4. Design

4.1 Design Exploration

The Heimdall project, overlooked by Professor Matthew Nelson and supported by a dedicated team of students within the Make To Innovate (M.2.I.) organization, working hard to develop a high-altitude weather balloon payload equipped with a Pluto Board to collect data and ensure reliable video communication over a 5.8GHz radio signal. Key design decisions, including sensor selection for accurate environmental data measurement, implementation of an efficient power management system, and the design of a robust antenna system for video communication, are critical to the project's success in meeting client's expectations and delivering innovative solutions in high-altitude data collection and communication.

4.2.1 Design Decisions

We chose the Pluto Board for the Heimdall project because it's versatile, powerful, and compact. It's good at collecting data, processing it, and communicating, which is what we need for getting environmental data and sending videos over a 5.8GHz radio signal. Plus, it doesn't use too much power, and lots of people know how to use it, so it's easy to work with for our balloon mission.

- Selection of Sensors:
    - Decision: Choosing the appropriate sensors for measuring temperature, pressure, humidity, and altitude.
    - Importance: Accurate environmental data is crucial for scientific analysis and understanding atmospheric conditions at high altitudes. Selecting reliable sensors ensures the quality and integrity of the collected data, essential for the project's success.
- Power Management System:
    - Decision: Implementing an efficient power management system to sustain the operation of the Pluto Board and associated components throughout the flight.
    - Importance: Balloon flights can last several hours, and power constraints are significant. An optimized power management system ensures uninterrupted operation, maximizes battery life, and prevents premature shutdowns, thereby guaranteeing continuous data collection and communication capabilities.
- Antenna Design:

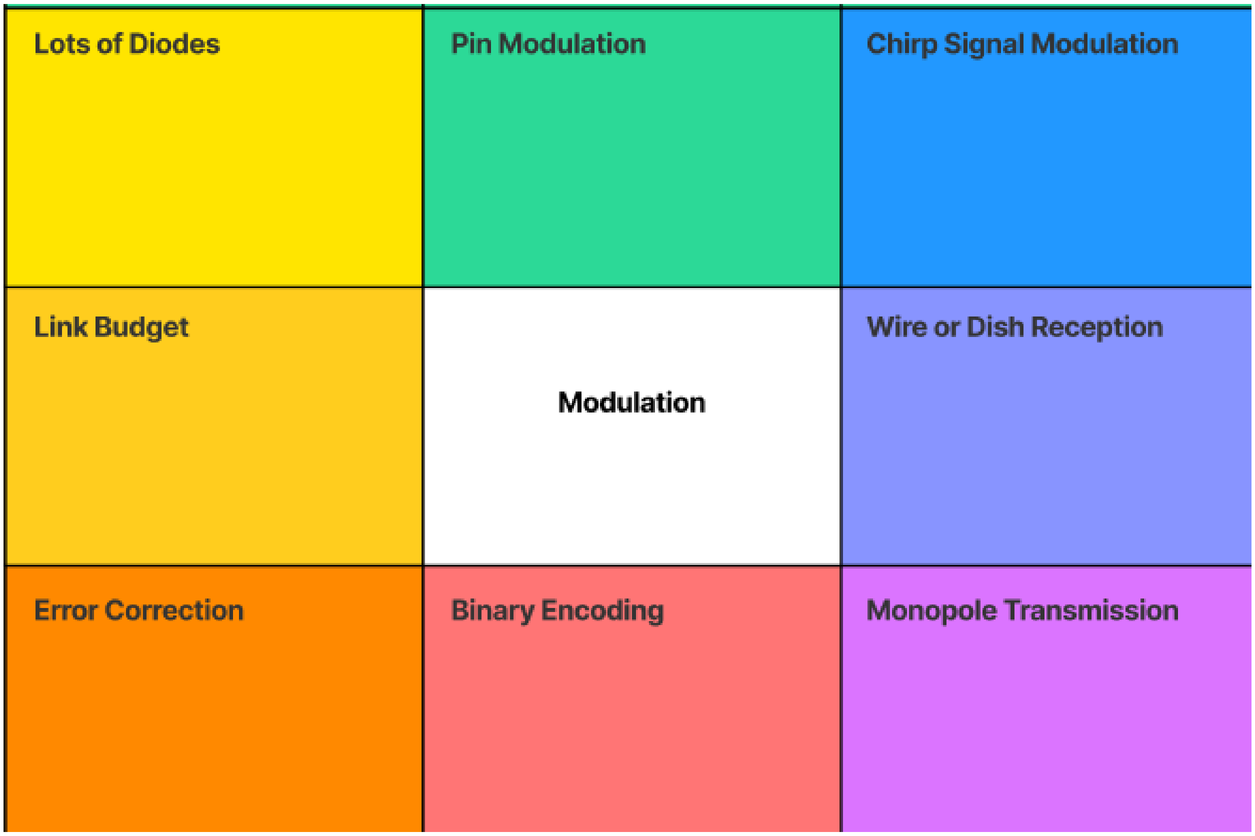
  - Decision: Designing an appropriate antenna system for reliable video communication over a 5.8GHz radio signal.
  - Importance: The success of the project relies heavily on maintaining a stable video transmission link between the payload and the ground station. An efficient antenna design with suitable gain, polarization, and radiation pattern ensures robust and consistent communication, even under challenging atmospheric conditions encountered during the balloon ascent and descent phases.

