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A Cubesat Communication System Development For Gto Mission

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A CUBESAT COMMUNICATION SYSTEM DEVELOPMENT FOR GTO MISSION

by

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ABSTRACT

Tracking, telemetry and command (TT&C) systems on traditional small satellites have advanced significantly in last few decades. The capabilities, requirements and expectations of the communication system have been increased significantly for the smaller satellites. Small satellites are now performing the tasks near to the bigger satellites which increases the dependency on the communication system in terms of reliability and data management. This thesis paper will focus on development of the communication system of a 1U cube Satellite named Orbital Factory II (OFII). The satellite will be launched into a geostationary transfer orbit (GTO) onboard a United Launch Alliance (ULA) Atlas V rocket. OFII was awarded this launch opportunity for winning first place in ULA's CubeCorps CubeSat design competition. OFII will study additive manufacturing in microgravity. This will be performed by using a small printer which will create a conductive trace between two electrical terminals onboard. OFII's secondary experiment is the Electron-Emitting Film (ELF) and Surface Charge Monitoring (SCM). This experiment will study the feasibility of using ELFs to manage vehicle charge. OFII's last experiment is an experimental S-band patch antenna provided by Lockheed Martin Space Systems. This antenna will go through qualification testing at UTEP before being tested in GTO. Due to the extreme radiation occurred in the Van Allen belts, OFII will test a method of radiation mitigation using a thick-walled Titanium chassis. The nominal mission duration is five days, which will allow for OFII to complete its experiments and downlink data before it succumbs to radiation damage. Data will be downlinked to a network of ground stations via UHF and S-band, with UHF serving as the primary frequency. The telemetry, tracking, and control (TT&C) subsystem of a satellite provides a connection between the satellite itself and the facilities on the ground. The purpose of the TT&C function is to ensure the satellite performs correctly. As part

of the spacecraft bus, the TT&C subsystem is required for all satellites regardless of the application. Tracking, telemetry and command system of a nanosatellite which has been designed for GTO mission is a challenging and critical issue. GTO is a Geostationary transfer orbit which is a highly elliptical orbit with an apogee of almost 40000 kilometers from the sea level. The thesis mainly focuses on the analysis that allow us to select the proper transceiver and antenna module. The next section is the ground station proposal which includes different options and features of the ground system that will can receive the OF-II signals. The proposal includes analysis that validates the selection of the components. Finally, the thesis includes the proposed test procedures that can be followed to verify and validate the performance of OF-II communication subsystem.

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1. INTRODUCTION:

1.1 Growth of cubesat:

Recent high growth of small satellite programs worldwide is clear evidence that the barrier to space is diminishing gradually. There is an explosive growth in 1 to 10 kg range of Satellites in recent years, most of which are CubeSats. From 2013 to 2015, the number of 1 to 10kg satellites launched was 350. Among those, 262 satellites have been launched by the US. In recent years developing countries are also getting their interest in developing small satellite. The growth of the CubeSat development process can be partially attributed to the long design, fabrication, and testing timelines associated with traditional small satellite programs. Up to now there have been five batches of CubeSat launches, and one solo launch. Those batches were comprised of 30 1U CubeSats, three 2U CubeSats, and five 3U CubeSats (denMike, 2009). There are an additional three batches scheduled to launch in 2009 on various platforms, and are comprised of 16 1U CubeSats and one 3U CubeSat. There are also more than 20 documented 1U CubeSats in different stages of development, and perhaps many more that have not been formally introduced. There are various kinds of CubeSats mission ranging from commercial to personal use. Historically, small satellites have been used as a platform to do hands-on training of engineers. There are increasing number of countries who wish to utilize small satellites, especially CubeSat for space-related capacity building. [12]

1.2 UTEP Cubesat program:

Orbital Factory II (OFII) is a 1U CubeSat project of UTEP which will be launched into a geostationary transfer orbit (GTO) onboard a United Launch Alliance (ULA) Atlas V rocket. OFII was awarded this launch opportunity for winning first place in ULA’s CubeCorps CubeSat

design competition. OFII will study additive manufacturing in microgravity. This will be accomplished using a small printer which will simulate the repair of a solar array by printing an electrically conductive trace between a simulated tear on a solar panel. OFII's last experiment is an experimental S-band patch antenna provided by Lockheed Martin Space Systems. This antenna will go through qualification testing at UTEP before being tested in GTO. Due to the extreme radiation encountered in the Van Allen belts, OFII will test a method of radiation mitigation using a thick-walled Titanium chassis. The nominal mission duration is five days, which will allow for OFII to complete its experiments and downlink data before it succumbs to radiation damage. Data will be downlinked to a network of ground stations via UHF and S-band, with UHF serving as the primary frequency.

1.3 Cubesat Subsystem & Architecture:

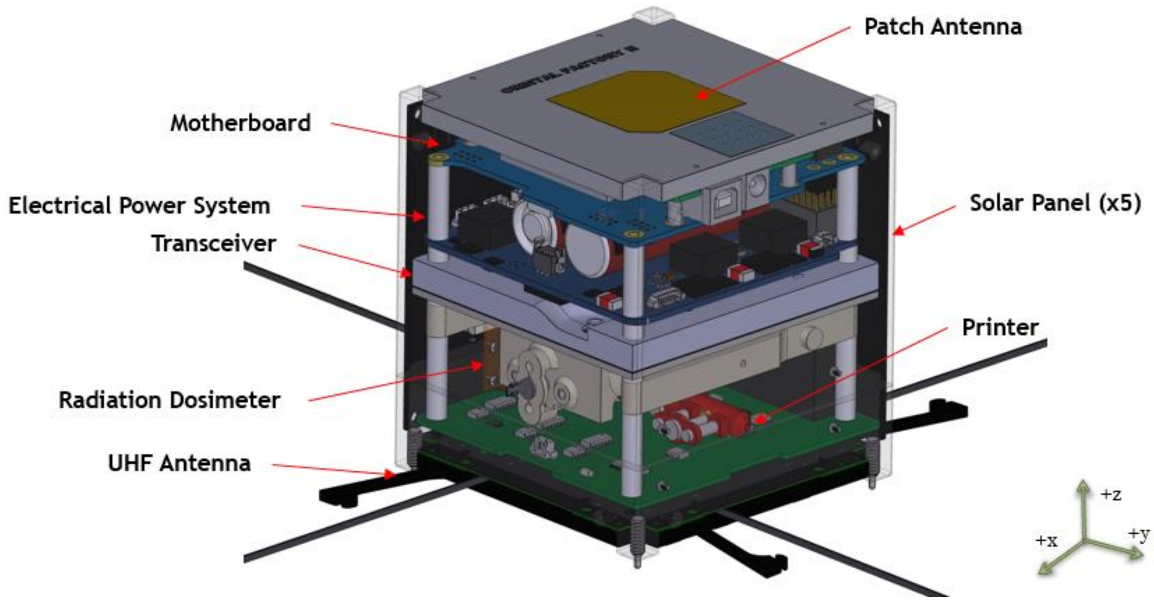

Figure 1: Satellite Chassis Assembly

OF-II on board payload consists of the following:

- **Single axis 3D printer:** A single axis 3D printer has been installed in the OF-II for repairing damages in solar panel caused by the space radiation. This will be accomplished using a small printer which will simulate the repair of a solar array by printing an electrically conductive trace between a simulated tear on a solar panel. This is for the first time a nanosatellite carrying an on-board printer which makes the OF-II mission unique.
- **Experimental S-Band patch antenna:** An experimental S-Band patch antenna will be flown as well in the OF-II mission. The patch antenna will be provided by one of the industry partners of UTEP who has a leading role in United States defense and space

missions. The antenna is made of special type of Copper and will be flown for the first time in space with OF-II.

- **Surface charge monitor (SCM) :** OFII's secondary experiment is the Electron-Emitting Film (ELF) and Surface Charge Monitoring (SCM). This experiment will study the feasibility of using ELFs to manage vehicle charge by emitting electrons that are collected on the spacecraft as it passes through the highly radioactive Van Allen belt. The SCM will measure changes in the charge of OFII's structure.
- **Transceivers:** OF-II have two signal transmitters for Ultra High Frequency and S-Band signal transmission. These are also capable of receiving signals sent from ground station in earth. The function of the transceiver is to process the data acquired from the On-board computer and convert the instructions to radio signals. The radio signals are being transmitted through the antenna. There are two antennas as well in the Cubesat structure to transmit two of the mentioned frequencies.
- **3D printed chassis / radiation shield:** OF-II chassis has been developed in house at UTEP campus. The chassis has been developed by 3D printer at W.M Keck Center at UTEP. The chassis is made of titanium alloy. Since the mission of OF-II is based on the tentative environment of the GTO. The chassis has been designed to withstand the radiative environment in GTO.

1.4 OF-II mission objective and challenges:

- Print a conductive trace in microgravity to simulate an in-space repair
- Perform a flight demonstration of a 3D printed S-Band patch antenna

- Test a Electron Emission Film and Surface Charge Monitor (ELF/SCM) in the highly radioactive Van Allen Belts
- Provide educational outreach to UTEP students

2. LITERATURE REVIEW

A first batch of CubeSats propelled June 30, 2003, on an Eurockot dispatch vehicle from Pletsak, Russia, contained a wide range of CubeSats with different communication systems. Two attributes that were basic among the CubeSats, were the utilization of the AX.25 Link Layer Protocol and the frequency go from 432-438 MHz in the Amateur radio band (AM). [1] For OF-II two types of frequency will be used. UHF is the primary method of communication. An S-Band transceiver and antenna will be used to communicate over S-Band. Most of the CubeSats are using the CubeSat space Protocol (CSP) at Data Link Layer. CubeSat Space Protocol (CSP) is a small network-layer delivery protocol designed for CubeSats. The idea was developed by a group of students from Aalborg University in 2008, and further developed for the AAUSAT3 CubeSat mission that was launched in 2013. The protocol is based on a 32-bit header containing both network and transport layer information. Its implementation is designed for embedded systems such as the 8-bit AVR microprocessor and the 32-bit ARM and AVR from Atmel. OF-II UHF module will be controlled by the CSP. [25] The S-Band module will be using the AX.25 link layer protocol. The main deviation from the AX.25 convention was the CanX-1 satellite because of the exclusive idea of the data it was gathering. The decision of this broadly utilized convention permitted beginner radio administrators worldwide to gather data from the satellites and improve the ground station exertion. By using the beginner radio group, the satellites could possibly transmit more information, in this way give greater utility. The advantage For the most part, the CubeSats utilized a Commercial Off-the-Shelf (COTS) radio, and adjusted it for use in space. Using the COTS radio decreases the complexity of the design and the development of the satellite becomes faster. The main distributed exemption from the utilization of COTS hardware was the Japanese CubeSat XI-IV, which utilized a handset and guide that was produced inside

the University. For OF-II link budget calculation, NPS-CAT CubeSat communication system development approaches have been followed in most cases. Another good resource is the Protocol of Communication with the VORSAT satellite. They have calculated the communication losses in a reasonable manner. But as per the OF-II mission need, the link budget has been modified so that the OF-II can communicate from beyond LEO. The main modification has been made in the transceiver and antenna development. The COTS components have been customized according the OF-II mission need. The Radio has been chosen with high signal transmit power capability. Also, the transmitter will be integrated with a control board which will be developed in-house at UTEP. OF-II communication team has worked with the vendors for a long time to ensure all the requirements of the OF-II TT&C system can be achieved from the COTS components. The antenna vendor has modified their commercial antenna module in terms of size, power and reliability.

For the ground station development BIRDS constellation ground station network was a good source for understanding the concept. BIRDS constellation will be operated by 7 UHF/VHF ground stations distributed worldwide. The five BIRDS satellites are the same design, including their uplink/downlink frequencies, although the call sign is different. Each ground station is connected to an operation server and receives the operation schedule, the orbit information and the command set to be uplinked. The data downlinked are transferred to the archive server. OF-II communication team has tried to contact the InfoStellar, a Japanese company who runs the BIRDS ground station constellation. A formal proposal has been received from Infostellar by which UTEP ground station can get the access to the same network. [Appendix 8]. The network includes three main parts such as Ground Station Network Device (GSN Device), Central Server

and Mission Control Centre. Ground Station Network Device will be installed at each BIRDS ground station. The GSN device is comprised of a data transfer module and a Software Defined Radio (SDR). The function of this equipment is used to provide a communication channel between each ground

station to the central server. In addition, the GSN device is used to transfer the mission data from ground station PC and I/Q data from SDR to be collected in the central server. Moreover, it shall access to the central server to a satellite operation schedule that used to control each ground station. The central server has a database to accumulate the mission data that has been received from satellite and collect the satellite operation schedule to send to command each ground station. The central server will be located at Kyushu institute of Technology, Japan. Mission Control Centre is used to program the satellites operation schedule following the project mission and send to collect in the central server. [12] UTEP ground station proposal also includes other ground station networks from which RBC runs the largest network. They run more than twenty ground station all over the world. Both Infostellar and RBC signals proposal have been included in the main proposal which increases the reliability on getting mission data.

3. OF-II CUBESAT SPECIFICATION:

OF-II structure is based on PC/104 standard which is a modular embedded computer standard. This structure allows modules to easily be stacked and routed. High current and reliability is the main benefit of the structure. The PC 104 standard makes the process of integrating the other subsystem bus inside the satellite easy. Also the structure is readily available.

