Conceptual Design Document

ARGUS
Auto-tracking RF Ground Unit for S-Band

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Department of Aerospace Engineering Sciences
ASEN 4018

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1. Information

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Table of Acronyms

Acronym	Definition
LEO	Low Earth Orbit
SDR	Software Defined Radio
SmallSat	Small Satellite
TLE	Two Line Element Set
EIRP	Equivalent Isotropically Radiated Power
G/T	Antenna Gain-to-Noise-Temperature
QPSK	Quadrature Phase Shift Keying
BER	Bit Error Rate
RF	Radio Frequency
LNA	Low Noise Amplifier
DR	Derived Requirement
FR	Functional Requirement
OSHA	Occupational Safety and Health Administration
AC	Alternating Current
DC	Direct Current
CONOPS	CONcept of OPerationS
FBD	Functional Block Diagram
Auto-Track	Satellite tracking with TLE data
Program-Track	Satellite tracking based of received signal strength
COTS	Commercial Off-The-Shelf
S/C	Spacecraft

2. Project Description

2.1. Purpose

Small satellites provide significant science data and communication with minimal size and cost. From forecasting weather to providing internet, SmallSats require reliable Earth communication via a ground station. Current ground station systems are primarily stationary. Thus, engineers are unable to transport them to locations around the world for on-demand data collection. With as many as 3000 SmallSats predicted to launch into low Earth orbit between 2016 and 2022, autonomous and portable ground stations are of emerging interest. Mobile ground stations are far more versatile, establishing the ability to autonomously communicate with LEO SmallSats to uplink commands and downlink data while in remote locations.[1]

The purpose of ARGUS, with collaboration from Raytheon, will be to develop a communication solution to downlink data from future large LEO constellations more often than currently possible (with more portable, cheaper ground stations), as well as with more geographic diversity. This will allow for a network of ground stations similar in size to the constellation for constant communication. Raytheon may eventually have one of these constellations of various priority-level satellites requiring communication access to any location around the world. The overarching motivation for ARGUS includes the ability to quickly receive an image of a specified location. For example, this could be a military unit needing an immediate image of an out of sight location to ensure their safety.

The markets for this mobile ground station will be large constellation operators including commercial and government customers. As it is envisioned to be relatively cheap compared to current systems, the ground station could also be marketed towards academia and other single satellite operators.

2.2. Objectives

The main objective of ARGUS is to create a portable ground station system capable of S-Band downlink. This ground station may be transported using person(s) or a small truck to a remote location where assembly will occur. The ground station will use simulated Two-Line Element satellite data to mechanically sweep across the sky using the pre-programmed path calculated from the TLE data, as well as be able to fine-tune the satellite's location based on the strength of the received signal. The ground station dish must have an Equivalent Isotropically Radiated Power (EIRP) specification of 10 dbW to allow communication for future satellite missions. This unit will be designed to allow for upgrades such as multi-band and uplink capabilities in the future.

Table 1 below specifically defines the project's objectives. ARGUS level 1 completion will result in a functional but less-than-ideal portable S-band communication solution. Portability will be limited to a standard pickup truck and tracking will rely on TLE data. Levels 2 and 3 reflect easier portability and more accurate communication, as well as reconfigurability to other bands such as X-band. Level 3 is the current design goal, which includes decryption as well as auto-tracking based on signal strength.

Level	Communication	Ground Station Structure	Software
1	• The ground station shall be capable of generating data packets from a simulated LEO satellite using S-band frequencies with a G/T of at least 3dB/K‡ • Received data packets shall have a bit error rate no greater than 10^{-5}‡	• The ground station shall be able to be transported in the back of a standard pickup truck • Two people shall be able to assemble the ground station within two hours‡ • The ground station antenna shall be able to track LEO satellite at 3.4°/s azimuth and elevation rates • The ground station antenna shall be able to communicate with LEO satellite at and above 10° elevation‡	• The ground station software shall be able to ingest TLE data to provide the appropriate pointing commands to the antenna to establish communications. • The ground station shall interface with a standard personal laptop computer • Received data packets shall be demodulated using QPSK modulation standards
2	• The ground station shall be reconfigurable* to communication in other frequency bands‡	• Two people shall be able to transport ground station using unpowered rolling vehicle • Two people shall be able to assemble the ground station within one hour‡	• Transmitted data packets shall be modulated using QPSK modulation standards
3	• Transmitted and received data packets shall have a bit error rate no greater than 10^{-9} ‡	• Two people shall be capable of carrying ground station of 45 kg total • Two people shall be able to assemble the ground station within half an hour‡	• The ground station software shall be able to predict LEO satellite location to 0.1° accuracy using tracking algorithm based on signal strength • Downlinked data shall have the ability to be decrypted according to AES-256 encryption standard‡

* Reconfigurability is defined as the ability to replace certain components of the device used for S-band communication with components used for other bands such as X-band, i.e. the antenna dish and RF components.
‡ Customer specified requirements.

Table 1. ARGUS levels of success

2.3. Concept of Operations

Ground stations are an important product in the aerospace community as they provide the ability to communicate with objects orbiting the Earth, such as satellites and spacecraft. The need for these ground stations continues to grow as the number of objects orbiting Earth increases due to more smallsat launches and deployment as well as space debris. Traditional ground stations use a large satellite dish that operates at a fixed location. This limits the ability to provide support as communication with the satellite can only occur when it passes overhead, which can be infrequent. The ground station is operational for this fixed location, but is unable to track outside of those bounds due to its lack of mobility. This leads to a need for portable ground stations that can be used in military reconnaissance operations to track and command satellites in remote locations. The following CONOPS describes the portable ground station design and a high level overview of how it will operate.

The first element for the project is the ability to be transported. The user shall be able to travel with the portable system to non-traditional locations across the world. This allows the use of the ground station to be dynamic and flexible. The user can then assemble the necessary components and set up the station at any desired location. Once assembled, the ground station will be powered by a provided external source. For a minimum of one pass, the ground station will operate by tracking Low Earth Orbit (LEO) satellites across the sky by following the satellite's signal. Using its downlink capabilities, the user may receive data from a desired satellite, transmitting to a computer connected to the ground station.

Figure 1 describes the goal of this project. ARGUS will be able to receive data packages from LEO satellites that currently transmit in S-Band. The ground station will be connected to a standard, constant power source. ARGUS shall also be able to be transported by two people to any desired location. Figure 1 shows the overall concept of projects like ARGUS, where the ground station will be able to downlink successfully from satellites in the field. Figure 2 shows the specifications of the ground station, showing the steps of acquiring the signal, amplifying it, demodulating it, and returning it to the user.