4.2.2 Ideation

To cover modulation techniques for the Heimdall project, we utilized the Lotus Blossom Technique, which is a brainstorming method that allows for the exploration of multiple ideas and options. In this technique, the main concept (in this case, modulation) is placed at the center of a diagram, with branches representing various subtopics or potential options. We then explored different modulation techniques and their associated aspects to determine the most suitable approach for our project.

- Monopole Transmission: This technique involves using a single antenna element, which simplifies the design and reduces complexity. It was considered for its simplicity and ease of implementation, making it suitable for the payload's limited space and resources.
- Binary Encoding: Binary encoding is a common method for representing data using two distinct signal levels. It offers efficient data transmission and is widely compatible with digital communication systems.
- Error Correction: Error correction techniques such as forward error correction (FEC) help improve the reliability of data transmission by detecting and correcting errors in the received signal. This was considered essential for ensuring accurate communication over the radio link, especially in noisy environments.
- Link Budget: Link budget analysis helps determine the feasibility of a communication link by accounting for various factors such as transmitter power, receiver sensitivity, antenna gains, and path loss. It was crucial for evaluating the performance of the chosen modulation technique under real-world conditions.
- Chirp Signal Modulation: Chirp signal modulation involves varying the frequency of the transmitted signal over time. It offers advantages such as improved resistance to interference and better range performance compared to traditional modulation techniques.
- Etc.

(Figure #1: Lotus Diagram for Modulation)



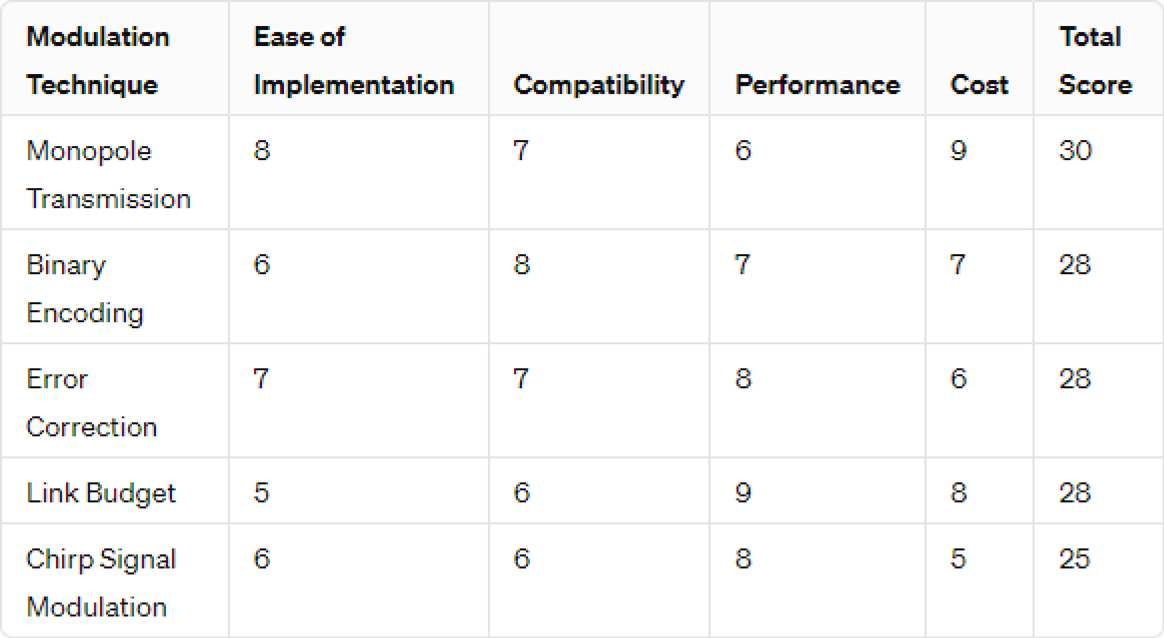
Lots of Diodes	Pin Modulation	Chirp Signal Modulation
Link Budget	Modulation	Wire or Dish Reception
Error Correction	Binary Encoding	Monopole Transmission

