Project ELSA
Europa Lander for Science Acquisition

University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Conceptual Design Document (CDD)

1 Information

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Contents

2 Project Description

2.1 Purpose and Objective

Europa, one of Jupiter's four Galilean moons, is believed to have a sizable ocean 100 km below its icy surface. Spacecraft sent through the Jovian system have revealed that Europa has one of the smoothest surfaces in the Solar System and has few impact craters which indicates a "young" and geologically active surface. Pictures of Europa also show many large streaks along its surface called lineae. These lineae are suspected to be the result of tidal flexing on Europa's surface as it orbits Jupiter. In 2013 the Hubble Space Telescope spotted significant plumes of water spouting from the surface, which further suggests that bodies of water exist under the ice. While all of this evidence is extremely compelling, none of it is definitive. If an ocean does indeed exist, it would be one of the most hospitable places in our Solar System for simple extraterrestrial life. Project ELSA (Europa Lander for Science Acquisition) will provide a stepping stone for future missions exploring Europa, by demonstrating the feasibility of collecting science data that would be critical to understanding more about the surface of Europa.

The ELSA probe will collect this relevant data for 4 days from inside a relatively low cost, low mass, and low volume spherical structure. The 4 day timeframe accounts for more than one full orbit of Europa around Jupiter, which is approximately 3.5 days. The instrumental test suite shall provide data which is relevant to the currently uncertain conditions on the surface of Europa. Information such as temperature, pressure, magnetic field parameters, seismic activity, and images of nearby surface features could prove helpful to scientists characterizing the surface. The ELSA team will develop a data acquisition and handling system which will collect and store a minimum of 4 days worth of data, from these sensors. The ELSA team shall be responsible for creating functional communications, power, and data flow systems that will allow the data collected by the scientific instruments to be transmitted wirelessly to a ground station (developed by the team) set some distance away, representative of the transmission environment on Europa, over a 4 day period, at a maximum of 128 kbps. This will either be demonstrated through testing or modeling, depending on the feasibility. The ELSA team will also provide a computer model of the probe structure which can withstand the harsh radiation environment that is expected on the surface of Europa. The ELSA team is expected to integrate the procured sensors with the avionics board and communications system, as well as provide a structural housing to fit all equipment within the spherical shell creating an autonomous system capable of collecting and transmitting data.

This project shall utilize hardware developed by previous student projects to create a probe which is capable of tabletop testing, and has flight grade avionics, or their equivalent. Ball Aerospace will provide the project team with an avionics board, communications hardware, the spherical housing system, and a CAD model of the existing probe and previous work. If Ball Aerospace is unable to provide an avionics board, the project team will be responsible for providing an alternative solution for the board and integrating it with the other system components.

2.2 CONOPS

The Concept of Operations (CONOPS) images that are shown in this section are used to give context to how the ELSA project will operate. These are the visual descriptions of what the project will look like.

Figure 1 below, shows the Europa Mission CONOPS. This is meant to describe the mission that a flight ready version of the probe would carry out. In this mission, the orbiter, carrying the probes travels from Earth to Europa. Once in orbit around Europa, the orbiter will deploy 5-10 of the probes. The 10 kg mass requirement and 30 cm diameter radius requirement are meant to allow multiple probes to be carried by the orbiter. These probes fall approximately 100 km before landing on the surface. The mission accounts for a 14 hour settling time, allowing the probes to stop moving along the surface after landing. Once settled on the surface, the probe would collect science data. As the orbiter flies overhead, it would command the probe to transmit the data it had collected. Based on the limitations of the orbiter, the probe limited to a 128 kbps data rate.

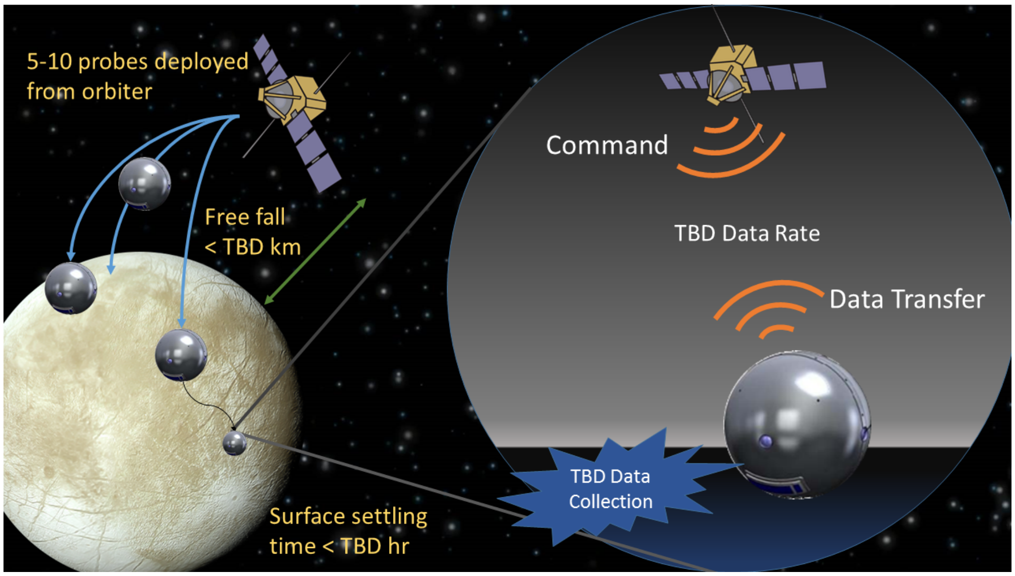

Figure 1: Europa Mission CONOPS

While many of the challenges associated with this particular mission are ignored due to the added complexity, certain mission parameters carry over to our project, and help frame some of the constraints for our project. For our table-top probe, we can ignore the temperature, descent and landing impacts, as well as radiation hardening for components required to operate on Europa. What does carry over is the general mission timeline as well as constraints like size, volume, and data rate. THe Europa mission also drives the need to be able to power the probe for over 4 days, and communicate with a ground station that we develop to imitate the orbiter.

Figure 2 below, shows the CONOPS for the ELSA mission. This CONOPS highlights the important functional aspects of the system being developed by the project team. First, the NeoPod will power on and begin collecting science data. After receiving a command from the Ground Station, the NeoPod will begin to transmit data back to the Ground Station. The Ground Station then receives and records the data. All of this is done at a distance that will replicate the Europa Transmission environment in an Earth air environment, or can be modeled to show sufficient transmission.

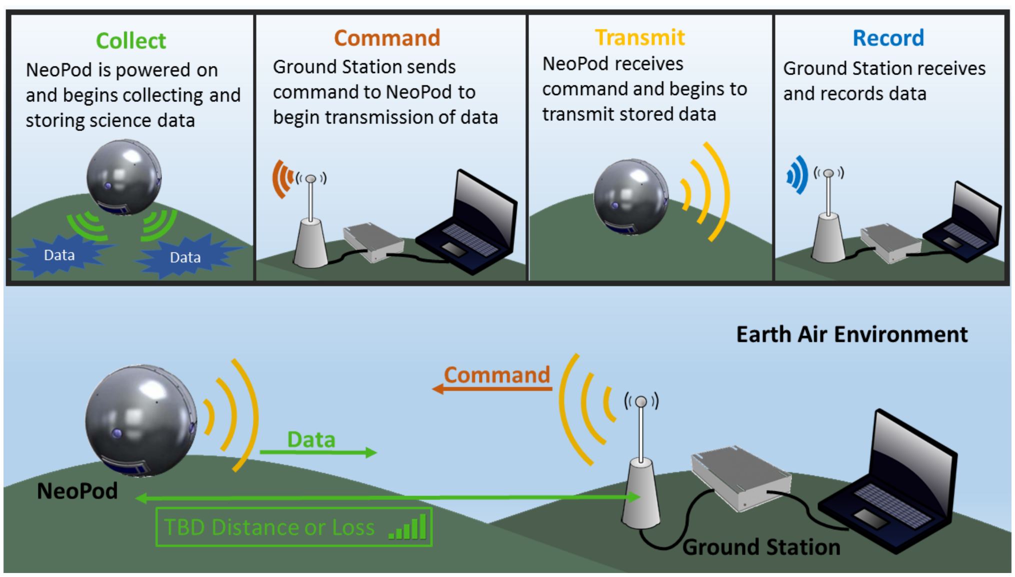

Figure 2: ELSA Mission CONOPS

2.3 Functional Requirements

The ELSA project has 3 Functional Requirements based on the project presented by the customer, and the CONOPs. These are the top level requirements that will be the motivation for all other project requirements and design decisions. These requirements can be seen as the critical aspects of the project that help to define our goals.

1. The NeoPod shall collect scientific data relevant to Europa
2. The NeoPod shall communicate with the Ground Station
3. The NeoPod shall integrate with existing mission architecture

2.4 Functional Block Diagram

To further illustrate the system needed to meet these ambitious mission objectives, a functional block diagram was made as shown in Figure 2.4. This diagram shows each of the major subsystems on the NeoPod, as well as the power, data, and command connections between them. The Power subsystem integrates will all parts of the NeoPod. The main flow of data goes from the two sensors in the Payload subsystem, and run through the Avionics subsystem which processes and stores the data before it is sent to the Communication system, which relays the data back to the Ground Station. The Ground Station is also capable of sending commands to the Avionics, through the Communications system.

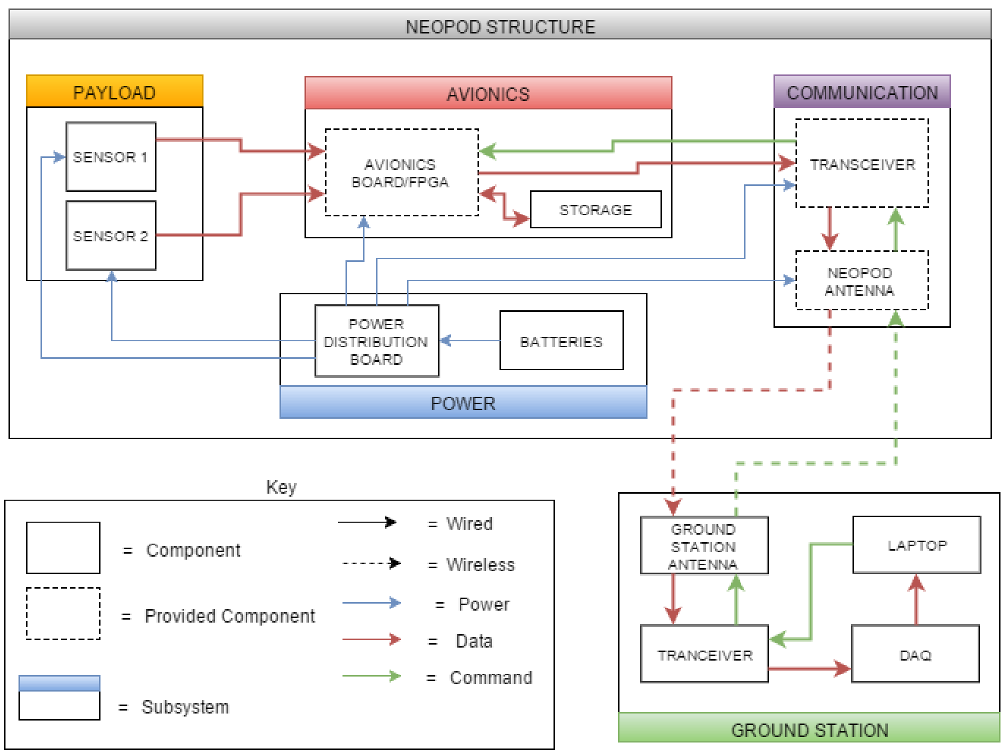

Figure 3: Functional Block Diagram of ELSA Mission

3 Design Requirements

The requirements for this project are based on several different sources. The first is from the function requirements and and customer input. These are the most basic requirements and constraints for our project. From these, we could begin to derive requirements that line-up with the CONOPs documents and the FBD. As the design has become more clear, and more details have been developed, more specific requirements for each subsystem and be added. Additionally, each requirement has a motivation as well as verification and validation. The motivation is the reasoning behind the requirement. The verification and validation (V&V) is the approach that the team has for completing this requirement.

<u>SCI 0:</u> NeoPod shall collect scientific data relevant to Europa

SCI 1: Neopod shall contain 2 scientific instruments.
Motivation: Customer Specified Requirement. Will show potential scientific value of NeoPod with different types of sensors as well as to show that they system is capable of handling the output and additional weight/volume from two sensors.
V&V: Inspection.

SCI 2: NeoPod shall record data over a 96 hour period.
Motivation: Customer Specified Requirement. Europa orbits Jupiter every 3.5 Earth days. The 96 hour period will capture data from the entire orbit.
V&V: Test. Completion of Req SCI 2.1 and SCI 2.2

SCI 2.1: NeoPod Power Subsystem shall sustain the scientific instruments for a 96 hour period.
*Motivation:*Derived. In order to collect data the power system must be able to power the sensors for 96 hours.
V&V: Test. Run a test to demonstrate that the power system will be able to keep the sensors on for 96 hours.

SCI 2.1.1: Power subsystem shall provide 5 V to Sensor 1.
Motivation: Derived. Sensor 1 will require 5 V.
V&V: Demonstration. Use a Multimeter to measure correct voltage.

SCI 2.1.2: Power subsystem shall provide 5 V to Sensor 2.
Motivation: Derived. Sensor 2 will require 5 V.
V&V: Demonstration. Use a Multimeter to measure correct voltage.

SCI 2.2: NeoPod sensors shall mechanically and electrically interface with Avionics subsystem.
Motivation: Derived. Required for data to be stored and transmitted.
V&V: Test/Demonstration. Show that data is going from the sensor to the Avionics subsystem.

SCI 2.2.1: Sensors shall have an output voltage of 1.2, 1.5, 1.8, 2.5, or 3.3 V.
Motivation: Derived. Based on the input voltage values for FPGA board supplied by Ball.
V&V: Demonstration. Use a Multimeter to measure the voltage from sensor.

COM 0: NeoPod shall communicate with Ground Station

COM 1: The NeoPod shall wirelessly accept commands.
Motivation: Customer Specified Requirement. The NeoPod must be able to receive commands from the Ground Station to begin transmission of data.
V&V: Test. Completion of COM 1.1 and then a test of the receive capability of the NeoPod.

COM 1.1: NeoPod shall use a FR10 receiver to receive commands.
Motivation: Hardware provided by Ball Aerospace.
V&V: Inspection.

COM 1.1.1: NeoPod shall receive commands on the 2400 MHz frequency band.
Motivation: Derived. Based upon the specifications of the receiver.
V&V: Test. Show receiver accepts commands in specified frequency band using spectrum analyzer.

COM 2: NeoPod shall wirelessly transmit data.
Motivation: Customer Specified Requirement. It is critical to this project that the NeoPod is capable of transmitting data collected back to the ground station.
V&V: Test. Show that the NeoPod is successfully transmitting to the Ground Station. Proven with COM 2.1 - 2.6.

COM 2.1: NeoPod shall use a VT15 transmitter to send data.
Motivation: Hardware provided by Ball Aerospace.
V&V: Inspection.

COM 2.1.1: NeoPod shall send data on the 433 MHz frequency band.
Motivation: Derived. Based on specifications of transmitter.
V&V: Test. Show transceiver transmits at specified frequency using spectrum analyzer.

COM 2.2: NeoPod shall use a binary frequency shift keying (BFSK) modulation.
Motivation: Derived. Based on specification of hardware.[1]
V&V: Test. Show that NeoPod comms are using a BFSK modulation.

