Modulation**: Analog FM
  - **Output Impedance**: 50 Ohms
  - **Data Format**: RS 232
  - **Volume**: 1.7 Cubic Inches (1.25”x3.50”x0.38”)
  - **Weight**: < 1.70 oz



Receiver: VR-75

- **Specifications:**
  - **Frequency Range**: 340.0 - 399.9 MHz
  - **Modulation**: Analog FM
  - **Output Impedance**: 50 Ohms
  - **Data Format**: RS 232
  - **Volume**: 7.4 Cubic Inches (2.50”x3.50”x0.85
  - **Weight**: < 6.0 oz



Command Link

- **FR-10**
- **Frequency Range**: 433.0 - 434.8 MHz
- **Modulation**: Binary Frequency Shift Keying (BFSK)
- **Output Impedance**: 50 Ohms

- **FT-10**
- **Frequency Range**: 433.0 - 434.8 MHz
- **Modulation**: Binary Frequency Shift Keying (BFSK)
- **Output Impedance**: 50 Ohms

Data Link

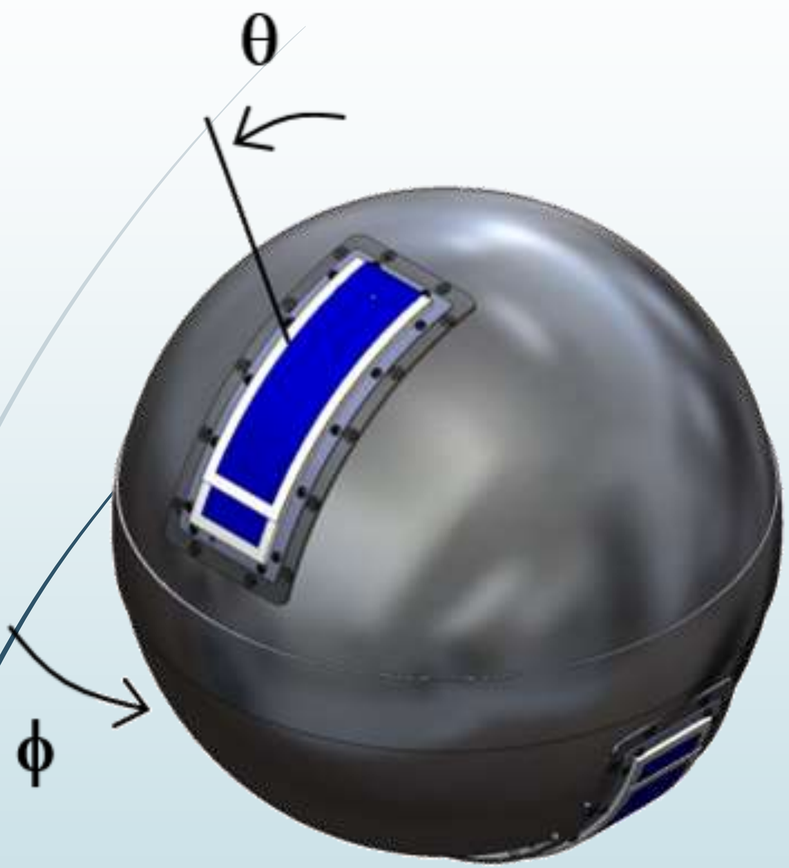
- **VR-75**

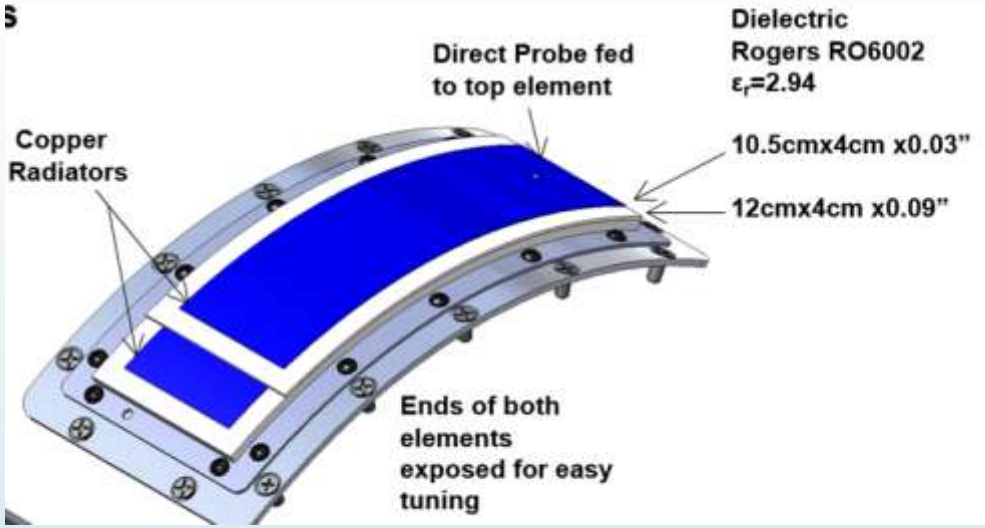
- **Frequency Range**: 340.0 - 399.9 MHz
- **Modulation**: Analog FM
- **Output Impedance**: 50 Ohms

- **VT-15**

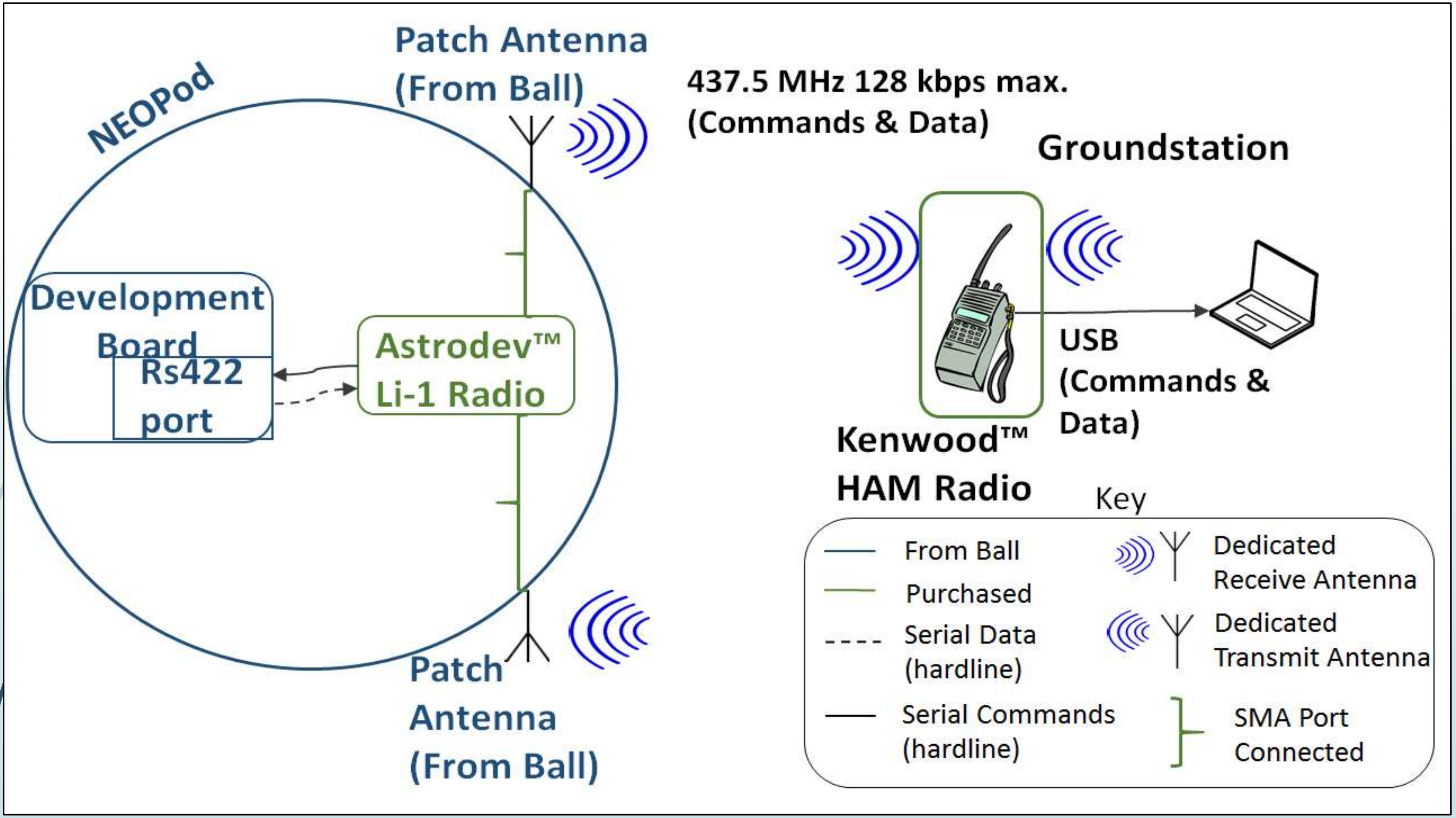
- **Frequency Range**: 340.0 - 399.9 MHz
- **Modulation**: Analog FM
- **Output Impedance**: 50 Ohms