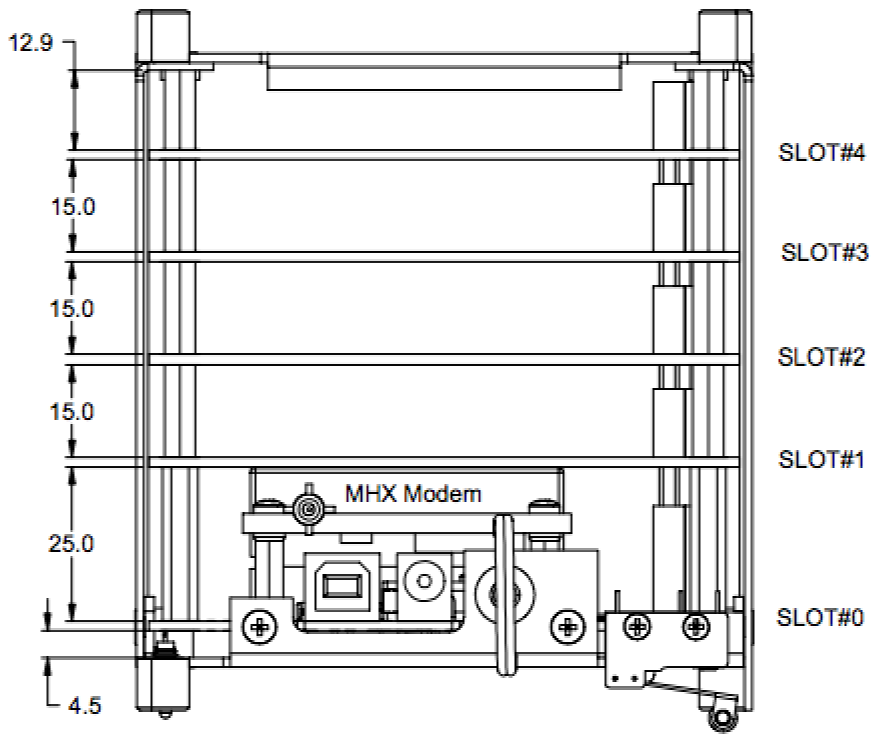

Figure 2: Chassis Structure

3.1 System Buses:

Orbital factory-II includes different subsystems. Some of the subsystems have been planned to build in house at UTEP and some of them are going to be purchased from COTS components vendors. Some basic payloads include printed electrical repair of solar panel arrays on orbit,

3D printed S-Band patch antenna, Electron-emitting film (ELF)/Surface charge monitoring (SCM) demonstration for vehicle charge management, Camera(s) – Internal (with LED) and possibly external Radiation dosimeter (tentative). However, there are other subsystems that is going to be purchased. Major subsystems and their functional descriptions are provided in the following section.

3.1.1 UHF TRANSCEIVER:

UHF transceiver has been purchased from GOMspace a Danish satellite product company. The model of the transceiver is Nanocom ax 100.

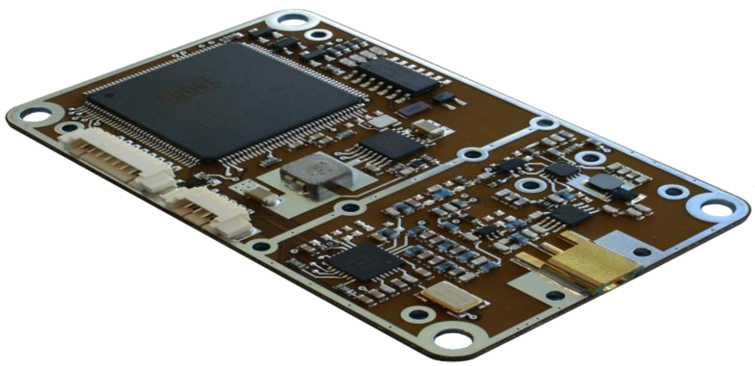

Figure 3: Nanocom ax100 Transceiver [18]

The NanoCom AX100 (AX100) is a half-duplex software configurable radio transceiver specifically designed for long-range transmissions. The combination of forward error correction, AFC and digital filters results in a high sensitivity system, without sacrificing flexibility. The radio module can be fully configured on orbit. The frequency, bitrate, filter-bandwidth, and modulation type are adjustable according to the mission needs. Smart CSMA/CA (listen before talk) medium access control combined with a small RX/TX switching duration gives a short satellite ping time, thus effectively removing the need for fullduplex radios, even for high

volume data download. In turn this simplifies satellite design, because only a single antenna is required. The integrated design of microcontroller, transmitter, receiver, LNA and power amplifier results in a small PCB module that fits up to four times onto a CubeSat PCB. Multiple hardware components are reused from the NanoCom U482C, including the PA, DC-DC converter, RX/TX switch, microcontroller, oscillators, and RAM memory. [18]

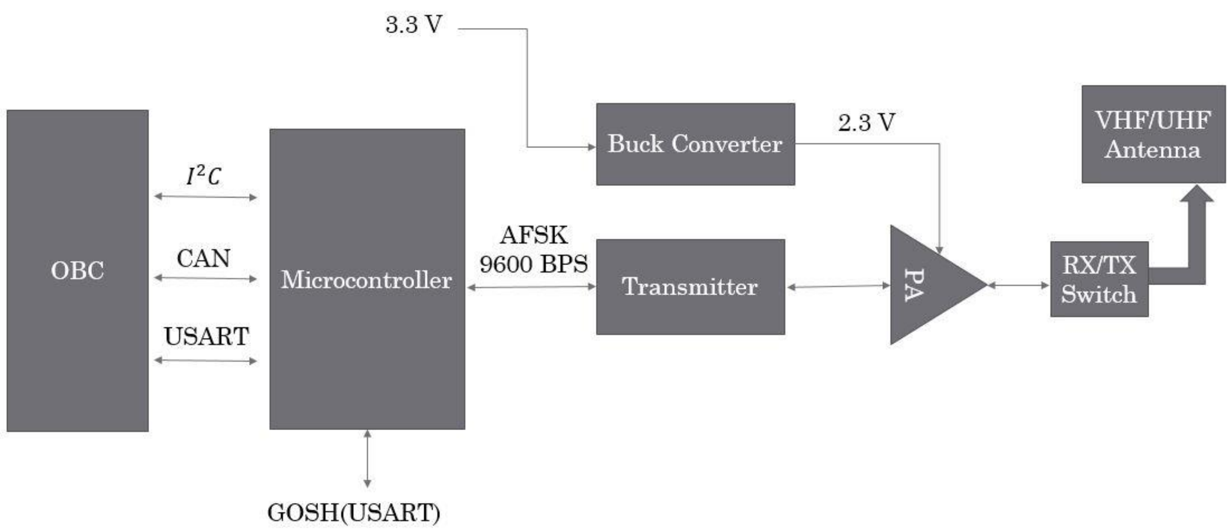

Figure 4: Communication System Block Diagram

A block diagram of the communication module is shown here. The transceiver system is mainly operated by an internal micro controller which receives the instructions from the On-board computer. The instructions can include the housekeeping data of the satellite, commands or any information that is needed to send to the ground system. The controller receives the command from the OBC and sends the data to transmitter at 9.6kbps rate. Transmitter converts the baseband signal to RF signal. There is another power amplifier at the transmitter end in order to increase the transmit power as the typical output of the transceiver is very low. A buck converter

is required to feed the PA which converts the 3.3V input to 2.3V and supply to Power amplifier. The Rx/Tx switch will be kept at transmitting mode for all the time to send the signal to the antenna for transmitting.

When the signal comes to the transmitter, it is converted into radio waves. However, this signal needs to be amplified as the system is going to communicate over a long distance so the signal power level should be high enough so that it can be restored when it reaches the ground station. The processed signal is transferred to the antenna which creates the radio waves at ultra-high frequency to send the radio signal towards earth.

3.1.2 ANTENNA MODULE:

UHF antenna has been purchased from Endurosat a Bulgarian company.

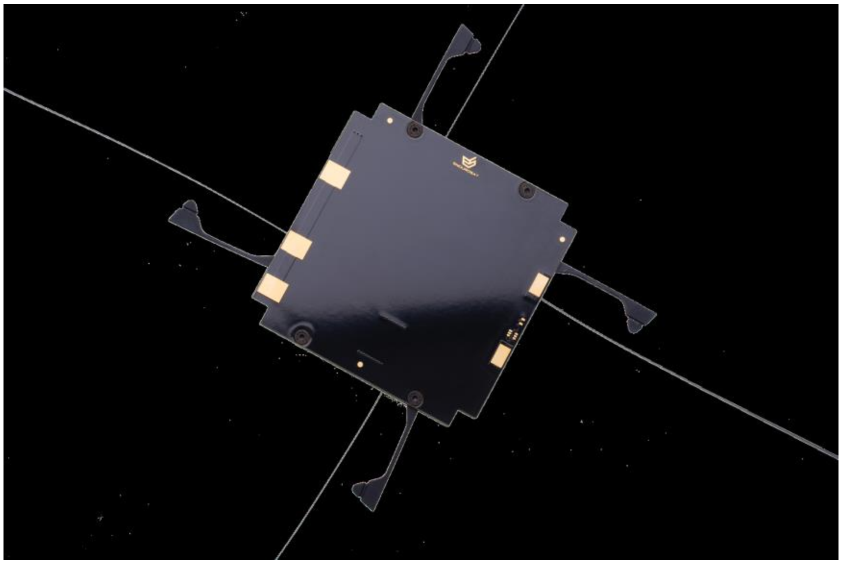

Figure 5: Antenna Module [21]

Primarily the antenna has been chosen to use 145MHz VHF frequency as the link budget analysis proves that lower frequency is more efficient for long distance communication. Order had been placed for building an antenna with the mentioned capability. Antenna provider was a Bulgarian company named ‘Endurosat’. [Appendix 5] But later, due to some difficulties with frequency coordination the proposed VHF antenna order was being changed. The new frequency that had been decided to use for OF-II was UHF. A same antenna configuration has been ordered with the UHF capability from the same company.

Some basic specifications of the previous antenna module is provided below:

Table 1: Antenna Specification

No	Parameter	Value
1	Center frequency	145 MHz
2	Bandwidth	5 MHz
3	Polarization	Circular
4	Weight	< 100 g
5	Height (excluding connector)	< 6 mm
6	Deployment system	Burnwire mechanism with individual rod deployment and feedback
7	Interface	IIC (Details in dedicated IIC User Manual)
8	Max RF output power	3.5 W @ 3kbps continuous
9	Horizontal dimensions	98 mm x 98 mm with extrusions for rails 8.5 mm x 8.5 mm in each corner (1U CubeSat Z side compatible)
10	RF connector	TBD – SMA / MCX / MMCX
11	Typical deployment consumption	Up to 300 mA @ 5V

The gain was supposed to be +/- 1dB. A simulation of antenna gain pattern is shown in the following figure:

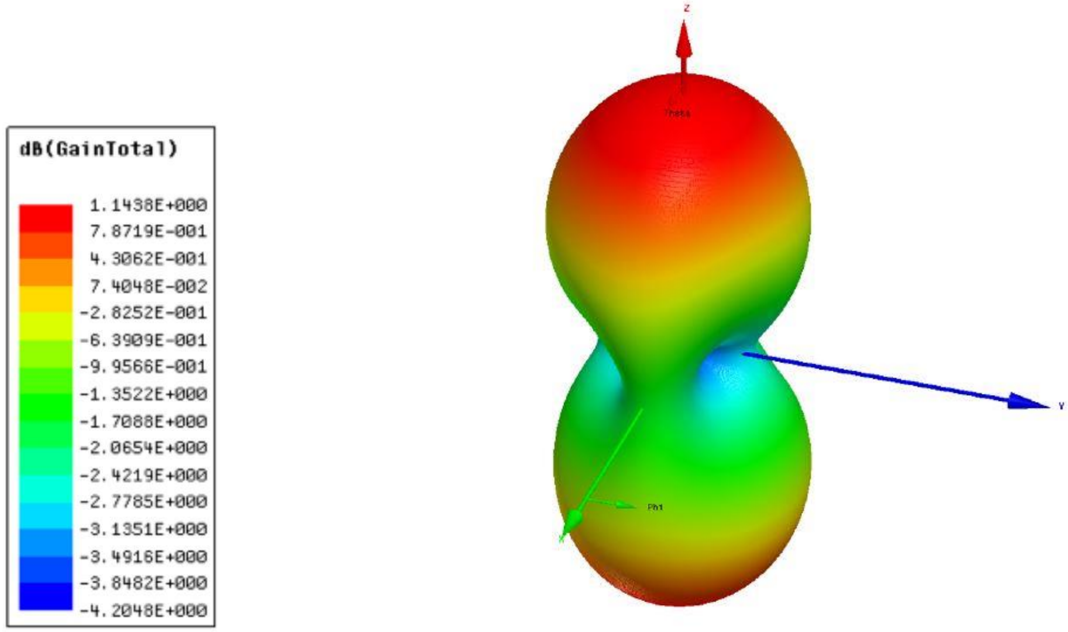

Figure 6: Gain pattern of the Antenna [21]

3.1.3 POWER MODULE:

Function of EPS module is to deliver enough power to the satellite subsystems. 2 rechargeable Li-Ion battery are available in the module to provide constant power to the subsystems. The module gets power from the solar panel as well. It stabilizes the power received from solar panel and utilize the power to charge the batteries. EPS module has also been purchased from GOMspace. The power supply is the heart of a satellite. The NanoPower P31 (P31) is designed as a reliable and flight proven system with digital interface and advanced features like maximum power point tracking and latchup-protection. [22]

Figure 7: Power Module [22]

The P31 power supplies are designed for small, low-cost satellites with power demands from 1-30 W. Employing a strictly KISS design philosophy, the P31 interfaces to triple junction photo-voltaic cells and uses a highly efficient boost-converter to condition their output power in order to charge the provided lithium-ion battery. The incoming power along with the energy stored in the batteries is used to feed two buck-converters supplying a 3.3 V @ 5 A and a 5 V @ 4 A (configurable) output bus. Six individually controllable output switches with over-current shut-down and latch-up protection, each separately configurable to either 3.3 V or 5.0 V output. [22]

3.1.4 S-BAND TRANSCEIVER:

Due to limited space inside the satellite, two frequency operations by single module was highly encouraged. But since, no module was found with the anticipated feature of operating two frequencies simultaneously we had to include two different transceivers with two frequency operations. The S-Band transceiver was purchased from ISISpace a Netherland based company. Some important feature of the transceiver system will be discussed in the following section.