COM 2.3: NeoPod shall transmit data at as near as possible to a maximum of 128kbps.
Motivation: Customer Specified Requirement. Based upon the orbiter in the Europa mission, there is a maximum transmission rate. The NeoPod must communicate below that level.
V&V: Test/Analysis. Check transmission rates of the comm system to ensure a rate below the specified limit.

COM 2.4: NeoPod shall transmit data upon command from Ground Station.
Motivation: Customer Specified Requirement. The NeoPod must be able to begin transmission once it has received a command from the Ground station to do so.
V&V: Test. Show that the NeoPod begins transmission after receiving a command from the Ground Station.

COM 2.5: NeoPod shall be capable of sending 58.15 MB of data over one Europa eurosol (3.5 earth days).
Motivation: Derived. This requirement is based upon the expected data generation rate of the sensors as well as the expected number of transmission events between the NeoPod and the orbiter on a mission to Europa.
V&V: Test/Analysis. This requirement will be shown by modelling the number of passes the orbiter would make, as well as our overall link budget and transmission rate.

COM 2.6: NeoPod shall transmit data over 10 meter distance.
Motivation: Derived. Transmission over this distance will be used to model how the NeoPod would perform in communication on Europa. Losses and noise will be applied to this short distance to show that long distance communication is possible.
V&V: Test. Communication test from 10m away, with Ground Station.

COM 3: NeoPod shall employ single port patch antennae supplied by Ball Aerospace (x2).
Motivation: Hardware supplied by Ball Aerospace.
V&V: Inspection.

COM 4: The NeoPod communications system shall interface with the system using a RS232 port.
Motivation: Derived. The communication system needs to integrate between an RS422 port on the FPGA and RS232 on the transmitter/receiver.
V&V: Demonstration. Show that the system is using RS232.

COM 5: NeoPod communications system shall be powered by onboard power system.
Motivation: Derived. NeoPod must be self-sufficient.
V&V: Demonstration. Show that power system powers communications system.

COM 6: The Ground Station shall wirelessly send commands.
Motivation: Customer Specified Requirement. Ground Station must be able to command NeoPod.
V&V: Test. Ensure that the Ground Station is sending commands to NeoPod.

COM 6.1: Ground Station shall use a FT10 transmitter to send commands.
Motivation: Hardware provided by Ball Aerospace.
V&V: Inspection.

COM 6.1.1: Ground Station shall send commands on 2400 MHz frequency band.
Motivation: Derived. Based on specification of transmitter.
V&V: Demonstrate. Show that the transmitter is operating in frequency band using spectrum analyzer.

COM 6.2: Ground Station shall downlink commands at 2 kbps.
Motivation: Derived. Based upon heritage from TIRESIAS project.
V&V: Test/Analysis. Show that commands downlink at given rate.

COM 7: The Ground Station shall wirelessly receive data.
Motivation: Customer Specified Requirement. Ground Station must be able to receive the data that is transmitted by the NeoPod.
V&V: Test. Show that data transmitted by NeoPod is being received and stored by the Ground Station.

COM 7.1: Ground Station shall use a VR75 receiver to receive data.
Motivation: Hardware provided by Ball Aerospace.
V&V: Inspection.

COM 7.1.1: Ground Station shall receive data on the 433 MHz frequency band.
Motivation: Derived. Based upon specifications of receiver.
V&V: Demonstrate. Show that the Ground Station is receiving on the correct frequency band using spectrum analyzer.

COM 7.2: Ground Station shall use a binary frequency shift keying (BFSK) modulation.
Motivation: Derived. Based on specification of hardware.[2]
V&V: Test. Show that NeoPod comms are using a BFSK modulation.

COM 7.3: Ground Station shall store data that is transmitted from the NeoPod.
Motivation: Derived. The Ground Station must be able to save the data that is being transmitted by the NeoPod in order for it to be useful.
V&V: Demonstration. Show that the Ground Station saves the data that is transmitted to it.

INT 0: NeoPod shall integrate with existing mission architecture

INT 1: NeoPod shall have a mass less than 10 kg.
Motivation: Customer Specified Requirement. Based on Europa Mission Parameters. This applies to the CAD model of the NeoPod with extra shell thickness for radiation shielding. The actual model built by the ELSA team will not weigh this much in order to meet the requirement.
V&V: Demonstrate/Analysis. Combination of component weighing and CAD analysis of structure.

INT 1.1: The power system shall not weigh more than 6 kg.
Motivation: Derived. Based on the power and mass budgets, the power system must not weigh more than the given amount.
V&V: Demonstrate. Based on weight of components used in NeoPod.

INT 2: NeoPod shall have a maximum diameter of 30cm.
Motivation: Customer Specified Requirement. Based on Europa Mission Parameters.
V&V: Demonstration. Measurement of shell size.

INT 3: ELSA Team shall design a version of the shell of the probe (CAD only) to keep internal TID radiation dose below 225 krad.
Motivation: Customer Specified Requirement. This is based on the intense radiation environment on Europa. Even though the NeoPod is only meant for tabletop use here on Earth, a CAD design of the shell must show protection from radiation.
V&V: Analysis/Test. Based on CAD and radiation model. Possibility for some testing at facility in Colorado Springs to validate model.

INT 4: NeoPod shall have an internal structure that attaches the components to the external shell.
Motivation: Customer Specified Requirement. The NeoPod is required to be fully integrated with all essential components mounted within the structure.
V&V: Inspection.

INT 5: NeoPod shall have an independent power system.
Motivation: Derived. In order for the NeoPod to be self sufficient and fully integrated, it must be able to supply its own power.
V&V: Inspection.

INT 5.1: The power system shall not occupy more than $3000cm^3$.
Motivation: Derived. Based on the power and volume budgets, the power system must be below this volume.
V&V: Analysis/Inspection. Measurement of power system to ensure volume requirement has been met.

INT 6: NeoPod shall have an Avionics Board that will store data from sensors and relay that data to the communication system.
Motivation: Customer Specified Requirement / Derived. The customer is providing an FPGA board, yet it was obvious that this system would require some sort of system to store and transmit data, as well as interpret commands from the Ground Station.
V&V:

INT 6.1: The Avionics subsystem shall store data collected during 96 hour period.
Motivation: Derived. The Avionics system must be able to store data for the 96 hour data collection mission.
V&V: Demonstrate. Show data from payload is stored within Avionics subsystem.

INT 6.1.1: Avionics board shall store 4GB of data.
Motivation: Derived. Based upon the data generation rate of the sensors, and mission lifetime.
V&V: Test/Analysis. Demonstrate. Show that storage system has 4 GB available.

INT 6.2: Power subsystem will provide power to the Avionics subsystem.
Motivation: Derived. Power system must be able to power the Avionics subsystem.
V&V: Test. Show power system is able to independently power Avionics for entire mission lifetime.

INT 6.2.1: Power subsystem shall provide 1.5 Volts to the Avionics subsystem.
Motivation: Derived based on hardware requirements.
V&V: Demonstrate. Use Multimeter to test voltage.

INT 6.2.2: Power subsystem shall provide 2 Amps to the Avionics subsystem.
Motivation: Derived based on hardware requirements.
V&V: Demonstrate. Use Multimeter to test current.

4 Key Design Options

The unique challenge presented with this project is that there are a multitude of subsystems that will all need to have individual design solutions, as well as global design solutions in order to integrate into the larger system. Possible design solutions for each subsystem will be presented below.

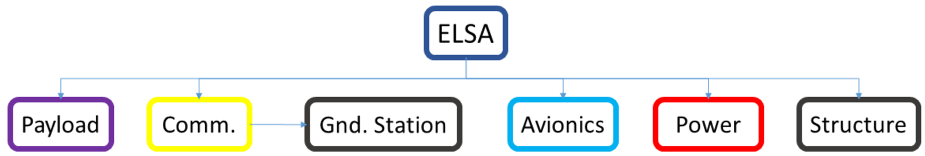

Figure 4: ELSA Mission Main Subsystems

4.1 Payload

The selection of two sensors for the NeoPod is critical for the design of every other subsystem and will be driven by critical project elements. While it is important to consider the size, mass, cost, etc. of a payload, the first step in selecting the correct instrument suite is to identify science data that would be of most use to the scientific community. The study of Europa can be broken into three main categories: Ice Shell and Ocean Characterization, Surface Composition, and Surface Geology[3]. Each of these categories present a diverse problem set that has a broad set of solutions. Some solutions may be capable of providing data on more than one category of study. Instrument identification will be based on the scientific need for each category, and the instruments ability to deliver data that will meet that scientific need. Then the instruments will be assessed for their ability to integrate with our mission design, requirements, and constraints.

4.1.1 Ice Shell and Ocean Characterization

Table 4.1.1: Ice Shell and Ocean Characterization Sensor Pros/Cons

	Pros	Cons
Magnetometer	• COTS HW • Many different types available • Size between 2 cm/Lightweight • Low Cost Options	• Attitude knowledge and additional signals (3 B-field vectors, 1-3 accelerometer vectors, 1-3 gyro vectors) needed for 3D characterization

4.1.1.1 Magnetometer

Studying the in-situ magnetic field over the course of an orbit around Jupiter would allow for the verification of a subsurface conductor, which in Europa's case would provide strong evidence for a salty ocean.

Europa lies at a unique orbit of 9.4 Jupiter radii R[4] away from the planet. Jupiter's magnetosphere extends out to approximately 10 R[4], placing Europa well within this magnetosphere. Furthermore, Jupiter's magnetic field is tilted at a 10^{o} angle from its rotation axis, which also happens to be the axis about which Europa orbits[4]. The combination of these features along with a slightly eccentric orbit means Europa is experiencing continual changes in magnetic flux[5]. According to Faraday's Law, when a conducting object experiences an external change in magnetic flux ($d\phi/dt$), an induced current results in the conductor. This induced current creates its own magnetic field which opposes the external flux. As ice is poorly conductive but salt water is extremely conductive, magnetic field measurements would more accurately characterize Europa's interior. Larger induced magnetic fields would imply more subsurface water while no conductivity would indicate a small or non-existent ocean. This information would be critical when planning a larger, more expensive, mission to Europa to investigate its ability to be home to extraterrestrial life.

During initial research, two types of magnetometers were considered- scalar and vector magnetometers. As the names imply, the former only measures the field strength while the latter measures both the strength and direction. However, as it turns out, scalar magnetometers are rarely used alone, and are often meant for calibrating vector magnetometers. In fact, there aren't many COTS options available and choosing a scalar magnetometer would likely mean building one. In addition, low cost vector magnetometers are available on boards that include accelerometers and gyros for directional calibration. The table below shows the magnetometer options that were considered once narrowed down by the desired measurement range (roughly +-1 uT) as well as eliminating magnetometers that were simply not available as affordable COTS options. The range was determined by the estimated magnetic field strength on Europa with Jupiter's field being 500 nT and fluctuations ranging from approximately 1 nT to 300 nT[6]. Figure 5 shows a breakdown of magnetometer applications and costs.

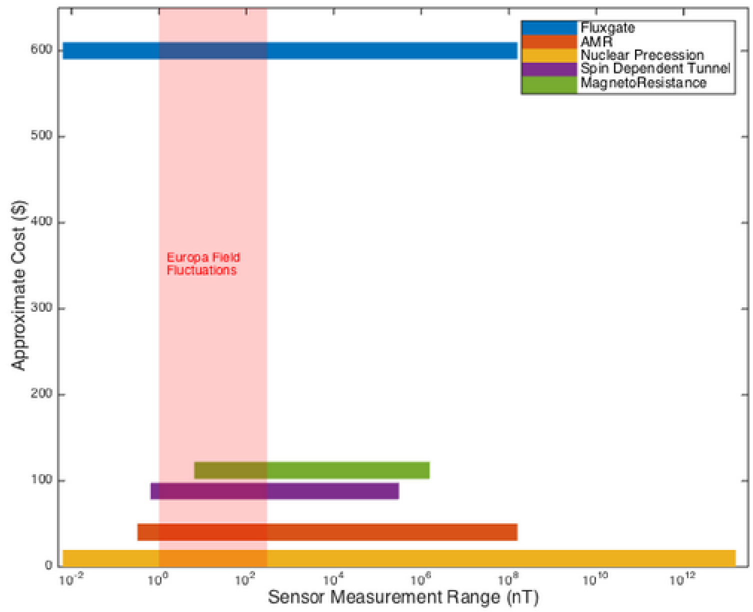

Figure 5: Comparing Magnetometers to Europa's Magnetic Field[7]

Table 4.1.1.1: Magnetometer Types Pros/Cons

Magnetometer	Pros	Cons
Fluxgate	• Widely used in space applications • Smaller resultion (1pT-.1nT) • Robust/mature	• Expensive • No provided directional calibration • Availability unclear through manufacturer • Larger mass/size
AMR	• Cheap • Widely used and available • Mature • Small	• Larger Resolution (1nT) • More noise
Nuclear Precession	• Scalar reading (does not require directional calibration, only one signal)	• Not easily available • Most purchasing options involve building kits for sensor • Does not provide unique results
SDT	• High range • Small	• Not easily available • Low bandwidth
MI	• Large range • Small	• Large resolution (10nT) • Not easily available

Through evaluating the options listed above, the Fluxgate magnetometer would be the clear choice for a flight level spacecraft that needed the extra sensitivity and could handle the larger relative mass and size of the sensor. However, environmental testing and space-grade hardware is not within the scope of this project and would not provide any additional benefit towards the main goal of developing a communications system and FPGA board. This similarly eliminates the Nuclear Precession, Spin-Dependent Tunnel (SDT), and MagnetoResistance (MI) sensors, as the difficulty of procurement would only add unnecessary risk to the subsystem. This leaves the best option for the magnetometer as the Anisotropic MagnetoResistance (AMR) sensor. At the cost of less sensitivity, it is easily the most cost-effective available option, has a long history of usage and documentation, and comes in boards already configured with sensors that will aid in its calibration. The ranking of these options, however, could easily change through developed power and financial budgets.

Implementation: Measurements would be taken statically from inside the NeoPod shell. The small board would need to be mounted to the internal structure of the NeoPod. This sensor is beneficial because it avoids the additional complexity of interfacing with the external structure. With board configurations already available, most of the work involved with this sensor would be making the proper electrical connections to the Avionics and Power systems.

4.1.2 Surface Composition

Table 4.1.2: Surface Composition Sensors Pros/Cons

	Pros	Cons
Spectrometer	• Valuable science (characterizes surface compostion)	• Large • Heavy • Not readily available • Expensive
Pressure Sensor	• Small • Lightweight • Available • Low cost • Simple to implement	• Minimal science value • Static measurement
Temperature Sensor	• Small • Lightweight • Available • Low cost • Simple to implement	• Minimal science value • Static measurement • Possible Errors from electronic heat
Radiation Sensor	• Highly available • Simple to implement • Low cost	• Can be large • Science value complicated by radiation shielding

4.1.2.1 Spectrometer

One of the primary science objectives that NASA has identified for Europa is the characterization of Europa's surface. A mass spectrometer helps fulfill this objective by determining the chemical composition of mass samples. Spectrometers have been used in previous space missions to characterize the atmospheric composition of Mars and Titan. Unfortunately, they are very large and expensive and are usually used in labs. Engineers are currently seeking to design smaller versions that are more practical for space and field applications.