Dual-Band UHF Patch Antennas





Two Way Radio Option



Analog ADF7020 Transceiver

- **Frequency:** 135-600 Mhz
- **Modulation:** FSK 200 kbps Max.
- **Debugging:** Digital RSSI (received signal strength indicator)

Transceiver - Lithium Radio

- **Frequency: 130-450 MHz**
- **Transmit Power: 250mW – 4 W**
- **Baud Rate: 9600**
- **Req'd Power at 4W: 250 mW**

Kenwood Radio

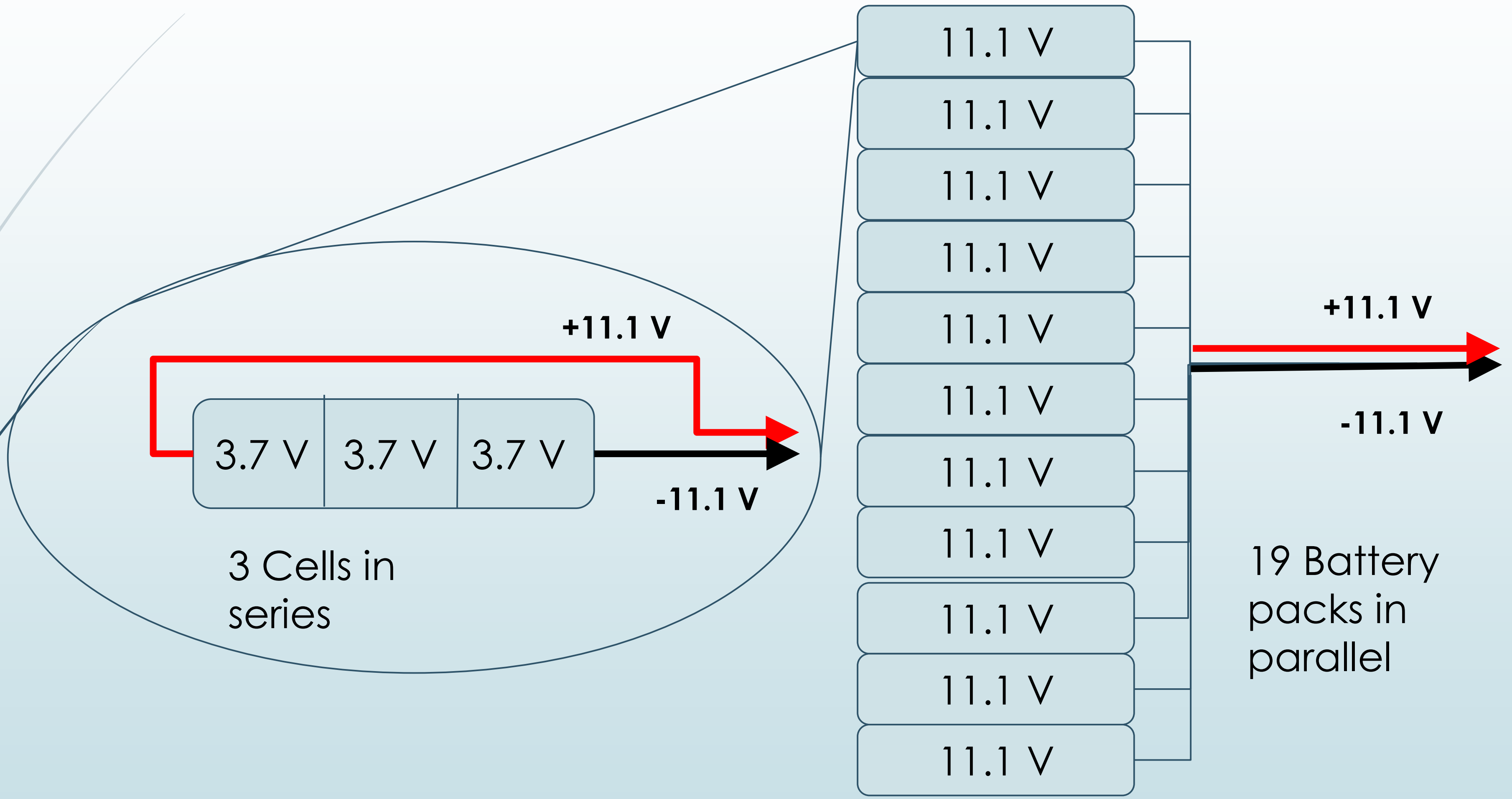
- Frequency: 144-440 MHz
- Baud Rate: 9600
- Debugging: Adjacent Channel Scanner
- Transmit Power: 5 Watts max. (4 selectable powers)
- USB Capable
- Matlab compatible for commands

Mission Timeline

	Time (Hrs)										Power (Wh)
Instrument	<-0	<-1	<-2	<-3		<-96	<-97	<-98	<-99	<-100	
Avionics Board											632
Receiver											111
Transmitter											16
Sensors											17
										Total	776

- Avionics board will be powered for 100 hours
  - Power saving modes may be utilized
- Receiver will be powered for 100 hours
- Transmitter will be powered for ~8 minutes once every two hours
- Sensors will be powered for 96 hours to collect required amount of data

Power Source Configuration



Power Budget

POWER BUDGET

Power	Payload	Avionics	Comms

Component	Quantity	Time [hr]	Current draw [mAh]	Voltage [V]	Power draw [Wh]	Margin [Wh]
Lithium polymer 5200mAh	19	100	98800	11.1	1096.68	0
Sparkfun DC/DC Converter	2	100	5324.849869	11.1	59.10583355	17.73175006
Geiger Counter	1	96	2880	5	14.4	4.32
9 DOF Sensor Stick	1	96	648	3.3	2.1384	0.64152
Avionics Board	1	100	173326.8967	3.3	571.978759	171.5936277
FR10 Receiver	1	100	10000	11.1	111	33.3
RS-232 to RS-422/485 Converter	1	6.09	548.6486486	11.1	6.09	1.827
VT15 Transmitter	1	6.09	1015.203	11.1	11.2687533	3.38062599

Totals	[Wh]
Power Available	1096.68
Power Needed	775.9817
Power Margin	232.7945
Additional Power Margin	87.90373

Back-up: FPGA Power Budget

Parameter	Value	Units	Description
Total Power	1.586932964	W	
Static Power	0.56446	W	
Dynamic Power	1.020887616	W	
PDC0	0	mw	sleep
PDC1	30	mw	active
PDC2	0.00375	mw	idle
PDC3	30	mw	flash/freeze
PDC4	2.55	mw	PLL @ 1.5V
PDC5	30	mw	
PDC6	5.71	mw	input pin power consumption
PDC7	42.21	mw	output pin power consumption
PDC(1,2,3,or4)	30	mW	power mode (see page 27 in DS)
N Banks	8	#	# of I/O banks powered in the design
PDC5	30	mW	
N Inputs	22	#	# of I/O input buffers used in the design out of 341
PDC6	5.71	mW	
N Outputs	4	#	# of I/O output buffers used in the design out of 341
PDC 7	42.21	mW	
P Clock	551.42064		
P S-Cell	301.636608		
P C-Cell	0		
P Net	124.93824		
P Inputs	1.293072		
P Outputs	1.964256		
P Memory	36.96		
P PLL	2.6748		
PAC1	0.01303	mW/MHz	
N Spine	252		# of global spines used in design out of 252 (see UG 57)
PAC2	0.00669	mW/MHz	
N Row	83		# of VersaTile rows
PAC3	0.00146	mW/MHz	
N S-Cell	74368	#	# of VersaTiles used as sequential modules out of 74368
PAC4	0.00013	mW/MHz	