Figure 8: S-Band Transmitter Module [20]

Frequency range of the transmitter can be selected between 2200-2290 MHz (EESS/SRS/SOS allocations). Transmit power can vary between 27 to 33 dBm. Modulation options include Offset Quadrature Phase-shift Keying (OQPSK). Pulse shaping feature is available with Square Root Raised Cosine, Roll-off 0.5, 0.35 (other options on request). Channel coding: Concatenated Reed Solomon and Convolutional coding [C(7, ½) and RS (255, 223)]. Data rate selectable between 3.4 Mbps (½ , ¼ and 1/8). Data link layer protocol is CCSDS. Please look into Appendix 6 for more information.

3.2 Payloads:

3.2.1 PRINTER:

OF-II consists of novel payloads which includes an on-board printer, Surface charge monitor and Electron emitting film. The purpose of the printer is to demonstrate in-space self-repair of an electrical system. The function of the printer is to print a trace between two terminals. Actuation

will be 2-axis carriage. The dimension of the stepper motor is 6 mm x 9 mm (FDM0620). Additively manufactured parts are making the structure of the printer. It has been fabricated from low outgassing materials.

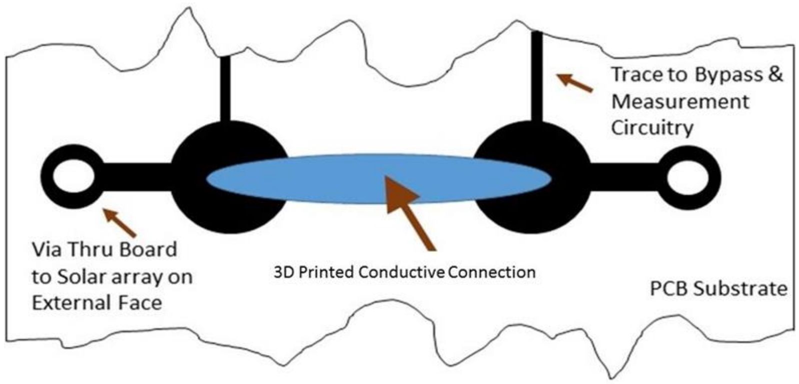

Figure 9: Printer Functionality Diagram

3.2.2 ELECTRON-EMITTING FILM, SURFACE CHARGE MONITOR ELF/SCM:

Surface charging from trapped particles can cause dangerous arcing. ELF regulates surface charge by emitting electrons. It also reduces risk of electrostatic discharge. SCM allows measurement of surface potential. ELF/SCM has previously flown on Horyu 2 in low earth orbit. GTO will allow more versatile testing of the ELF/SCM due to the Van Allen belts

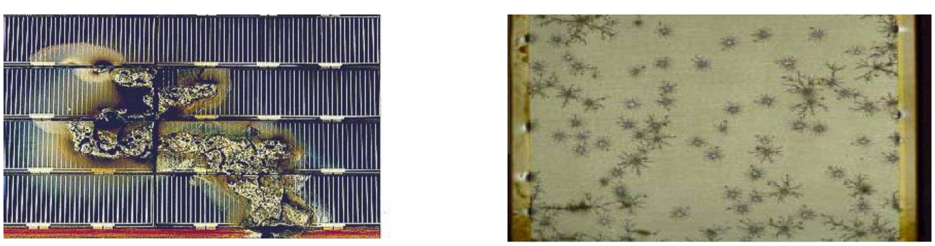

Figure 10: Solar array and anodized aluminum plate damaged by arcing

Spacecraft charging is what happens when charged particles from the surrounding energetic environment stop on either the exterior of a spacecraft or the interior, such as in conductors.

Charge build up on spacecraft can cause dangerous arcing. ELF emits electrons off of the satellite once charge reaches above a certain threshold. Reduces risk of electrostatic discharge. SCM allows measurement of surface potential. ELF/SCM has previously flown on Horyu 2 in low earth orbit. Orbital Factory II's GTO will allow more versatile testing of the ELF/SCM due to the Van Allen belts.

4. MISSION PLANNING:

OF-II Will be launched into a highly eccentric geostationary transfer orbit. Our launch is not manifested yet, so we have been working on the orbital simulation which gives us a clear vision of the orbit and it's environment. STK has been used to simulate the Orbital condition. Prior Atlas V GEO launches to develop an estimated orbit for preliminary analysis, such as: communications windows, radiation exposure, solar power generation. Following picture demonstrates a tentative orbit where the OF-II is going to be deployed.

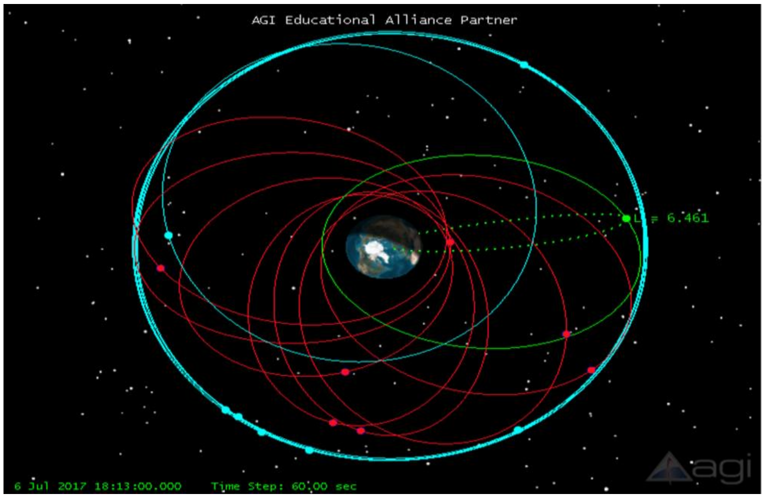

Figure 11: Orbital estimation simulated in STK

GTO with a perigee over 2000 km is considered as a NASA-approved disposal orbit.

4.1 Averaged orbital data from spent Centaur stages:

Apogee: 35,065 km (say approximately 35,000)

Perigee: 3,978 km (say approximately 4000)

Inclination: 21.4 degrees (say approximately 21 degrees)

Period: 11 hours, 31 minutes (say approximately 11 and a half hours)

Estimated orbital parameters used in STK simulations of radiation, communication, and solar power generation. For the first time in world's history the UTEP's cube satellite is going to the geostationary transfer orbit where highly radiative van allen belt exists. Trapped particles damaging to electronics. STK used to model Van Allen belts and estimated radiation dosage over 5 days.

A simulated view for the Van-Allen belt is shown in the following picture.

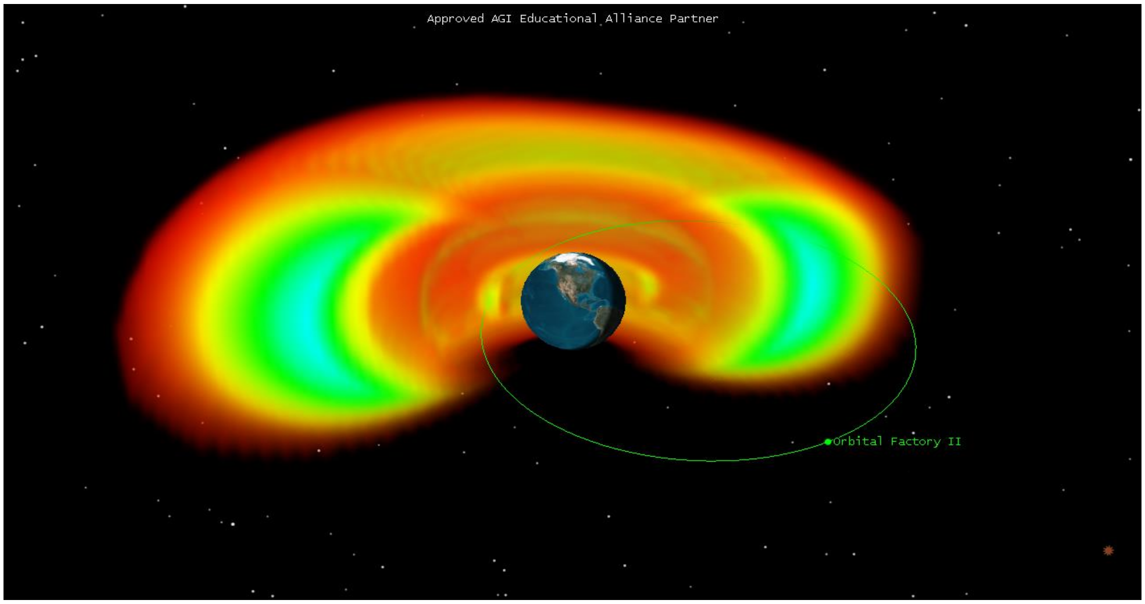

Figure 12: Simulated view of the Van-Allen belt

GTO will take us through the Van Allen radiation belts. Here the trapped particles damaging to electronics STK used to model Van Allen belts and estimated radiation dosage over 5 days.

4.2 SOLAR ACTIVITY:

Inner belt: The inner belt contains high concentrations of electrons in the range of hundreds of Kev and energetic protons with energies exceeding 100 MeV, trapped by the strong (relative to the outer belts) magnetic fields in the region.

Outer belt: The outer belt consists mainly of high energy (0.1–10 MeV) electrons trapped by the Earth's magnetosphere.

4.3 Mission Challenges:

- Limited communication windows
- Radioactive Van Allen belts
- Implementing systems into a 1U architecture
- No attitude controls
- Short development timeline
- Steep learning curve

5. REQUIREMENTS ANALYSIS:

Table 2: Requirements table

COM 1.0		Communication-System Requirements	Source	Verification Method	Status	Planned Testing
	COM 1.1	The COM uplink shall use the UHF Band	COM-6	Testing	In Progress	
	COM 1.2	CW Beacon signal should be sent through UHF Band	COM-6	Testing	Planned	
	COM 1.3	COM shall transmit mission data packets processed by OBC to GS	COM-6	Testing	Planned	
	COM 1.4	UHF receiver should be well within power and volume budget	INS-1	Testing	Planned	
	COM 1.5	COM System should not exceed power, nor mass budget.	EPS-3	Testing	In Progress	
	COM 1.6	COM should not create interference to other signals	SAT-1	Analysis and Testing	Planned	

	COM 1.7	The COM receive data packets from OBC	MOS-2	Testing	Planned	
	COM 1.8	The COM shall not create interference with other satellite signals	IARU	Testing	Planned	
COM 2.0		Communication-Design requirements	Source	Verification Method	Status	Planned Testing
	COM -2.1	OF2 shall have an externally mounted experimental patch antenna	MSC-2	Inspection	In Progress	
	COM 2.2	Patch antenna shall be designed for communication in the 2.4-3.5 GHz frequency range	COM-1	Analysis	In Progress	
	COM - 2.3	Patch antenna cannot protrude more than 6.5 mm from OF2's face	CDS 3.2.3	Inspection	In Progress	
	COM 2.4	Patch antenna must fit in the 83 mm x 83 mm	CDS	Inspection	In Progress	

		surface allowed on OF2's external face				
	COM -2.5	Patch antenna shall be designed to operate at TBD gain	COM-1	Analysis	In Progress	
	COM -2.6	The COM system shall be able to send CW beacon signal	COM1	Testing	Planned	
	COM - 2.7	The COM system shall transmit housekeeping data	COM2	Testing	Planned	
	COM 2.7	Uplink data rate will be of 1200bps	COM3	Testing	Planned	
	COM 2.8	Uplink frequency will be same as downlink	COM4	Testing	Planned	
	COM 2.9	Satellite receiving monopole antenna should have 1.1 dB (TBR) gain	COM5	Testing	Planned	
	COM 2.10	Size of the receiver will be according to PC104	COM6	Testing	Planned	
	COM 2.11	Uplink digi-singer files using MIDI format	COM7	Testing	Planned	

	COM 2.12	CW will be transmitted at 20 wpm	COM8	Testing	Planned	
	COM 2.13	CW transmission power will be 0.1 W	COM9	Testing	Planned	
	COM 2.14	Receive data packets from OBC	COM10	Testing	Planned	
	COM 2.15	Transmitt data packets through BPSK modulation	COM11	Testing	Planned	
	COM 2.16	Transmitt data at 1200 bps	COM12	Testing	Planned	
	COM 2.17	Downlink frequecy will be 437 MHz	COM13	Testing	Planned	
	COM 2.18	Transmitting antenna should have 1.5 dB gain	COM14	Testing	Planned	
	COM 2.19	Mode of communication between OBC-MCU and COM-MCU shall be IIC	COM15	Testing	Planned	
	COM 2.20	COM shall communicate with 9600 bps transmiter via IIC	COM19	Testing	Planned	

	COM 2.21	COM shall transmit image data to ground station through monopole antenna	COM20	Testing	Planned	
	COM 2.22	COM shall control path selection mechanism	COM21	Testing	Planned	
	COM 2.23	COM electronics should accommodate within PC104	COM22	Testing	Planned	
	COM 2.24	FM transmission power should be 0.8 W	COM23	Testing	Planned	
	COM 2.25	Transmitter must quickly turn off upon receiving command (IARU regulation RR 22.1)	COM25	Testing	Planned	

6. LINK ANALYSIS

A link budget is a calculation of all the gains and losses from the transmitter, through the medium (free space, cable, waveguide, fiber, etc.) to the receiver in a telecommunication system. Link budget analysis is the process by which we can determine the required capabilities of the telecommunication devices. It accounts for the attenuation of the transmitted signal due to propagation, as well as the antenna gains, feedline and miscellaneous losses. Randomly varying channel gains such as fading are considered by adding some margin depending on the anticipated severity of its effects. The amount of margin required can be reduced using mitigating techniques such as antenna diversity or frequency hopping. In this project link analysis has allowed us to choose the proper transceiver which is going to be integrated in OF-II. Transceivers, Antenna module and ground system all of these have been selected based on the performance observed from Link analysis. So link analysis plays a very important role in the communication system development of OF-II. An elaborate description of the link budget analysis has been provided in the following section.