A mass spectrometer consists of an ion extraction system, a mass analyzer, and a detector[9]. The extraction system removes ions from the mass sample and accelerates them through the mass analyzer, which deflects the trajectory of the ion particles based on their mass-to-charge ratio. The detector measures the deflections of the ion trajectories and provides data that can be used to determine the ratio of different ions present.

Implementation: A hole would be made in the external probe shell. The mass spectrometer would be integrated such that the ion extraction system occupies the hole facing outward toward the environment, thus allowing it to collect ions from the surface. The mass analyzer and detector would be contained inside the probe.

4.1.2.2 Pressure Sensor

It is already known that Europa has an extremely tenuous atmosphere, however, in-situ pressure sensors could provide more information regarding the surface conditions and their fluctuations throughout an orbit of Jupiter.

Implementation: Pressure sensors would take measurements from inside the probe from a mechanically fixed location.

4.1.2.3 Temperature Sensor

The surface temperature is another value that is already generally known via remote sensing efforts. However, surface measurements could validate previous measurements, as well as measure fluctuations that occur throughout an orbit of Jupiter

Implementation: Temperature sensors would take measurements from inside the probe from a mechanically fixed location. The sensor would need to be isolated from heat producing electronics in order to obtain accurate readings.

4.1.2.4 Radiation Sensor

Jupiter has a very hostile radiation environment due to it magnetic field. These Van Allen radiation belts, just like the ones here on Earth are trap radiation and keep it belts around the planet. It is because of these belts, that Europa is thought to have a very intense radiation environment as well. Previous probes sent to Jupiter observed these radiation belts, and scientist have since used that data to estimate the radiation environment on Europa. Radiation has a very damaging effect on large organic chemicals that are indicative of life, so it would be important for future science mission to have a very clear understanding of the radiation environment that is on the surface. Additionally, any science mission to Europa would have to plan for very high radiation doses. Having more data on the radiation found on the surface would help to find optimal locations for a larger, more complicated landers that would be endangered by large amounts of radiation.

Geiger counters are used to measure the number of radioactive particles that hit the sensor. This is done by charging a tube full of inert gas. When a radioactive particle hits the gas, it is ionized, and the geiger counter is able to measure the number of times this happens in a given time interval. This number can be used to estimate the dose that a particular location would experience.[10] Placing a geiger counter on the surface of Europa would help further characterize the conditions on the surface both for the exploration of life and for the safety of future landers.

Geiger counters are made all the more attractive by their high availability and proven track record. Geiger counters have been around for over 85 years, and are used throughout the world as well as in space applications. Additionally, there are many kits available through electronics companies that allow you to purchase, build, and program your own geiger counter circuitry.

One of the biggest drawbacks of using a geiger counter is how it fits in with our mission architecture. Because of the harsh radiation environment on Europa, the electronics components need to be shielded from radiation. Part of the ELSA project is to design a CAD model of the NeoPod that would minimize radiation inside the shell. Having a geiger counter within this shell would be somewhat counter intuitive, because we are trying to collect radiation from inside a shell that is shielding from radiation. The work around for this is that the material protection provided by an aluminum shell is well studied, and some radiation dose will penetrate the shell. The geiger counter would still be able to get a radiation measurement that would be scaled based on the thickness of the shell, and its protective properties. This information would still be valuable in validating the radiation models that exist for the surface of Europa.

Implementation: A geiger counter could be implemented statically inside the shell. However, special consideration should be taken in choosing the location such that the radiation dosage could be extrapolated based on the objects near it. For example, placing it right next to the spherical shell wall would allow for the extrapolations to be as accurate as possible by minimizing internal radiation sources or shields.

4.1.3 Surface Geology

Table 4.1.3: Surface Geology Sensors Pros/Cons

	Pros	Cons
Camera	Individual cameras are small, lightweight and would provide information that could not be obtained by satellite. Relatively inexpensive and readily available	Lack of control and mobility may limit scientific potential. Having 6 may increase the difficulty of structural integration and handling the data load
Micro-Imager	The total system would be similar in weight to camera system with only an additional inclusion of a lense assembly for each camera	Due to uncontrolled descent, multiple cameras with lense must be used to increase likelihood of obtaining proper imagery, will also include modifications to exterior of spherical housing. Additional length of lense assembly will complication integration with current structure
Thermal Imager	Cameras are small and lightweight. Available to order online from specific companies	Probe is stationary, so science mission is not very relevant with this payload. Cameras are expensive and would need multiples. Integrating six cameras adds significant complexity to the NeoPod design
Seismometer	Seismic data would lead to much better modeling of Europa. Extremely low current draw.	Very few vendors, unreliable data if used with NEOPod, slightly large, large complexity with integration

4.1.3.1 Seismometer

The seismic activity on Europa will reveal whether or not the lineae on its surface were created from expansion or compression which would then reveal the magnitude of material exchange between the ocean on Europa and the barren surface. This result would point to the frozen ridges created by this material exchange as being a prime target for future missions seeking the discovery of ET DNA. A large amount of seismic activity would also strongly suggest the existence of deep ocean heat vents which may harbor methane based lifeforms just like they do on Earth. Furthermore, seismology would help to more accurately characterize the interior structure of Europa which would lead to more accurate models of the history and future of Europa and its geological characteristics.[11] Current models consider Europa to be an extremely active geological body which would make it perfect for harboring life as this geologic activity provides the necessary energy to sustain life on a planet where solar energy is nearly negligible. However, if this were to be proven wrong then the possibility of life on Europa would significantly decrease and future costs of high price missions could be avoided.

Seismometers are usually extremely large and housed in cement bunkers 100 ft. below the ground, there is an extremely small market for low-volume and low-mass seismometer. Mainly hobbyists occupy this low-size market which makes the instruments less reliable and also more expensive, the costs of such small seismometers is around $450 with limited support. Another issue is that the size of these instruments is still around 3 to 5 inches in width and height and around an inch thick, although this is extremely small in terms of seismometers it is considered bulky for the scope of this project.[12] Also Seismometers collect data on the order of 8-56 samples per second this simply is not desirable with communications being limited at 128 kbps and having two science instruments with data.

Implementation: A seismometer would typically require direct contact with the surface for accurate readings. If implemented statically inside the shell, the internal material properties could disrupt or dampen the seismic readings. Direct access to the surface would be required for high fidelity data, however low fidelity reading could be taken statically from within the shell.

4.1.3.2 Camera

While several probes have taken pictures of Europa from orbit, it would still be useful to capture images from the surface. These could be used to further characterize the geomorphology and scout potential landing sites for future missions. It is also important not to discount the public interest that photos would generate. However, there are several reasons why this particular probe may not be well suited for cameras. The NeoPod will have an uncontrolled descent, and will probably remain stationary for the entire mission with no control of orientation.

Implementation: In order to increase the chance that the NeoPod could take useful picture, we would like to install multiple cameras evenly spaced across the outer surface of the probe. These cameras would take pictures periodically at a rate of once every half hour. For the purposes of this project, we will likely only use one camera as proof of concept.

4.1.3.3 **Micro-Imager**

Since images of Europa have only been obtained during flybys, it would be useful to take close up images of the surface of Europa. A micro-imager is a type of device used to take imagery of close up objects to offer greater insight towards the details of the objects. One of the best uses of a micro-imager on the surface of another celestial body would be to image the particles on the surface allowing greater insight towards the composition of the surface. As Europa is covered in ice, a proper micro-imager would be able to closely examine the crystalline structure of any ice adjacent to the probe upon settling.[13] Due to size and power limitations as well as the need for cryogenic cooling, a standard micro-imager was determined unfeasible, but alternatives were considered.

Instead of using a proper micro-imager, a method of gaining similar information including close images of the surface of Europa would be to fit a lens assembly to a set of standard cameras. Similarly to the camera implementation, multiple of these pseudo-micro-imagers would need to be placed around the NeoPod structure in order to ensure proper data collection. Again, as a proof of concept, most likely only one camera and lens assembly would be integrated into the probe.

Implementation: Using multiple cameras to insure the capture of the surface would be a must. In order to create a micro imager, a lens would be fitted over the camera port.

4.1.3.4 **Thermal Imager**

A thermal imager has been used on many different satellite missions. The purpose of a thermal imager is to be able to map a surfaces temperatures and temperature fluctuations over a period of time. Currently, JPL is planning a mission to Europa in which the orbiting satellite will contain an infrared imager. JPL hopes to be able to find areas on Europa that are active thermal sites, such as warmer water coming to the surface.[14] From this data they will be able to better characterize Europa's surface.

For the ELSA mission, the Neopod would not be orbiting the moon of Europa, but would instead be landing on the surface. Science data would be collected from the stationary probe over the period of 96 hours from a single point on Europa's surface. Because these infrared images are taken from a single point, this would be a significantly different science mission than what JPL is planning and would not be as useful. Like the previous camera option, six cameras would likely have to be installed on the NeoPod to ensure that at least one camera is getting useful data when the probe comes to rest. Thermal images would be taken periodically throughout the mission from all cameras and relayed to the orbital clipper.

4.2 Avionics

The avionics board will serve as a central component of the NeoPod data handling system. While the avionics board will be provided by Ball, however, will come with no software. The software that will be developed by the ELSA team must accomplish the following tasks:

1. Handling Data from Instrument Suite
2. Responding to Commands
3. Initializing Data Collection and Transmission Modes
4. Controlling Peripheral Power Allocation

The provided avionics board will process information via an FPGA. The FPGA in use will be a Microsemi ProASIC3 L3000, with Cortex-M1 soft processor support. The soft processor support means that the FPGA will have the ability to have a processor core coded into its logic gates. This allows for software to be written for both the FPGA and the microprocessor which allows for different tasks to be handled by the more appropriate system.

4.2.1 Development Process Design

Because FPGA development differs from microprocessor development, the development design options will be shown in detail. FPGA software is written in a hardware description language (HDL), that is typically Verilog or VHDL. When an HDL system is compiled, it is returned in a register transfer language (RTL). The RTL system must then be synthesized into the logic gates of the FPGA. This means that functionally correct software written in an HDL may be logically sound and compilable, but not synthesizable. This also presents obstacles in correctly creating a test environment that simulates the hardware being used. Subsequently, a development FPGA is typically used prior to flashing the production FPGA. In order to execute the development and simulation, software packages are available. Below are a few different development process designs.

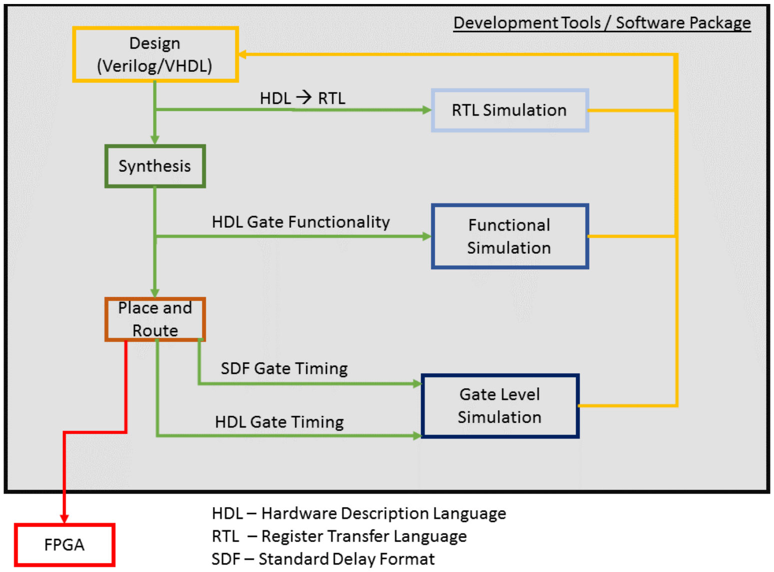

Figure 6: HDL design using software simulation and testing tools

The above design utilizes a rigorous process of testing and simulation that could be used if the used development tools are able to simulate the ProASIC 3L hardware. This method would provide an efficient and rigorous software validation process. It would allow for rapid development changes to be made and testing in a single environment. This method would also allow for a development FPGA to be used as a validation step prior to flashing the production FPGA. However, a downside to this method is that the simulation functionality and depth would be dependant on the capabilities of the development tools that are used.

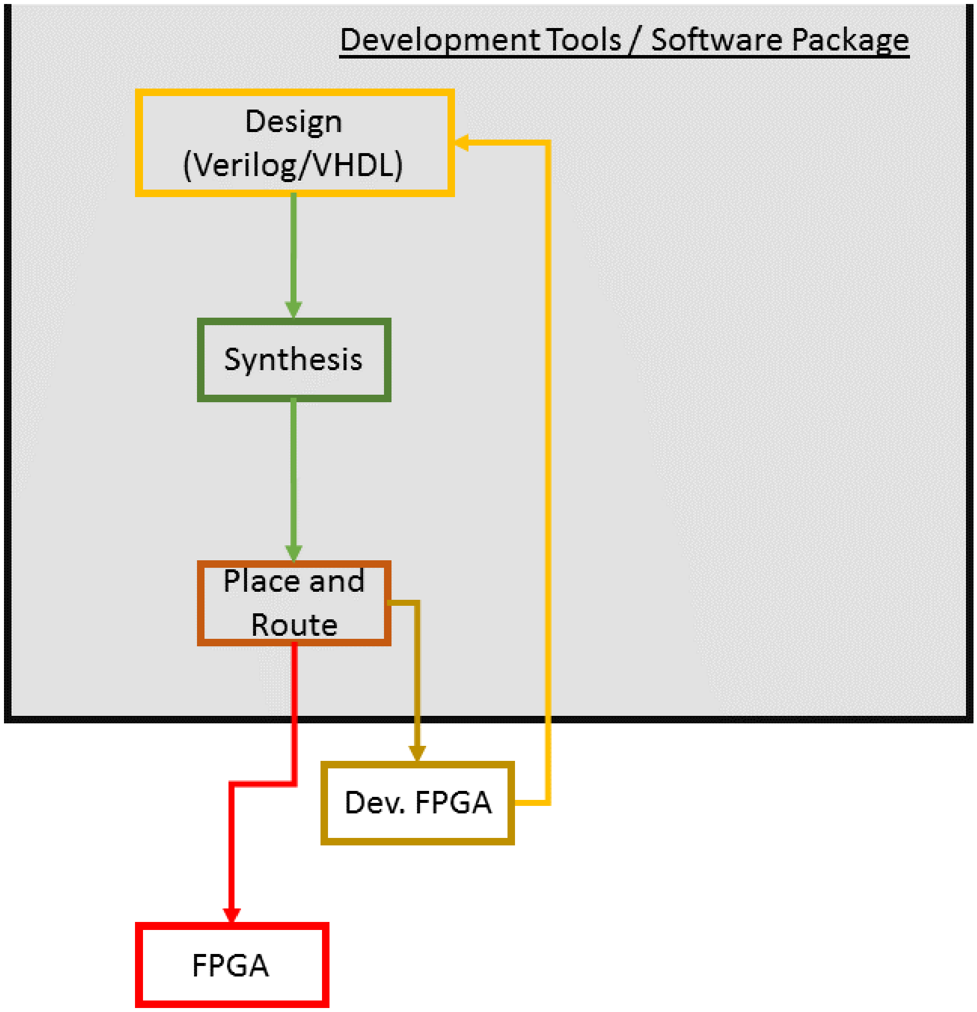

Figure 7: HDL design using a development FPGA for all testing

The design shown in Figure 4.2.1.2 is a design method that would rely on the testing of all software on a development FPGA. This method is advantageous in the fact that it would provide hardware validation of the developed software. However, this method would be less efficient in that development would be tied to the hardware, making rapid changes more difficult to implement.