Parameter	Value	Units	Description
F CLK	48	MHz	Global clock signal frequency
PAC5	0.00007	mW/MHz	
alpha1	0.1	%	toggle rate of VersaTile outputs
PAC6	0.00029	mW/MHz	
N C-Cell	0		# of VersaTiles used as combinatorial modules
PAC7	0.00029	mW/MHz	
PAC8	0.0007	mW/MHz	
PAC9	0.02449	mW/MHz	
N Inputs	22		# of I/O input buffers used
alpha2	0.1	%	I/O buffer toggle rate
N Outputs	4		# of I/O output buffers
beta1	1	%	I/O buffer enable rate
PAC10	0.20461	mW/MHz	
PAC11	0.025	mW/MHz	
N Blocks	112		# of RAM block used out of 112?
F Read-Clock	48	MHz	memory read clock frequency up to 250 MHz
beta2	0.125	%	RAM enable rate for read operations
PAC12	0.03	mW/MHz	
F Write-Clock	48	MHz	memory write clock frequency up to 250 MHz
beta3	0.125	%	RAM enable rate for write operations
PDC4	2.55		
PAC13	0.0026	mW/MHz	
F CLKOUT	48	MHz	output clock frequency (probably between 256 - 280 MHz

Project Overview | Communications | Power | Avionics | Structure | Logistics | Summary | Backup Slides

Avionics Board Power Budget

Part	Current [A] (One Part, Worst-Case) +5A	-5A	+3.3D	+1.5D
LL4148 Diode			0.152	
IRHLUB770Z4 Transistor			0.182	
48SD1616			0.303	
UT54LVDS032LV (5962H9865202VYC)			0.379	
ISL706ARH (5962R1121304QXC)			0.001	
UT54LVDS031LVUCA			0.379	
26CLV31RH (5962F9666302QXC)			0.000	
QT625LBM Oscillator			0.030	
HS-26CLV32RH (5962F9568902QXC)			0.013	
3DFN32G08VS8157MS			0.638	
3DFN32G08VS8157MS (Power-down)			0.050	
3DFN32G08VS8157MS (Power-down 95%)			0.0794	
RT3PE3000L-CG484B FPGA			0.171	0.681
RHFL4913KPA1 Linear Regulator				
RHFACT245K1			0.000	
Totals				

Active w/Software

Part	Qty	Current [A] (All Parts) +5A	-5A	+3.3D	+1.5D	Power [W]	Percentage
LL4148 Diode	1	0.000	0.000	0.152	0.000	0.500	5%
IRHLUB770Z4 Transistor	1	0.000	0.000	0.182	0.000	0.600	6%
48SD1616	1	0.000	0.000	0.303	0.000	1.000	10%
UT54LVDS032LV (5962H9865202VYC)	1	0.000	0.000	0.379	0.000	1.250	13%
ISL706ARH (5962R1121304QXC)	1	0.000	0.000	0.001	0.000	0.002	0%
UT54LVDS031LVUCA	1	0.000	0.000	0.379	0.000	1.250	13%
26CLV31RH (5962F9666302QXC)	1	0.000	0.000	0.000	0.000	0.000	0%
QT625LBM Oscillator	1	0.000	0.000	0.030	0.000	0.100	1%
HS-26CLV32RH (5962F9568902QXC)	1	0.000	0.000	0.013	0.000	0.043	0%
3DFN32G08VS8157MS	1	0.000	0.000	0.638	0.000	2.105	22%
3DFN32G08VS8157MS (Power-down)	0	0.000	0.000	0.000	0.000	0.000	0%
3DFN32G08VS8157MS (Power-down 95%)	0	0.000	0.000	0.000	0.000	0.000	0%
	1	0.000					
RT3PE3000L-CG484B FPGA	1	0.000	0.000	0.171	0.681	1.585	16%
RHFL4913KPA1 Linear Regulator	1			0.681		1.225	13%
RHFACT245K1	1	0.000	0.000	0.000	0.000	0.000	0%
Totals						9.661	

Idle w/Software

Part	Qty	Current [A] (All Parts) +5A	-5A	+3.3D	+1.5D	Power [W]	Percentage
LL4148 Diode	1	0.000	0.000	0.152	0.000	0.500	5%
IRHLUB770Z4 Transistor	1	0.000	0.000	0.182	0.000	0.600	6%
48SD1616	1	0.000	0.000	0.303	0.000	1.000	10%
UT54LVDS032LV (5962H9865202VYC)	1	0.000	0.000	0.379	0.000	1.250	13%
ISL706ARH (5962R1121304QXC)	1	0.000	0.000	0.001	0.000	0.002	0%
UT54LVDS031LVUCA	1	0.000	0.000	0.379	0.000	1.250	13%
26CLV31RH (5962F9666302QXC)	1	0.000	0.000	0.000	0.000	0.000	0%
QT625LBM Oscillator	1	0.000	0.000	0.030	0.000	0.100	1%
HS-26CLV32RH (5962F9568902QXC)	1	0.000	0.000	0.013	0.000	0.043	0%
3DFN32G08VS8157MS	0	0.000	0.000	0.000	0.000	0.000	0%
3DFN32G08VS8157MS (Power-down)	0	0.000	0.000	0.000	0.000	0.000	0%
3DFN32G08VS8157MS (Power-down 95%)	1	0.000	0.000	0.079	0.000	0.262	3%
RT3PE3000L-CG484B FPGA	0	0.000	0.000	0.000	0.000	0.000	0%
RHFL4913KPA1 Linear Regulator	1			0.000		0.000	0%
RHFACT245K1	0	0.000	0.000	0.000	0.000	0.000	0%
Totals						5.007	

Active w/o Software

Part	Qty	Current [A] (All Parts) +5A	-5A	+3.3D	+1.5D	Power [W]	Percentage
LL4148 Diode	1	0.000	0.000	0.152	0.000	0.500	5%
IRHLUB770Z4 Transistor	1	0.000	0.000	0.182	0.000	0.600	6%
48SD1616	1	0.000	0.000	0.303	0.000	1.000	10%
UT54LVDS032LV (5962H9865202VYC)	1	0.000	0.000	0.379	0.000	1.250	13%
ISL706ARH (5962R1121304QXC)	1	0.000	0.000	0.001	0.000	0.002	0%
UT54LVDS031LVUCA	1	0.000	0.000	0.379	0.000	1.250	13%
26CLV31RH (5962F9666302QXC)	1	0.000	0.000	0.000	0.000	0.000	0%
QT625LBM Oscillator	1	0.000	0.000	0.030	0.000	0.100	1%
HS-26CLV32RH (5962F9568902QXC)	1	0.000	0.000	0.013	0.000	0.043	0%
3DFN32G08VS8157MS	0	0.000	0.000	0.000		0.000	0%
3DFN32G08VS8157MS (Power-down)	0	0.000	0.000	0.000		0.000	0%
3DFN32G08VS8157MS (Power-down 95%)	0	0.000	0.000	0.000		0.000	0%
RT3PE3000L-CG484B FPGA	1	0.000	0.000	0.171	0.681	1.585	16%
RHFL4913KPA1 Linear Regulator	1			0.681		1.225	13%
RHFACT245K1	1	0.000	0.000	0.000	0.000	0.000	0%
Totals						7.555	

Idle w/o Software

Part	Qty	Current [A] (All Parts) +5A	-5A	+3.3D	+1.5D	Power [W]	Percentage
LL4148 Diode	1	0.000	0.000	0.152	0.000	0.500	5%
IRHLUB770Z4 Transistor	1	0.000	0.000	0.182	0.000	0.600	6%
48SD1616	1	0.000	0.000	0.303	0.000	1.000	10%
UT54LVDS032LV (5962H9865202VYC)	1	0.000	0.000	0.379	0.000	1.250	13%
ISL706ARH (5962R1121304QXC)	1	0.000	0.000	0.001	0.000	0.002	0%
UT54LVDS031LVUCA	1	0.000	0.000	0.379	0.000	1.250	13%
26CLV31RH (5962F9666302QXC)	1	0.000	0.000	0.000	0.000	0.000	0%
QT625LBM Oscillator	1	0.000	0.000	0.030	0.000	0.100	1%
HS-26CLV32RH (5962F9568902QXC)	1	0.000	0.000	0.013	0.000	0.043	0%
3DFN32G08VS8157MS	0	0.000	0.000	0.000	0.000	0.000	0%
3DFN32G08VS8157MS (Power-down)	0	0.000	0.000	0.000	0.000	0.000	0%
3DFN32G08VS8157MS (Power-down 95%)	0	0.000	0.000	0.000	0.000	0.000	0%
RT3PE3000L-CG484B FPGA	0	0.000	0.000	0.000	0.000	0.000	0%
RHFL4913KPA1 Linear Regulator	1			0.000		0.000	0%
RHFACT245K1	0	0.000	0.000	0.000	0.000	0.000	0%
Totals						4.745	