We chose the Monopole Transmission technique as an example and further explored its potential enhancements through the Lotus Blossom Technique. By blossoming with half a dipole transmission, frequency agility, antenna matching, and ground plane design, we aimed to optimize the performance of the monopole transmission for our specific application. Additionally, leveraging the physical pole on the payload box for modulation integration was a practical consideration to maximize space utilization and simplify the overall design. Through this iterative exploration process, we identified and refined the modulation technique best suited for reliable video communication over a 5.8GHz radio signal in the high-altitude environment of the Heimdall project.

4.2.3 Decision-Making and Trade-Off

To identify the pros and cons or trade-offs between each of the ideated options for modulation techniques, we employed a weighted decision matrix. Figure #2 shows a simplified example of how the process might look.

(Figure #2: Weighted Decision Matrix for Modulation Techniques)



Modulation Technique	Ease of Implementation	Compatibility	Performance	Cost	Total Score
Monopole Transmission	8	7	6	9	30
Binary Encoding	6	8	7	7	28
Error Correction	7	7	8	6	28
Link Budget	5	6	9	8	28
Chirp Signal Modulation	6	6	8	5	25

In this simplified example, we considered factors such as ease of implementation, compatibility with existing systems, performance under varying conditions, and cost. Each factor was assigned a weight based on its relative importance to the project.

After evaluating each modulation technique based on these criteria, we calculated a total score for each option. The option with the highest total score indicates the most favorable choice considering all factors.

4.3 Proposed Design

The proposed design for the Heimdall project is an exciting initiative aimed at capturing amazing images and important data from high altitudes. Our design includes a specialized Pluto Board attached to a weather balloon, which will collect data and send back pictures in real-time. We've focused on reliability and accuracy by using advanced sensors and a top-notch camera. With this design, we're excited to share stunning views and valuable insights from the edge of space.

4.3.1 Overview

The Heimdall project aims to capture amazing views from the edge of space using a weather balloon carrying a special device called the Pluto Board. This board is like the brain of the operation, collecting important information about things like temperature, pressure, and altitude using small sensors. It also has a camera to take stunning pictures and videos of the Earth from way up high.

To make sure we can see these amazing views back on the ground, we use a clever system that sends the pictures and data down to us through the air using a special radio signal called 5.8GHz. This signal travels from the Pluto Board to a receiver on the ground, where we can see everything in real-time.

The Pluto Board is powered by a battery to keep it running during the whole adventure. We carefully plan and track the progress of our balloon using tools like GPS and online systems called YouTrack and GitHub, which help us manage tasks and keep track of our data and documents. Below are the key components implemented on our project.