4.2.2 Development Packages

One of the key development tools will be the development software package that is used. Most major FPGA manufacturers provide development software. However, the main downside to this is that the given software package only supports the given manufacturer's products. Each software package listed is available for a free download.

Table 4.2.2: Development Packages' Features

Software	Features
Libero SoC	ProASIC3L Hardware Support, HDL Graphical Design, Microcontroller Configuration, Optimization, Pre and Post Synthesis Simulation, Power Analysis, FPGA Programming, On Chip Debugging, Matlab/Simulink Design Support
Altera Quartus II	HDL Graphical Design, Testbench Simulation, FPGA Chip Editor, Logic Analyzer, Synthesis Limited to Small Devices, Matlab/Simulink Design Support
Xilinx ISE	HDL Graphical Design, Testbench Simulation, FPGA Chip Editor, Logic Analyzer, Synthesis Limited to Small Devices, Matlab/Simulink Design Support

The Microsemi software package, Libero System on Chip (SoC) serves as a design and testing tool that can generate hardware simulations of their products. Libero SoC also includes a synthesizer tool that executes the FPGA programming process. Other open source packages are available for HDL simulation, however, are not as feature rich as Libero SoC in the specific hardware support. Libero SoC is particularly advantageous based on its support for the ProASIC3L line of FPGAs.

4.2.3 Development Hardware

Another key option to consider is the procurement of a development FPGA. While the FPGA that is part of the provided avionics board is re-programmable, it is not common practice to develop with a production board. Below are several of the validation and development kit options that are available.

Table 4.2.3a: Development Hardware Features

Development Kit	Features	Cost
Microsemi ProASIC3L Dev. Kit	ProASIC3L-M1A3P1000L FPGA (1 Mil. Gates), USB Prog., USB RS-22 Port,3X 40 Pin GPIO, 16 MB flash memory, 4MB SRAM	\$600
Altera DE0	Cyclone III FPGA (200k Gates), 346 GPIO, USB Prog., 4MB flash memory, 8 MB DRAM, Used in ECEN 2350	\$81
Bemicromax10	USB Prog., 250 GPIO, 256 kB flash memory, 8MB SRAM, ADC	\$30

The Microsemi ProASIC3L Development Kit offers hardware compatibility with the FPGA that is being used on the avionics board. This board provides substantially more power and functionality, however, is much more expensive. However, this board could also serve as a viable contingency option in the event that the provided avionics board is not available. This would allow for one main software design to be applicable to both the Ball-provided avionics board, and the contingency plan. The Altera DE0 and Bemicromax10 are lower cost development boards that could be obtained quickly for instructional purposes. While designs will not be directly portable to the production board, these development boards could be a valuable resource in building a knowledge base for FPGA design in the very near future.

In addition to development hardware and environments, a rough curriculum can be developed that presents instructional FPGA development tasks that meet specific functional goals that will need to be accomplished for the in production board.

Table 4.2.3b: Development Hardware Features

Level	Objective	Motivation
0	Understand dev environment and FPGA programming process	These skills will be needed in order to actually put code on the production FPGA.
1	FPGA flashes a light	Basic clock, process, and output needed for production FPGA
2	Inputs logic value, blinks light according to true or false	Gives basic understanding of inputs and functional processing
3	Inputs 2 logic values, flash separate lights according to true or false	Provides basic understanding of parallel processing
4	Inputs logic values, stores values in FIFO (First In First Out) or RAM, outputs logic value	Exposure to FIFO and RAM operation
5	Inputs logic values, stores values in flash memory, outputs to light	Input, storage, and output all necessary for production FPGA functionality
6	Inputs sinusoidal signal, stores values in flash memory, reads from memory, packetizes data, outputs to serial port	dynamic data must be store and data packets must be formed for proper transmission of data in the production FPGA
7	Repeat 6, add a logical input that turns output on or off	Command handling is required for the production FPGA

By following the instructional curriculum above, a solid knowledge base and skillset will be developed that directly correlate to the functions necessary for the production avionics board. Another instructional resources could be the Electrical Engineering department, most notably, the ECEN 2350 digital logic course that covers some FPGA development. Literature and online tutorials may also prove to be a valuable resource.

4.2.4 Software Design Language

One of the main design options present at a high level is the choice of hardware design language (HDL). Due to the fact that synthesizing is not always compatible with compiled code, some languages present more challenges than others.

Table 4.2.4: FPGA Software Design Languages

Language	Pros	Cons
VHDL	• Strongly Typed • Fewer Synthesis Errors	• Large learning curve • More verbose
Verilog	• Smaller learning curve • C-like/concise • Larger Support Network	• Errors more common during synthesis
MyHDL (Python)	• Python development • Synthesizeable code conversion	• Less control of converted code • Allows for lack of understanding
MATLAB/Simulink	• Familiar environment • Libero integration and support	• Less control of converted code • Often results in inefficient code

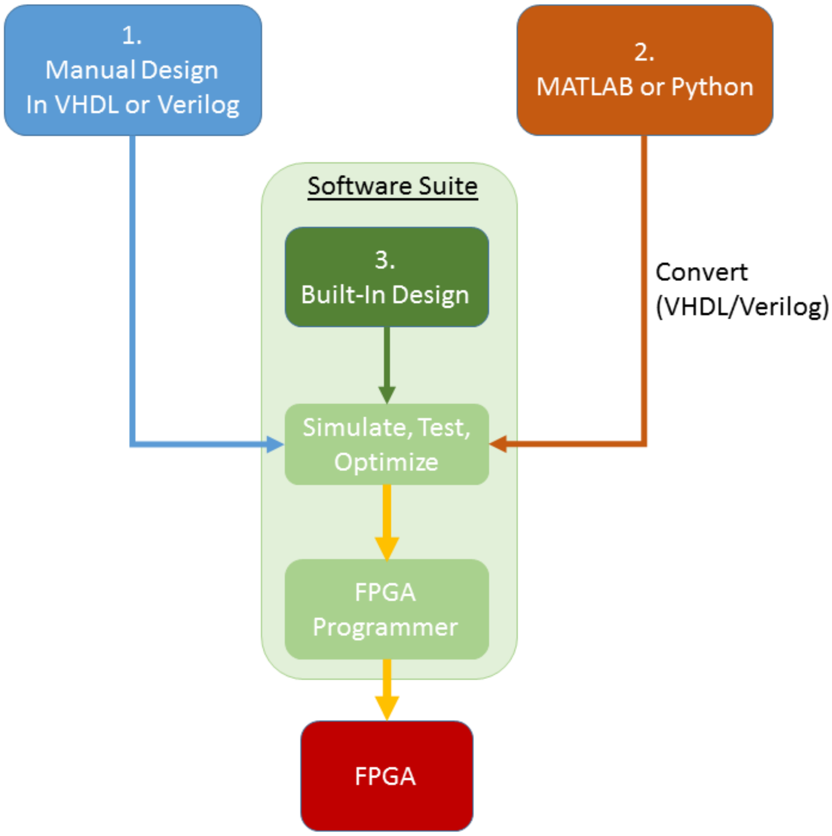

Figure 8: Design entry options and flow down

4.2.5 FPGA Software Design

While much of the options discussed up to this point have been related to the development process and environment, no amount of tools can fix an inherently bad software design. While there are fewer high level design choices to be made in regards to software, there are still several choices that can accomplish the same goals. The critical functions that the FPGA software must be able to achieve are sensor data input, data storage, packetization, packet output, command reception, and subsystem power control.

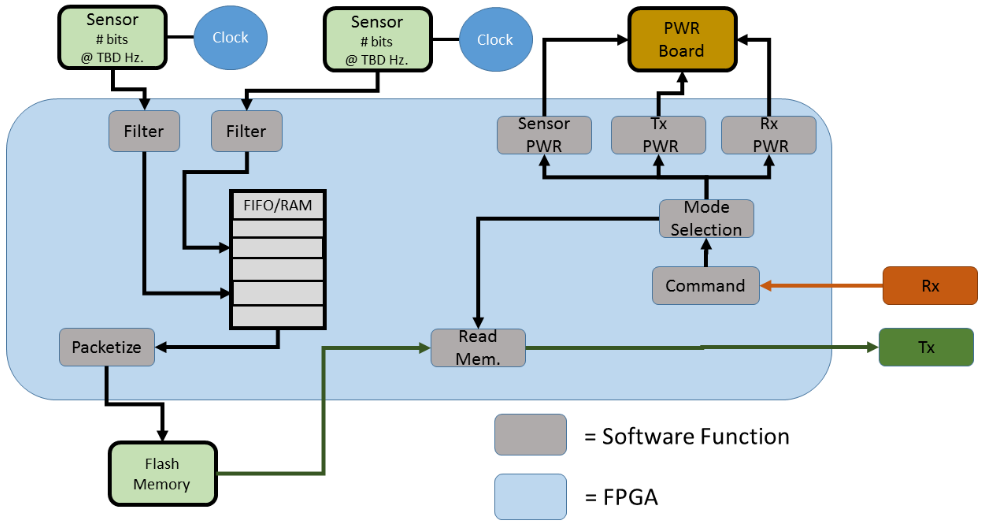

Figure 9: FPGA functional software design design with all functions in embedded logic

Figure 4.2.5.1 outlines a functional software design for the FPGA. Essentially, the system is broken into two main sections; data ingest and packetization , and command and data transmission. Due to the parallel nature of FPGA's, these processes will be executing in parallel, however, could be on separate clocks. A key to this design is that data ingest will be only writing to memory, and the data transmission will only be reading the data memory. This simplifies the memory access process and eliminates the need for a complex gatekeeper. One of the advantages of this design is that all of the process will happen in the FPGA logic. This allows for maximum power efficiency and speed of the FPGA. The ProASIC3L can achieve speeds up to 350 MHz. However, one of the downsides is that the more intensive commanding and data processing operations could be more complex to design.

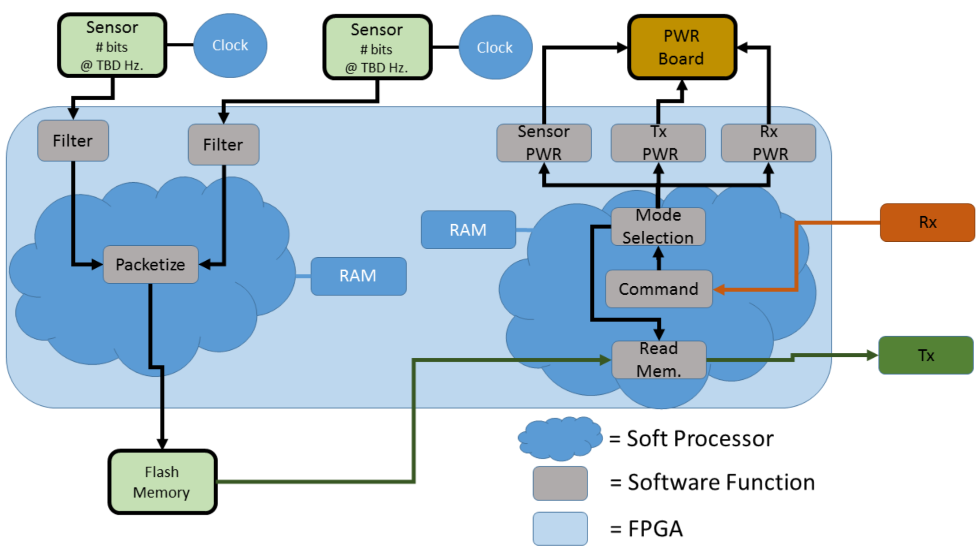

Figure 10: FPGA functional software design with 2 soft processors

The figure above outlines a functional software design that includes the implementation of 2 soft processors. The rationale behind a soft processor is that sequential processes can be embedded into the logic of the FPGA. This makes intensive data processing simpler from a programming perspective. Soft processors also allow for more flexibility in software design. Changes can be made more freely in that they can be isolated from the logic design of the FPGA. In this design, using separate soft processors for data ingestion and process commanding allows for more flexibility[17] in how data commands are processed. Each processor would be devoted to its specific task. Each process would have their own dedicated RAM, eliminating possible process conflicts. Also,similar to Option 4.2.5.1, the ingest process would only write to flash memory, and the commanding process would only read from flash memory. Again, this eliminates the need for a devoted memory gatekeeper. However, the downside to this design is that soft processors are typically slower and require larger power consumption due to their sequential nature. The maximum speed of the soft processor would be 60 MHz whereas the maximum speed of the FPGA is 350 MHz. They are also more RAM intensive.

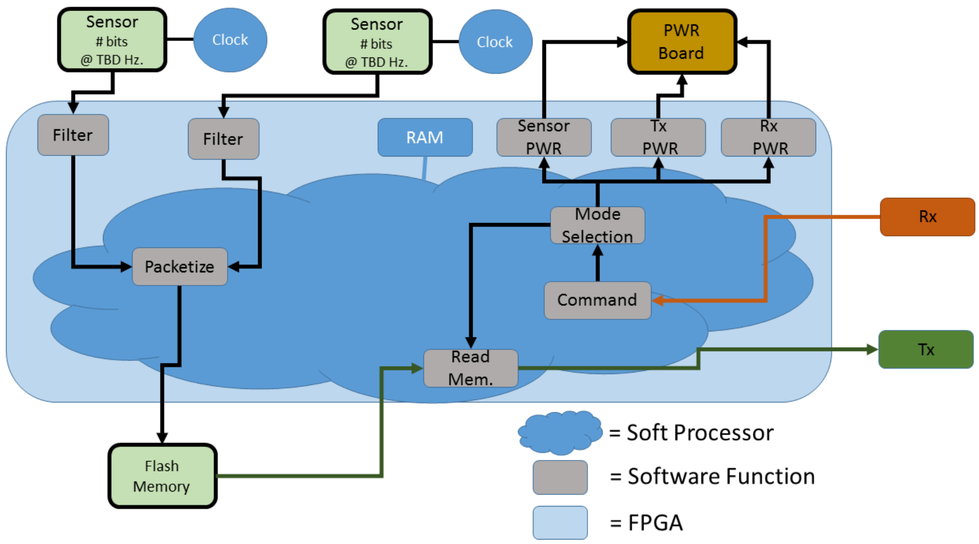

Figure 11: FPGA functional software design with 1 global soft processor

In this design a single soft processor would be implemented to handle all of the data processing and commanding. This design would be analogous to using a single core microprocessor. This design could be appealing due to its similarities to known microprocessor systems. However, since several functions would be all running in the same process, it would be difficult to design the system to handle data at the appropriate rates. The entire system would be locked to a single clock. This may not be advantageous if data ingest and transmission have different clock requirements. Utilizing this design could also present RAM conflicts as the system would be on one shared RAM system. This design would also consume more power and have a lower processing speed. The maximum speed of the soft processor would be 60 MHz whereas the maximum speed of the FPGA is 350 MHz.

4.2.6 COTS Microcontrollers

In addition to the FPGA options, it is crucial to consider the case where the FPGA software unforeseeably reaches a point outside of the scope of the project itself, or if problems arise in obtaining the proper hardware from Ball. In these scenarios, quick alternatives must be considered such that the payload and communications systems may still communicate to meet the project goals. The microcontroller will provide a simple solution should there be any problems with the FPGA. It would provide a processor, I/O, A/D converters, serial communication capabilities, and timers that would all be sufficient in still producing a fully communicating NeoPod. At the cost of higher power consumption, lower efficiency, and abandoning the goal of testing a flight-grade Avionics board, a microcontroller would be a simpler task, only requiring higher level, and familiar C programming techniques in a field that is highly developed with various testing and debugging resources. The major differences between using an FPGA and microcontroller are outlined below in Table 4.2.6a.