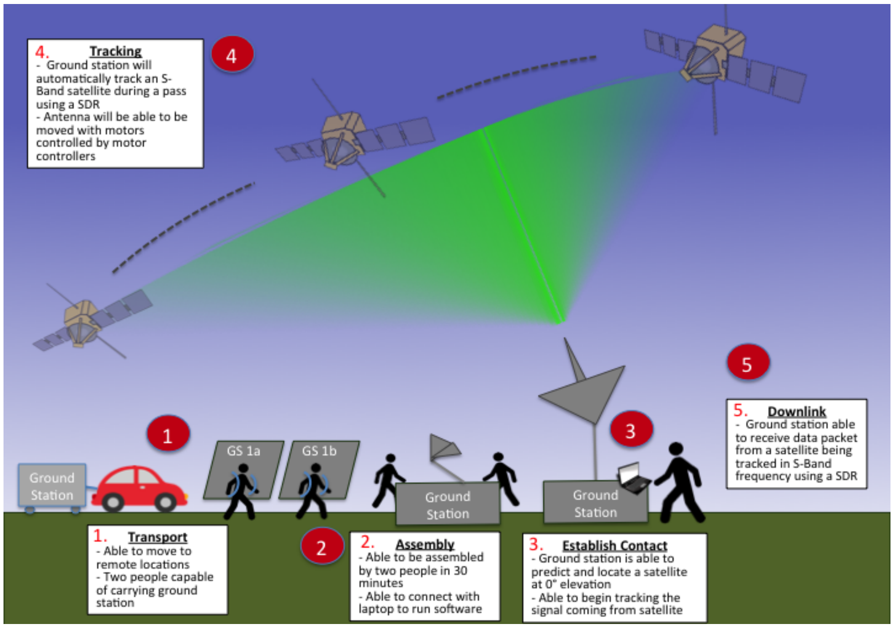

Figure 1. Concept of Operations for the testing and simulation of the project

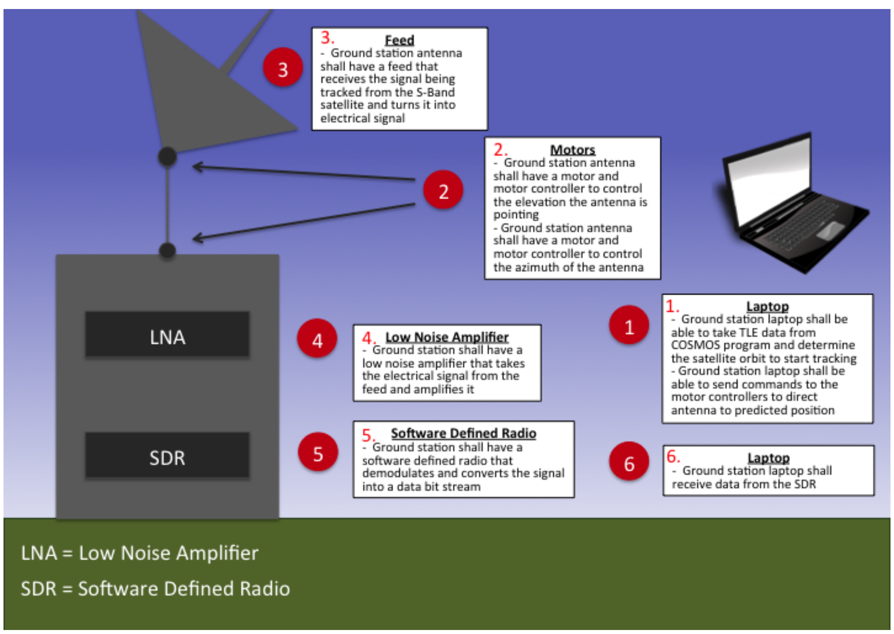

Figure 2. Concept of Operations for specific components of the ground station

2.4. Functional Block Diagram

Figure 3 shows the major project components and interfaces recognized at this stage of the design process in a functional block diagram. The power source, as defined by Raytheon, will consist of a 120V Alternating Current (AC) source. This source must be converted to a Direct Current (DC) for most, if not all, components. These components will also need to operate at specific and varying voltages. These tasks will be completed within the power regulation block. It is uncertain at this time what voltage these power lines (red) will operate at.

The portable computer handles the data feed to and from the radio controlled by a user interface that is to be developed. The portable computer will also run the tracking software and convert that information into commands for the pointing control hardware using the pointing control software which is also to be developed. The antenna unit block consists of the physical antenna as well as the pointing control hardware, including servos and potentiometers, responsible for keeping the antenna pointed in the correct direction during a satellite pass. The signal processing circuit will consist of Radio-Frequency (RF) components such as low-noise amplifiers and other conditioning components the group may need in order to close the link with a satellite in LEO. Prior to completion of the link budget it is assumed that the signal processing circuit shall consist of a band-pass filter for the desired frequency window and an amplifier to make the best use of the radio's ADC. The radio demodulates from QPSK to a bit stream to the user portable computer for processing.

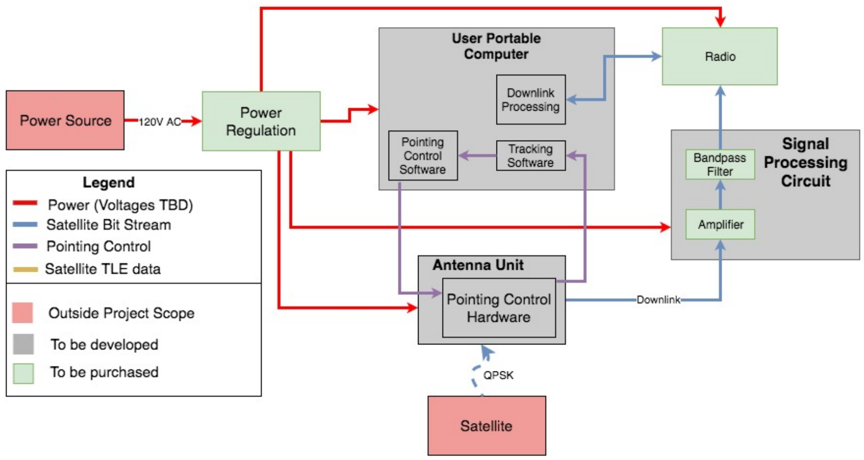

Figure 3. Functional Block Diagram (rev. 1.5)

2.5. Functional Requirements

ARGUS has five functional requirements that are driven by the customer's requirements as well as the project's concept of operations. These requirements are at the project's highest conceptional level and drive all other design requirements. These functional requirements are summarized as follows:

Functional Requirement	Description
FR 1	The ground station shall be capable of tracking a LEO satellite between an orbital elevation of 200 km and 600 km between 10° elevation and 170° elevation.
FR 2	The ground station shall be capable of receiving signals from a LEO satellite between 2.0 to 2.5 GHz. ‡
FR 3	The ground station shall be reconfigurable to be used for different RF bands.*
FR 4	Two people shall be capable of carrying and assembling the ground station.‡
FR 5	The ground station shall interface with a laptop using a Cat-5 ethernet cable.‡

* Reconfigurability is defined as the ability to replace certain components of the device used for S-band communication with components used for other bands such as X-band, i.e. the antenna dish and RF components.
‡ Customer specified requirements.

3. Design Requirements

FR 1: The ground station shall be capable of tracking a LEO satellite between an orbital altitude of 200 km and 600 km between 10° elevation and 170° elevation.

Motivation: This requirement is necessary to downlink data from the satellite. The antenna feed must be able to collect data through the focal point of the feed. This requires tracking the satellite accurately as it passes overhead.

Verification: Test: A satellite that transmits in S-Band will be followed across the sky using TLE data. The demonstration will indicate movement capabilities between 10° and 170°. The fact that we are actually pointing at the satellite will be verified by ensuring the signal-to-noise ratio is greater than 5.

DR 1.1: The antenna shall have pointing control in azimuth and elevation to mechanically follow a satellite passing overhead.

Motivation: The antenna must be capable of tracking the satellite in both the azimuth and elevation directions to utilize downlink capabilities.

Verification: Inspection/Test: This requirement will be verified through the design of the motor controllers (one in azimuth, one in elevation), which will be able to demonstrate multi-axis tracking capability.

DR 1.2: The pointing control accuracy must be within one degree to maintain downlink capabilities throughout the entire pass.

Motivation: An inaccurate tracking mechanism results in the ground station being unable to communicate due to loss of signal stemming from pointing loss.
Verification: Test: An S-band satellite will be tracked to ensure the signal-to-noise ratio is above 5 and we are within the beamwidth.

DR 1.3: The antenna motor shall be able to move the antenna at a slew rate of 3.4 degrees per second.

Motivation: The antenna must be able to track LEO satellites from 10° to 170° elevation with a speed of 2.267 degrees per second, calculated assuming the worst case of a hyperbolic orbit with a perigee altitude of 200km and an apogee altitude of 600km, at the point where the satellite is in a retrograde orbit at perigee directly overhead the ground station. With a factor of safety of 1.5, the antenna will require a slew rate of 3.4 degrees per second.
Verification: Test: The pointing motors will be commanded to move at a rate of 3.4 degrees per second and the action will be timed to verify that the motors are capable of the worst-case angular velocity for tracking a LEO satellite.

DR 1.4: The mechanism for tracking the satellite must contain capabilities of movement between 10° and 170° elevation angles.

Motivation: To properly track the satellite between 10° and 170° elevation angles, the mechanical device must have movement within this range to track for a full pass.
Verification: Test: After mechanical assembly, the motor will demonstrate movement between 10° and 170° elevation angles against backdrop indicating range of motion.

FR 2: The ground station shall be capable of receiving data from a LEO satellite in the S-Band frequency.

Motivation: The main goal of the project is to be able to downlink with a LEO satellite through the S-band.

Verification: Test: Will downlink data from LEO S-band satellite passing overhead through the assembled ground station.