Link Budget Analysis which will include following calculations:

- Equivalent Isotropic Radiated Power Calculation
- Distance considered for different elevation angles
- Different types of losses
- Calculation of received power
- Approximate data transfer rate and received data
- Energy per bit per noise ratio
- Maximum detectable signal
- Calculation of receiver G/T

- Noise Power & Career to Noise ratio
- Antenna Performance at Different frequency
- Maximum Detectable Signal calculation
- Ground Station Block Diagram & Components
- Proposed antenna & transceiver module

Frequency selection was a critical issue for OF-II communication. Link budget analysis was performed to ensure that an effective link can be established between OF-II and the ground station.

6.1 Assumptions for Link Analysis

- For greater distance lower frequency should be selected as the higher frequency wavelengths are more easily absorbed the air molecules.
- Amplitude and frequency are the most important parameters for transmitting the signal. Higher amplitude makes the signal strong for transmitting the signal on a long distance.
- For example, AM and FM radio can be considered. AM radio can be received from a very long distance whereas the FM radio has a very small range.
- The frequency and strength of the transmitted signal, which is called the 'carrier wave', determines the distance of propagation.

In order to calculate the distance and free space loss due to the elevation angle we will use the following formula:

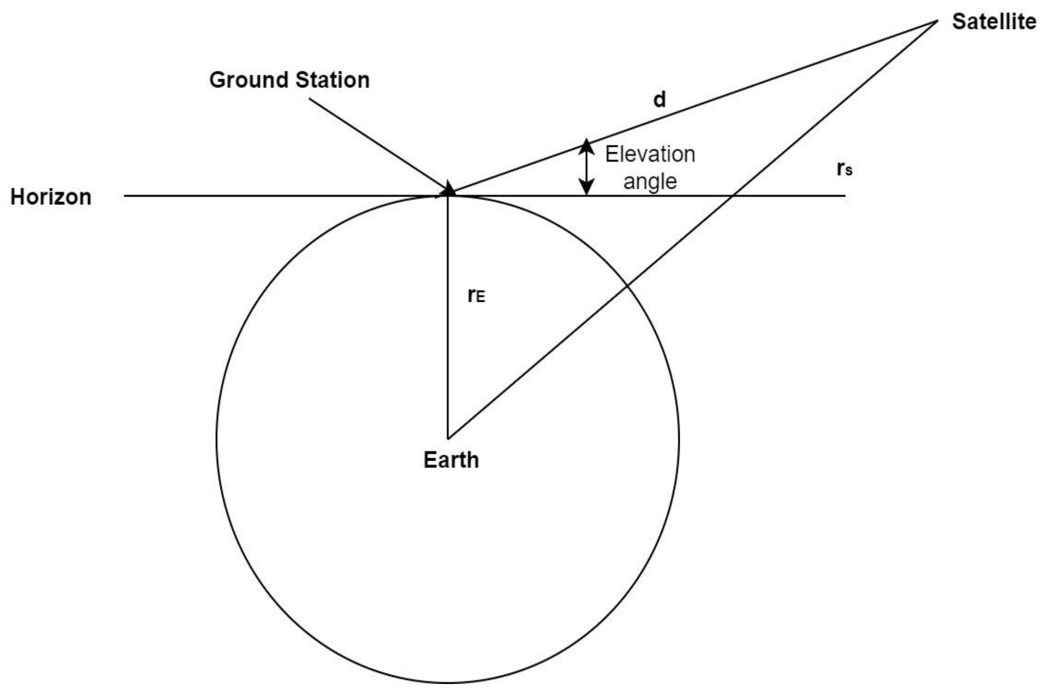

Figure 13: Line of Sight Distance

$$\boldsymbol{d = -r_E \sin(\theta) + \sqrt{(r_E^2 . sin^2(\theta) + r_s^2 \; - \; r_E^2)}} \text{ [3]}$$

Where , d = Distance GS to Satellite

r_E= Mean radius of Earth

$\theta =$ Eleveation Angle

r_s = Distance from Centre of Earth to Satellite

Distance considered : 3500 miles

Mean radius of the earth : 3959 miles

Distance from the center of the earth to the CUBESAT : 7459 miles.

Following table is the data obtained from the formula mentioned earlier. Distances for different elevation angles are shown here. Elevation angles have been varied from 10degree to 160 degrees.

Table 3: Distances for elevation angle

Elevation angle (Degree)	Distance (Miles)
10	5671
25	4866
40	4269
55	3861
70	3614
85	3507
100	3528
115	3680
130	3978
145	4446
160	5110

6.2 Received power:

Received power calculation allows to assume the approximate signal strength at the receiving station which is important for selecting the proper antenna and receiver.

Formula used for the received power calculation:

Friis transmission equation: $P_r = P_t + G_t + G_r + 20log_{10}(\frac{Wavelength}{4*\pi*Distance})$ [26]

Here , P_r = Received Power

G_t = Gain of the transmitting antenna

G_r = Gain of the receiving antenna

P_t = Transmitter power

Table 4: Signal strength for distances

Distance (Kilometers)	Signal strength (dBm)
500	-82.644
1000	-88.664
2000	-94.685
3000	-98.207
4000	-100.706
5000	-102.644
6000	-104.227
7000	-105.567
8000	-106.727
9000	-107.75
10000	-108.665
11000	-109.492
12000	-110.248
13000	-110.943

14000	-111.587
15000	-112.187
16000	-112.747
17000	-113.274

Here is a chart showing change of received power due to frequency changing. Transmitter power of 31dbm, Receive antenna gain of 15db, Transmit antenna gain of 2dB, Distance as 5500 kilometers and varying the wavelength from 100 MHz to 400 MHz received power has been calculated.

Table 5: Frequency, wavelength and received power relationship

Frequency (MHz)	Wavelength (m)	Received power (dBm)
100	3	-99.2
150	2	-102.7708
200	1.5	-105.2
250	1.2	-107.2
300	1	-108.6
350	0.857	-110.12
400	0.75	-111.29
450	0.667	-112.3
500	0.60	-113.2

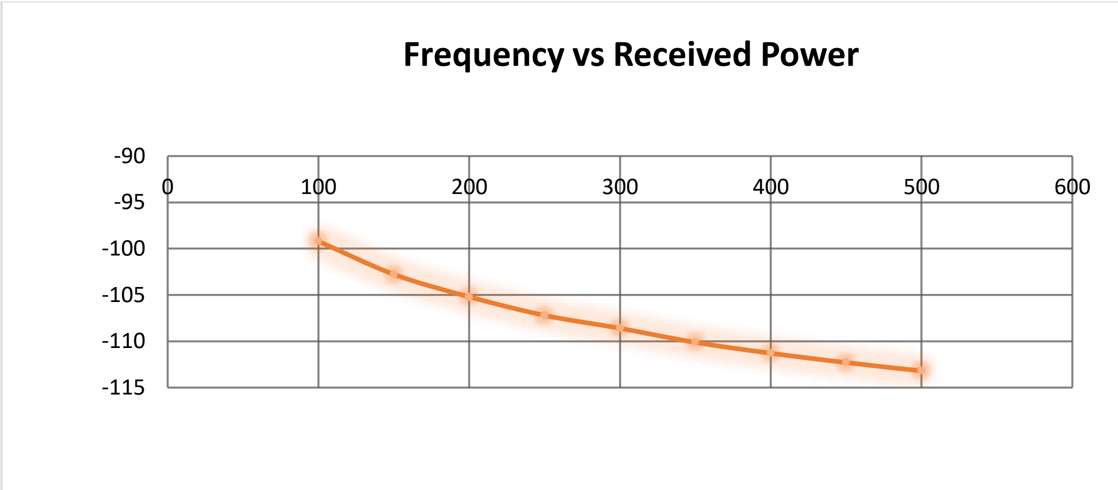

Figure 14: Frequency vs Received Power

Received power can be calculated in some other ways. This may justify the previous calculation and brings more reliability for selecting the components.

EIRP is the Effective Isotropic Radiated Power which is the amount of power that a hypothetical antenna can emit to produce the peak power density towards it's given projection. EIRP can be obtained by adding up transmission Power, transmission antenna gain and subtracting transmission Loss.

For OF-II transmit power has been considered as 30dBm. Transmission antenna gain is considered as around 2dB. Transmission loss is around 1dB

So, the equivalent isotropic radiated power is = 30dBM + 2dB – 1dB

EIRP is close to 31dBM which is equivalent to 1dBW.

6.3 Total Losses:

Losses are the attenuation of the radio energy when the signal passes a distance. For calculating losses of OF-II signal, following classifications have been introduced. Total losses can be categorized into two types. Which are propagation loss and local loss.

Propagation losses occur when the signal travels the long way after transmission. These types of losses occur before reaching the ground station. Free space loss is the most important loss in this category.

Free-space path loss (FSPL) is the attenuation of radio energy between the feed points of two antennas that results from the combination of the receiving antenna's capture area plus the obstacle free, line-of-sight path through free space (usually air).

Atmospheric loss are the types of losses caused by the environment. Usually signals get weak while passing through ionosphere, troposphere and other levels as the particles and charges inside these levels cause disturbance in the radio signal.

Pointing loss occurs when the satellite cannot be tracked accurately and as a result antenna is not pointed directly towards the satellite. This will cause the signal to get weak.

Environmental and equipment loss mainly occur at the ground site. There will be many devices present inside the ground site which will have internal losses. Also, the receiving antenna temperature is an important issue in terms of losses. If the antenna temperature gets high it will introduce losses in signal reception.

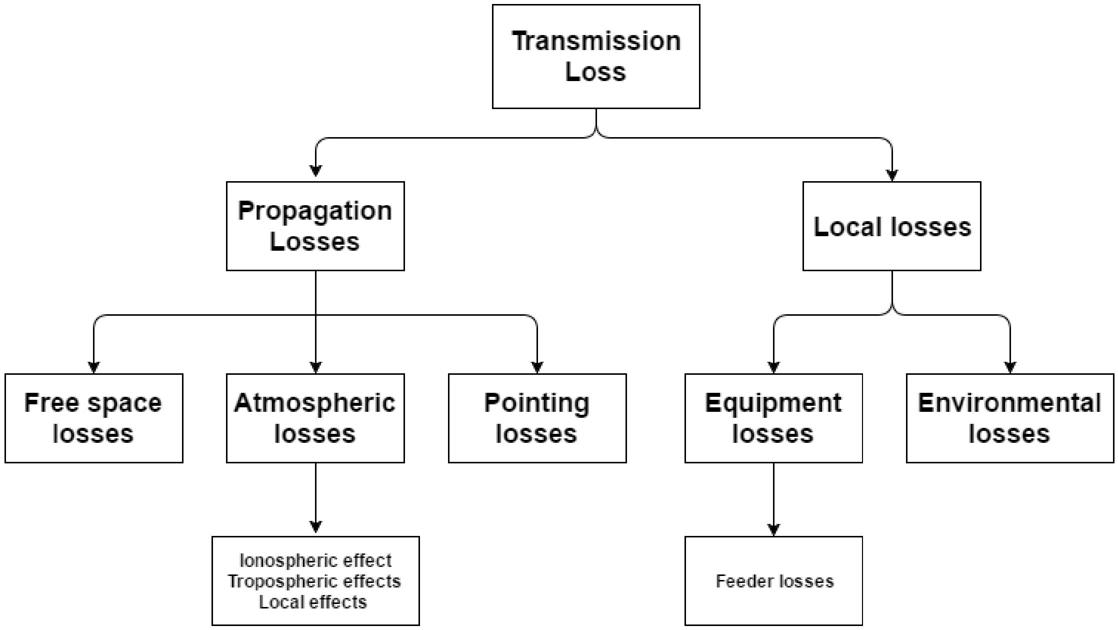

Figure 15: Types of Losses

OF-II will be using Ultrahigh frequency for primary communication. The frequency range will be between 430MHz to 440MHz. Since the communication distance is very high and the selected frequency is high enough for causing losses, total losses have been assumed for predicting the link quality. This will help to fix the parameters for receivers and ground station antenna.