Table 4.2.6a: FPGA vs Microcontroller Programming

	Pros	Cons
FPGA Avionics Board Config	• Most efficient power consumption • Higher control of gate logiv • Customer preferred	• Least experience within the team • Large learning curve • Requires synthesization • Dependant on delivery of board that is not ready yet
Microcontroller	• Previous team experience • More resources for help • Familiar programming languages • known development process	• less efficient • Does not fulfill customer desire of testing in-house board • Limiting function/processing capabilities

However, the process of choosing a microcontroller is a nontrivial one as well, as there are many COTS options available. Table 4.2.6b outlines a few of the possible microcontroller alternatives. The models were all chosen based on the brand's highest performance device for ease of comparison and necessity of high performance. As can be seen below, a general trend is that with higher performance, complexity tends to increase. That is that the BeagleBone and Raspberry Pi products lack the analog capabilities of the Arduino that is preferred for working with sensors. This leads to a difficult choice between ease of use and control/performance.[18]

Table 4.2.6b: FPGA Software Design Languages

Microcontroller	Pros	Cons
Microsemi ProASIC3L Dev. Kit Comparison SRAM: 4 MB CPU: 350 MHz GPIO: 120	• High performance • Most I/O options	• Small community
Arduino Due[E] SRAM: 96 kB CPU: 84 MHz Analog I/O: 12 Digital I/O: 54	• Large community • Ease of working with analog signals • Used for TIRESIAS	• Lack of multithreading • Less debugging support • Does not run full operating system
Netduino 3[F] RAM: 164 kB CPU: 168 MHz Analog I/O: 6 Digital I/O: 14	• Multithreading • debugging support	• Poorer performance - large memory footprint • Small community
Raspberry Pi Compute Mod.[G] RAM: 512 MB CPU: 700 MHz Analog I/O: 0 Digital I/O: 48	• Large community • High performance	• No analog I/O
BeagleBone Black[H] DRAM: 512 MB CPU: 1 GHz Analog I/O: 7 Digital I/O: 65	• Highest performance	• Small community • Poorly supported

4.3 Power

4.3.1 Power Source

The most important aspect of the power system is the power source. While there are many options for powering our probe, most of these not feasible for our project. Preliminary research is enough to rule out many of these options.

One commonly used option is using solar panels to absorb radiation from the sun which can be converted to electricity. It is particularly useful for missions orbiting Earth, and is a viable option for interplanetary missions as far out as Mars as long as the solar panels have enough surface area. However, past this point it is nearly impossible to capture enough of the sun's radiation to power even a small vehicle. For deep space missions, many spacecraft rely on radio isothermal generators (RTG). Sometimes referred to as a "nuclear battery", these devices use extreme the temperature differences between decaying radioactive material and space to generate voltage. These devices are very reliable and can provide energy for 10-20 years with even a small amount of radioactive material. They are relatively inefficient and very heavy due to the extensive shielding that is required to protect the other equipment for the radiation. As a result, the energy density of most RTG's is about 1-3 Wh/kg.[23] Mechanical energy storage systems are a less common option that has high energy density and is capable of high maximum power outputs. Generally, a wheel is mechanically spun up to a high velocity. Energy can then be extracted or stored by decelerating or accelerating the wheel respectively. Efficiency and lifespan can be problems because they are largely dependant on having a near frictionless wheel. Additionally, devices with moving parts can be more complicated to implement in confined spaces. Supercapacitors also have high power density, and are able to handle large currents to charge and discharge quickly. For this reason they are commonly used to power tools and other small devices in space. One downside is that they have low energy density, and are not capable of storing large amounts of energy for significant periods of time.[24] Finally, there are some more experimental methods that would be particularly in an environment similar to Europa. Jupiter emits large amounts of background radiation that could potentially be converted into electricity. Also, converting a changing magnetic field into electricity could make use of the current induced on Europa by Jupiter's magnetic field. However, both of these methods are largely unproven and it would be very difficult to replicate the conditions necessary for them to function.

Based on the information above and the constraints of our project, the best option for the probe's power source is batteries. In general, batteries have a high energy density, and are able to store more energy for longer periods of time than supercapacitors. They will also be much simpler to implement than mechanical energy storage or an RTG. A collection of cells can be combined into a battery pack in order to be more space efficient. Several of these packs can be connected based on the energy need of the other systems. There are several types of chemical battery cells to be considered.

Table 4.3.1: Power Source Options

Battery Type	Temp Range (^{o}C)	Specific Energy (Wh/kg)	Pros	Cons
Nickel-Cadmium	0-25	60	Secondary source. Flight heritage	Low specific energy. Expensive
Silver-Zinc	-20 - 75	100	Large temperature range	Expensive and high potential for hazardous chemical release.
Lithium-ion polymer[25]	-10 - 40	200	Inexpensive, High specific energy, rechargeable	Small operating temperature range
Lithium Sulfur Dioxide	-55 - 70	250	Large temperature range. High specific energy	Expensive and high potential for hazardous chemical release. Primary source only.
Alkaline	-20-54	200	Inexpensive and safe	Primary source only. Lower current capacity
Energizer Ultimate Lithium	-40-60	350	Safe, very high specific energy, large temperature range	Primaty source, not rechargeable

4.3.2 Power Distribution Board

The final aspect of the power system that involves multiple design options is the power distribution board. All of our systems have different power requirements that must be accommodated: the FPGA requires 1.5 volts, the VT15 transmitter and FR10 receiver require about 12 volts, and the average voltage value for the sensors being considered is about 5 volts. Additionally, not all of the systems will have to be powered for the same amount of time. The efficiency of the mission could be improved by incorporating ways to command the power supply to individual subsystems. With this in mind, five possible power board designs were developed.

4.3.2.1 Single Battery Package

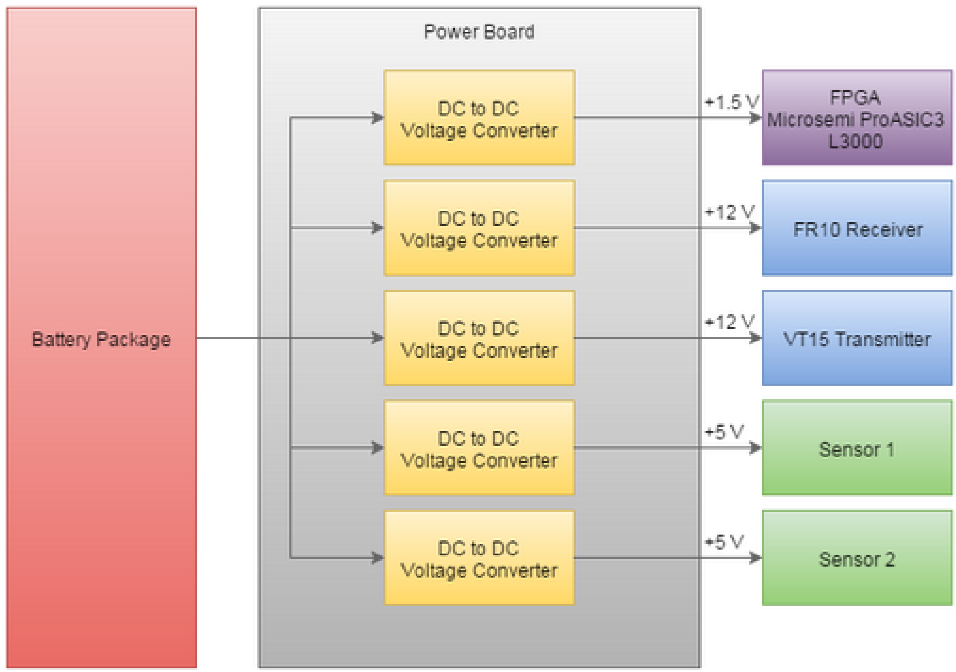

Figure 12: Single Battery Package Design

With this design, all the batteries will be stored in a single brick and supply a single voltage to the distribution board. From there, this voltage will be conditioned using DC-DC regulators and then connected to each corresponding device. If necessary, additional signal conditioning and noise reduction could be applied to each of these signals depending on the requirements of the subsystem.

4.3.2.2 Single Battery Package with Switches

The second design is the same as the first except it incorporates commanded switches to control the power supply to each subsystem as shown below.

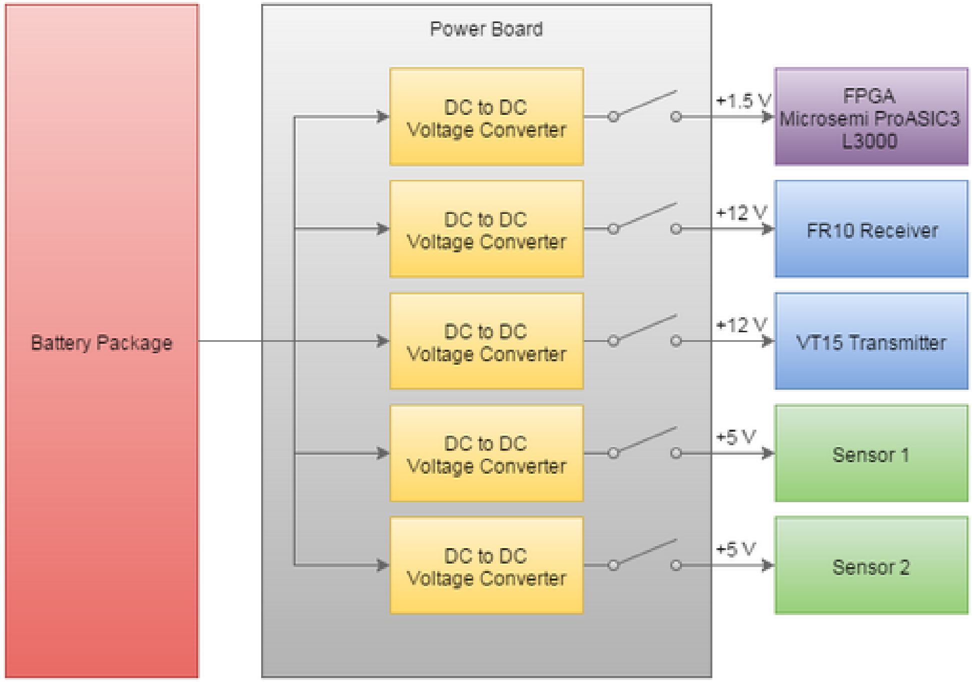

Figure 13: Single Battery Package w/ Switches Design

4.3.2.3 Individual Battery Packages

The third design is a direct path power distribution board, where each subsystem received power from its own battery package.

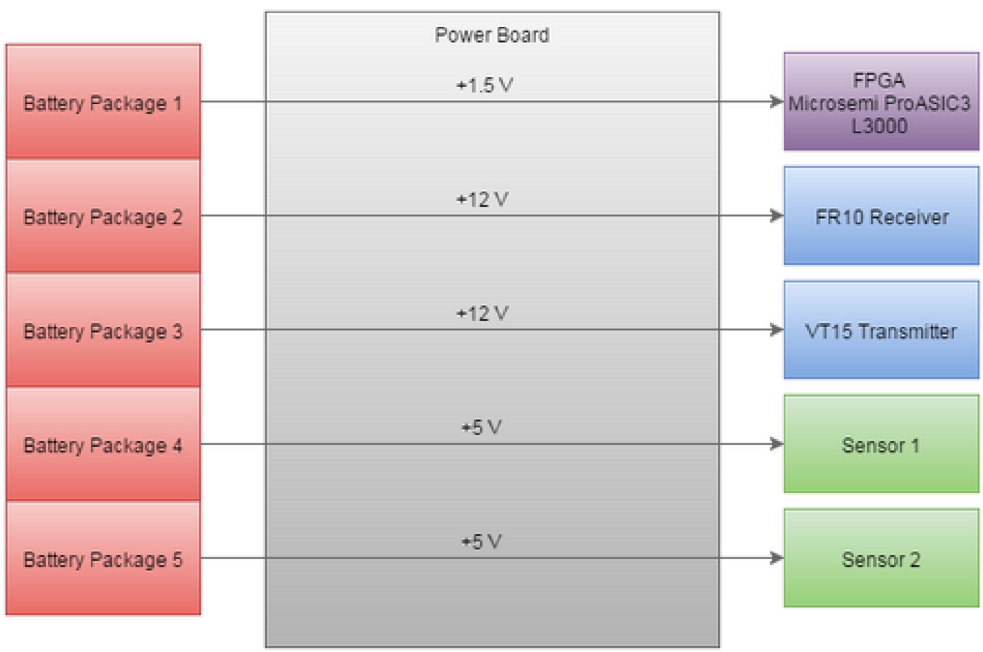

Figure 14: Individual Battery Packages Design

4.3.2.4 **Hybrid 2 Battery Packages with Switches**

The fourth design is a hybrid between the first three design concepts. It involves multiple power sources, but now incorporates a more efficient command scheme. This is illustrated below.

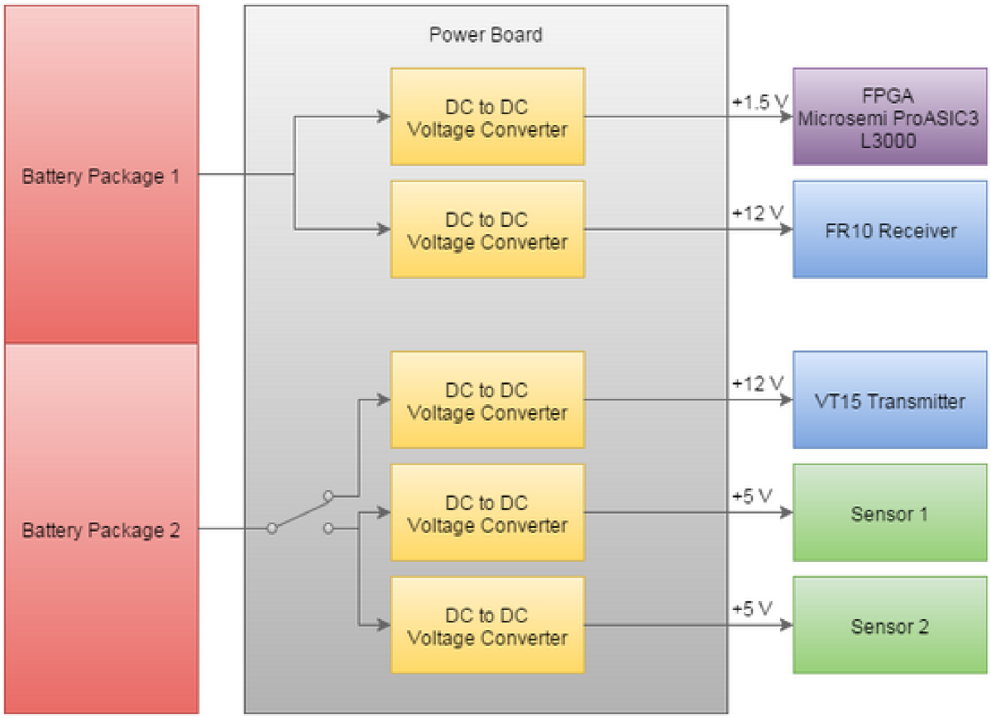

Figure 15: Hybrid 2 Battery Packages w/ Switches Design

This design is based on the logic that two out of four of our subsystems require constant power, while the other two would not need to be powered when the other was on. One power supply would go through two DC-DC regulators and then supply power to the avionics board and the receiving communication system. These subsystems will need to be powered for the duration of the mission. The other power supply would go through a commanded switch, through DC-DC regulators, and then to the payload sensors and transmitting communication systems. This would allow for one of these systems to be powered off while it is not in use. Having two power supplies would allow for greater control over the voltage supplied to each of the different systems.