DR 2.1: The ground station shall receive between 2.0 GHz and 2.5 GHz.

Motivation: The S-band frequency range required by the customer is defined between 2.0 GHz - 2.5 GHz, and the specific desired frequency for downlink is between 2.2 and 2.3 GHz.
Verification: Test: The ground station shall track an S-band satellite transmitting between 2.0 and 2.5 GHz and ensure accurate data.

DR 2.2: The downlink bit error rate (BER) shall be no more than 10^{-9}.

Motivation: The received data packets must have a low bit error rate to ensure that the incoming data is accurate.
Verification: Test: A test signal will be created, attenuated to a power level similar to what will be received by our antenna, and sent through our RF system and compared to the original test signal. This comparison will be performed on 5 billion bits to ensure that the BER is less than 10^{-9} at 99% confidence.

DR 2.3: The ground station shall passively filter signals outside the target window from the received signal to less than -6 dB.

Motivation: In order to accurately track satellites using the signal to noise ratio, any signal outside of the target frequency window should be weakened to lower the noise floor.
Verification: Test: Generated signals outside of the target frequency window can be run through the downlink signal conditioning circuit to measure the signal loss in dB.

DR 2.4: The ground station shall be capable of demodulating the signal using the QPSK modulation scheme.

Motivation: The SeeMe satellite uses QPSK modulation for downlink and so all received signals must be demodulated using this scheme.
Verification: Test: A signal will be put through our SDR and MATLAB's comm.QPSKModulator function and the output signals will be compared to ensure functionality.

DR 2.5: The ground station antenna shall have a gain of at least 24.3 dBi.

Motivation: To be able to communicate with the satellite, the antenna must have sufficient gain for the signal to reach the satellite and back.
Verification: Inspection: The antenna shall be purchased and the antenna gain will be found in the data sheet.

DR 2.6: The ground station shall have a G/T of at least 3 dB/K.

Motivation: This is a customer-defined requirement to ensure the ability to communicate with the satellite.
Verification: Analytic: This will be shown using the antenna noise temperature and the antenna gain.

DR 2.7: The ground station antenna shall have an EIRP of at least 10 dbW.

Motivation: This is a customer-defined requirement to ensure the ability to communicate with the satellite.
Verification: Analytic: This will be shown using the transmitter power and antenna gain.

DR 2.8: The ground station shall be capable of decrypting signals using AES-256 encryption standards.

Motivation: The satellite downlink data uses AES-256 encryption and to be able to communicate, our ground station must be able to perform the decryption.
Verification: Demonstration: An encrypted data packet will be decrypted using our code and compared to the actual data to ensure correctness.

DR 2.9: The ground station link budget shall have an overall margin of 5 dB.

Motivation: This is a customer-defined requirement to ensure the ability to communicate with the satellite.
Verification: Analytic: This shall be verified using our link budget calculations.

DR 2.10: The ground station shall be able to receive a data rate of at least 2 million bits per second.

Motivation: The SeeMe satellite transmits at 2 million bits per second, and to be able to receive data from that satellite our ground station must be able to handle that data rate.

Verification: Inspection: This requirement will be verified by looking at the purchased components and ensuring this high speed capability.

DR 2.10.1: The SDR shall have a sampling frequency of at least 5 MHz.

Motivation: The SDR needs to be able to sample at at least double the data rate to ensure aliasing does not occur.

Verification: Inspection: This will be verified by looking at the SDR datasheet and ensuring that it has a high enough sampling rate to capture the received data.

DR 2.11: The antenna shall be capable of receiving Right Hand Circular Polarized (RHCP) signals.

Motivation: This is the polarization that SeeMe satellite (along with many other S-band satellites) uses to send signals to ground stations.
Verification: Inspection: This shall be verified through the type of antenna purchased.

FR 3: The ground station shall be reconfigurable to be used for different RF bands.

Motivation: LEO satellites communicate over a large range of frequencies. The ability to downlink within multiple RF bands is critical for unconstrained, reliable communication.

Verification: Inspection: Ensure that the S-Band signal conditioning circuit and associated antenna are able to be removed and replaced with the equivalent for other bands such as X-band without fully dissembling the system.

DR 3.1: The signal conditioning circuit and antenna shall be easily accessible and removable.

Motivation: Removes the constraint of communication only with S-Band.
Verification: Test: Removal of the conditioning circuit and antenna shall take less than 30 minutes.

DR 3.1.1: Removal and installation of alternate RF components shall require minimal tools.

Motivation: Ground station needs to be easily carried and assembled by two people.
Verification: Inspection: Total tooling will not exceed a standard toolbox.

FR 4: Two people shall be capable of carrying and assembling the ground station.

Motivation: ARGUS must be smaller and more portable than current systems that weigh several hundred kilograms.

Verification: Test: Two people will demonstrate carrying ARGUS for 100 meters.

DR 4.1: The entire system shall weigh less than 45 kg, with each operator carrying less than 22 kg individually.

Motivation: The OSHA requirements for periodic heavy-lifting state that the maximum carry weight should not exceed 50 lbs (22.7 kg) per person.
Verification: Test: The ground station, in assembled and/or travel configurations, will undergo a weight test and physical 2 person lift demonstration.

DR 4.2: ARGUS shall be able to be assembled by 2 operators in less than 30 minutes.

Motivation: Customer driven requirement for maximization of ease of in-field assembly.
Verification: Test: Timed assembly by 2 trained operators.

DR 4.2.1: Minimal Tools - the assembly process shall need minimal hand tools (less than 10) to assemble the station.

Motivation: The ground station is to be assembled in the field where tools may be limited, also the more tools required for assembly is proportional to the overall complexity of set up.
Verification: Inspection: The number of required tools shall be counted.

DR 4.2.2: All Tools Included - ARGUS shall equip and store all tools necessary to assemble. The number of required tools shall be less than 10.

Motivation: Due to assembly in the field it may not be possible to bring separate tools along, therefore the ground station shall be able to store all necessary tools.
Verification: Inspection/Test: The number of required tools shall be counted and it shall be shown that the tools all fit within the ground station.

FR 5: The ground station shall interface with a laptop using a Cat-5 Ethernet cable.

Motivation: Data from ground station to user computer will be transmitted through Cat-5 Ethernet cable per user request.

Verification: SDR control software on users computer shall send signals to microcontroller. When data is received, external light on ground station shall indicate reception of signal. When data is received to computer, user shall see data in portal.

DR 5.1: The ground station laptop shall run Linux to ensure compatibility.

Motivation: The SDR will run Linux, and most likely the programs will be run in C and Python which run much better on Linux than other operating systems.

Verification: Inspection: Linux will be installed on the purchased computer.

DR 5.2: The ground station laptop shall have an Ethernet port pre-installed.

Motivation: The computer shall communicate with the ground station using an Ethernet cable, so this is a requirement for the kind of computer we decide to buy.

Verification: Inspection: This will be determined when deciding on the computer to buy.

DR 5.3: The ground station laptop shall have a high-end processor (i7+) and sufficient RAM (8gb+).

Motivation: The laptop must be powerful enough to process the high rate of data coming from the SDR.

Verification: Inspection: This requirement will be verified through the type of computer purchased.

4. Key Design Options Considered

4.1. Antenna Type

The antenna is the key to receiving data from the satellite. Various antenna types can be used for radio communications depending on the characteristics of the system. Antennas vary based on gain, radiation pattern, polarization, frequency, bandwidth, directionality, size, and weight.

The customer specified a $\frac{G}{T_s}$ figure of merit for the system of 3 $\frac{dB}{K}$. A rough estimate for system temperature can be taken from SMAD Chapter 13[10]:

TABLE 13-10. Typical System Noise Temperatures in Satellite Communication Links in Clear Weather. The temperatures are referred to the antenna terminal. [See Eq. (13-25)].

