University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document
Auto-track **RF** **G**round **U**nit for **S**-Band (**ARGUS**)

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Approvals

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1. Problem Statement

Small satellites (SmallSats) 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 (LEO) between 2016 and 2022, autonomous, portable ground stations are of emerging interest. Mobile ground stations are far more versatile, establishing the ability to autonomously communicate with LEO satellites to uplink commands and downlink data while in remote locations.[2]

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. For Raytheon, the primary goal will be to command, control, and downlink data from future large constellations more often than currently possible, 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. Eventually Raytheon may have one of these constellations of various priority level satellites requiring communications access to any location around the world. The customer's design idea included the ability to uplink a set of coordinates to an imaging satellite, and quickly receive an image of the 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 goal of this project is to create a portable ground station system containing S-Band uplink and downlink capabilities. 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 (TLE) satellite data to mechanically sweep across the sky using the pre-programmed path calculated from the TLE data, as well as be able to track the satellite 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 capabilities in the future. This portable, easy-to-use ground station allows for S-band satellite communication in varying locations, allowing for real-time imaging of locations of interest; a function that stationary ground stations are incapable of.

2. Previous Work

The Raytheon Company is a major defense contractor specializing in weapons, military and commercial electronics, and cybersecurity. As of 2018, Raytheon is also entering the SmallSat industry. Raytheon is planning on launching their first SmallSat, "SeeMe", in late 2018. This satellite will be performing Electro-Optical (EO) imaging, tasked directly from (and downlinked to) the user. "SeeMe" sparked the idea for a SmallSat ground station terminal. While Raytheon is already in the business of creating ground terminals, the creation of a system with more mobility, portability, and cost effectiveness was proposed.

Current ground station systems can cost upwards of $60,000[3]; this is with minimal portability and frequency bands of only UHF/VHF. This project is aimed at creating a similar satellite-tracking ground station with increased portability at a lower cost, utilizing the more challenging S-band (as a result of shorter wavelengths). The mobility of the design will ideally enable satellite tracking and communication in a backcountry setting. The design will also consist of mostly off-the-shelf or 3D printed parts, which will keep the system easily maintainable.

Although there are no similar projects that are currently produced by Raytheon, there are other commercial and academic stations that are similar in nature. ISIS (Innovative Solutions in Space) sells an S-band ground station that weighs 263 kg total, at a cost of €64,500, or around 75,000 US dollars.[3] A design of similar weight and cost is beyond the scope of ARGUS, so unique solutions must be explored in order to manufacture a station with similar core capabilities with reduced mass and cost. A significant goal of ARGUS is to create an S-band ground station that is mobile enough to be carried by two people – an objective that is unfulfilled by current systems with a large mass. Another similar system is from Tiger Innovations, who created, tested, and now sells a small ground terminal to communicate with the LEO satellite STPSat-l, in collaboration with the Naval Research Lab.[4] This system implements autonomous tracking procedures desirable for this project, although likely once again for a higher price.

Many ground stations track satellites by using a tabled orbital trajectory. Another method of tracking involves following the satellite based on power levels of the signal. An article in Springer outlines a technique using the Doppler Frequency Shift[5]. Both methods will be investigated for use in ARGUS, though tracking based on signal power (also known as "auto-tracking") would be ideal.

3. Specific Objectives

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 structure shall have the ability to operate in clear weather • 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 shall be able to withstand temperatures between TBD and TBD, and the ground station shall be water resistant. • The ground station antenna shall be able to track LEO satellite at TBD 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 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 capable of sending data packets to a LEO satellite using S-band frequencies with an EIRP of at least 10dBW‡ • Transmitted data packets shall have a bit error rate no greater than 10^{-5} ‡	• 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‡ • The ground station shall be water proof.	• Transmitted Data packets shall be modulated using QPSK modulation standards
3	• The ground station shall be reconfigurable*to X-band frequency communication‡ • 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 TBD weight and TBD volume • Two people shall be able to assemble the ground station within half an hour‡ • The ground station shall be hermetic.	• The ground station software shall be able to predict LEO satellite location to TBD accuracy using tracking algorithm based on signal strength • Both uplinked and downlinked data shall have the ability to be encrypted and 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 X-band, i.e. the antenna dish and RF components.
‡ Customer specified requirements.

4. Functional Requirements

4.1. Concept of Operations (CONOPS)

Ground stations provide the ability for humans to communicate with objects in space such as satellites and spacecrafts. The need for these ground stations continues to grow as the number of satellites in orbit around Earth increases every year. The traditional ground station uses a large satellite dish operating at a fixed location. This provides support only when the corresponding satellite passes overhead, which can be infrequent. The station remains operational for that location but is limited in its capabilities for tracking outside of those bounds. This leads to a need for a portable ground station that may be used in military reconnaissance operations, allowing for commanding and tracking satellites in rural locations. The following CONOPS describes the portable ground station design and a high level overview of the portable ground station.