4.3.2.5 **Voltage Division with Control Switches**

The fifth design brings elements from several of the previous designs. It is unique in that it takes advantage of the fact that some of the systems use the same supply voltage. This is similar to direct path board in that the batteries are arranged such that there is no need for voltage conversion. Additionally, this design implements command switches for the systems that will not be on during the entire mission.

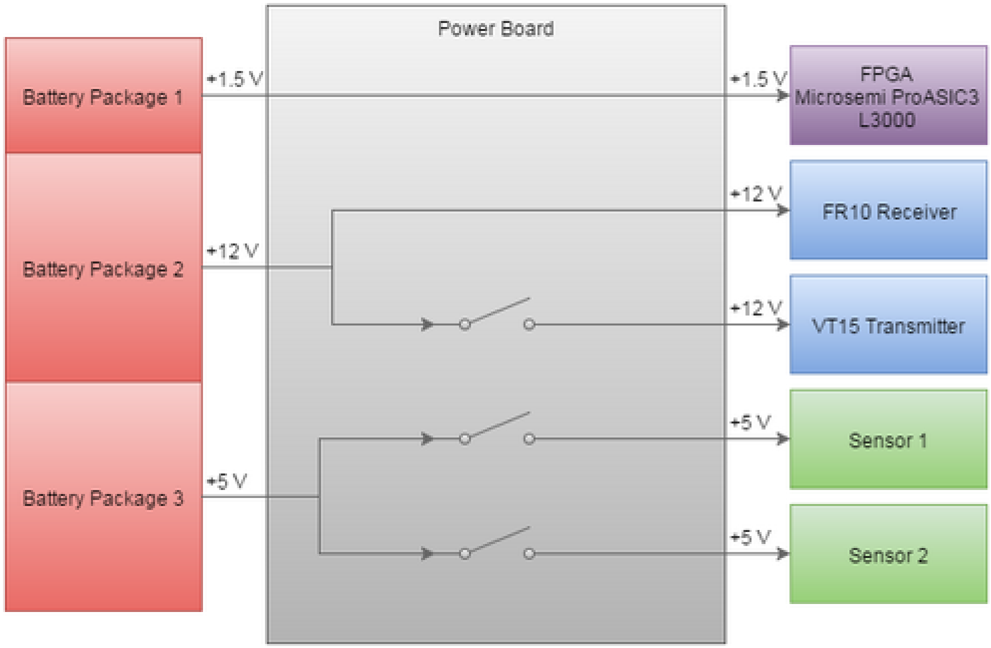

Figure 16: Voltage Division w/ Control Switches Design

No matter what design is selected, we need a general plan for how the board will be constructed. It is unlikely that we will be able to buy a board that meets all of our exact specifications. However, it is possible to purchase components of the board individually such as the DC-DC converters and command switches. These can then be connected to create the chosen power board design.

4.3.2.6 **Voltage Division with Control Switches**

The final option would be to build the entire board by ourselves. This would potentially be cheaper, and allow a greater amount of control that could improve the volume and energy efficiency of the board. This design will be highly affected by the other design choices made.

4.4 Structure

4.4.1 Internal Mounting

The structural design of the NeoPod must be able to house and mount all internal NeoPod components: batteries, avionics board, power board, two science payloads, transmitter, receiver, antennas, adc converter, and wiring between components. Three basic designs were compared in a study to determine the feasibility of each option capable of housing all of these components. The first option considered was the TIRESIAS heritage structure which was the final design of a previous senior project. Another option was a simple shelf structure which separates the neopod into three separate compartments. The last option was similar to the shelf option, however divides the NeoPod into four quadrants.

One of the main concerns for the mounting structure is that the NeoPod will be able to contain enough batteries to collect science data over a 96 hour period and relay the data to the orbital clipper. Therefore, a significant amount of space was reserved for batteries in each of the designs while still being able to accommodate the other components

4.4.1.1 **TIRESIAS Heritage Structure**

The TIRESIAS heritage structure was an obvious option to consider for the structure trade study, simply because the it has been designed and manufactured previously. In the TIRESIAS project, the NeoPod was required to last a duration of 10 days which included the acquisition of data from a science instrument and the ability to transmit the data. This structure provided the TIRESIAS team with enough batteries to meet the 10 day goal. Because the ELSA mission requires that data needs to be taken for 4 days and transmitted to a clipper, it is reasonable to assume that this structure would be sufficient for the proper amount of battery storage. In this structural configuration, all batteries were housed within the four center pylons of the structure. All circuit boards and science instruments were mounted parallel to the outer surface of the pylons. This configuration would be nearly identical to the ELSA NeoPod configuration with the exception of a different science instrument, and different circuit board dimensions. (mass 820 grams)

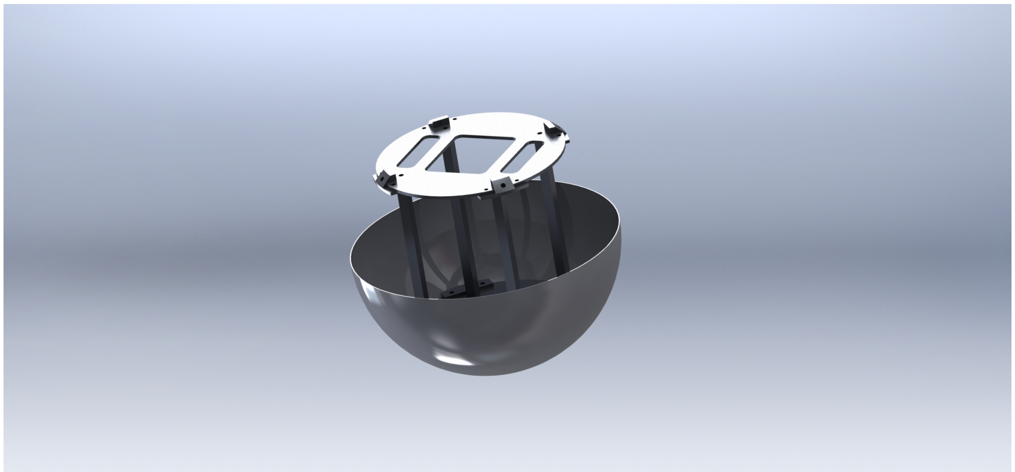

Figure 17: TIRESIAS Hertage Structure

4.4.1.2 Circular Shelves

The circular shelves structure option aims to reduce the complexity of manufacturing, while still ensuring that all components are able to be mounted within the sphere. This option also utilizes a significantly larger portion of the sphere's volume as a whole, which is advantageous for a longer mission lifetime if more batteries can be added.. Two circular disks will be bolted to the inside of the sphere (2 bolts per disk, per side of sphere) making the sphere as a whole become more rigid. All boards and science instruments will be mounted to the top and bottom compartments with bolts to ensure they do not move in any orientation . The center compartment will contain all of the batteries needed for the mission timeline. Again, due to the size of this compartment, more batteries can be added, resulting in a longer mission timeline.

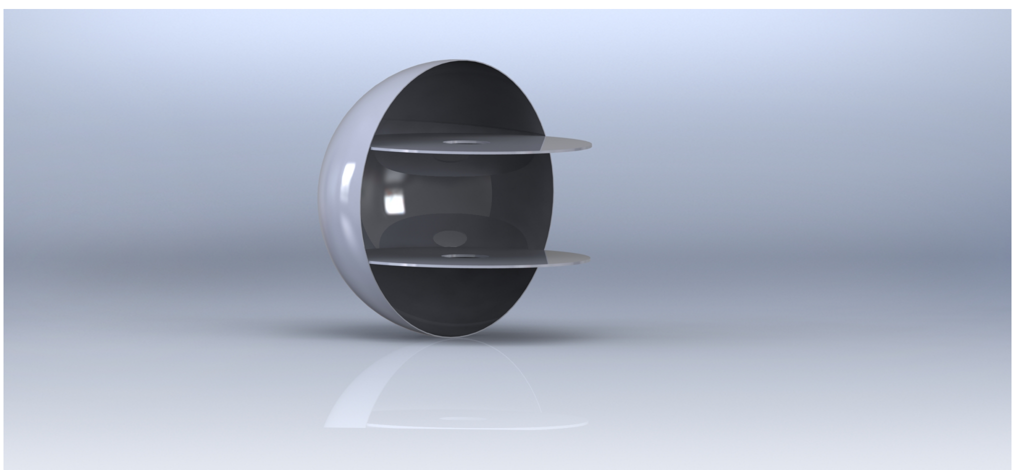

Figure 18: Circular Shelves

Wiring will be routed through the circular holes in the center of each disk allowing all subsystems to communicate to one another. The antennas will be mounted on the outside of the probe directly above each of the sections containing the circuit boards and payloads for ease of wiring.

A benefit of this design is its ease of use. The shelves are easily removable, making the mounting of each component fairly simple. Development and debugging also make this layout a good candidate as components can be added and removed with relative ease. (mass 820 grams)

4.4.1.3 Quadrants

The final option considered is similar to the shelves option which divides the sphere into sections. The quadrants design uses larger internal disks mounted with bolts to the outside of the sphere to divide the volume of the sphere into four equal sections. As with the shelves option, most of the NeoPod's volume will be utilized. The walls of each disk will be used for mounting batteries, circuit boards and science instruments. Two sections diagonal to one another will be used for battery storage while the the other two diagonal sections will be used for mounting circuit boards and science instruments. Mounting each component with bolts will ensure that the components are stable in any orientation. It is possible that additional shelves will be need to be added to accommodate the mounting of particular science instruments.

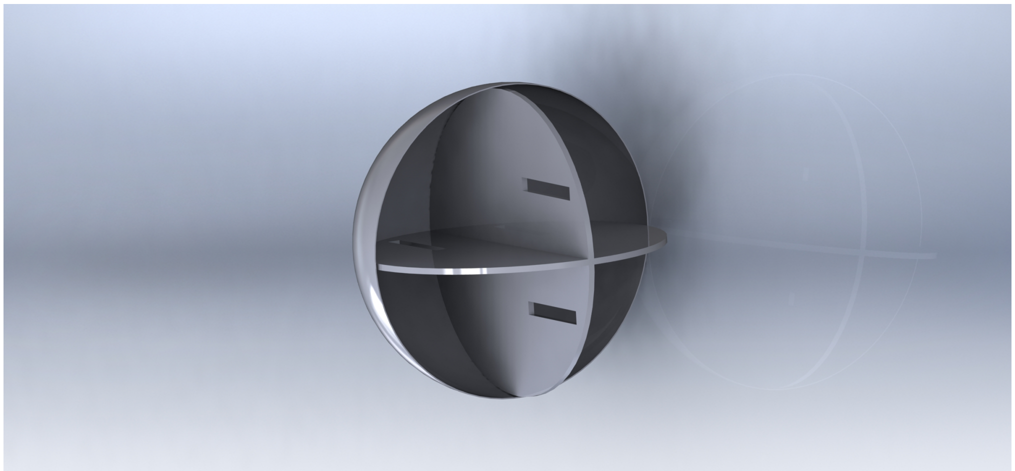

Figure 19: Quadrants

This design is more complex than the shelves design in that the internal structure would not likely be manufactured from a single piece of metal. Likely, welds would have to secure the disks together.

Wiring will flow through the rectangular cutouts in each quadrant allowing for proper subsystem communication. Similarly to the shelves option, antennas will be mounted to the outside of the sphere above the quadrants that contain the circuit boards for ease of wiring. (mass 900 grams).

4.5 Communications

4.5.1 Configuration

Shown in the following few pages are 5 physical block diagrams, which are design options for two-way communication between the NeoPod and a ground station. All receivers and transmitters shown each have 1 SMA port, each antenna is a single port patch antenna (unless specified otherwise) with unknown specs at this point as they are custom made. Modeling and testing must be done in order to exactly determine the capabilities of these antennae and therefore meeting the distance requirement may not be possible without purchasing or manufacturing different antennae. Antennae aside, the receivers and transmitters provided are configured to work only in the unlicensed ISM bands therefore any work in regards to regulations would be minimal to non-existent. A laptop with open-source command software is shown in each diagram along with a microcontroller, assumed to be an Arduino, are the commanding (master) pieces of the communication system. The pros and cons of each design option are discussed in the underlying paragraphs along with any clarifying remarks, in regards to the intricacies of each system. Each design is considered and is evaluated from financial, logistical, complexity, and potential to achieve all levels of success as well as fulfilling requirements. As the designs progress certain things are carried over but may not be explicitly stated or shown, for example design 2 mentions a RS 232 to RS 422 digital converter chip needed to go from the development board to the VT 15, therefore it is safe to assume any design shown with these two components connected that this chip is needed.

Table 4.5.1 below summarizes the communication design discussion into a pro/con relationship. This table will be used to pick the final communications design instead of a typical number-valued trade study.

Table 4.5.1: Communication Design Pros/Cons

Communication System Config.	Pros	Cons
Hardline Commands	• Simple design proven By TIRESIAS • All equipment provided by Ball Aerospace	• Only capable of Level 1 success • Interference with other subsystems • Distance limited
Duplexed Base Station Antenna	• Eliminates unnecessary equipment inside NeoPod • Capable of Level 4 success	• Requires purchase of one antenna ($100) • Requires purchase of duplexer ($350) • Added complexity for ground station • Does not run full operating system
Triple Duplexed Antennae	• Level 4 and beyond success • Simultaneous communication • debugging support	• Bulky duplexers and splitters inside NeoPod • High price endeavor ($1400) • Added complexity using FDD
Four Dedicated Antennae	• Eliminates unnecessary equip[ment inside NeoPod • 2 way simultaneous communications • Simple design • Level 4 success	• Dual frequency • Requires the purchase of two antennae ($120)
TDD Switch	• Single frequency • Eliminates unnecessary equipment inside NeoPod	• Added complexity of working with TDD Switch • Creation of timing schedule with commands

4.5.1.1 **Hardline Command**

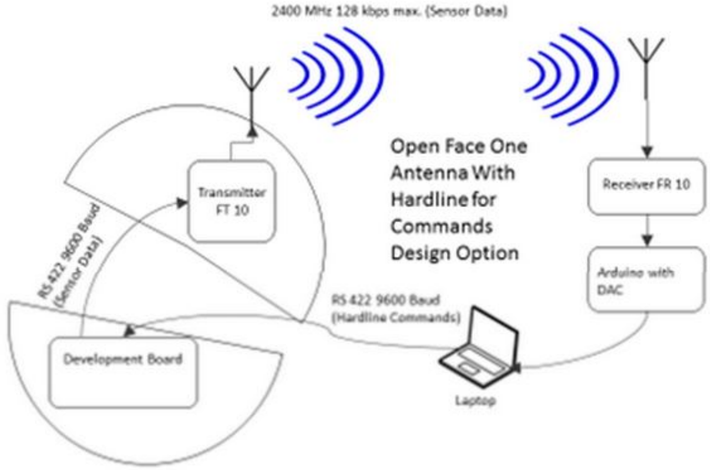

Figure 20: Hardline Command Design

The design above involves a non-autonomous pod which has hardline connection to the command station which would be a laptop with Cosmos installed onto it. The one and only frequency used in this option is 2400 MHz which is in the unlicensed ISM (Industrial Scientific & Medical) band. The lower power receiver and transmitter (FR 10 & FT 10) were selected for this design to absolutely minimize the power demand from the power system, while also still being capable of achieving 128 kbps. This design achieves short-distance tabletop success however it is not capable of long distances which stems from cable loss and logistics. This design is simple and does not involve the purchase of extra communications equipment which can be costly. However, there will likely be problems interfacing with other subsystems and even preventing the operation of those subsystems because this design essentially splits NEOPod in half.