Noise Temperature	Frequency (GHz)					
	Downlink			Crosslink	Uplink	
	0.2	2–12	20	60	0.2–20	40
Antenna Noise (K)	150	25	100	20	290	290
Line Loss (dB)	0.5	0.5	0.5	0.5	0.5	0.5
Line Loss Noise (K)	35	35	35	35	35	35
Receiver Noise Figure (dB)	0.5	1.0	3.0	5.0	3.0	4.0
Receiver Noise (K)	36	75	289	627	289	438
System Noise (K)	221	135	424	682	614	763
System Noise (dB-K)	23.4	21.3	26.3	28.3	27.9	28.8

With a desired receiver center frequency of 2.25 GHz, the system temperature T_s can be extracted from this table as approximately 21.3 $\frac{dB}{K}$. More precise calculations will be completed later in the design process once contributions to noise from selected components are better known. However, using this estimate of $T_s = 21.3 \frac{dB}{K}$ along with the customer's required $\frac{G}{T_s} = 3\, dB$, the antenna requires a gain of **G = 24.3 dBi**. The polarization and frequency specified by the customer are right hand circular polarization (RHCP) and 2.25 GHz, respectively. The frequency bandwidth is about 250 MHz. In addition to technical specifications, the antenna must be appropriate for outdoor use and maintain the mobility requirements of the system.

The antennas considered here include helical, Yagi, and parabolic. Other types of antennas are available, but cannot meet the specifications designated by the customer. This is mostly due to their lack of ability to generate a powerful enough signal. For example, a dipole antenna is omnidirectional–that is, it sends signals in all directions. The power of an antenna decreases with distance. The gain is related to the directionality of the antenna by

$$G(\theta, \phi) = \eta D \tag{1}$$

where η is the efficiency of the antenna. Thus, a more directional antenna has a higher gain. Average dipole antennas are in the single-digit dB range. Yagi, helical, and parabolic are all highly directional.

4.1.1. Helical Antenna

Figure 4. Helical Antenna (via www.tutorialspoint.com)

A helix, or helical, antenna consists of a ground plate and a conducting wire that forms a helix pattern, as seen in Figure 4. This type of antenna can be used in normal or axial mode. Axial mode generates waves off the end of the antenna, along the central axis of the helix. The ground plate reflects waves off of the back of the antenna for increased directionality, as shown in Figure 5. For this project, axial mode is superior. A helix antenna in this mode can meet the frequency and polarization requirements.

The gain of a helical antenna can be approximately determined with the equation[3]

$$G_{\text{helix}} \approx K_G C^2 n S \tag{2}$$

Where:

K_G = Empirical constant ≈ 15
C = Helix circumference
n = Number of turns
S = Spacing between turns

However, this gain equation is empirical in nature. From research, the circumference of a helical antenna is generally considered to be about one wavelength, with the spacing between turns at about one quarter of the wavelength, for maximum directionality[4]. Given a wavelength of 0.13 m for 2.25 GHz, the number of turns needed would be approximately 30,000 turns. This is obviously unrealistic. The literature seems to suggest that this equation was determined with experiments on helical antennas of a relatively short axial length and lower frequencies than this application demands. Due to the imprecise nature of these necessary calculations, a successful project with a helical antenna will likely require high-accuracy modelling and even some prototyping. This is likely out of the skill-set and budgetary constraints of the ARGUS team, making a helical antenna an unlikely design candidate.

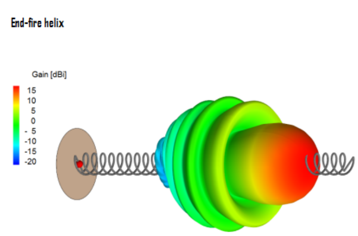

Figure 5. Axial Helical Antenna Radiation Pattern (via antennamagus.com)

4.1.2. Yagi Antenna

A Yagi antenna is made up of a dipole antenna at the base with a reflector and several directors added parallel to the dipole, as seen in Figure 6. The directors positively interfere with the dipole and increase the directionality and radiation pattern of the antenna depending on their separation distance, as seen in Figure 7. The length of the antenna is generally proportional to the gain, so that more directors can be added to increase the gain. However, there is a limit to its length; the gain decreases with increasing number of directors after approximately fifteen directors[5].

Figure 6. Yagi Antenna (via www.lairdtech.com)

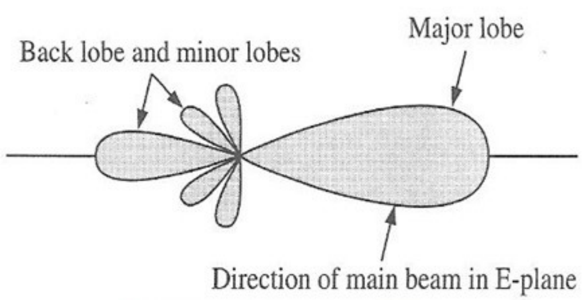

Figure 7. Yagi Antenna Radiation Pattern (via www.rfwireless-world.com)

Despite its directionality and modifiability, there are several downsides to the Yagi. To achieve circular polarization, two Yagi arrays must be arranged at right angles[5]. This adds considerable weight and bulk to the system. Additionally, Yagi antenna gain is typically determined with an experimental table look-up, which will mean additional testing would be necessary to find the definitive gain of the antenna.

4.1.3. Parabolic Antenna

A parabolic antenna is designed with a feed in the center of a parabolic dish. The parabola of the dish determines the focus and reflectivity of the signal emitted from the feed.

Figure 8. Parabolic Antenna (via www.q-files.com)

The parabolic dish antenna provides the highest gain of the antennas considered here. This gain is directly proportional to the efficiency and diameter of the dish and inversely proportional to the wavelength of the frequency used. More specifically, the gain of a parabolic dish antenna can be calculated with

$$G_{\text{parabolic}} = \eta \left(\frac{\pi D}{\lambda}\right)^2 \quad (3)$$

Where:

η = Aperture efficiency
D = Dish diameter
λ = Wavelength

Assuming an efficiency of $\eta = 50\%$ and the required gain of 24.3 dBi, the diameter of the dish must be at least **D = 0.984 m**. This is the best choice of size when compared to the Yagi or helical antennas. Right hand circular polarization and the desired frequency range is easily achieved with a parabolic antenna. Furthermore, the dish can be made out of mesh, which greatly decreases the wind loading on the antenna. The feed can be encapsulated in a weatherproof container and the dish has no electrical or moving parts that need to be protected from the weather.

Description	Helical	Yagi	Parabolic
The antenna can be placed outdoors with minimal additional protective cases	✗	✗	✓
The generated signal can be pointed in a specific direction	✓	✓	✓
The antenna can achieve the required gain with its largest dimension 1.5 meters or less	✗	✗	✓
The antenna can be made relatively lightweight while still achieving the required gain	✗	✗	✓
A single antenna can receive the required RHCP polarization	✓	✗	✓
An antenna can be purchased off-the-shelf with the ability to communicate at the required frequency	✗	✓	✓
No part of the antenna's signal is blocked by its own components	✓	✓	✗
The antenna's contributions to a link budget are mathematically well-defined and do not require empirical modeling	✗	✗	✓
The antenna's 3dB beamwidth is large compared to alternatives, which allows for more wiggle-room in tracking precision	✓	✓	✗

Table 2. Antenna Pros/Cons

4.2. Container/Rack - No Trade Study

The ground station needs a container to allow the user to be able to transport it and use it in various locations. It must be able to withstand weather conditions and must be light enough to be carried by two people. The kinds of containers ARGUS is considering are hard cases with handles, cases with wheels, large hiking backpacks, and carts with wheels. The ground station will have different uses, either backcountry or remote locations. For the possible future of ARGUS being a military reconnaissance aid out in the field, a backpack or a hard case that can be carried between two people would be the most likely option due to their ease of transport. In order to comply with Department of Defense regulations for military gear and safety regulations, all cases will be cross referenced with International Product Outdoor Cases and will have a certificate by the company for guarantees and specifications.[2]

4.2.1. Hard Case

A hard case with handles would be a durable, compact, waterproof container that could hold the entirety of the ground station's components. This would be able to be transported to remote locations without the components being damaged. This case would be relatively light weight and would have lots of organized space. Most Pelican hard cases have dual casing to protect the components from the elements as well as any submersion in water. The hard cases will have a foam inside to protect the various components of the ground station, which can be cut into divisions to completely secure each part. Hard cases come in different sizes, but a medium size hard case with side handles can easily be carried by two people. Therefore, cost based on the durability, inside foam protection, and buoyancy in case of water will be key elements for the protection of all the ground station components.