Scratchpad

Part	Qty	Current [A] (All Parts) +5A	-5A	+3.3D	+1.5D	Power [W]	Percentage	Use
LL4148 Diode	1	0.000	0.000	0.152	0.000	0.500	5%	
IRHLUB770Z4 Transistor	1	0.000	0.000	0.182	0.000	0.600	6%	
48SD1616	1	0.000	0.000	0.303	0.000	1.000	10%	
UT54LVDS032LV (5962H9865202VYC)	1	0.000	0.000	0.379	0.000	1.250	13%	
ISL706ARH (5962R1121304QXC)	1	0.000	0.000	0.001	0.000	0.002	0%	
UT54LVDS031LVUCA	1	0.000	0.000	0.379	0.000	1.250	13%	
26CLV31RH (5962F9666302QXC)	1	0.000	0.000	0.000	0.000	0.000	0%	Clock
QT625LBM Oscillator	1	0.000	0.000	0.030	0.000	0.100	1%	
HS-26CLV32RH (5962F9568902QXC)	1	0.000	0.000	0.013	0.000	0.043	0%	
3DFN32G08VS8157MS	1	0.000	0.000	0.638	0.000	2.105	22%	SDRAM (Active, best guess @ 48 MHz)
3DFN32G08VS8157MS (Power-down)	0	0.000	0.000	0.000	0.000	0.000	0%	SDRAM (Power-down)
3DFN32G08VS8157MS (Power-down 95%)	0	0.000	0.000	0.000	0.000	0.000	0%	SDRAM (Active 5% of the time, power-down 95%)
	1	0.000						
RT3PE3000L-CG484B FPGA	1	0.000	0.000	0.171	0.681	1.585	16%	FPGA (Active)
RHFL4913KPA1 Linear Regulator	1			0.681		1.225	13%	
RHFACT245K1	1	0.000	0.000	0.000	0.000	0.000	0%	IO Ports (No load)
Totals						9.661		

Conditions:	Typical
Summary	
Active w/Software	5.525 W
Idle w/Software	1.812 W
Active w/o Software	4.549 W
Idle w/o Software	1.738 W

Lithium Iron Disulfide AA Batteries

	AA Battery	8 Battery Case	Total per battery
Voltage (V)	1.5	12	1.5
Capacity (Ah)	3	3	3
Mass (g)	14.5	190	23.75
Volume (cm^3)	8	175	21.875
Total Energy (Wh)	4.5	36	4.5
Specific Energy (Wh/kg)	310.345	189.474	189.474
Energy Density (Wh/cm^3)	0.563	0.206	0.206
Cost ($)	1.70	6.00	2.45

- While the batteries themselves are more efficient, the casing must accounted for

System Efficiency: Possible Improvements

- **Avionics board elements will not run at maximum capacity for entire mission**
- Switching avionics board to idle mode
- Reducing number of pins used on board
- Reducing time receiver is powered
- Selecting landing site with most transmission time

Lithium-Ion Polymer

Multistar High Capacity Lipo Pack

- Capacity: 5.2 Ah
- Voltage: 11.1 V (3 cells of 3.7 V in series)
- Constant Discharge: 10 C
- Volume: 153 cm^3
- Mass: 331 g
- Cost: $32

DC-DC Voltage Converter Selection

Step-up/down switching regulator

- Adjustable
- ~ 90% efficiency at specified input voltage and output current
- Efficiency decreases as current load decreases
- Significant ripple/noise addition
- Introduces need for additional signal processing

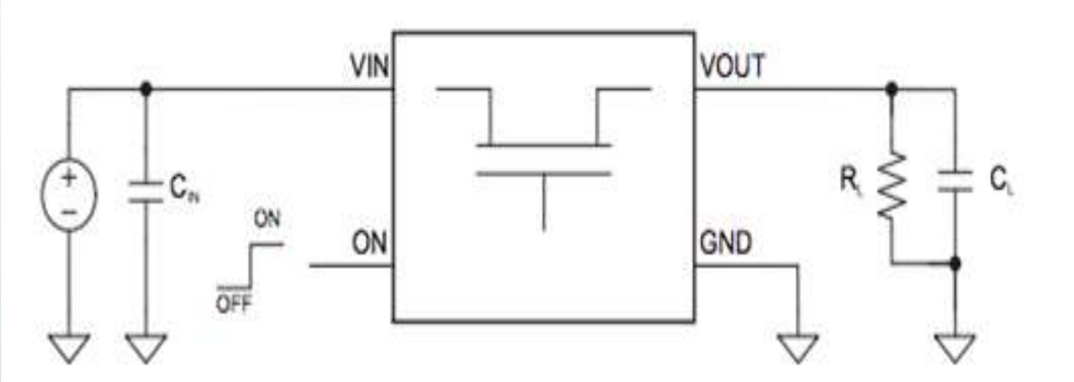
Linear Voltage Regulator

- Fixed output voltage (5 V and 3.3 V available)
- Output voltage tolerance within ±1%
- ~85% efficiency with large voltage difference
- Efficiency increases as voltage difference decreases

Control Switch

Load Switch

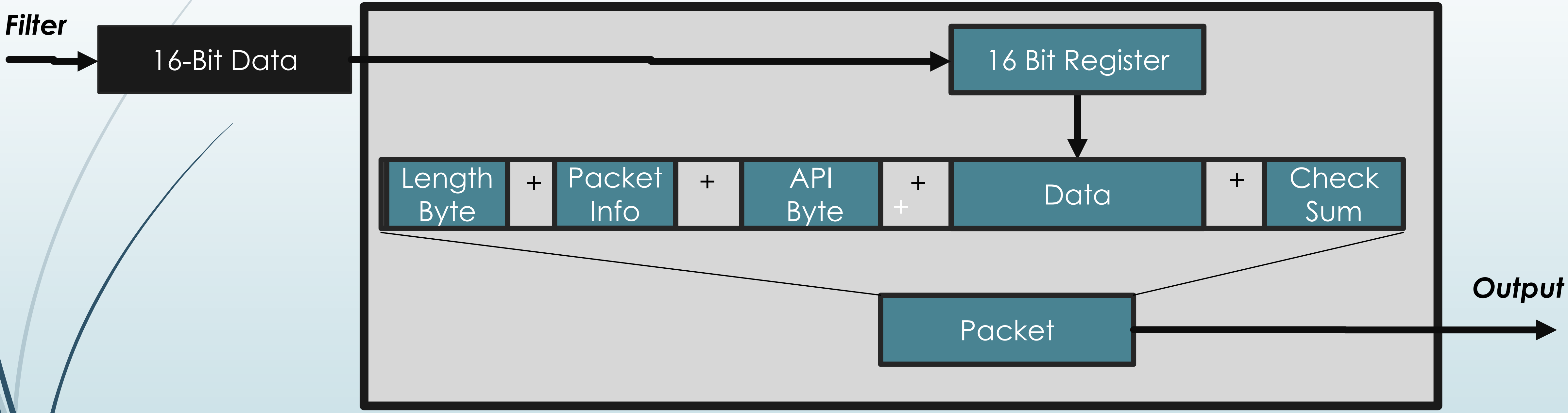
- MOSFET Power controller
- 5 needed for board design
- Input voltage range of 3.3 - 11.1 V
- Maximum current of 5 A
- Commanded by avionics board