Polarization loss has been assumed as 3dB. Atmospheric loss is 1dB.

Antenna misalignment loss is 1dB

Propagation losses are the combination of all the items mentioned so far.

Total propagation loss has been calculated by adding Free space loss, Atmospheric loss, Polarization loss and Antenna Misalignment loss. This will be the total amount of losses that can occur in the signal. [3]

Total propagation loss = 151.4 + 1 + 3 + 1 = 156.4 dBm

The received power can be calculated by subtracting total propagation loss from the EIRP. For OF-II the received power is almost -125 dBm, which is equivalent to -155dBw.

The FSPL formula expresses a loss value that is the reciprocal of gain and assumes the directivity for the transmit and receive antennas are isotropic and therefore unity. The free space path loss can be calculated by the following formula.

10log10 ($(\boldsymbol{4 * \pi * Distance * Frequency})/(\boldsymbol{Speed\ of\ light})$)^**2**

Based on the assumptions of orbital parameter the path loss will be around 150dB (approximately).

Calculation of free space loss:

- The free space path loss : *10log10* ($\frac{4 * \pi * Distance * Frequency}{Speed\ of\ light}$)^2
- If the distance is 3500 miles and frequency of 430 MHz the free space path loss is 159dB.
- Path loss can also be calculated by,

  Maximum Path loss = Transmit Power – Receiver sensitivity + Antenna gains – Fade margin

  = 31 – (-120) + 4 – 4 = 151dB

Table 6: Frequency vs path loss

Frequency (MHz)	**Path loss (dB)**
100	147.2
140	150.1
180	152.35

220	154.09
260	155.54
300	156.8
340	157.88
380	158.84
420	159.71
460	160.5
500	161.22

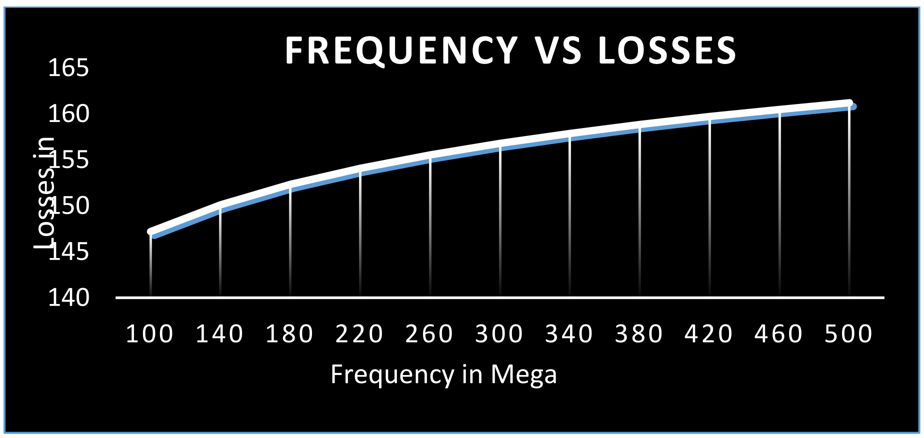

Figure 16: Relationship between frequency and received power

6.4 Receiver sensitivity:

Receiver sensitivity is what minimum power level does it require to establish a link. Given this and the link budget, we can determine the required gain of the receiving antenna. This usually dictates the type of antenna we choose.

For example, suppose the receiver requires -90 dBm minimum power to establish a link. Our link budget says there is -120 dBm at the receiver. So, the sum of their gains must be at least 30 dB to get we from -120 dBm to -90 dBm. Since our transmitting antenna gain is really low we need to have the receiving antenna gain of 30 dB (approximately). Gain is important as it directs the signal towards a particular point. 30 dB gain means we will need a large aperture antenna. The most common are parabolic dishes, but array antennas may also be an option for us. The array antenna is like what the amateur club said about using multiple antennas and adding the signals. It can get tricky to do it correctly, but is workable. But if we can have a large parabolic dish, it's possible to set the gain at 30dB using just one antenna.

Considerations for selecting the frequency:

- Higher frequency wavelengths are absorbed more easily by the air molecules
- As amplitude is kept constant by the transceiver specifications frequency is the only parameter that can be varied
- Longer wavelength travels faster than shorter wavelength
- For example, AM radio with low frequency has a long range whereas FM radio with higher frequency has a very short range

6.5 EIRP and Basic link analysis

EIRP = Transmission Power + Transmission antenna gain – Transmission Loss

Maximum transmit power : 30 dBM

Transmission antenna gain is considered as around 2dB

Transmission loss is around 1dB

Equivalent isotropic radiated power is = 30dBM + 2dB – 1dB

EIRP is close to 31dBM which is equivalent to 1dBW.

Total loss calculation:

Polarization loss = 3dB

Atmospheric loss = 1dB

Antenna misalignment loss = 1dB

Propagation losses are the combination of all the items mentioned so far.

Total propagation loss = Free space loss + Atmospheric loss + Polarization loss + Antenna Misalignment loss

Total propagation loss = 151.4 + 1 + 3 + 1

= 156.4 dBm

So, The received power can be calculated as

Received power or Isotropic receive level = EIRP – Total propagation loss = 31 – 156.4 dBm

= -125 dBm

Which is equivalent to -155dBw.

6.5.1 Energy per digital bit:

$\frac{E_b}{N_o}$ is energy per bit per noise spectral density ratio. Energy per bit to noise power spectral density ratio) is an important parameter in digital communication or data transmission. It is a normalized signal-to-noise ratio (SNR) measure, also known as the "SNR per bit". It is especially useful when comparing the bit error rate (BER) performance of different digital modulation schemes without taking bandwidth into account. For calculating the energy per bit noise figure needs to be finalized. [3]

Noise figure is the amount which represents how much noise has been added in a signal

NF(db) = 10log (1+Te/290) where Te is the effective noise temperature of the device. [3]

Thermal noise power level of an ideal receiver operating at room temperature is Pn= -228.6dBW/Hz + 10log 290 which equivalent to -204 dBW/Hz

We are assuming the received signal is -150dBW, Data rate is 10 kbps, Noise figure is 3dB

Energy per bit is Eb= -120dBm – 10log (10.00E+3) = -160dBm = -190dBW.

Energy per bit noise can be developed as Eb/No = RSL (db) – 10log(Bit rate) + 204 dBw – NF (db) = -150dBW – 10log(10000) + 204 dBW – 3dB = 11dB

6.5.2 GAIN TO NOISE TEMPERATURE:

System Noise temperature is the sum of all the noise temperature that occurs in the receiver end. System noise temperature = Antenna noise temperature + Increase in antenna noise due to rain + LNA noise temperature + Down converter and demodulator noise temperature. Receiver G/T (dB/K) = Receiver Antenna gain – 10 log(system noise temperature) (dB/k).

So, For 12dB gain of the receiver antenna and 290K of system temperature the receiver G/T is -12.62dB/K [3]

6.5.3 NOISE POWER & CAREER TO NOISE RATIO:

Noise Power = Boltzman Constant * Standard Room Temperature * Bandwidth [3]

For 10MHz of Bandwidth the noise power can be calculated as :

1.38E-23 * 290K * 10MHz = 0.04002pW = -103.977 dBm

Down link C/N_o(dB Hz) = Satellite operating EIRP - Downlink path loss - Down link rain attenuation - Receiving antenna pointing loss + Receiver G/T +228.6

=3.0dBw – 151dBw – 0dB – 2.5dB – 12.62dB/K + 228.6 = 65.48 dB Hz

Ratio of received power (Pr) to noise spectral density,

$\frac{P_r}{N_o} = \frac{G * P_r}{k * T_s}$ = -8.28 dBHz

6.5.4 ANTENNA PERFORMANCE:

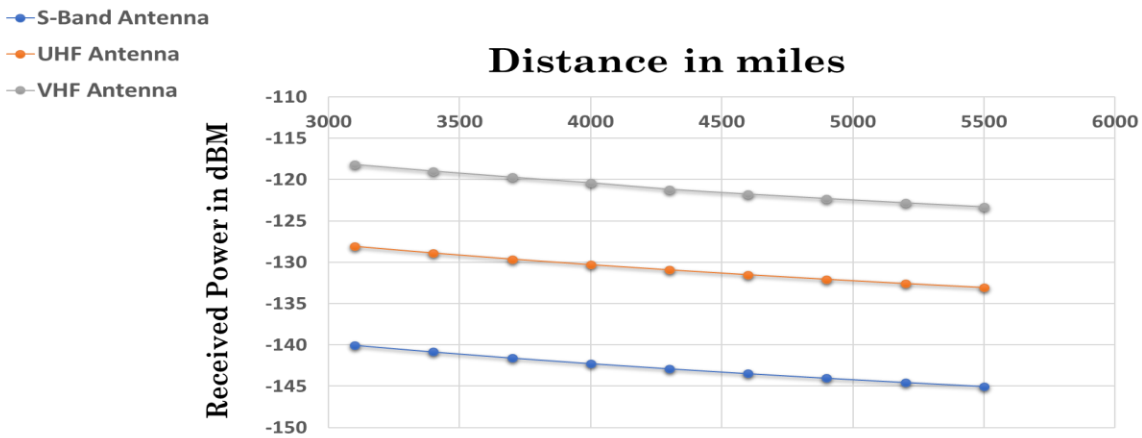

Figure 17: Antenna Performance

6.5.6 DATA RATE CALCULATIONS:

- Communication time: 10 Minutes
- Communication type: Line of Sight
- Data transfer rate: 10kbps
- Total transferred data in Bits: 6.00E+6
- Total transferred data in Bytes: 750 Kilobytes
- Time taken = $\frac{\boldsymbol{Distance}}{\boldsymbol{Velocity}} = \frac{\mathbf{4500E+3}}{\mathbf{3.00E+8}}$ = 0.015s

Contact time (Minutes)	Data rate (kbps)	Received data (KB)