4.2.2. Case With Wheels

A case with wheels would be a commercial, off-the-shelf, and variably sized container that could hold the entirety of the ground station's components. It would be an affordable and easily found option that could be replaced for future iterations. A case like this would be cased in plastic which allows for durability, but would be heavy and difficult to carry. In addition, these cases would be difficult to transport on their wheels if the terrain was not perfect. Furthermore, if the wheels were used, it would be difficult to find an off the shelf affordable container like this that would be guaranteed to work in remote locations. In addition, most cases with wheels have handles to carry the case, yet they are not in easy access locations, making it quite difficult to carry.

4.2.3. Backpack

A large backpack would be a commercial, off the shelf, and easily portable option for the container for the project's ground station. Most backpacks are considered water resistant, light weight, and easy to carry. However, backpacks lack a large space that could easily fit the components of the ground station. Also due to the size of our antenna and also requirement to protect the antenna it will be harder to find a reasonable size backpack that can maintain all the components secured.

4.2.4. Cart

A cart would allow for heavier components to be transported. However, the components would be open to damage from the environment, would not be able to be carried by two people, and would be difficult to transport over rocky and variable terrain. Moreover, a cart would most likely be the most expensive option. A cart would be a good option if the ground station were to be transported in and out of a building on flat terrain, but it would be very difficult and heavy to move over variable terrain likes rocks and dirt. Transportation carts can be used by Raytheon when loading and unloading the ground station from an aircraft if this were to be shipped, but the ground station itself should be in one case for the success of this project.

Description	Hard Case	Case with Wheels	Backpack	Cart
The container can be knocked over or dropped from short distances with little damage to components	✓	✓	✗	✗
The container can be picked up and carried easily over long distances	✓	✗	✓	✗
The container is lighter than alternatives	✓	✗	✓	✗
Space within the container can be structured and well-organized	✓	✓	✗	✓
The container is not prohibitively expensive	✓	✓	✓	✗

Table 3. Container Pros/Cons

With the table listed above, it is clear which option the team will use as the container for the components. The Hard Case, with handles for hassle-free carrying, is the most advantageous choice that fits all of the project's needs. Therefore, there will be no trade study done. It is likely that the team will consider the Pelican iM2450, Monoprice Weatherproof Hard Case, and the Condition 1 16inch Medium Case as possible options for the actual container. All these cases are not only certified by the Department of Defense's International Product Outdoor Cases, but also recommended by various outdoor personnel of multiple status (military, hobbies, hunters etc).

4.3. Central Processor - No Trade Study

4.3.1. Small Single-Board Computer

The first option looked at for a processor was a small single-board computer for the tracking software. This is a cheap option, however may not have the processing power and speed to be able to both track the satellite and handle the SDR output. Some examples looked at were the Raspberry Pi 3 Model B+ (pictured below), the BeagleBone Black, and the Odroid XU4. It was determined that this was not a good option to be able to handle the SDR output, and a separate computer would be needed to handle the user interface.

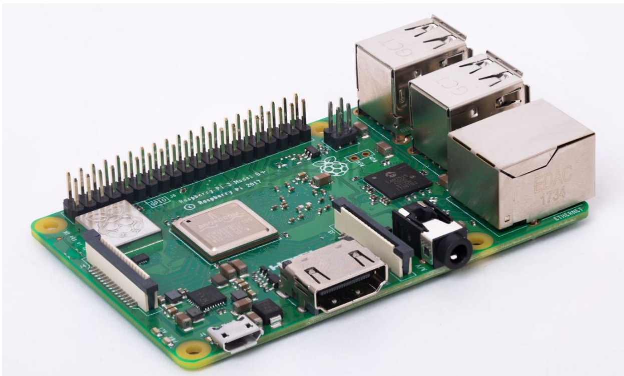

Figure 9. Raspberry Pi 3 - Model B Plus (`https://www.raspberrypi.org/products/raspberry-pi-3-model-b-plus/`)

4.3.2. Laptop

The other option looked at was to use a Laptop as both the user interface and the processor. This is a better option than the small single-board computer, as it should have a lot more processing power as long as it has a high-quality processor such as an Intel Core i7 or i9. The laptop seems to be a much more expensive option, but a laptop is necessary in either case to interface with the ground station so in reality it is cheaper to combine all functionality into one computer. This makes the laptop a much better option than the small single-board computer. Some options the team is considering are the Inspiron 15 5000 (pictured below), the Acer Travelmate 4, and the Lenovo Ideapad 530s.

Figure 10. Inspiron 15 5000 (`https://www.dell.com/`)

4.4. Tracking Software

Tracking is composed of two different methods: program-track and auto-track. Program-track will require a software program to generate TLE data for a specific satellite from a given latitude and longitude over a specific region of the sky. For auto-track, the TLE data will be fine-tuned with received signal strength. This will require a significantly more advanced algorithm than reading the TLE data, and will likely be written manually, due to no such software programs being commonly available. There are a number of software options to generate TLE data. Two are considered below.

NOVA

NOVA is an all-encompassing software package capable of generating TLE data for real-time antenna control. Several motor systems with a comprehensive calibration interface is already built-in. This would avoid the need to create a motor calibration system and a program-tracking algorithm. However, NOVA was last updated in 2006, is not capable of auto-tracking based off signal strength, and is only compatible with a number of heritage motor systems. Additionally, NOVA has limited help resources and is only compatible with pre-1998 Windows operating systems.

Gpredict

Gpredict is a real-time satellite tracking and orbit determination program. Unlike NOVA, Gpredict cannot directly interface with a motor system. However, Gpredict is a more recent program with more user support and is able to run on Linux. Auto-tracking is also not an option for Gpredict.

Gpredict is the obvious choice because it runs on the planned operating system (Linux), and has available user support which will help us ensure everything works properly. NOVA is impractical because it only runs on old Windows systems and has no user support.

Description	NOVA	Gpredict
The software can be installed and run on Linux	✗	✓
The software can be licensed at no cost	✓	✓
The software is capable of program tracking with inputted TLE data	✓	✓
The software is under continual development and has current documentation readily available	✗	✓
The software is capable of directly interfacing with a motor system	✓	✗

Table 4. Tracking Software Pros/Cons

4.5. Control Software

After using tracking software to obtain the TLE data, a closed-loop control system capable of commanding elevation and azimuth will be implemented in one of two software programs outlined below.

Simulink

Simulink is a versatile modeling and simulating environment for dynamical systems. In ASEN 3128 (Aircraft Dynamics), ARGUS team members utilized Simulink to implement a proportional derivative (PD) controller for a PARROT quadcopter. Developed by MathWorks, Simulink is also desirable due to ARGUS team members experience in MATLAB. Simulink is more desirable for motor control. It is licensed for CU Boulder students, and easily generates C code, but is only compatable with certain devices.

LabVIEW

LabVIEW's Control Design and Simulation Module is another promising software interface. While more focused on measurement applications, LabVIEW is also capable of deployment to real-time hardware. ARGUS team members have experience with the measurement interface, but are not as familiar with development and deployment. LabVIEW is more desirable for motor control. It is licensed for CU Boulder students, and easily generates C code, while having a comprehensive embedded development module.

The pros and cons for each software are tabulated below.

Description	Simulink	Labview
Team members are more familiar with the framework	✓	✗
The program is licensed by the University of Colorado	✓	✓
Hardware deployment is compatible with a wide array of devices	✗	✓
The program easily generates C code to interface with hardware	✓	✓

Table 5. Control Software Pros/Cons

4.6. Radio - No Trade Study

In order to track the satellite using signal communication, as well as receive data from the satellite, a radio must be implemented in the design of the ground station. This will aid in the tracking of the satellite as the ground station dish and antenna track across the sky. For this system, the frequency in which RX will be operating is 2.1 GHz - 2.3 GHz. Given the data rate of 2 Mbps, the necessary resolution was calculated to be between 8-12 bits. The maximum bandwidth of the radio is 2 MHz, which is proportional to the data rate given the QPSK demodulation scheme. With this information and the requirements established by the customer, a trade study will be performed to determine which radio system is the most qualified and cost effective. An important aspect that will be taken into consideration will be the portability and mobility of the radio, this ties into the motivation for this project.

HAM Radio

An amateur radio (HAM radio) can transmit and receive radio signals in which ever frequency is desired. This radio requires licensing and is often times bulky. There are a transceiver systems that can be implemented for receive and transmit capabilities, these systems are expensive but it is comparable to buying two separate receive and transmit radios.