The first element is the ability to be transported. The user may travel with such a portable system to non-traditional locations across the world. This allows the use of the ground station to be dynamic and flexible. The user may then assemble the necessary components and set up the station. 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 satellites across the sky. Using its uplink and downlink capabilities, the user may communicate with the desired satellite, receiving and transmitting data to a computer connected to the ground station.

Figure 1 describes the goal of this project. ARGUS will only communicate with a simulated satellite, generated via COSMOS software. Success of telemetry and commands will be verified by the same software. The ground station will be connected to a standard, constant power source. The portability goals remain the same. Figure 1 also shows the future of projects like ARGUS. Ideally, a future prototype will be able to communicate using downlink and uplink successfully with satellites in the field.

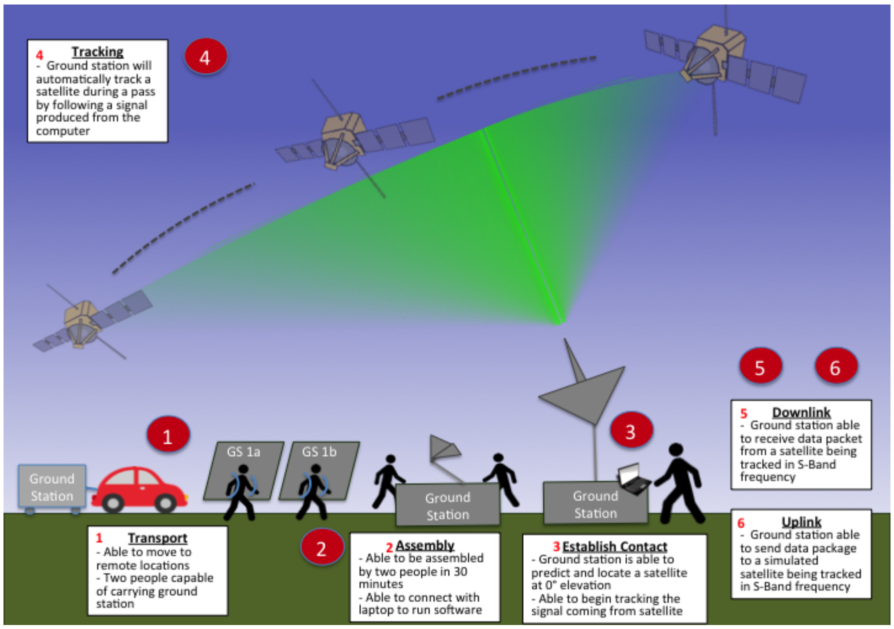

Figure 1. Concept of Operations for the testing and simulation of the project

4.2. Functional Block Diagram (FBD)

Figure 2 shows the major project components and interfaces recognized at this early 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 unsure at this time what voltage these power lines (red) will operate at.

The central processor of the assembly will handle the processing of the program track and automatic track functions, modulating (uplink) and demodulating (downlink) the signal using Quadrature Phase Shift Keying (QPSK) modulation, and sending commands to the antenna pointing control assembly. 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 conditioning circuit will consist of Radio-Frequency (RF) components such as bandpass filters, a software defined radio, low-noise amplifiers, power amplifiers and other conditioning components the group may need in order to close the link with a satellite in LEO. The user interface has been defined by Raytheon to be a laptop that is connected to the main processor via a Cat5 (Ethernet) cable. An unprocessed bit stream of downlinked data will be fed into the user interface/laptop for processing. The laptop will also input commands for the satellite that pass through the main processor into both the pointing control and signal conditioning circuit, pointing the antenna towards the satellite and sending the given commands.

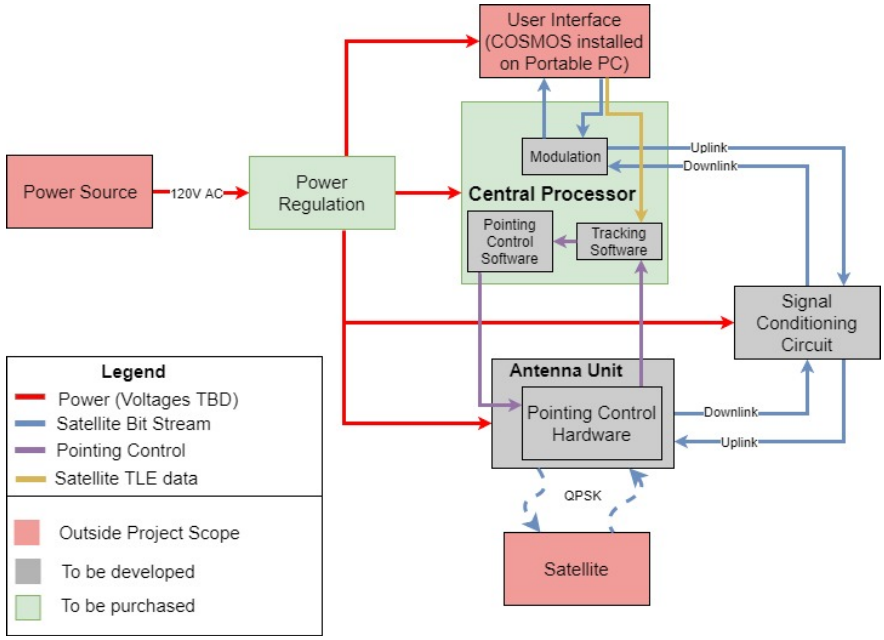

Figure 2. Functional Block Diagram (rev. 1.0)