5	5	187.5
10	10	750
15	15	1687.5

6.6 Expected Performance Summary of UHF

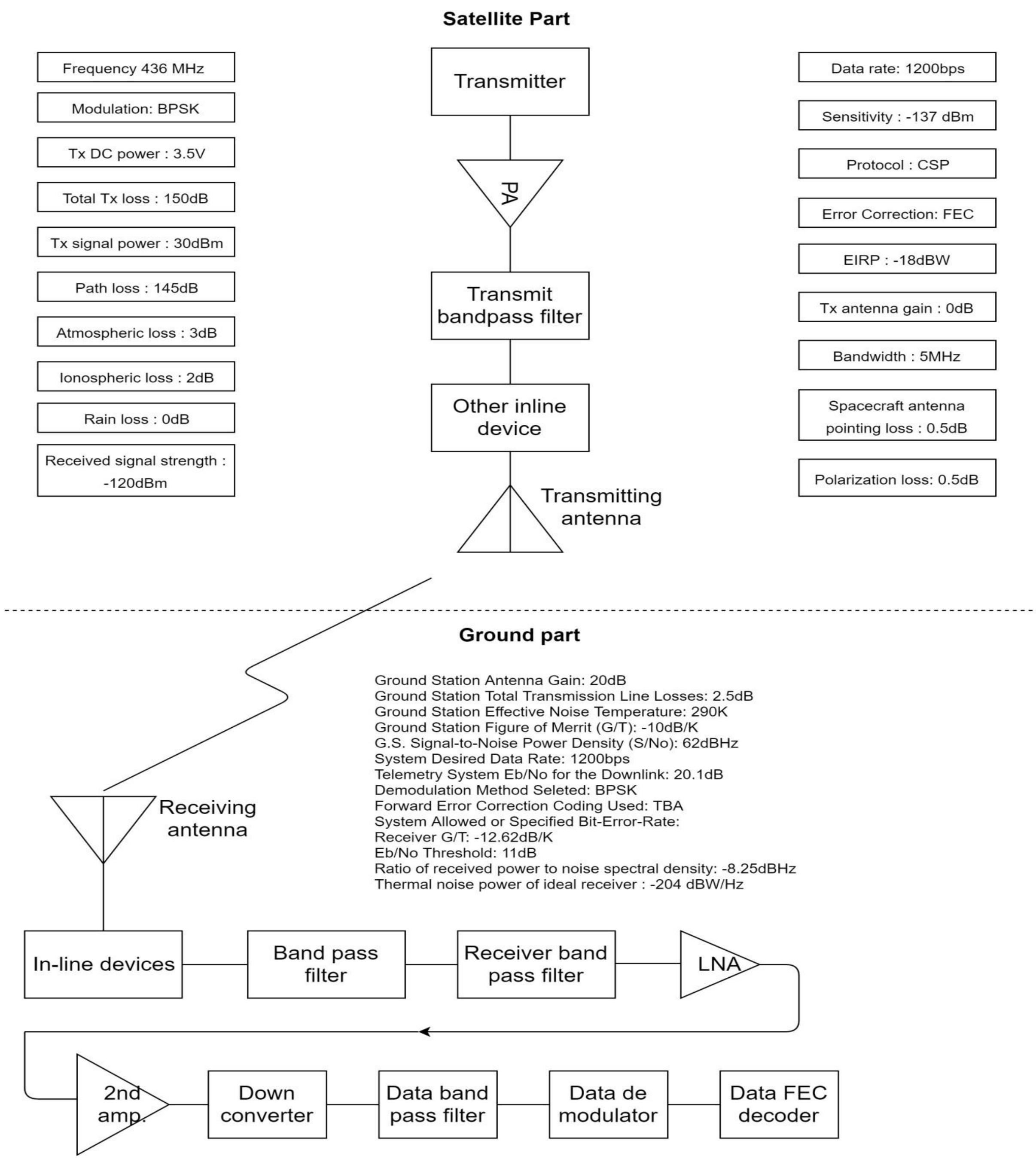

Figure 18: UHF Performance Summary

6.7 Expected performance summary of S-Band:

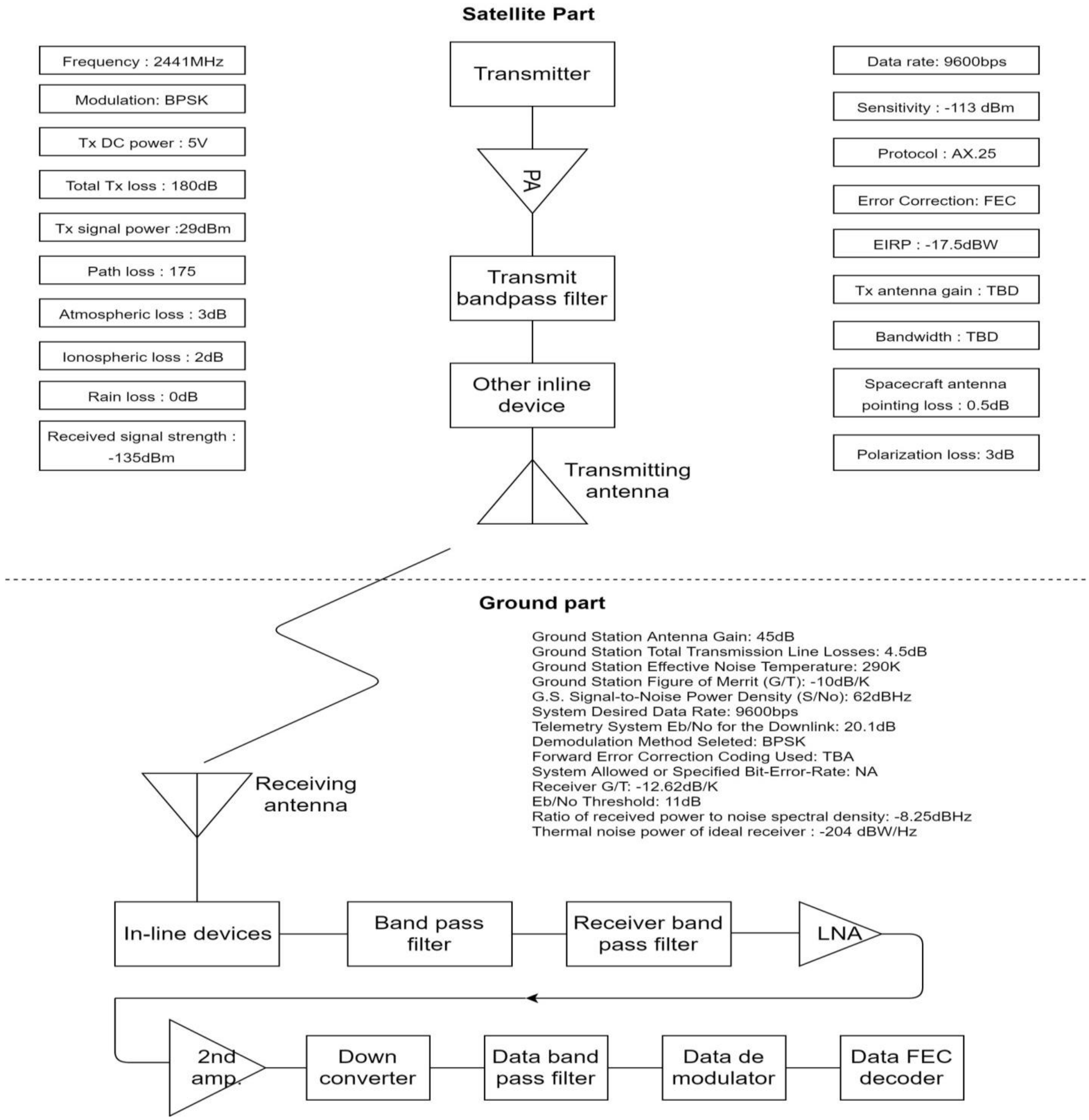

Figure 19: S-Band Performance Summary

6.8 Final link budget:

Table 7: Link Budget Parameters

		Bit rate 9600	Bit rate 1200	CW beacon
Beam objective(s)	[-]	Backup FM (mission and satellite off-time housekeeping (OTHK)	Satellite real time HK (RTHK), Main FM (mission and OTHK)	Beacon transmission
Type of emission	[-]	TBD	TBD	TBD
Height of Apogee	[km]	38000	38000	38000
Height of Perigee	[km]	5500	5500	5500
Mean Orbital altitude	[km]	21750	21750	21750
Earth radius	[km]	6334	6334	6334
Mean Orbital Radius	[km]	6790.64	6790.64	6790.64
Slant Range Elevation Angle	[deg]	10	10	10
Slant range distance	[km]	9073	9073	9073
Transmitting central frequency	[Hz]	140000000	140000000	140000000
Bandwidth	[Hz]	5000000	5000000	5000000
Transmitter output	[W]	1.5	1.5	1.5

Transmitter output	[dBW]	1.76	1.76	1.76
Maximum power flux density	[wb/m^2]	9.26E-15	9.26E-15	9.26E-15
Light speed	[m/s]	3.000.E+08	3.000.E+08	3.000.E+08
Transmission power supply loss	[dB]	1	1	1
Transmitting antenna gain	[dBi]	2	2	2
EIRP transmission	[dBW]	2.26	2.26	1.5
Transmitting antenna pointing loss	[dB]	2	2	2
Free path loss	[dB]	151	151	151
Polarization loss	[dB]	3	3	3
Atmospheric absorption loss	[dB]	1	1	1
Rain attenuation	[dB]	0	0	0
Reception power supply loss	[dB]	TBD	TBD	TBD
Receiving antenna pointing loss	[dB]	TBD	TBD	TBD

Receiver's received power	[dBm]	-120	-120	-120
G/T reception	[dB/K]	-12.62	-12.62	-12.62
Receiving antenna gain	[dBi]	TBD	TBD	TBD
Demodulator loss	[dB]	1	1	1
Receiver noise	[dB]	2	2	2
System noise temperature	[K]	290	290	290
System noise temperature	[dBK]	TBD	TBD	TBD
Sky noise temperature degradation	[dB]	0	0	0
System required data rate	[bps]	9600	1200	100
Modulation scheme	[-]	BPSK	BPSK	BPSK
Acceptable BER	[-]	TBD	TBD	TBD
Boltzmann constant	[J/K]	1.38E-23	1.38E-23	1.38E-23
Boltzmann constant	[dBW/Hz・K]	228.6	228.6	228.6
Received Eb/No	[dB]	11	11	11
Received C/No	[dBHz]	65.48	65.48	65.48

Required C/No	[dBHz]	TBD	TBD	TBD
System margin	[dB]	TBD	TBD	TBD
Ratio of received power to noise spectral density	[dBHz]	-8.28	-8.28	-8.28
Thermal noise power of ideal receiver	[dBW/Hz]	-204	-204	-204

6.9 Frequency Coordination Process

Frequency coordination is a very important process for fixing the communication parameters. The process involves several applications and filling out forms which will be submitted to different government institutions. Based on the mission needs and availability of the link a specific frequency will be allocated from the IARU for initiating communication from the satellite. The process should be started as early as possible because it takes time to get approval from the related departments after revision at different stages. While working on the communication system development of the OF-II, the following processes I could figure out for stating the frequency coordination process. Processes have been mentioned below:

1. Writing IARU frequency coordination request.
2. Filing the frequency coordination request with the local amateur radio community
3. Once approval has been received from local amateur radio community, sending the frequency coordination request to IARU

4. After examination, IARU will allocate U/L and D/L frequencies
5. Writing API
6. Submitting API to the Ministry of Communication
7. Upon approval of the Ministry of Communication, submitting API to ITU
8. Examination will occur, after that license can be issued

There are different types of coordination requests. Appropriate request should be made based on the mission needs. A ham radio license is required to apply for the frequency coordination. A copy of the obtained license can be found in appendix 4.

Regarding 5 specific software to write the entries are necessary for API. There are two software, "Space Cap" and "Space Val". They can be downloaded from ITU website (http://www.itu.int/en/ITU-R/software/Pages/spacecap.aspx and http://www.itu.int/en/ITU-R/software/Pages/spaceval.aspx)

Regarding 8), the application is open internationally and comments might be received from different countries fearing for interferences. These concerns need to be addressed otherwise the license can’t be granted if someone opposes the application. [23]

7. GROUND STATION PROPOSAL

This proposal is intended to provide options and recommendations for the telemetry, tracking, and control (TT&C) infrastructure for the Orbital Factory II mission. This includes recommendations on options for buying a ground station for Fabens, TX, as well as options for leased ground station networks and options for volunteer ground stations.

7.1 Background of Orbital Factory II

7.1.2 ORBITAL PARAMETERS

For the purposes of this proposal, two GTO orbits are analyzed featuring high and low Perigee values. The limits of 185 km and 4,000 km perigees have been selected as they represent both the low and high forecast values.

Disclaimer: This proposal is intended to provide insight to available communication frequencies, as well as options for ground station development. The data provided herein is not suitable for mission design as the assumptions for orbital parameters are based upon average values of prior missions and forecast expectations. They do not represent the actual orbit for OFII.

Table 8: Assumptions utilized for orbital simulations

	Low Perigee (185 km)	High Perigee (4,000 km)
Apogee:	35786.2 km	35065 km
Perigee:	185.2 km	3978.39 km
Inclination:	27 deg	21.4238 deg

Arg. Of Perigee:	180 deg	180 deg
Long. Ascn. Node:	189.399 deg	189.399 deg

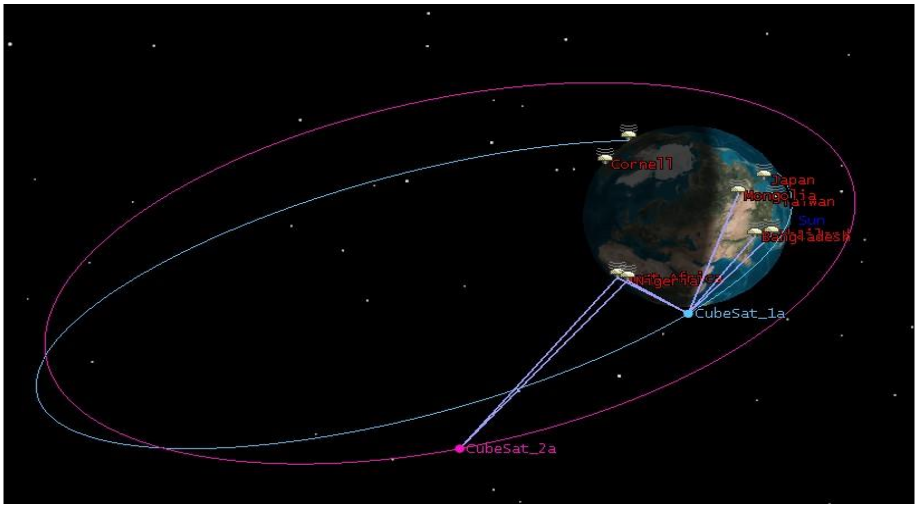

Figure 20: Example simulation showing two orbits and line of sight access between the satellite and ground stations

The location of ground stations is important because if a ground station is at too high or too low of a latitude, then it may not be able to see the satellite. Because OF-II will be deployed into a highly eccentric orbit with an approximately 12-hour period, OF-II will tend to have its apogee and perigee pass over either the launch site in North America, or Asia on the opposite side of the Earth. This will alternate, with Because of this, ideal ground station locations are in North America or Asia. Systems Tool Kit (STK) can be used to verify the access window when ground station locations will be able to see the satellite.

7.1.3 Orbital Factory II's Communications System

Orbital Factory II will utilize two frequency bands. A UHF deployable dipole antenna from EnduroSat will be OF-II's primary communication system as a dipole provides an

omnidirectional radiation pattern that increases the chance of reception. This is important as OF-II lacks attitude control. Further, UHF is a well-developed and cost-effective frequency band, with many ground stations supporting UHF. The UHF system is controlled by a GomSpace NanoCom AX100 transceiver. Please refer to appendix 5.