Software Defined Radio

A Software Defined Radio (SDR) can cover a wide range of frequency as well as large bandwidths. This system is also small, which aids in keeping the ground system mobile and portable. The SDR is compatible with software to demodulate the signal. The software that will be used in partnership with the SDR is GNU radio, an open source free toolkit for these applications.

Description	HAM	SDR
The radio system does not require a significant portion of the budget	✗	✗
The radio system is well-documented	✓	✓
The radio system is small and light enough to be comfortably carried by one person over a long distance	✗	✓
The radio system can be reconfigured to handle signals with different frequencies and modulation schemes	✗	✓
The radio system only requires one unit to be capable of transmitting as well as receiving	✗	✓

Table 6. Radio Pros/Cons

4.7. Low-Noise Amplifier - No Trade Study

A low-noise amplifier (LNA) must be used when downlinking data from a satellite. This is because the received signal will be too weak for the SDR to accurately convert to a digital signal. Each LNA considered has SMA-type connections and require a constant DC voltage as they are an active component. All considered LNAs are configured similar to the following image.

Figure 11. Low-Noise Amplifier (via minicircuits.com)

LNAs differ from one another in their frequency window, signal gain in dB, noise floor levels in dB, and connector types. There is no trade study necessary at this stage of the project, but an LNA will end up being used. Until the exact link budget is finished it will be unknown what signal gain will be needed to close the link between the ground station and the satellite. A low noise amplifier is preferred because the automatic track function will likely follow the highest signal-to-noise ratio. Therefore, background noise and signals outside of the desired frequency window should be minimized. LNAs have a more narrow band and lower noise figure than most other types of amplifiers.

4.8. Motor Hardware

In pursuit of designing a two axis (azimuth and elevation) pointing system, motor hardware is at the forefront of making the system possible. Some simple back of the envelope calculations determined that a motor between 5 to 25 Nm would be required to point and hold the elevation component of the antenna. This number is fairly high, limiting available motors. Additional research will be done to more accurately determine the required torque once a baseline direction has been decided. There are numerous kinds and types of motors to consider including; AC, DC brushless, direct drive, servos, stepper, and torque motors. Each of these motors are very applicable for the intended design, but each has drawbacks if used.

AC

An AC motor is one of the most common types of motors available. AC motors use the basic concepts of electromagnets and rotating shafts. One main concern with this selection would be the use of electromagnets, which can cause interference with radio signals. In addition, most general AC motors use analog controls based on frequency manipulation. This would require the use of an encoder to determine position and a motor controller to control speed.

DC Brushless

Brushless DC motors are a type of synchronous motor which receive a DC current that passes through an inverter or switching power supply to drive the motor phases. Due to the fact that the alternating power supply is created by an embedded controller, DC motor have the advantage of excellent speed control in both directions yet are less efficient than AC motors. Additionally, DC motors are characteristic for high power to weight ratios and high speeds.

Direct Drive

Direct drive motors are a type of permanent-magnet synchronous motor, in which the power is directly provided from the shaft to the load. This is advantageous because it eliminates the need for any belt or gear system resulting in a lower torque-inertia ratio. This means less torque required to accelerate the motor and increased speed control. Additionally, the direct drive motor requires fewer moving parts than alternative electric motors meaning, decreased size and complexity, and increased life span. Direct drive motors are also susceptible to torque ripple during operation. Overall direct drive type motors are small, lightweight, low power, and provide optimal speed control.

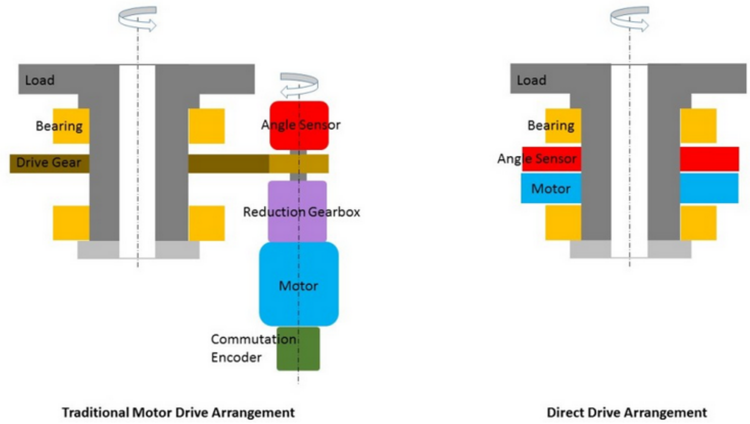

Figure 12. Direct Drive and Torque Concept [9]

Servos

The basics of a servo are a small DC or AC motor, potentiometer, and a control circuit. This is an all-inclusive package that can be used to simply control the motors and, in turn, the pointing. These are usually smaller in size and do not have large torques. However, there are viable options in the 5-10 Nm range that are readily available.

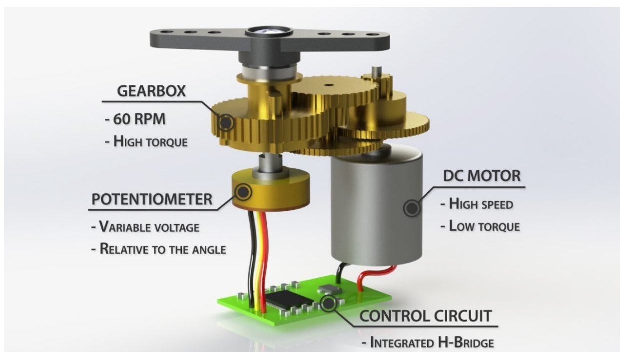

Figure 13. Servo Motor Theory [6]

Stepper

A stepper motor uses the basic concepts as the DC and AC motor, but the magnets and stator are flipped; with a static stator on the outside and magnets on the inside of the housing that rotate. In addition, instead of one large magnet, there is numerous much smaller magnets that are surrounded by electromagnets. Precision and accuracy is a point of concern due to limited documentation. This could be remedied by implementing some form of gearbox.

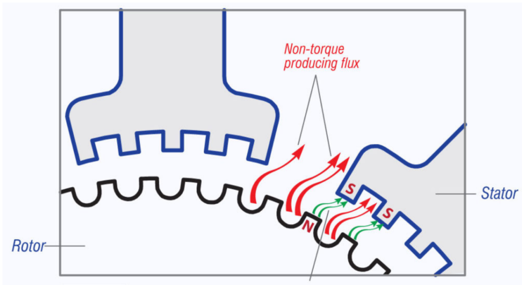

Figure 14. Stepper Motor Theory[7]

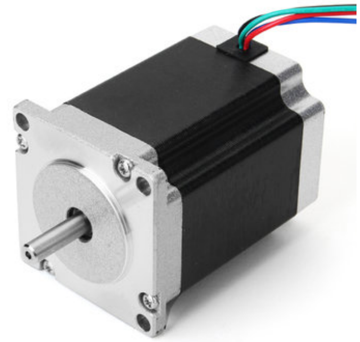

Figure 15. Stepper Motor[7]

Torque

A torque motor is a specialized form of electric motor which can operate indefinitely while stalled, that is, with the rotor blocked from turning, without incurring damage. Torque motors is less of a type of motor, but a special version of a motor. This is still an attractive option due to operating near stall conditions. These motors produce large torques at low to no RPMs. One downside of all the available torque is these motor tend to be very expensive, and will still require an encoder to determine position.

Description	AC	DC	DD	Servo	Stepper	Torque
Can generate enough torque to point antenna	✓	✓	✓	✓	✓	✓
Accurate enough to meet pointing criteria	✓	✓	✓	✓	✗	✓
Within budget	✓	✓	✓	✗	✓	✗
Uses digital control/input	✗	✗	✓	✓	✓	✓
Robust/Reliable	✓	✓	✓	✗	✓	✓
Feedback Sensor Included	✗	✗	✗	✓	✓	✓
Light and small	✗	✓	✓	✓	✗	✓

Table 7. Motor Hardware Pros/Cons

At the conclusion of the research for each of these viable options, all still remained valid solutions. In addition, the need for a digital format was determined to be essential over an analog motor, as determined by other group members as to not require a DAC. The importance of having high torque at low RPMs was another essential constraint. This included stepper, torque and direct drive. With this information in mind, a trade study will be conducted on all possible motors to determine the ideal motor type for the system.