5. Critical Project Elements

5.1. Portability

The ground station shall be portable for transportation. This can be achieved whether the ground station is transported in the back of a truck, on a non-motorized vehicle, or by hand. The lack of movement of the ground station renders the objective as unsatisfied and operationally leaves the ground station useless for providing real-time support in a remote location. This requirement for portability will create a strain on other design objectives and is unique to this design. This element must be completed without hindering the success of the other design objectives.

5.2. Calculated Antenna Movement and Tracking

The antenna shall be mechanically designed/built to allow for calculated tracking across the sky, without the need of physical human manipulation, given TLE data provided by the customer. Software will be built to input TLE data and determine the position of the satellite at each specified time. The movement of the antenna will require control software development as well as creation of a mechanical control system. The portability of the ground station will be affected by the mechanics necessary to allow antenna movement, as they could be sensitive, heavy, or complicated.

5.3. Link Budget

The link between the LEO satellite and the ground station is absolutely essential for this project. Building a portable system that is able to close the link and sustain it throughout a satellite pass is a large challenge for this type of system. If the link is not closed then no data can be passed from the user to the satellite and the satellite could not return the requested data. Without communication, the ground station provides no purpose and the user with no data.

6. Team Skills and Interests

Critical Project Elements	Team Member(s) and Associated Skills/Interests
5.2, 5.3	S. Penkowsky - Microcontrollers/embedded systems, orbit determination
5.2, 5.3	A. Dodge - Software, satellite tracking, embedded systems, GNC, state estimation
5.1, 5.2, 5.3	J. Lopez - Systems engineering, embedded systems, GNC, satellite tracking, manufacturing, electronics, software
5.2, 5.3	D. Mata - Software and satellite tracking, embedded systems, testing and integration
5.2,5.3	T. Barth - Systems engineering, software, embedded systems, satellite tracking, integration and testing
5.1,5.2,5.3	A. Blaisdell - Project management, systems engineering, orbital determination, electronics, structures, software, testing, integration, and manufacturing
5.1,5.3	G. Fuentes - Telemetry data analyst, electronics, system testing, satellite tracking, management certificate
5.1, 5.2	T. Fulton - Manufacturing, machining, structures, mechanics, satellite tracking
5.1, 5.2	T. Murphy - Manufacturing, Machining, 3D Printing, Electronics, and Structures
5.2, 5.3	M. Tzimourakas - Project Management, Systems Engineering, Investing, Finance, Commanding and Controlling, satellite tracking, scripting
5.2, 5.3	A. Hess - Systems engineering, testing, integration, RF system construction, theoretical modeling

7. Resources

Critical Project Elements	Resource/Source
Downlink capability (5.3)	Raytheon
Antenna design and RF (5.2,3)	Michele Kuester @ Digital Globe, Dennis Akos
Satellite program tracking (5.2)	NOVA software
Satellite uplink simulation (5.3)	COSMOS software
Satellite uplink and downlink testing (5.3)	On-campus anechoic chamber (unconfirmed)
Materials and structural capability (5.1)	Matt Rhode, Francisco Lopez-Jimenez
Financial (5.1,5.2,5.3)	Raytheon, Joan Wiesman

References

[1] Jackson, Jelliffe. "Project Definition Document (PDD)," University of Colorado–Boulder, Retrieved September 4, 2018, from https://canvas.colorado.edu.

[2] Thilker, Steve. "Small Satellite Ground Terminal," Raytheon, Retrieved September 4, 2018, from https://canvas.colorado.edu.

[3] "Full Ground Station Kit VHF/UHF/S-Band. ISIS - Innovative Solutions in Space, from https://www.cubesatshop.com/product/full-ground-station-kit-vhfuhfs-band/.

[4] D. Firestone et al., "Low-cost, automated ground station for LEO mission support," in IEEE Aerospace and Electronic Systems Magazine, vol. 26, no. 3, pp. 12-18, March 2011, from http://ieeexplore.ieee.org.colorado.idm.oclc.org/stamp/stamp.jsp?tp=&arnumber=5746180&isnumber=5746173.

[5] Rouzegar, H., Nasirian, M. & Ghanbarisabagh, M. Wireless Pers Commun (2017) 96: 2161, from https://doi-org.colorado.idm.oclc.org/10.1007/s11277-017-4291-3.