The decision to select the AX100 was made based on the following criterion:

- GomSpace is a publicly traded company
- The GomSpace board of directors includes key individuals
    - Jukka Petola – CEO Siemens A/S
    - Anna Rathsmann – CTO Swedish Space Corporation
- Flight Heritage
    - GOMX-3 – Deployed from ISS on 10/5/2015
- NASA classified as TRL 8 as of December 2015
- Price/Availability
- Mass/Power Capability
- Available in 3 bands: VHF, UHF-L, UHF-H

OF-II's secondary communication system is an S-band patch antenna provided by Lockheed Martin Space Systems. This patch antenna is experimental in nature. Further, the radiation pattern of a patch antenna is more directional in nature, decreasing the chance of signal reception. As such, S-band has a lower priority than UHF. The S-band system is controlled by an ISISpace TXS S-Band transmitter. The S-band system does not support uplink.

7.2 Ground Station Selection Methodology

In order to provide global coverage, a network of ground stations will be required. Ground stations can either be built and funded by UTEP, leased from for-profit companies which provide ground station networks, or be operated by Universities, amateur radio clubs, and private individuals who are either volunteers or have a memorandum of understanding with UTEP. An effective solution will utilize all three of these categories.

7.2.1 Building a Ground Station

In order to build a ground station for UTEP, several fundamental components are required:

- Antenna(s) with sufficient gain and frequency band
- Azimuth/Elevation (AZEL) mount for tracking capability
- Controller for the AZEL mount
- Transceiver/radio for each frequency band
- PC/Server to connect the ground station to UTEP and any required third-party networks

Most vendors will supply all of these components except the transceiver/radio, software, and PC/server as a turn-key solution. The high gain required for a GTO mission poses a unique challenge as the larger antennas lead to increased costs in the AZEL hardware. The AZEL tends to be the most expensive piece of ground station hardware. Further, care must be taken such that the AZEL will not be overloaded as this will lead to premature failure. If the surface area is too great, then a radome will also be required to protect antenna systems from the elements, such as wind loads, which also drives up prices. Building a ground station to support both UHF and S-band poses the additional challenge of requiring a unique antenna and transceiver/radio to support both frequency bands. If both antennas are installed on a single AZEL, this can also

overload the AZEL. For a system capable of producing adequate gain for a GTO mission, it is recommended not to combine UHF and S-band as this drives up the cost dramatically.

7.2.2 Leasing a Ground Station Network

Several companies offer the ability to lease a ground station network. These networks are made up of ground stations placed all over the world. These companies primarily target customers in commercial bands, however several state that they have ground stations available on amateur bands. Some of these companies even offer the option of assisting UTEP in building a ground station, then taking in UTEP’s ground station as a node, such that when it is not being utilized, UTEP’s ground station will be leased to other users with UTEP receiving a share of the revenue. However, there are still questions about this model which have yet to be answered, such as if its use on the amateur band will violate FCC and ITU regulations regarding amateur usage, and how liability will work for UTEP if UTEP were to participate in revenue sharing. One company has stated that they are exploring loop holes to the amateur usage regulations, however at the time of writing the problem has not been resolved.

7.2.3 Volunteer Ground Stations

There are many universities, amateur radio clubs, and even private individuals all over the world who operate UHF and S-band ground stations. These ground stations vary in performance from handheld receivers all the way up to large antenna arrays and parabolic dishes. Due to FCC and ITU requirements, ground stations operating on the amateur band cannot charge for their services. However many of these organizations are willing to volunteer their services and some have even offered to sign a memorandum of understanding regarding becoming a primary ground station for OF-II. The International Amateur Radio Union (IARU) has a requirement for

small satellites utilizing the amateur service to publicly release information regarding how to communicate with the satellite, which will open up the possibility for any amateur radio operator to receive information from the satellite, however there is no guarantee that all operators will send their data to UTEP.

7.3 Ground Station Options

This section will discuss various options available from vendors whom have been contacted. Vendors who have either not responded or declined involvement are mentioned however further details are excluded.

7.3.1 Ground Station Options: Build Option

Table 9: Table summarizing the vendors available who can supply ground station.

Company Name	Description	Price	Status
GomSpace	Turnkey UHF Ground Station	• $33,500 (UHF) • Cost of installation support and software development not included	Price received
ISISpace	Turnkey S-band (3 m dish). This ground station is downlink-only	$78,113.11	Quote received [Appendix 7]

• M2 Antenna Systems (Antenna/AZEL Hardware) • Gomspace (UHF Transceiver) • ISISpace (S-band Transceiver)	UHF or UHF/S-Band (1.8 m dish)	• $32,596.87 (UHF) • $55,401 (UHF/S-band) • Cost of installation support and software development not included	Quote received
ORBIT Communications	Turnkey S-Band (2.4 to 4.5 m dish)/UHF ground station	Estimated $200,000 to $300,000 depending on dish size	Awaiting quote
• RBC Signals (Antenna/AZEL Hardware sourced via M2) • Gomspace (UHF Transceiver) • ISISpace (S-band Receiver)	Turnkey UHF or UHF/S-Band (2 m dish) ground station. Includes installation support/software development	• $49,000 (UHF) ***(Recommended)*** • $68,784.13 (UHF/S-Band)	Proposal received
Tek Terrain	Turnkey network with separate UHF, VHF, and S-	• $425,000 (Chain 1, excludes markup/overheads) • $628,000 (Chain 2)	Proposal received

	Band (7.4 m dish) stations. Chain 2 includes second redundant set of ground stations		

7.3.1.1 Build Options: GomSpace

Background

GomSpace is a SmallSat company based in Denmark. GomSpace is one of the leading CubeSat suppliers, and is also the manufacturer of OF-II's UHF transceiver. GomSpace's NanoCom GND UHF ground station comes with the UHF antenna, all associated hardware, a UHF transceiver, and a mission computer to provide all necessary hardware. The ground station can be completely controlled and operated over Ethernet/internet.

Figure 21: Gomspace Antenna [14]

Itemized Components

Table 10: Gomspace Itemized Components

Item	Price	Lead Time
NanoCom GS 100 Transceiver • Contains two NanoCom AX100 transceivers • Externally controlled switchable RF bypass • 19" rack cabinet	$14,000	10 weeks
NanoCom MS100 Mission computer • Rotor software • CSP ground network interface • Hub between user workstation and the satellite	$6,700	10 weeks
NanoCom AS100 UHF Antenna System • Antenna • AZEL rotor • LNA • Cabling	$20,100	10 weeks
Total:	$33,500 (18% discount)	

Advantages

This system has a relatively low price and features an 18% discount if all components are bought as a package.

Disadvantages

The antenna's 17 dBi gain is intended for LEO missions and may be insufficient for a GTO mission. This option does not feature installation support, software support, nor training. Additionally, this option does not leave room for expandability of the antenna.

7.3.1.2 Build Options: ISISpace

Background

ISISpace is a SmallSat company based in the Netherlands providing services for satellites ranging from 1 kg to 30 kg. ISISpace is also the vendor providing OF-II's S-band transceiver. ISISpace can provide a turnkey S-band ground station solution, including the transceiver, a 3 m antenna dish, all required hardware, as well as ground station installation, training, and an RF checkout box for ground support equipment. Please look into Appendix 7 for the quote.

Figure 22: ISISpace Dish Antenna [13]

Itemized Components

Table 11: ISISpace itemized components

Item	Price	Lead Time
ISIS TXS S-band Transmitter	$9,518	6 weeks

Complete S-band Ground Station Kit • S-band dish, 3 meter • Feed LNA • Mountable support structure • AZEL rotor • Lightning protection system • Rackmounted PC with SDR receiver	$52,071.67	22 weeks
Ground station installation and training	$13,437.85	
RF checkout box (GSE)	$3,085.11	4 weeks
Total:	$78,113.11	

Advantages

The advantage of the ISISpace system is that it provides a complete turnkey ground station solution including all of the hardware as well as installation and training. The 3-meter antenna can provide approximately 35.4 dBi of gain.

Disadvantages

The disadvantage of the ISISpace system is the high cost as well as the support for downlink only, and from S-band only. It is most important for UTEP's ground station to support UHF as this is OF-II's primary frequency. Additionally, this option does not leave room for expandability of the antenna.

7.3.1.3 Build Options: M2 Antenna Systems

Background

M2 Antenna Systems is a company based in California which provides antenna systems to a variety of different fields. M2 has experience building SmallSat ground stations for a variety of customers including major universities and even government agencies.

The backbone of M2's proposed system is the AZEL 1000 rotor. This rotor can support a variety of different antenna configurations for UHF, VHF, and S-band.

M2 provides two options for building a ground station at UTEP: A UHF-only ground station, and a dual UHF/S-Band ground station. Both options would utilize the AZEL 1000. The UHF option would feature two stacked Yagi antennas to provide 21.7 dBi of gain. The UHF/S-band option would feature the same Yagi antennas, but with the addition of a 1.8 m dish for S-band. M2 has warned that the UHF/S-band option could overload the AZEL, and it was recommended that this configuration not be deployed for long-term use. However the AZEL may be able to sustain the load if OF-II is launched during a time of the year with low winds, and also if the antenna is disassembled after OF-II's short mission is over.

M2 only supplies the hardware. As such, installation, software development, and training would require additional costs and services contracted from a third party.

M2's quotes are provided in the appendix 1.

Itemized Components

Option 1: UHF Only

Table 12: M2 Electronics UHF Ground Components

Item	Price	Lead Time
AZEL1000, Pedestal Crossboom	$9,225	6-8 weeks
Pipe Mount Kit	$925	6-8 weeks
ACU AZ/EL Control Unit	$2,950	6-8 weeks

Control Cable	$404	6-8 weeks
Custom Crossboom	$405	6-8 weeks
430-440 MHz CP Yagi, Qty 2	$923.98	6-8 weeks
70cm 2 Port Divider	$125.99	6-8 weeks
UHF-50, Tuned Phase Kit, Qty 2	$357.90	6-8 weeks
Non-Penetrating Mount, 10’7” x 10’7”	$2,600	6-8 weeks
Crating Charge ISPM-15 Compliant	$680	
Total:	$18,596.87	

Option 2: Dual UHF/S-Band

Table 13: M2 Electronics S-Band ground station components

Item	Price	Lead Time
AZEL1000, Pedestal Box Frame	$11,225	10-14 weeks
Pipe Mount Kit	$925	10-14 weeks
ACU AZ/EL Control Unit	$2,950	10-14 weeks
Control Cable	$404	10-14 weeks

Dish, 6’ (1.8 m)	$4,950	10-14 weeks
Dish Adapter Kit, 6’	$105	10-14 weeks
Feed Leg Foot Kit	$850	10-14 weeks
Septum Dish Feed, 2.39-2.45 GHz	$4,250	10-14 weeks
Crossboom extension with counter balance	$585	10-14 weeks
430-440 MHz CP Yagi, Qty 2	$923.98	10-14 weeks
Vertical Riser/T-Brace Kit	$685	10-14 weeks
70cm 2 Port Divider	$125.99	10-14 weeks
UHF-50, Tuned Phase Kit, Qty 2	$357.90	10-14 weeks
Non-Penetrating Mount, 10’7” x 10’7”	$2,600	10-14 weeks
Crating Charge ISPM-15 Compliant	$680	10-14 weeks
Total:	$31,616.87	

Advantages

M2 provides custom-built and balanced ground station systems to allow for an almost turnkey solution. The large 21.7 dBi gain would increase the chance of closing OF-II's link budget in GTO. The AZEL 1000 can be reconfigured after OF-II to fit the needs of other SmallSat missions in the UHF, VHF, and S-band frequencies. Due to the high cost of the AZEL 1000 relative to the other components, this is a valuable feature with regards to expandability.

Disadvantages

M2 does not provide installation, software development, nor training support. These costly services would have to be provided by a third party, such as RBC Signals. The S-band option significantly increases the cost of the system by $22,800 while also adding a risk of overloading the AZEL mount.

7.3.1.4 Build Options: ORBIT Communication Systems

Background

ORBIT is a company based in Florida which provides communication services to a variety of industries. For SmallSats, ORBIT's Gaia 100 system is primarily designed for S-band and X-band, however the option is available to mount a third-party UHF antenna. The Gaia 100's S-band antenna can vary from 2.4 m to 4.5 m, allowing for the high gain necessary for LEO and MEO satellites. Due to the large antenna size, a radome is required to be installed around the ground station. [15]

Figure 23: ORBIT Radome Structure [15]

Itemized Components

Unknown. Antenna control software is included; however installation will have to be managed by a third party. A transceiver is not included. Estimated cost is between $200,000 to $300,000. A formal quote is in progress. Estimated lead time is 6 months.

Advantages

The Gaia 100 features a large antenna size that is ideal for providing the gain necessary for OF-II. The enclosed antenna requires very little maintenance, and would only need inspected approximately once a year.

Disadvantages

The high cost of the Gaia 100 may be outside of budget. Installation support and the transceiver are not included in the package.

7.3.1.5 Build Options: RBC Signals

Background

RBC Signals is a company based in Washington which provides ground station network services as well as support in the design and setup of ground stations. A unique service offered by RBC Signals is revenue-sharing where RBC will assist customers in setting up a ground station, then allow the ground station to enter their network. By doing so, RBC will lease out use of the ground station when it is not in use, and share the revenue.

RBC Signals would source the hardware, provide installation and software support to configure the ground station, and additionally provide support in the operation of the ground station.

RBC's antenna hardware is sources from M2 Antenna Systems.

RBC Signal's ground station network services are discussed later in this proposal. RBC's full 8-page proposal is provided in the appendix 3.