5. Trade Study Process and Results

5.1. Antenna Type

One ARGUS critical project element is closing the communications link budget, and the main contribution to this project element is the design of an antenna. With this in mind, the first design decision for an antenna is choosing a general type of antenna. For reasons discussed earlier, the team is considering three different types: helical, yagi, and parabolic. Several criteria have been selected to choose this critical design component, and are discussed in Table 8 below.

Criteria	Weight	Rationale
Size-to-Gain	20%	Portability is a CPE, so the antenna size should be small relative to the gain it is able to produce.
Beamwidth Size	10%	A larger beamwidth allows tracking accuracy requirements to be less strict.
Available COTS	35%	Having available components-off-the-shelf at the required gain relieves pressure on the design process for a component that team members have little experience with.
Ease of Modeling	35%	Having strong analytical knowledge of an antenna system's performance is vital to properly modeling the system and understanding how it will behave upon construction.

Table 8. Antenna Type Criteria Definitions

A large beamwidth size would make designing the tracking system easier, but this is ultimately less important than the other criteria listed here. The size-to-gain is important to designing a portable system; however, both the availability of components off-the-shelf and ease of modelling are vital to obtaining any level of success in this project. The levels of these criteria are tabulated below.

Criteria	1	2	3	4	5
Size-to-Gain	Achieving the required gain necessitates an antenna that does not fit in a pickup truck	Achieving the required gain necessitates an antenna that fits in a pickup truck	Achieving the required gain necessitates an antenna that can be rolled by two people	Achieving the required gain necessitates an antenna that can be carried by two people	Achieving the required gain necessitates an antenna that can be carried by one person
Beamwidth Size	The antenna can produce a 3dB beamwidth smaller than 5° at the required gain	The antenna can produce a 3dB beamwidth smaller than 10° at the required gain	The antenna can produce a 3dB beamwidth smaller than 15° at the required gain	The antenna can produce a 3dB beamwidth smaller than 20° at the required gain	The antenna can produce a 3dB beamwidth smaller than 25° at the required gain
Available COTS	Few components are available off-the-shelf, and other components cannot be easily manufactured	Few components are available off-the-shelf, and other components can be easily manufactured	Most components are available off-the-shelf, with the exception of a difficult-to-manufacture component	Most components are available off-the-shelf, with the exception of an easily-manufacturable component	The entire antenna system is available off-the-shelf
Ease of Modeling	No analytical expressions exist for antenna performance and no empirical approximations exist for this application's frequency and gain requirements	No analytical expressions exist for antenna performance, but empirical approximations exist for this application's frequency and gain requirements	Approximate analytical expressions exist for antenna performance and cannot be easily optimized with some modeling	Approximate analytical expressions exist for antenna performance and can be optimized with some modeling	Clear analytical expressions exist for antenna performance

Table 9. Antenna Type Criteria Levels

These criteria have been applied to the three types of antennas, seen in Table 10. As discussed in the key design options, the size of both the Yagi and helix antennas increase with an increase in gain. The beamwidth size is better for the Yagi, but the ease of modeling is far less. The helical antenna has slightly better modeling options, though neither are as accurate as that available for a parabolic antenna.

	Helical	Yagi	Parabolic
Size-to-Gain	1	2	5
Beamwidth Size	3	4	2
Available COTS	1	2	5
Ease of Modeling	3	1	5
Weighted Total	1.90	2.45	**4.70**

Table 10. Antenna Type Scoring

Overall, it has been determined that the parabolic antenna is the best choice for ARGUS. There are many options available off the shelf at the desired frequency, gain, and polarization. Many of these options are small enough to meet the mobility requirement, while larger ones will still fit in the back of a truck. Finally, the parabolic system will be easy to model and verify. The beamwidth, as explained in the scoring, is not as critical as these other elements.

5.2. Control Software

Simulink and Labview are the two software programs of interest for motor control. Four criteria areas are used on a one to five scale to determine ranking and are specified by Table 11 below.

Criteria	Weight	Rationale
User support	30%	Online assistance or from CU students/faculty is critical for when problems arise.
Team Experience	30%	Less problems will arise with previous team knowledge.
Hardware Compatibility	30%	Selection of hardware should not be contingent on compatible software.
User Interface Compatibility	10%	GUI-oriented programs helpful but not necessary.

Table 11. Control Software Criteria Definitions

Both user support, team experience, and hardware compatibility have the same 30% weight. It is equally important to have the resources and hardware compatibility for a successful control system. The user interface compatibility is weighted significantly lower at 10%. While a user interface would make the control system more user-friendly, it is not required.

The scoring level criteria is given in Table 12. A score of one is the least-desirable (red), and five is the most-desirable (green). The final scoring between the two programs is given in Table 13.

The elected control software after scoring is Simulink. While both programs are equally capable, the ARGUS team has more experience with Simulink (and/or MATLAB). Despite a score of 3 in team experience, there are many resources available on the CU campus as well as online for troubleshooting.

Criteria	1	2	3	4	5
User Support	Not supported	No longer supported	Current, minimal support	Current, full support	Currently supported w/ online and on-campus resources
Team Experience	None	1 member w/ minimal experience	1 member w/ proficient experience	1+ members w/ proficient experience	Full team experience
Hardware Compatibility	No compatible external hardware	1-2 compatible devices/-drivers	2-5 compatible devices	5-10 compatible devices	10+ compatible devices
User Interface Compatibility	Not supported	Supported but not well-documented, hard to implement	Supported and well-documented, hard to implement	Moderate in implementa-tion	Fully supported and easily implemented

Table 12. Control Software Criteria Levels

	Simulink	LabView
User Support	5	5
Team Experience	3	1
Hardware Compatibility	5	5
User Interface Compatibility	5	5
Weighted Total	**4.4**	3.8

Table 13. Control Software Scoring

5.3. Motor Hardware

Due to the current unknown estimates for motor torque, each of the motors were examined with the pursuit of finding motors that can create a peak torque of 5-25 Nm. With this basis in mind, each motor was examined to see possible real world motors that could be applied to the ARGUS pointing system. In Table 14, the weights and the reasoning on their selection is outlined. The greatest priority is motors with high torque and good pointing accuracy. In addition criteria levels are outlined in Table 15 and the final results of the trade study are found in Table 16. Sources for each motor can be found in References.

Criteria	Weight	Rationale
Peak Torque	30%	Selecting the a motor with the correct peak torque rating ensures that the antenna can quickly accelerated and pointed to the desired location. Also, the selection needs to be high enough to allow continuous torque application during tracking
Precision	20%	The ground station must be able to point accurately enough to meet the requirements of the link budget
Size	10%	The ground station will have to be carriable by hand, so the motors can not be overly large.
Mass	10%	The ground station must be light enough for a two person carry so, the motors should be as light as possible.
Cost	20%	Budget is one of the main constraints on this project so, the price of the motor should be taken into account.
Simplicity	10%	Choosing a motor that is relatively simple in aspects of number of parts, difficult to replace parts, easily damaged parts, is important if issues arise.

Table 14. Motor Hardware Criteria Definitions

Criteria	1	2	3	4	5
Peak Torque [Nm]	τ <1	1-10	10-15	15-20	τ >25
Precision [°]	>1	1-0.8	0.8-0.5	0.5-0.2	<0.1
Size [cm] (Length)	>50	50-40	40-30	30-20	<20
Mass [kg]	>40	40-30	30-20	20-10	<10
Cost [USD]	>1,000	1,000-500	500-100	100-10	<10
Simplicity	Many intricate, hard to replace, and/or expensive components	Three to five fragile components that are hard or expensive to replace	One or two fragile components that are hard or expensive to replace	One or two fragile components that are replaceable	One or no easily damageable components, all with readily available replacements

Table 15. Motor Hardware Criteria Levels

	AC	DC	Direct Drive	Servo	Stepper	Torque
Peak Torque	5	5	5	3	2	5
Precision	3	3	5	5	2	5
Size	4	3	5	3	5	4
Mass	1	4	4	5	5	5
Cost	3	3	4	2	4	3
Simplicity	4	4	5	3	5	5
Weighted Total	3.6	3.8	**4.7**	3.4	3.3	4.5

Table 16. Motor Hardware Trade Study

As can be seen from Table 16 direct drive and torque motor are ahead of the other candidates. This is due to the similarity between the two motors, but direct drive is the ideal selection based on the above trade study.