4.5.1.2 Duplexed Dedicated Antennae

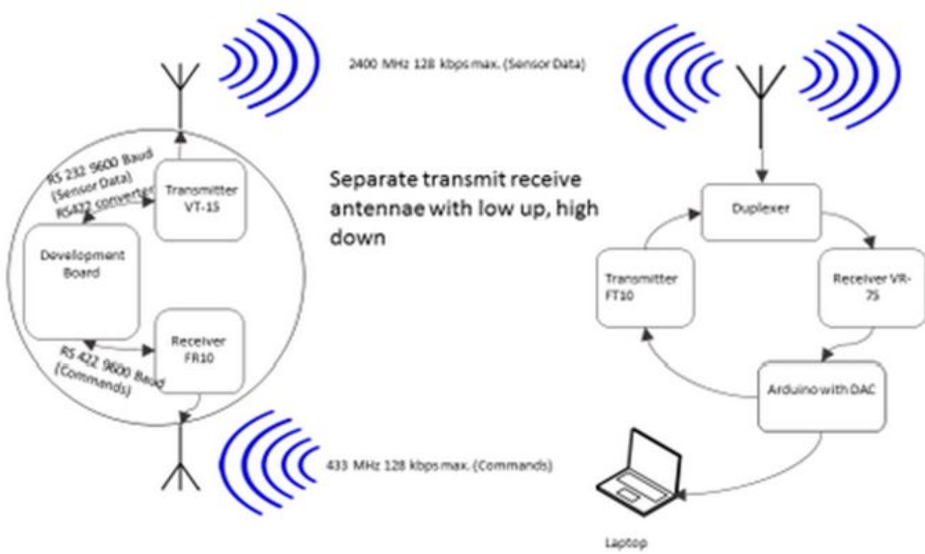

Figure 21: Duplexed Dedicated Antennae Design

This design involves three antennae in total with one being transmit and receive, the other two designated as either transmit or receive separately. There are two frequencies used with a large frequency separation between them which would make the duplexer slightly cheaper as it would not need to filter within the order of KHz but MHz however, these duplexers are around $350. The duplexer is also needed so that the ground station antenna may do transmit and receive with only one port. There are two models of receivers and transmitters in this diagram. The models which are enabled to do streaming video (VR-75, VT-15) use RS 232 for hardline communication, however, the FPGA development board only supports RS 422 therefore a digital converter chip is needed which has been researched to cost less than $100. This design would theoretically be unsuitable for an actual Europa mission due to the fact that the orientation of the Pod would be random and one antenna may be against the ground. However, as per the tabletop requirement the orientation of the Pod can be set by our group for the purpose of RF Comm. Another issue of distance exists because the power of each antenna is unknown, however it can be assumed that the strength of this system would be less than that of the following Option 4.5.1.3.

4.5.1.3 Triple Duplexed System

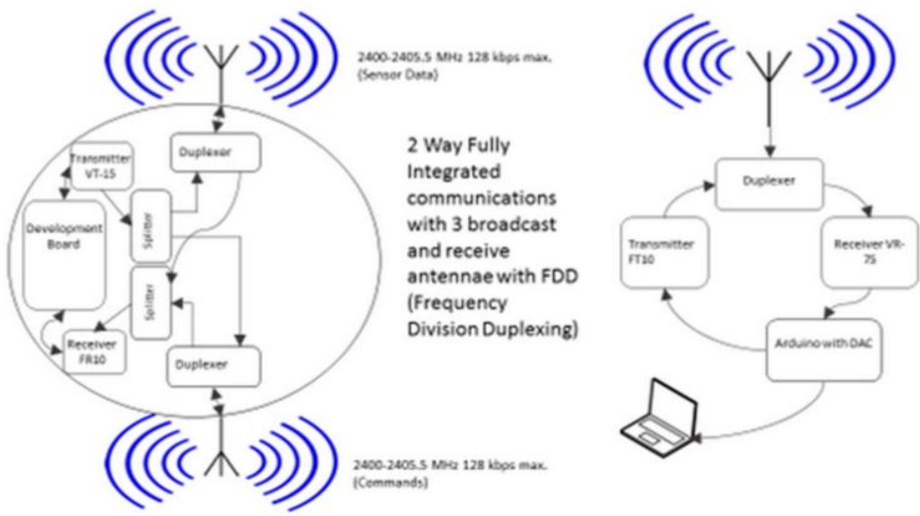

Figure 22: Triple Duplexed System Design

The schematic above enables all three antennae shown to transmit and receive, this design involves three duplexers using FDD (Frequency Division Duplexing) which will allow two-way communication to happen simultaneously, the advantage of having two-way communication with closer frequencies is that it involves knowledge of only one band and the realities that come along with that. Simultaneous communication is advantageous because it prevents the system from being limited by timing, this would apply to the Europa mission in that if the orbiter were to be slightly off of its orbit the length of transmission may change and a schedule doesn't need to be updated. Another advantage of this design is that the orientation of the Pod would not affect communications, which adds a capability to NEOPod. The use of multiple splitters and duplexers inside the pod is cumbersome in volume and mass as well as complexity, logistics, and even partially financially due to the cost of duplexers, which is estimated to be $1,050 for this design.

4.5.1.4 Four Dedicated Antennae

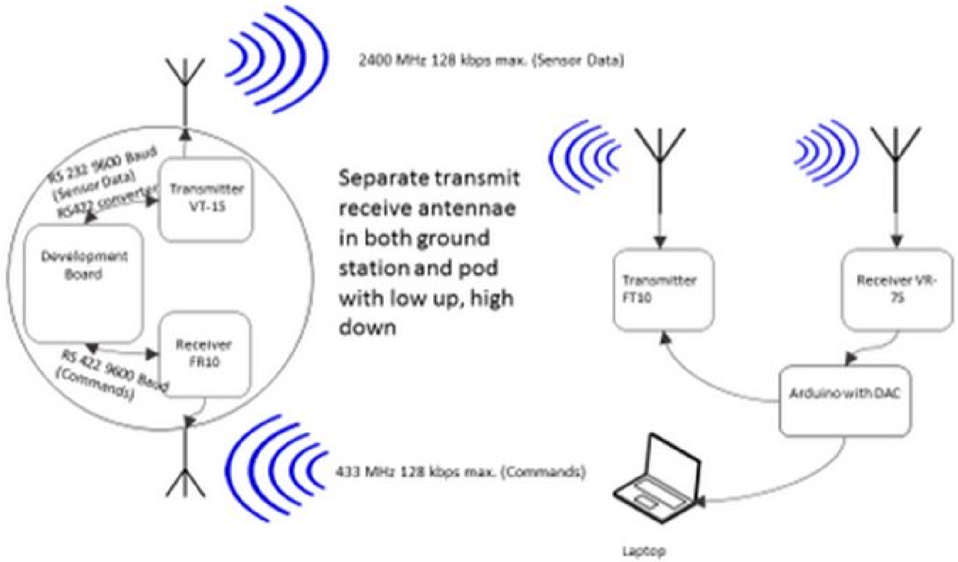

Figure 23: Four Dedicated Antennae Design

In this case we have added an extra antenna to the ground station in order to avoid any use of duplexer because of the cost. The "up" frequency would be 2400 MHz and the "down" frequency would be 433 MHz. Here the communications function of the Arduino is simply to handle going both ways at the same time so that the system is capable of transmitting commands and data at the same time. One large advantage of this design is the financial aspect of it as this design does not involve the purchase of anything besides an extra ground station antenna which could possibly be procured from the customer, otherwise the cost of an extra patch antenna compatible with the 2400 MHZ frequency and capable of 3.5 dBi costs about $60. This design is also suitable for a long distance test as the extra antenna could be purchased to achieve success in this test. The major initial driver of this design is to eliminate the use of bulky duplexers and splitters inside NEOPod. The downside to this design is that there would need to be separate considerations when using these different spectrums concerning path loss etc. Also in practice the two ground station antennae will need to be placed in a manner for minimal interference, which requires additional research.

4.5.1.5 Time Division Duplexing

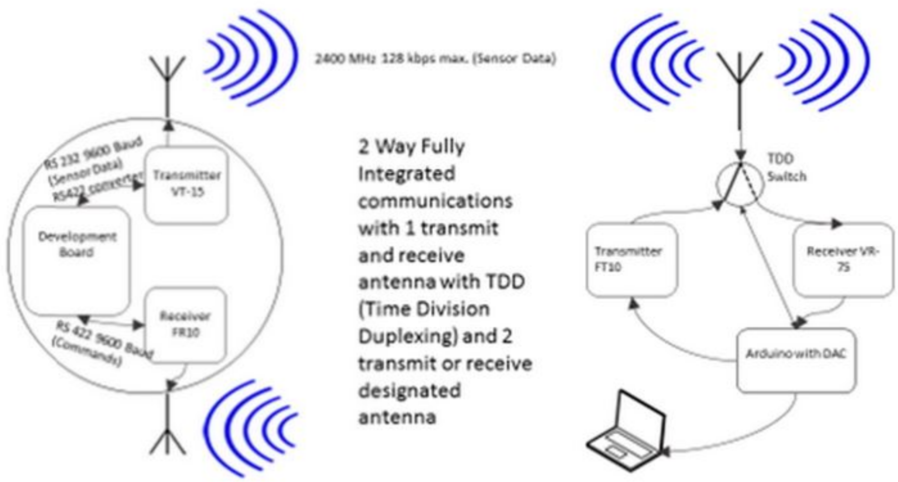

Figure 24: TDD Design

Again we have one antenna on NEOPod designated to transmitting data and the other NEOPod antenna dedicated to receiving commands. The ground station is set up for TDD which means that only one frequency is needed for communication but the ground station can only be either transmitting commands or receiving data at any given time, along with that, precise timing must be involved with the flipping of the switch which is controlled by the Arduino. The undesirable part of this design is designing a TDD system which can be slightly complex; mostly it involves high precision timing, however many moderately microprocessors have clocks and timers in them on the order of around 50 MHz.[R] This design includes an SMA compatible SPDT switch to be used with external input from the Arduino, the price of such a switch is about $60 and there are not many vendors who sell such a device. The weight or volume of the switch is not important because it is not inside NEOPod.

5 Trade Studies

5.1 Payload

5.1.1 Sensor Choice

Each metric in the trade study was rated on a scale of 1-5 with 1 being the lowest and 5 being the highest. Each metric and reasoning for its associated weighting value is given below:

Scientific Value (15%): A driving part of project ELSA is proving the feasibility of obtaining scientific information relevant to Europa. In order to demonstrate viability, scientific information relevant to Europa needs to be gathered therefore the scientific value of each type of information needs to be included in the decision process. While the value of each type of information is relevant, the main goal of the project is focused towards proving viability rather than collecting this data, therefore the scientific value of each instrument was weighted relatively low compared to other design metrics.

Cost (15%): Due to the highly constrained budget for this project, cost was determined to be an important factor for determining the types of scientific instruments to be integrated. Through research it was determined that a select few possibile instruments would cause a much greater strain on the budget compared to others, and due to the weighting of this characteristic, this metric will be able to show this increased strain.

Availability (16%): Since the project has a given timeline, the availability and ease of obtaining each instrument needed to be weighted. While this factor needs to be included in the choosing process, the multiple month period between picking a scientific instrument and the actual obtaining of hardware allows much of the complexity of the process to dealt with in manageable portions, therefore availability was weighted less than cost, complexity and size.

Complexity (20%): Due to the unknown aspect of integrating the FPGA as an avionics board and data handling system, the complexity of integrating the scientific instrument was given one of the largest weights. A standard sensor that may be plug and play on a hardware based microcontroller may be a much larger and more complicated operation to transfer to the FPGA environment.

Size (22%): Due to the size constraint of fitting within a 30 cm spherical housing, size is of the utmost concern when deciding scientific instruments. If an instrument does well in multiple other categories, but is too large to fit within the constraints, size must be weighted enough to show this shortcoming.

Mass (12%): The mass of the instrument to be used was determined to of lesser importance for this project. Upon research of possible instruments, it was determined that while mass affects the choice of instrument, many of the instruments had such similar weights that it was determined that mass does not need to be a heavily weighted factor between different instruments.

Table 5.1.1: Payload Trade Study

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

Metric	Weight	Imager (Zoom)	Spectrometer	Radiation [28]	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

5.2 Avionics

5.2.1 Development Packages

Each metric in the trade study was rated on a scale of 1-5 with 1 being the lowest and 5 being the highest. Each metric and reasoning for its associated weighting value is given below:

Design Entry (10%): Each software package will have built in tools for design entry. These tools may be as simple as a text editor, and as complex as a visual block diagram design builder that has preconfigured blocks that can be implemented. The design entry tools could simplify and expedite the design process if a streamlined design tool is available. This is the least important factor due to the fact that a multitude of design options exist, and are not dependant on the software package.

Device Support (40%): Specific device support is the most critical facet of the development package. The ability to design and model software specific to a piece of hardware will allow for simulation and synthesis testing to be more thorough and straightforward. Device support will also allow for direct programming on the FPGA itself from within the software package.

Simulation Tools (30%): The simulation tools are an important aspect that are necessary for code verification. These tools will aid in producing robust and functional software. Packages that include simulation on all levels of development will score higher than packages that can only provide higher level simulation. Also, direct simulation of supported hardware will provide a more robust simulation.

Synthesis Tools (20%): The synthesis tools are necessary for the final programming of the FPGA hardware. These tools are necessary for mapping the code to the actual hardware.

Table 5.2.1: Avionics Development Package Trade Study

Metric	Weight	Libero SoC	Altera Quartus II	Xilinx ISE
Design Entry	10%	4	3	3
Device Support	40%	5	1	1
Simulation Tools	30%	5	3	3
Synthesis Tools	20%	5	3	3
Total	100%	4.9	2.2	2.2

5.2.2 FPGA Software Design

While the software design will likely evolve as the development process is underway, it is appropriate to identify what factors are important to software functionality and development.

Flexibility (12.5%): Design flexibility refers to the ability to make rapid changes that do not affect the rest of the system. From a development standpoint, it is much better to work with a system that can be changed quickly. This allows for code revisions and updates to be made freely, making the development more efficient. This is a consideration on the development schedule and the ability to make improvements to the software under the time constraints of the project, however will not have as large of an effect as the complexity of the software.

Complexity (25%): Complexity is an important aspect in the fact that it is a major driver of the development schedule. A certain design may be the best match for a certain function, but is too complex to design under the time constraints of the project. For this reason, complexity is a critical design consideration. Complexity is equal in weighting to speed and power consumption since the design must be feasible to learn and create under the schedule of the project.

RAM Usage (12.5%): The RAM usage of a given method is also an important consideration. The command and data handling of large amounts of data could potentially be RAM intensive. If other processes in the design are RAM intensive, the entire system could suffer decreases in data transmission rates. RAM usage is important, but does not have as much of a direct impact on other subsystems.