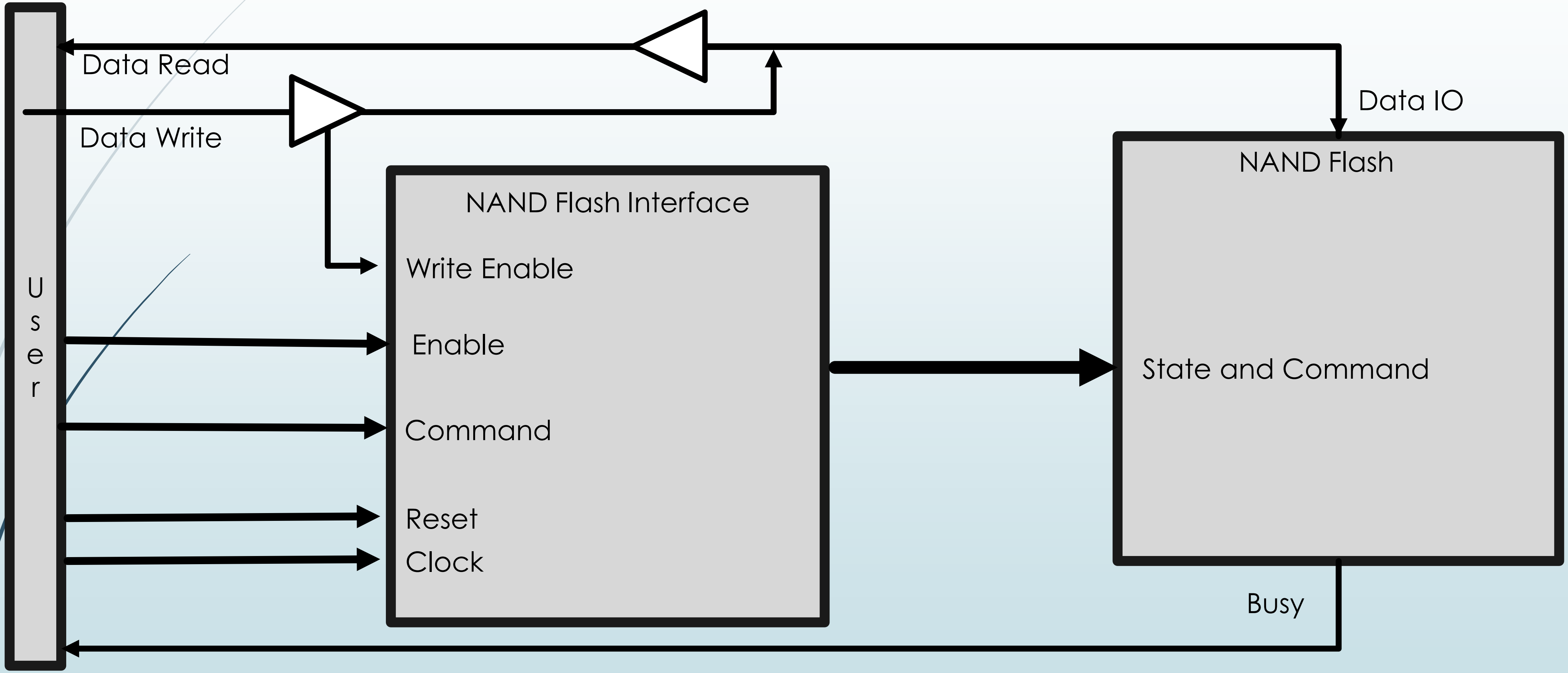
General load switch circuit diagram

Packetization

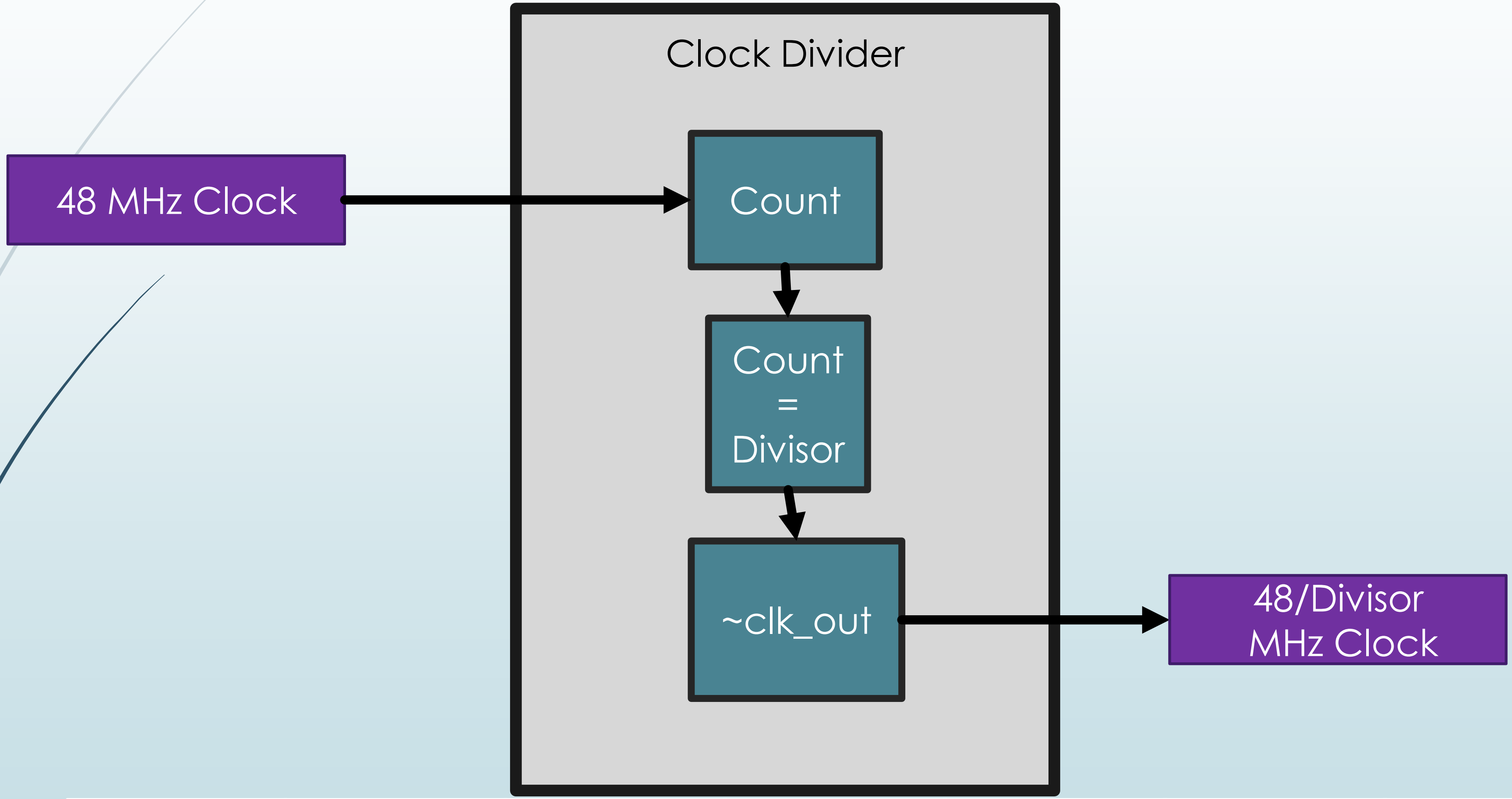
- RS-422 Protocol



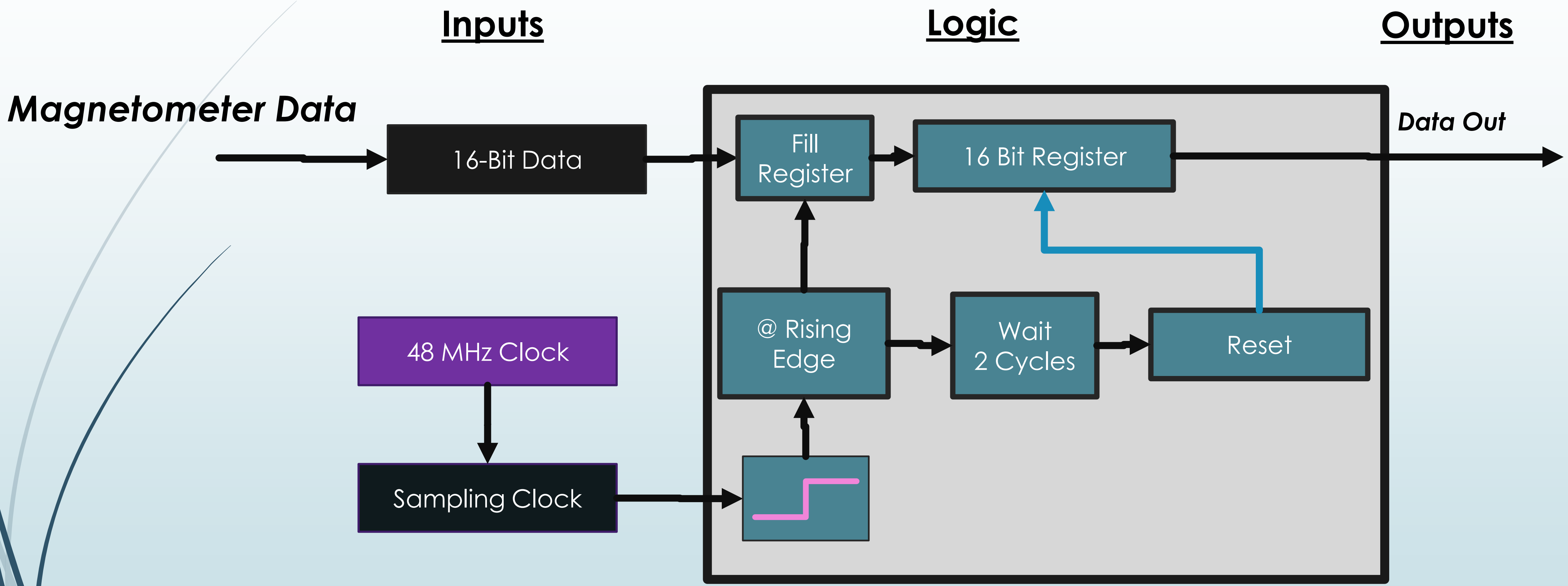
Flash Interface



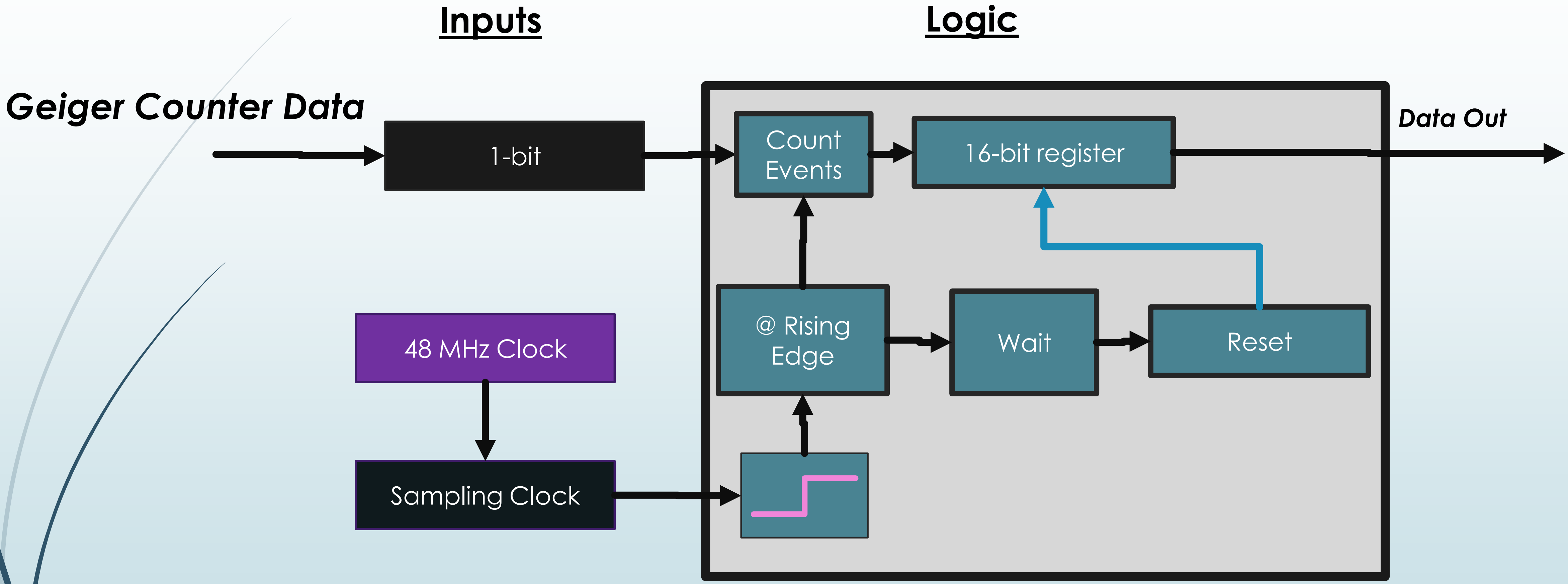
Basic Clock Division



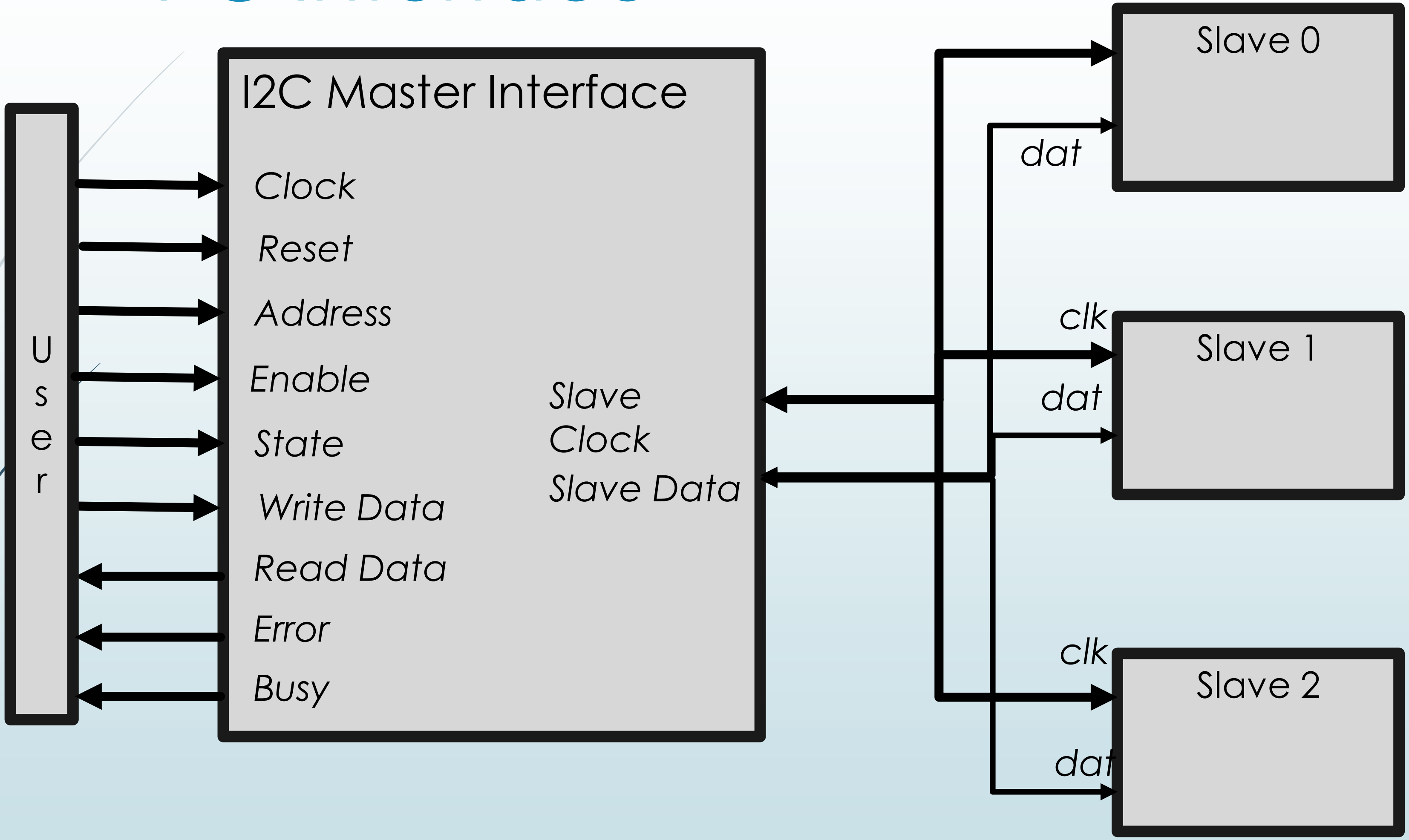
Magnetometer Ingest Filter



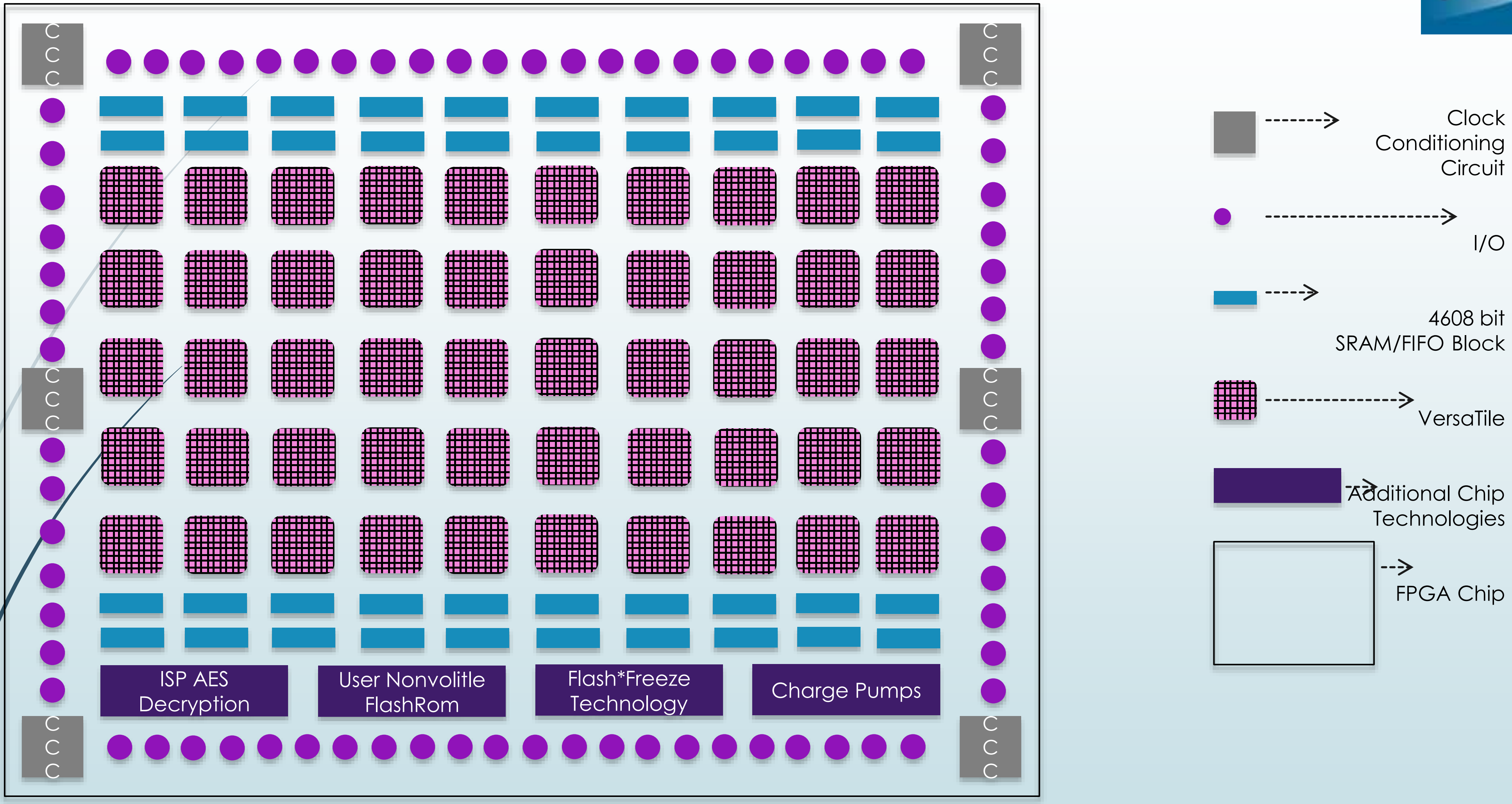
Geiger Counter Ingest Filter



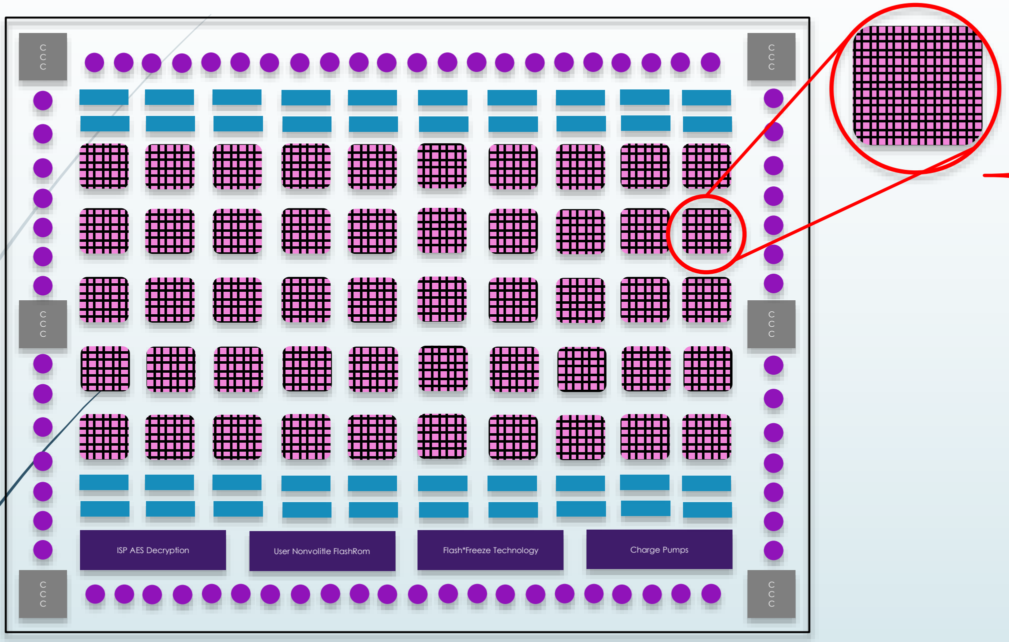
I^2C Interface



Backup? FPGA Layout



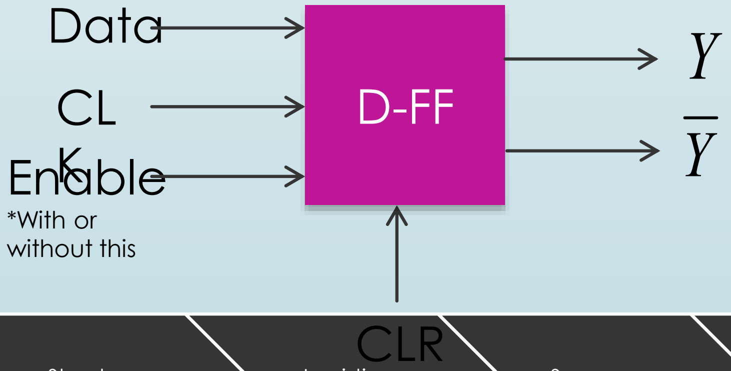
VersaTile Logic



3-input Logic

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

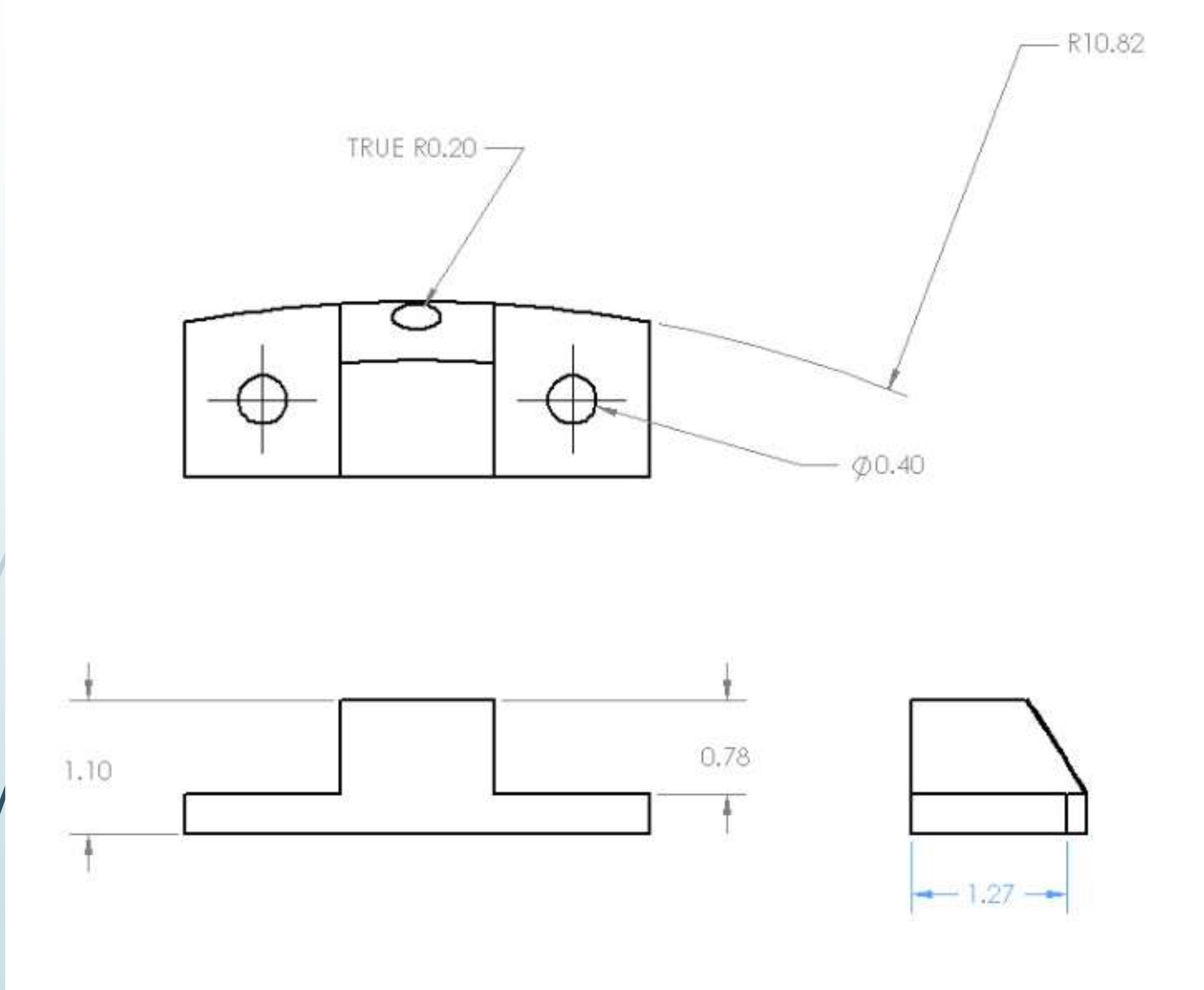
D-flip-flop Logic



*With or without this

Y changes on rising edge of clock

Clip Specifications