- Pluto Board:
    - The central device responsible for collecting data and images from the high-altitude balloon. It contains sensors for measuring environmental conditions and a camera for capturing photos and videos.
- Radio Transmission System:
    - Enables the Pluto Board to send data and images back to Earth using a 5.8GHz radio signal, allowing real-time monitoring of the flight's progress.
- Battery:
    - Provides power to the Pluto Board throughout the flight to ensure continuous operation and data collection.
- GPS:
    - Helps track the balloon's position during flight, aiding in recovery after landing and providing valuable location data for analysis.
- YouTrack and GitHub:
    - Online systems used for project management, task assignment, documentation tracking, and version control of coding files, ensuring smooth collaboration and organization among team members. This design allows us to explore the wonders of our planet from a unique perspective while collecting valuable data for scientific research and educational purposes.

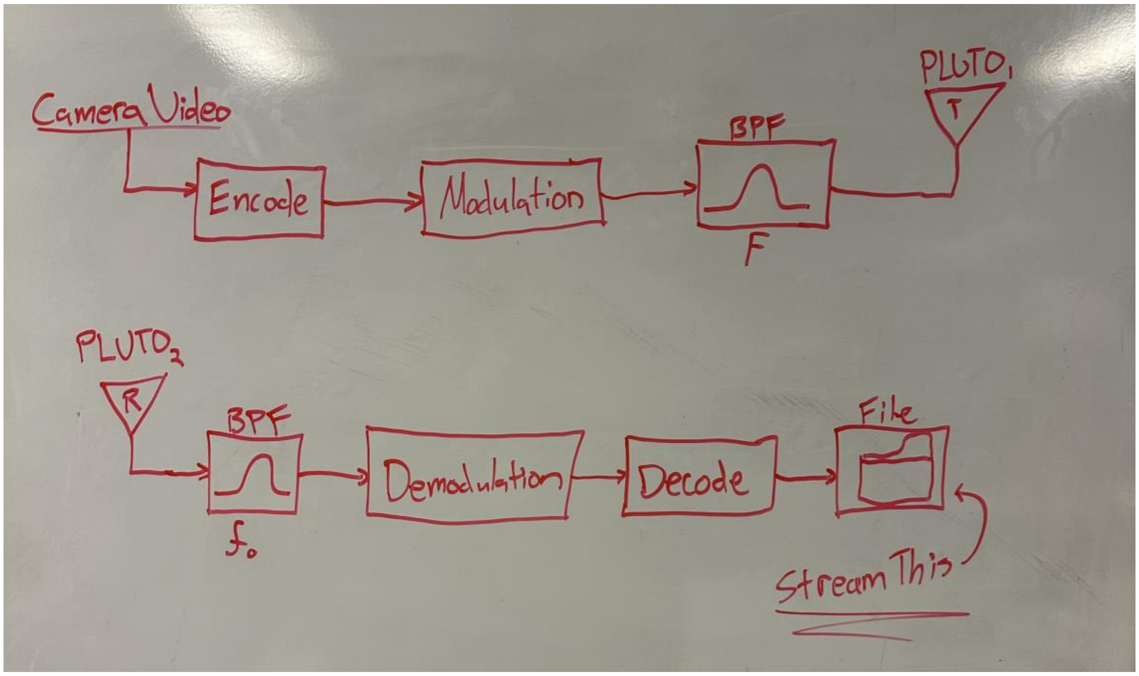
4.3.2 Detailed Design and Visual(s)

Our design for the Heimdall project comprises several interconnected subsystems, each playing a crucial role in the overall functionality of the payload. The Pluto Board serves as the central processing unit, responsible for data collection from sensors and the camera and communication with the ground station via the Software Defined Radio (SDR) and radio transmission system. Complementing the Pluto Board is the Raspberry Pi, which provides additional computing power and interfacing capabilities. GNU Radio and LynxOS facilitate signal processing and real-time operation, respectively. Sensors measure environmental parameters, while the camera module captures imagery. The power management system ensures reliable operation throughout the flight.

Internally, the Pluto Board conducts data collection from sensors, image capture, data processing, and communication protocol implementation. The Raspberry Pi interfaces with external devices and peripherals, such as sensors and the camera module, and assists in data processing tasks through Python scripts. The SDR facilitates radio communication between the payload and the ground station, implementing modulation and demodulation schemes, signal processing, and protocol handling. GNU Radio provides a software framework for designing and implementing SDR systems, facilitating signal processing tasks through block-based signal processing using flowgraphs and scripting in Python. LynxOS ensures precise timing and responsiveness for critical operations, such as data collection and communication, through task scheduling, inter-process communication, and resource management.