Speed (25%): Processing speed is also a key aspect of the system due to the high amounts of data that must be transmitted at certain rates. If the system is not able to process data and commands fast enough, the transmission data rate could suffer resulting in a loss of scientific data. Processing speed is equal in weighting to power efficiency since it has a direct impact on other subsystem success.

Power Efficiency (25%): Due to the stringent power requirement and finite power available, the power consumption of the software design is of greater importance. The avionics system requires the largest power consumption of any subsystem. Therefore, the power efficiency must aim to conserve power resources as it has the largest impact on the power subsystem. Power consumption is equal in weighting to speed since it has a direct impact on other subsystem success.

Table 5.2.2: Avionics FPGA Software Trade Study

Metric	Weight	No Soft Processor	2 Soft Processor	1 Global Soft Processor
Flexibility	12.5%	2	4	3
Complexity	25%	3	3	2
RAM Usage	12.5%	4	2	2
Speed	25%	4	3	3
Power Efficiency	25%	4	2	2
Total	100%	3.5	2.75	2.125

5.3 Power

5.3.1 Power Source

When choosing a type of battery, it is important to distinguish between the scope of our project, and the ultimate goal of the mission to Europa. The probe that actually goes to Europa will want to prioritize low operating temperatures and capacity, while cost, safety, and rechargeability will not be as important. For this mission, the most likely choice for this mission would be the Lithium Sulfur Dioxide batteries, since they were also used on the Huygens Titan lander. However, for this project, we are building a table-top model, and will prioritize different properties as a result. Each metric in the trade study was rated on a scale of 1-5 with 1 being the lowest and 5 being the highest. Each metric and reasoning for its associated weighting value is given below:

Operating Temperature (5%): While this factor is very important for the actual mission, it is nearly meaningless for our project because the majority of our work will be done in a lab near room temperature. One this is still a factor in the matrix is in case more extensive environmental testing is needed at a later stage.

Specific Energy (25%): This is the second most important factor for our power source. Since we are limited by both size and mass, it is important to get the most energy possible out of a given mass. Batteries will likely take up a majority of the volume inside the probe, so this is a critical feature in order to meet our requirements.

Cost (20%): Since we will need to purchase many batteries in order to meet our power requirements, it is likely that the cost of batteries will be one of the more expensive systems along with payload sensors. Anyway that this cost can be reduced should be considered as it will ultimately have a large impact on the budget.

Safety (20%): As described above, some of the candidates will produce hazardous materials if not properly maintained. While this could be carefully handled if necessary, it would be more convenient to use safer, more reliable options in a lab setting.

Rechargeable (30%): This is the most important factor, and is partially related to the cost. Throughout the development and testing process, we will likely drain the power supply several times. Having the ability to recharge the batteries rather than buy all new ones every time is greatly preferred.

Table 5.3.1: Power Source Trade Study

Metric	Weight	NiCd	Silver Zinc	Lithium-ion polymer	Lithium sulfur dioxide	Alkaline	Energizer Ultimate Lithium
Operating Temperature	5%	1	3	3	5	3	5
Specific Energy	25%	2	3	4	5	4	5
Cost	20%	2	1	4	2	5	5
Safety	20%	3	2	4	1	5	5
Rechargeable	30%	5	0	5	0	0	0
Total	100%	3.05	1.5	4.25	2.1	3.15	3.5

5.3.2 Power Distribution Board

Each metric in the power distribution board design trade study was rated on a scale of 1-5 with 1 being the lowest and 5 being the highest. Each metric and reasoning for its associated weighting value is given below:

Complexity (15%): The complexity of the power distribution board is a moderately important factor. Numerous command switches or indirect pathways will increase the possibility of the system failing if they are not implemented correctly. For this metric, more linear electronic pathways are more favorable. However, this is not a deal breaker and if a superior system is more complex, we would be willing to put in the effort to ensure that it function properly.

Power Drain Risk (35%): This metric looks at the possibility of each system draining the power supply prematurely. This is both a factor of the efficiency of the system, and the accessibility of the power supply. Using DC-DC voltage converters introduces additional losses into the system. Decreasing the number or the magnitude of these conversions would ensure that more of the power from the battery reaches the other systems. Another issue is that if the batteries are separated, there is a chance that they will drain unevenly, leaving one system without power and excess power in another. This is a critical metric because each subsystem must be powered to accomplish the mission objectives; premature failure of the power supply to any or all subsystems would result in failure of the system as a whole.

Configure Flexibility (25%): Between the batteries and the power board, the power system will be taking up a majority of our projects mass and volume. Based on our preliminary designs, it appears that space will be a more pressing concern than mass. Certain power board configurations allow for greater control over power source placement and could make better use of the limited space. All designs have their own advantages in this case. Modular designs allow the power system to be separated to fit in smaller spaces as needed while a single centralized system would cut down on the amount of wires and could make the power board more compact.

Control (25%): Another important factor is the ability to control the power supply. Having the ability to shut off power to certain systems when they are not in use could improve efficiency and increase battery life. This will also be beneficial during the testing phases when we can evaluate systems individually.

Table 5.3.2: Power Trade Study

Metric	Weight	Single Battery Package	Single Battery Package w/ Switches	Individual Battery Packages	Hybrid: 2 Battery sources with switches	Voltage Division w/control switches
Complexity	15%	5	3	4	2	3
Power Drain Risk	35%	3	4	1	2	2
Flexibility	25%	1	1	5	4	4
Control	25%	1	4	3	3	4
Total	100%	2.3	3.1	2.95	2.75	3.15

5.4 Structure

5.4.1 Internal Mounting

Each metric in the trade study was rated on a scale of 1-5 with 1 being the lowest and 5 being the highest. Each metric and reasoning for its associated weighting value is given below:

Mass (20%): The mass of the internal structure is one of the most important features of the design. Since project ELSA is constrained to have the NeoPod weigh a maximum of 10kg, the weight of the structure should be minimized as much as possible while still maintaining structural integrity. A weight of 20% was given to mass due to the strict mass constraint of the project.

Subsystem Layout Clarity and Ease of Use (20%): Subsystem Clarity and Ease of Use was considered to be the second largest factor for the project as a whole. The NeoPod layout should be easy to follow and team members will likely need to add and remove components from the structure frequently during subsystem integration phase. The easier it is to navigate the subsystems, the easier the design and integration process will be.

Ease of Manufacturing (15%): Ease of manufacturing also has a heavily weighted value placed on it because of its importance. Manufacturing the components may be very challenging and in some cases impossible due to available resources. Available software and machinery as well as total time to machine the structure are a part of this consideration. Parts for the internal structure are desired to be easy to manufacture.

Complexity (15%): The complexity of design ties directly in with the ease of manufacturing and Ease of Use. However, it deserves its own metric. A very complex design will take more time to develop and manufacture than a simple design would. Also in most cases, making small changes to a very complex design can result in bad consequences. Designs that are simple but effective are desirable.

Cost (10%): Since project ELSA is constrained by a $5,000 budget, cost is an obvious metric that was included. The internal structure should not take up the majority of the budget as there are many other important components needed to be purchased for this project. However, material selection for the structure is important. Time for labor and machining is not included in this cost estimate

Proven Design (10%): This category simply puts a weighting on the design that has been proven and manufactured before. The TIRESIAS senior project proved that their internal structure was successful in both design and manufacturing. Therefore, in this trade study, a weighting of 10% is given to the TIRESIAS Heritage design.

Battery Volume available (5%): The more batteries that are available in the structure, the longer the NeoPod will survive. This is an important metric for the weighting the internal structure design, however is not the most concerning issue given the short 96 hour data collection period.

Structure durability (5%): Structure durability is also an important factor that was placed in the trade study matrix. Because the NeoPod will not contain a flight-ready internal structure, it will not have to undergo significant structural testing. However, the structure will be required to last through the end of the project and provide a potential path towards a flight ready internal structure solution.

Table 5.4.1: Struture Internal Mounting Trade Study

Metric	Weight	TIRESIAS Heritage	Shelves	Quarants
Mass	20%	4	5	4
Subsystem Clarity and Ease of Use	20%	5	4	2
Ease of Manufacturing	15%	3	4	3
Complexity	15%	4	5	4
Cost	10%	4	4	4
Proven Design	10%	5	0	0
Battery Volume Available	5%	4	5	5
Durability	5%	5	3	3
Total	100%	4.1	3.95	3.05

6 Baseline Design

6.1 Payload

- Sensor 1: Magnetometer The magnetometer easily won in all categories through the conducted trade study. There are a variety of affordable COTS options available that measure in ranges that fit the environment on Europa. Furthermore, these options are all small and light enough that the sensor board would easily fit into the structure. Finally, although not a metric in the trade, the group had the greatest interest in implementing this sensor, confirming it to be the top choice.

- Sensor 2: Radiation Sensor Choosing the second sensor was a much more difficult choice than the first. Three sensors stood out as candidates for this option with similar post-trade totals. These were the radiation sensor, temperature sensor, and pressure sensor. The pressure and temperature sensors ranked slightly higher than the radiation sensor, however, it was not nearly enough to eliminate the latter. In fact, the higher ranking two were of the least interest in the group. Everyone felt that the temperature sensor would not be very useful, especially because the sensor would be located inside the NeoPod, within close proximity to internal hardware. With Europa's extremely low temperatures and small fluctuations, using a temperature sensor not only lacks in science relevance, but in testing and environmental feasibility. Finally, the radiation sensor was chosen over the pressure sensor for a similar reason. Pressure wouldn't be as affected by the internal hardware, however, the sensor would still be inside the NeoPod, which also limits testing feasibility.

6.2 Avionics

6.2.1 Development Process Design

The development process that will be used will be Option 1 (HDL Design with Layered Simulation). This design allows for rapid development to occur with a rigorous testing and simulation scheme. This process can be used with a development FPGA for an extra level of validation. This method will provide the most robust design while being more efficient than relying only on functional testing.

6.2.2 Development Packages

The development package that will be used is the Microsemi Libero SoC software package. Evaluating the trade matrix clearly recognizes Libero SoC as the best choice. The most desirable attributes of Libero SoC are mostly derived from the fact that it is supplied by Microsemi, and offers direct hardware support for the ProASIC3 L3000 used on the avionics board. This support will allow for more accurate simulation and synthesis. The other packages offer similar tools but, workarounds would be needed in order to model the Microsemi FPGA. Libero SoC is the best development option for the ProASIC3 L3000.

6.2.3 Development Hardware

The development board that will be used will be the Microsemi ProASIC3L Development Kit. While this board may be substantially more expensive than the other options, the hardware support offered by this board will allow for the smallest possible deviation between developments for the development board and the production avionics board. The development kit is supported by Libero SoC, which will be beneficial in that only one toolset will need to be learned. Using another board would require parallel development with a separate set of tools which would require a large time commitment. It has also been recommended by several faculty members that a compatible development board would be worth the price. This board will also serve as a contingency board in the event that the Ball provided avionics board is not delivered. Along with the development board, the instructional curriculum will be followed during the fall semester to ensure that development can be productive and on schedule during the spring semester.

6.2.4 Software Design Language

The selection of an HDL language may change as the team's knowledge base grows and can discern which option is best for the needs of the project. However, with that said, Verilog will be learned initially due to its more familiar syntax and larger support network. Verilog is typically easier to learn, and has more resources readily available. Verilog is also the language that is used in ECEN 2350, which could prove to be a valuable local resource.

6.2.5 FPGA Software Design

Evaluating the trade matrix in section X.X.X, it is clear that this option is the strongest. While it may present challenges in development when dealing with complex data manipulation with purely logic based programming, the speed and efficiency benefits outway this detriment. For overall system success, the software must be fast and efficient. This option offers the best speed and efficiency without too much added complexity and with a decrease in development flexibility.

6.2.6 COTS Microcontrollers

This decision was made considering three main features- performance, user-friendliness, and comparison to the FPGA dev. kit.[29] The last of those three features is key because, as the microcontroller is a backup to the Avionics board, it is important to meet or exceed the processing and RAM capabilities of the board. To begin, the Netduino was easily eliminated as its performance was relatively low and had a small support community. The Arduino Due is the winner in terms of being able to interface with the payload easily with a large support community and familiarity with the team, however, its performance trails far behind the others. At 84 MHz, when a key design consideration for the FPGA kit would be to utilize its 350 MHz capabilities, it could be eliminated as well. Between the remaining two, the Raspberry Pi community is much more developed and the board itself has higher performance than the FPGA kit. Therefore, the BeagleBone's 1 GHz speed, although nice to have, is beyond what is necessary when it lacks familiarity and support. This option could change as the team gains a better understanding of the necessary performance and capabilities.

6.3 Power

6.3.1 Power Source

Though they scored slightly less that the Energizer Lithium batteries, we believe the lithium-ion polymer batteries are still superior based on our needs for this project. Rechargeability is the deciding factor in this decision, as this is where these two candidates differ most. Additionally, Lithium polymer batteries are available in a wider variety of sizes, offering us greater flexibility in arrangements of the internal structure. Since volume is a more challenging constraint than mass, we will be using small, modular pack of lower capacity batteries rather than large bricks of high capacity batteries. The large bricks are more mass efficient, but the smaller batteries are more size efficient.

6.3.2 Power Distribution Board

The power distribution board trade study was difficult because many of the chosen metrics were not tied to hard numbers and were slightly more objective as a result. Additionally, some of the important aspects such as the exact command modes and internal configuration are not well defined at this stage. For these reasons the power distribution board may have to be reevaluated based on new evidence later in the design process. At this stage however, we have selected the voltage division board as our baseline design because it achieved the highest score in the trade study.

Since circuit building is not a strength of our team, we will plan on buying components whenever possible and then connecting them. We have found relatively inexpensive options for the components that we need, and believe that our time will be better spent working on other aspects of the project.

6.4 Structure

For the internal structure, the TIRESIAS heritage design was chosen to be the best option. This design was proven to be successful in a previous senior project and has previous analysis conducted on the structure. The mass of the structure is comparable to the other designs and by initial calculations, this structure will contain enough volume required to house the batteries for the mission timeline. It is also a structure that is flexible with power board and science instrument mounting. Manufacturing will not have many challenges as the design is fairly simple. Overall, the internal structure will function in a similar manner to the structure designed for the TIRESIAS project with the exception of different boards and science instruments being mounted to the structure.

6.5 Communications

The most important and sensitive aspects of the development of NeoPod to consider are the financial and mass/volume constraints. A communications system should simply get the job done, in this case the job is to operate in a tabletop setting on earth and interfere as little as possible with the operation of other subsystems. The term "tabletop setting" includes the orientation of NeoPod which makes design option 3 unnecessary especially considering the financial and volume cost of the components involved. Design option 1 is a great choice in terms of the communications subsystem complexity however it is extremely troublesome in regards to working with the other subsystems, option 1 will also not achieve the 4th level of success and any distance requirement because of the use of physical cable. The cost of duplexers and the complexity and limitations of working with TDD (option 5: switch design) & FDD (options 2&3: duplexer designs) are simply not reasonable or necessary especially considering design option 4 and thus the baseline design shall be the 4 antenna design (Design Option #4). This option removes the complexity of working with any type of duplexing TDD or FDD. Also because licensing is not involved in the use of the 433 and 2400 MHz bands the use of two bands will most likely not involve any extra labor[30]. Minimizing the volume and mass of NeoPod are of utmost importance to this project and ultimately the mission to Europa. In consideration of cost this option is also feasible because the difference between this option and the others is the purchase of an extra antenna which has been researched to be around $60 which is a very reasonable figure.

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