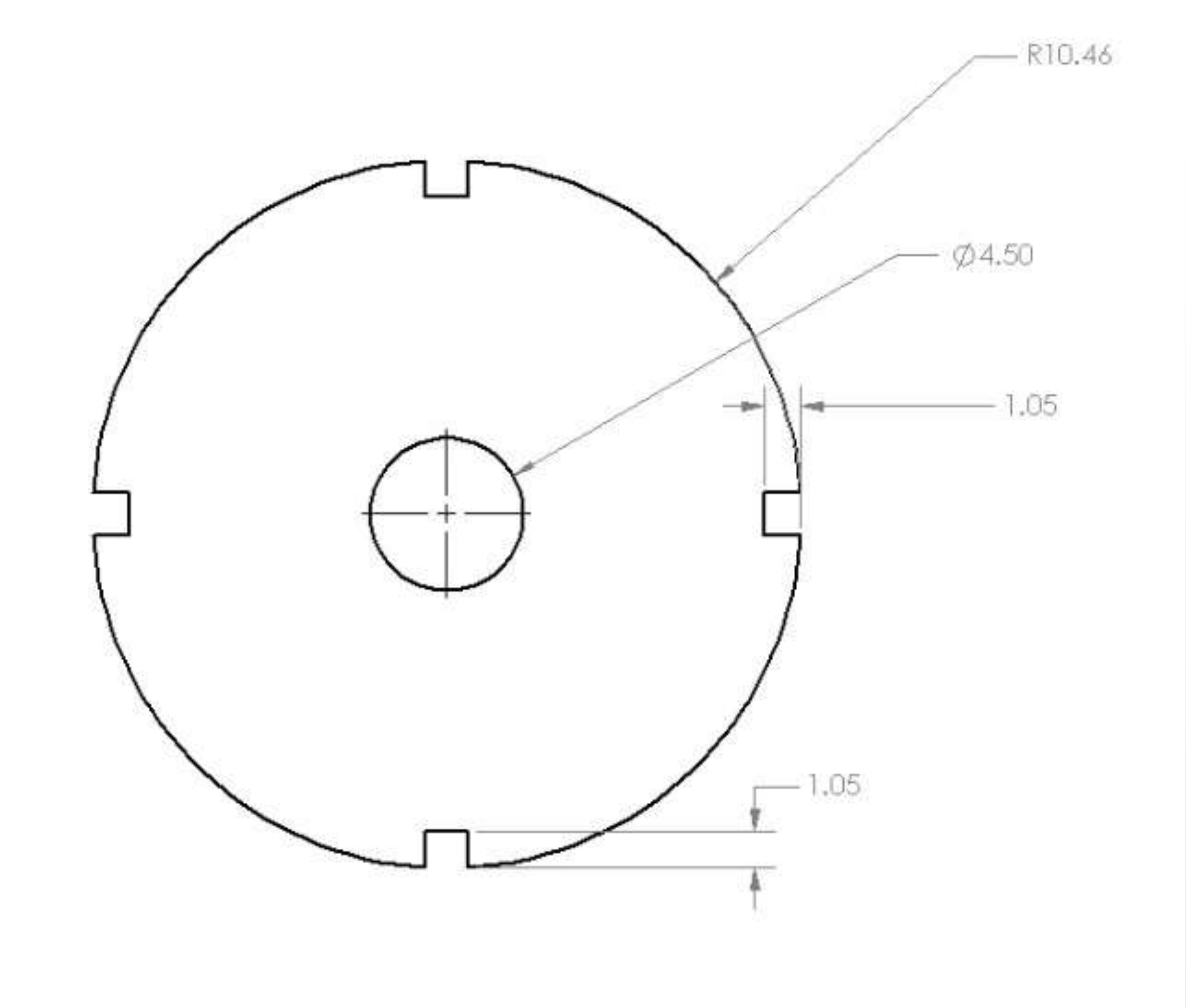


Modification of TIRESIAS method of securing flat shelves to spherical housing

All machining can be done in house, shown by TIRESIAS

Machining Tolerance +/- 0.005 inches - sufficient

Plate Specifications



Will be machined out of 6061 – T6 Aluminum

0.36 cm thickness – TIRESIAS heritage

Machining tolerance +/- 0.005 inches - sufficient

Center hole for ease of wiring

Mass Budget

	Raw Mass	Mass With 10% Margin
Communications		
VT15 Transmitter	48 g	53 g
FR10 Receiver	28 g	31 g
Science		
Magnetometer	10 g	11 g
Geiger Counter	50 g	55 g
Structure		
6061 Aluminum Alloy	1640 g	1804 g
Avionics Board	200 g	220 g
Power		
Power Board	150 g	165 g
Batteries	6289 g	6918 g
Total Mass:		**9.257 kg**
Margin:		**0.743 kg**