Additionally, sensors measure environmental parameters such as temperature, pressure, humidity, and altitude, while the camera module captures high-resolution imagery for visual observation and analysis. The power management system regulates power distribution and consumption to ensure continuous operation throughout the flight, involving battery charging, voltage regulation, and power allocation to subsystems based on priority. Lastly, the radio transmission system transmits collected data and imagery to the ground station using radio frequency signals, involving signal modulation, amplification, and transmission/reception protocols. Through the integration of these subsystems and components, our design aims to achieve reliable data collection, processing, and communication capabilities for the Heimdall project, enabling scientific research and exploration at the edge of space. Figure #3 below shows our diagram that we believe will successfully transmit our video footage data.

(Figure #3: Camera Video -> Pluto Board -> Streaming File)



4.3.3 Functionality

In the Heimdall project, the payload's actions follow a clear sequence. First, the user gets everything ready, making sure all parts are secure and there's enough power. Then, the balloon goes up to 30,000 meters, and the Pluto Board starts its checks. During the flight, the user watches the ground station to get live video from the payload, while the Pluto Board keeps collecting data and sending video over the radio. After the flight, the user gets the payload back and gathers the stored data for analysis. As the payload comes down, the Pluto Board saves power, keeping the important data safe for later.

4.3.4 Areas of Concern and Development

The current design aims to meet user needs by integrating sensors, a camera, and a radio transmission system into the payload. However, there are concerns about reliability, data transmission, power management, and data analysis that must be addressed to ensure the project's successful execution. Immediate plans include implementing redundancy measures, fine-tuning the radio transmission system, exploring energy-efficient components, and developing automated data analysis tools. Key questions for clients, TAs, and faculty advisers revolve around specific environmental conditions, additional requirements, power management optimization, and available resources for development and testing.

- Reliability:
    - The reliability of the payload's operation throughout the entire flight, particularly in the face of harsh environmental conditions at high altitudes, is a primary concern.

- Data Transmission:
  - Seamless and uninterrupted transmission of data, including real-time video streaming, from the Pluto Board to the ground station is essential for capturing and analyzing valuable information.
- Power Management:
  - Optimizing power usage to extend the operational lifespan of the payload during long-duration flights is crucial for maximizing data collection opportunities.
- Data Analysis:
  - Developing efficient methods for post-flight data analysis and interpretation to extract meaningful insights from the collected data is necessary for achieving the project's scientific objectives.

4.4 Technology Considerations

In our design for the Heimdall project, we utilize several distinct technologies to enable data collection, communication, and processing. Let's discuss each technology, along with its strengths, weaknesses, trade-offs, and possible solutions or alternatives:

- Pluto Board:
  - Strengths: The Pluto Board offers a compact form factor, ample processing power, and versatile connectivity options, making it well-suited for our high-altitude balloon payload. Its integrated FPGA provides flexibility for custom signal processing and modulation schemes.
  - Weaknesses: Limited I/O capabilities may constrain interfacing with external sensors or peripherals. Additionally, the software ecosystem may have a learning curve for users unfamiliar with embedded development.
  - Trade-offs: While the Pluto Board excels in performance and flexibility, its size constraints and learning curve may require careful consideration in design and implementation.
  - Solutions/Alternatives: Utilizing external modules or peripherals for additional I/O capabilities and providing comprehensive documentation and support resources can mitigate these limitations.
- Raspberry Pi:
  - Strengths: The Raspberry Pi offers a robust computing platform with a large community and extensive software support. Its versatility and

    affordability make it suitable for various applications, including data processing and communication.