5.4. Flowchart of Trade Study Selections

ARGUS can be broken down into three generally separate sections. Figure 16 shows the progression the project has taken through key design considerations and down into the trade study. The elements in green are the winning results of the trade study for each section.

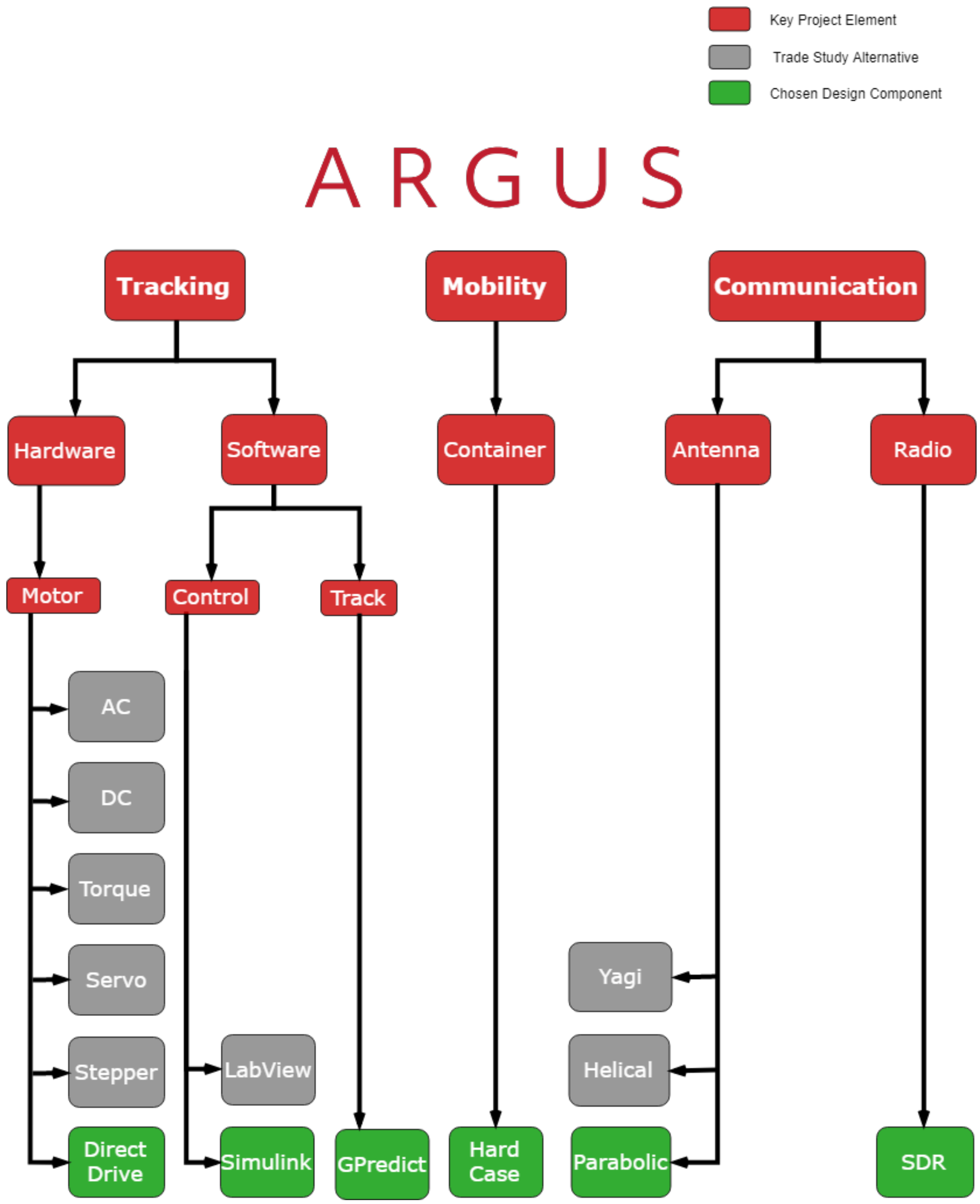

Figure 16. Summary of ARGUS's Trade Study Selections

6. Selection of Baseline Design

6.1. Central Processor

The central processor unit was determined to be a laptop. The required sample rate is 5 MHz which can only be achieved using a laptop (with a processor at least as powerful as an Intel i7) connected to the SDR. This will allow the user to process the data real-time, track the satellite (program and auto track), and collect telemetry data. The second reason for choosing a laptop is it contains a user interface. In order to downlink from the satellite and test requirements, a radio-commanding user interface is required. A single small board computer cannot run software like this and does not have the interface to allow command if it could. Similarly, the tracking software would be difficult or even impossible to use without some kind of interface. Lastly, the central processor must be capable of computing the tracking algorithm that will command the motors. The use of a laptop provides flexibility on what type of algorithm, language, and user interface used. The laptop is the clear choice, as a small single-board processor would not be feasible to be controlled by a user.

6.2. Antenna Type

The antenna best suited for this design is a parabolic antenna. Through the key design analysis, the parabolic shaped antenna was found to be the type best for satisfying the design requirements. The gain, polarization and frequency requirements are all met through the parabolic dish. These factors cannot be compromised, as the entire system will not work without the correct specifications. Furthermore, this type of dish is also lightweight and fairs well in meeting the size requirements at the necessary gain. Overall, the parabolic dish is the best design to satisfy our design requirements.

6.3. Radio

The team will use an SDR as the radio system, which was determined through research and comparison of HAM radio transceivers and receivers. The SDR is a smaller system that would be required for a hardware based radio. An SDR is also more flexible in varying the frequency. This system is more complicated than a hardware based radio due to its configuration requiring the usage of Linux programming; however, it is also less expensive than a hardware based radio. The SDR is the best fit for radio hardware and signal processing to ensure modularity to different frequencies, cost, and size advantages. It is also of key importance to the digital data processing required. It will interface with a software on the computer which is able to control the SDR and graphically show output for validation.

6.4. Motor System

The motor type chosen to best satisfy the needs of the system was the direct drive motor. This decision was based off of the on the pros/cons and trade study performed earlier in this document. Direct drive motors were the optimal choice because of their ability to produce and sustain significant torques at low to zero RPM. Additionally, direct drive motors experience little to no backlash, are small relative to their torque output, and are relatively simply in both construction and maintenance. Lastly, a direct drive motor can be coupled with a high resolution encoder to deliver accurate angular position and rate information.

6.5. Control Software

While equally capable programs, the results of the trade study placed Simulink at 4.4/5 and Labview at 3.8/5. This is due entirely to the increased team experience with Simulink. Therefore, Simulink will be used for implementing the auto and program-tracking algorithms. Within Simulink there are multiple control design toolboxes capable of hardware deployment. While ARGUS team members have little experience in Simulink, their experience using MATLAB can be easily translated.

6.6. Container Type

The container the team determined is most beneficial for ARGUS is a hard cased carry container. This container option would have durable handles and would be lightweight for two person carry. It would be durable enough to transport the components to remote locations without damage and would be spacious enough for organized storage with foam protection. The other options all had disadvantages that detracted from their appeal and only worked under very specific circumstances. This does not comply with our main goal of two person carry ground station with backcountry use. The pros and cons for each are listed earlier in the document, and the hard cased carry container is the obvious choice. The team is currently looking into possible options for the hard carry cases, but the Pelican iM2450, Monoprice Weatherproof Hard Case, and the Condition 1 16inch Medium Case are the most likely options for this.

6.7. Tracking Software

The tracking software we determined is the most applicable for our use is Gpredict. This is because it is a free open-source software which can be run on Linux. Our SDR will run Linux, and the rest of our code will be much easier to run on a Linux system than any other operating system. It has an excellent user interface, and can output a list of elevation and azimuth angles for our antenna to point towards during any given pass. It has the ability to control the motor, but this will most likely not be used because this can only use the program track function; this means the implementation of auto-track will require a different software using the azimuth and elevation angles from Gpredict as inputs. Gpredict will simply be used to track the satellite using TLE data, transform the output into azimuth and elevation angles based on the ground station location, and output to the separate motor control software.

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