Int. 2 Satisfied – Total mass is under 10 kg

Materials Cost Estimate

- From onlinemetals.com
- Plate to machine shelves $108
  - 6061-T6 Aluminum sheet
  - 22cm x 2cm x 12 inches
- Rectangular Blocks for Clips $69
  - 6061-T6 Aluminum Block
  - 6cm x 6cm x 16cm (x2 blocks)

Total Price Estimate: $177

Science Trade

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

Science Trade Cont.

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

Science Traceability

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

Science Traceability Cont.

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

Summary of Feasibility

- Communications: Feasible
  - Communications systems have some **heritage**
  - Antenna mismatch risk mitigated by **alternative designs** and **customer data**
- Power: Feasible
  - **Power budget** shows positive power remaining with **design margin**
  - Power risk mitigated by **spherical shell expansion** contingency plan
- Avionics: Feasible
  - **Learning Curriculum** with Development Board provides team with necessary skillset
  - Avionics delivery risk mitigated by **Development Board** contingency plan
- Structure: Feasible
  - Volume and mass with **design margin** meet requirements
  - Use of modified **heritage components**
- Logistics: Feasible
  - Current budget indicates that there will be **extra funds** in case of emergency
  - Avionics **delivery** and **cutoff dates** have been **coordinated with Ball Aerospace**

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