  - Weaknesses: Power consumption may be higher compared to other embedded systems, potentially impacting battery life in the payload. Additionally, it may not offer real-time capabilities required for certain applications.
  - Trade-offs: While the Raspberry Pi provides ample computing power and software support, its higher power consumption and lack of real-time capabilities may pose challenges in power management and timing-sensitive applications.
  - Solutions/Alternatives: Implementing power-saving strategies and supplementing the Raspberry Pi with dedicated real-time modules or microcontrollers can address these concerns.
- Software Defined Radio (SDR):
  - Strengths: SDR offers flexibility in configuring and adapting radio communication parameters, enabling efficient use of available spectrum and modulation schemes. It facilitates rapid prototyping and experimentation in radio communication systems.
  - Weaknesses: Complexities in configuring SDR hardware and software may require specialized knowledge or expertise. Performance may vary depending on the quality and capabilities of the SDR hardware.
  - Trade-offs: While SDR provides unmatched flexibility and adaptability in radio communication, its complexity and performance variability may necessitate careful calibration and testing.
  - Solutions/Alternatives: Providing comprehensive documentation and tutorials, as well as utilizing well-supported SDR platforms with reliable performance, can help mitigate these challenges.
- GNU Radio:
  - Strengths: GNU Radio offers a powerful framework for designing and implementing software-defined radio systems, with extensive signal processing and modulation capabilities. Its open-source nature fosters collaboration and innovation.
  - Weaknesses: GNU Radio may have a steep learning curve for users unfamiliar with signal processing concepts or software development.

    Performance may be constrained by hardware limitations or inefficient signal processing algorithms.

  - Trade-offs: While GNU Radio provides a robust platform for SDR development, its complexity and performance constraints may require careful optimization and expertise.
  - Solutions/Alternatives: Providing educational resources and tutorials for beginners, as well as optimizing signal processing algorithms for efficiency, can help address these challenges.

- LynxOS:
  - Strengths: LynxOS offers real-time capabilities and determinism, making it suitable for applications requiring precise timing and responsiveness. Its reliability and security features are well-suited for mission-critical systems.
  - Weaknesses: Licensing costs and proprietary nature may limit accessibility for certain users or projects. Compatibility with third-party software and hardware may vary.
  - Trade-offs: While LynxOS provides robust real-time capabilities and security features, its proprietary nature and potential licensing costs may pose challenges in adoption and integration.
  - Solutions/Alternatives: Exploring open-source real-time operating systems (RTOS) with similar capabilities, such as FreeRTOS or RTLinux, may offer cost-effective alternatives with broader community support.

Each technology in our design offers unique strengths and capabilities, along with associated weaknesses and trade-offs. By carefully considering these factors and exploring possible solutions or alternatives, we can design a robust and efficient system for the Heimdall project, meeting its requirements and user needs effectively.

4.5 Design Analysis

So far, our team has made significant progress in implementing our proposed design for the Heimdall project. We have successfully coded both the Raspberry Pi and the Pluto Board with the necessary measures to facilitate our first tethered test launch. This includes configuring sensors, setting up data transmission protocols, and ensuring compatibility with our ground station equipment. The tethered test launch will allow us to collect crucial data and evaluate the performance of our system in a controlled environment. This data will be invaluable for identifying any issues or areas for improvement before our main launch, which is scheduled to coincide with the solar eclipse in Texas.

While our initial implementation has been promising, we anticipate encountering challenges and areas for refinement during the test launch and subsequent analysis. It's possible that certain aspects of our proposed design may not function as expected or may require adjustments based on real-world performance. Additionally, factors such as power consumption, data transmission reliability, and sensor accuracy may need further optimization to ensure the overall feasibility and success of our project. Moving forward, our plans for future design and implementation work include:

- Conducting the tethered test launch and meticulously analyzing the collected data to identify any issues or areas for improvement.
- Making necessary adjustments and optimizations to address any issues uncovered during the test launch, such as refining sensor calibration or fine-tuning communication protocols.
- Iterating on the design and implementation based on lessons learned from the test launch to enhance reliability, performance, and overall system efficiency.
- Planning and preparing for the main launch during the solar eclipse in Texas, including logistical considerations such as travel arrangements, equipment setup, and coordination with local authorities and stakeholders.

Overall, while we have made significant progress in implementing our proposed design, there are still challenges and uncertainties ahead. However, through careful planning, testing, and iteration, we are confident in our ability to overcome obstacles and achieve success in the Heimdall project.