Itemized Components

Table 14: RBC signals UHF ground station components

Item	Price	Lead Time
Hardware • AZEL and Control Unit • Dual Yagi antennas • Pipe mount kit • Non-penetrating mount • Software support	$30,000	
Installation Support • Phone support for site preparation • 4 days of on-site support	$5000	

GomSpace GS 100 Transceiver	$14,000	
	$49,000	

Option 2: Dual UHF/S-Band

Table 15: RBC signals S-Band ground station components

Item	Price	Lead Time
Hardware • AZEL and Control Unit • Dual Yagi antennas • Pipe mount kit • Non-penetrating mount • Software support	$40,000	
Installation Support • Phone support for site preparation • 4 days of on-site support	$5,000	
GomSpace GS 100 Transceiver	$14,000	
ISISpace S-band Receiver	$9,784.13	
	$68,784.13	

Advantages

RBC would provide a complete turnkey solution as well as all services required to have a fully-functioning ground station. RBC would also help with licensing the ground station. Additionally, RBC's revenue sharing program would help the ground station pay for itself. RBC has already identified a customer who may be interested in having a ground station near El Paso. RBC has stated that they are flexible with acquiring the antenna system that was quoted by M2 Antenna Systems.

Disadvantages

The primary disadvantage of RBC's ground station is the cost, however the higher cost is justified by the other services included with the contract such as installation, software development, and licensing. These services are excluded from all cheaper proposal options.

7.3.1.6 Build Options: Tek Terrain

Background

Tek Terrain is a Nevada based company providing telecommunications services to the aerospace industry. Tek Terrain provided an ambitious proposal for the development of a ground station at Fabens utilizing VHF, UHF, as well as a large 7.4 m S-band antenna that would be suitable for MEO and HEO applications. Tek Terrain's proposal is divided into 5 key phases: Design, Development, and Fabrication; Testing, Validation, and Qualification; Antenna/infrastructure installation; Test, Turnup, Training, and Commissioning; Post Mission Support. Additionally, Tek Terrain provided an option to include redundant secondary VHF, UHF, and S-band ground stations. Tek Terrain's full 14-page proposal can be found in the appendix. [27]

Figure 24: Tek-Terrain Dish [27]

Itemized Components

Option 1:

Table 16: Proposed development phases by Tek Terrain

Item	Price	Lead Time
Phase 1: Design, Development, Fabrication	$106,000	8 weeks
Phase 2: Testing, Validation, and Qualification	$40,000	4 weeks
Phase 3: Antenna Kits, Infrastructure, Installation	$265,000	1 week
Phase 4: Test, Turnup, Training, and Commissioning	$11,000	1 week
Phase 5: Post Mission Support	$3,000	N/A
Total: (Excludes markup, overheads)	$425,000	

Option 2:

Table 17: Proposed secondary option phases by Tek Terrain

Item	Price	Lead Time
Phase 1: Design, Development, Fabrication	$150,000	8 weeks
Phase 2: Testing, Validation, and Qualification	$44,000	4 weeks
Phase 3: Antenna Kits, Infrastructure, Installation	$328,000	1 week
Phase 4: Test, Turnup, Training, and Commissioning	$14,000	1 week
Phase 5: Post Mission Support	$4,500	N/A
Markup, Overheads	$87,500	
Total:	$628,000	

Advantages

The advantage of Tek Terrain's proposal is that it would provide UTEP a robust and powerful ground station site capable of utilization with LEO, MEO, and HEO missions. The ground stations could even feasibly be used for deep space missions to an extent. Further, Tek Terrain would be available with every step from design, testing, installation, training, and post mission support.

Disadvantages

The disadvantage of Tek Terrain's proposal is the enormous cost associated with building a robust ground station site.

7.3.2 Ground Station Options: Lease Options

The table below summarizes the businesses available who lease ground station networks.

Table 18: Table summarizing the businesses available who lease ground station networks

Company Name	Description	Price	Status
InfoStellar	Network of <X> groundstations. InfoStellar provides service for the BIRDS project.	• TBD	Awaiting quote and more information
KSAT	Ground station network providing service to commercial customers	N/A	Declined due to inability to support amateur bands
RBC Signals	Network of 21 ground stations, supporting UHF and S-Band	$3,000 setup fee $10/minute (UHF) - ***Recommended*** $20/minute (S-Band) - ***Recommended***	Proposal received

Morehead State University	Very high gain 21 m Tracking Antenna, S-Band	$2,850/day - ***Recommended***	Pricing information received

7.3.2.1 Lease Options: InfoStellar

Background

InfoStellar is a Japanese ground station developer company who runs a network of ground station at different countries in Asia. Based on UTEP's orbital parameters and frequency bands that include amateur bands, Infostellar will provide priority access to our StellarStation platform that will include access to scheduling and monitoring for data transmissions. With priority access, UTEP will be able to step in front of currently scheduled transmissions (with adequate notice), to ensure continuous collection of mission and HK (house keeping) data. [Appendix 8] StellarStation is the on-demand delivery service of distributed satellite communication antenna access via the internet with pay-as-you-go pricing. As a proprietary platform for satellite operators, StellarStation enables continuous communication link with a network of ground stations. StellarStation allows communication with various satellites, and transfers data among satellite operators. Antenna owners provide antenna's idle time to the StellarStation scheduling platform in exchange for use 'credits. Antenna owners with owned satellites can use the credits to access OTHER antennas in the StellarStation network for their operation/service. StellarStation can provide UTEP with five ground station points in Japan, Taiwan, Singapore, South Africa and United Kingdom. If UTEP would like to provide Infostellar updated information on its orbital parameters, as well as mission launch timing, Infostellar can provide an

updated number of accessible ground station points. These access points may be subject to change. [Appendix 8]

Prior to launch, Infostellar will provide a period of compatibility testing for UTEP of StellarStation. Based on the timing of UTEP's mission launch, Infostellar expects to perform compatibility testing of UTEP's transceiver with a ground station site in North America (details to be confirmed). [24]

Pricing Model:

Following is a pricing model received from InfoStellar for getting access to their network.

Table 19: InfoStellar Pricing Model

Services	**Price**
Access to StellarStation Platform	$5000
Connection charge- Per Pass – UHF	$20
Connection Charge- Per Pass – S-Band	$200

Advantages:

- Cost effective
- High reliability
- Experienced company running GS network for getting satellite data
- Instant data reception capability from central server

Disadvantages:

- Comparatively small coverage
- Takes long time respond

7.3.2.2 Lease Options: RBC Signals

Background

RBC Signals is a company based in Washington which provides ground station network services as well as support in the design and setup of ground stations. RBC has a unique business model of allowing revenue sharing. Organizations are allowed to lease their ground stations to RBC, who will then sublease scheduled passes to end-users when the ground station is available. This allows organizations to benefit from otherwise dormant ground stations. RBC's network is made up of 7 ground stations in North America, 6 in Europe, 1 in Africa, 5 in Russia, and 1 in China. At least 7 of these ground stations are in ideal locations to receive visual access to OF-II, although specifications of the ground stations are not currently known. Because the ground stations are owned by multiple organizations, specifications are not homogenous. Once compatible ground stations are identified, RBC's platform will allow supported passes to be listed. Passes can then be scheduled, with data being delivered directly to UTEP's servers via the internet.

Participating in revenue sharing is not required to utilize RBC's service, and RBC has stated that their ground station network pricing model will stay the same regardless of if UTEP contributes a ground station to their network. [16]

Figure 25: RBC signals network [16]

Pricing Model

To utilize the network, RBC requires a $3,000 set up fee. Afterwards, TT&C support is priced at $10/minute for UHF and $20/minute for S-band. This per-minute pricing model is required for OF-II due to the extreme eccentricity of the orbit. For LEO satellites, where passes typically last approximately 8 minutes, pricing is set at $80/pass for UHF and $160/pass for S-band. UTEP will only be charged for services used.

Advantages

RBC Signals' service is advantageous because of the relatively low cost and variety of ground station locations. Further if UTEP moves forward with building a Fabens ground station, this will give UTEP an opportunity to join RBC's revenue sharing program. RBC has stated that they have already identified a potential customer interested in having a ground station located near El Paso.

Disadvantages

At present, the specifications of the ground stations in RBC's network are not known. This may need to be investigated to determine which ground stations will be a good fit to OF-II's mission. RBC has stated that they will recommend which ground stations will meet OF-II's technical needs.

7.3.2.3 Lease Options: Morehead State University 21 m Tracking Antenna

Background

The Space Science Center at Morehead State University in Kentucky has developed a 21 meter class antenna system for use in radio astronomy and as a TT&C station for satellite based missions. The antenna is configured for L-band, S-band, X-band, low C-band, and Ku-band. The large size of the dish allows for a very high gain of approximately 52.8 dBi for S-band. The antenna can even support LEO, MEO, GEO, lunar, and deep space missions, and will be utilized as a node in the NASA Deep Space Network for Orion Exploration Mission 1 (EM-1) in 2019. As such, UTEP will likely only be able to lease the 21 m antenna if it is before EM-1.

Along with data downlink, Morehead State University offers transmission and uplink capabilities at S-band. Details will be found in appendix 2.

To utilize the tracking antenna, Morehead State University asks that teams perform an RF compatibility test by bring their engineering or even flight model to Morehead to perform the tests (duration: a few days), develop a flight to ground ICD so that the Morehead station will have all of the operating parameters and requirements, perform an end to end test between the Morehead data server and the mission operation center, develop a services contract, and pass a scheduling plan to reserve aperture time. [17]

Figure 26: Morehead State University 21m dish [17]

Pricing Model

Due to the reconfiguration work involved in preparing for a pass, the antenna is typically leased for a daily rate of $2,850 per day for unlimited passes during the contracted 24-hour period. During this period, the end user occupying the dish is considered the sole user.

Advantages

Morehead State University's 21 m antenna has the great advantage of being relatively low cost while also providing enough gain to potentially receive downlink from OF-II even at apogee. Analysis in STK shows that OF-II could even be visible from Morehead State University for as long as 5 hours.

Disadvantages

The disadvantage is that the 21 m antenna is limited to S-band. CXBN, one of Morehead's CubeSat projects, had reported working on a UHF feed for the 21 m antenna for 400-480 MHz with 30 dBi gain although the status of this is unknown and is not currently advertised as a capability.

7.3.3 GROUND STATION OPTIONS: VOLUNTEER GROUND STATIONS

The table below summarizes organizations that could potentially be used as volunteer ground station. Due to very limited information available, expanded details are not provided. It is recommended for UTEP to partner with as many volunteer organizations as possible, however relying on volunteer organizations should be limited as a last resort.

Table 20: List of volunteer ground stations

Organization Name	Description	Status
Aalto University, Finland	Ground station features steerable VHF, UHF, and S-band antennas. No specifications are available. Aalto launched Finland's first satellite into LEO, and plans to deploy GTO CubeSats in the future.	Aalto is interested in trying to receive downlinks from OF-II in preparation for future GTO missions. Aalto's location is not ideal for satellite access, however access will still be available.
Alaska Satellite Facility	Downlinks, processes, archives, and distributes earth remote sensing data to scientific users.	Declined due to inability to support amateur bands
Arizona State University	ASU features a ground station for UHF as well as a new 3 m diameter dish. Unknown if the ground station is operational yet.	Communication not yet established

Georgia Tech	Ground station supports various CubeSat missions; however specifications and frequency bands are unknown.	Communication not yet established
International Space University, France	Ground station features: TRX: UHF (19.3 dBi), VHF (15.3 dBi), RX: S-band (21 dBi). Location is not ideal, but may work.	ISU is open to helping with OF-II downlink, and has even stated that they would be open to being a secondary mission ground station (if a licensed HAM is available) or primary ground station (if an OF-II team member were to be hosted)
Montana State University	Montana State University Space Science and Engineering Laboratory. Ground station features a roof mounted VHF and UHF Yagi antenna array. Specifications not available.	Open to trying to receive signal from OF-II on a non-interference basis
University of Michigan Amateur Radio Club, Michigan	Amateur radio club based at the University of Michigan. The club does not yet support S-band, however Yagi antennas are available in the VHF and	UMARC is open to helping with OF-II downlink.

	UHF spectrum. Limited specifications available.	
University of New South Wales, Australia	Ground station features VHF and UHF. S-band hardware is available but not yet installed. BPSK modulation hardware is not available, but may be able to be developed using a software defined radio.	UNSW is open to helping with OF-II downlink however more communication is required to identify UNSW's capability and availability.
University of Surrey, England	Surrey Space Centre. Ground station features 2 sets of large VHF and UHF antennas and a 3.5 m S-band dish.	Surrey is open to helping with OF-II downlink, but would like to wait until OF-II is closer to flight readiness review to continue the discussion.
University of Texas at Austin	UT Austin's Texas Spacecraft Laboratory ground station featured a VHF and UHF Yagi antenna assembly. Specifications are unknown.	Communication not yet established. The Texas Spacecraft Laboratory's founder has since moved to Georgia Tech. UT Austin's ARMADILLO CubeSat's TT&C has also moved to Georgia Tech and it is unknown what the current state of UT

		Austin's SmallSat program is, nor who the POC is.

7.4 Recommendations

OF-II is a unique mission in that the CubeSat will be in a highly elliptical orbit with a long orbit period, yet a short mission duration. To ensure that adequate coverage is available, an ideal TT&C architecture for OF-II will require a variety of different ground station sources, including a ground station built at UTEP or Fabens to serve as the primary ground station, leased ground station networks, and volunteer ground stations to fill in the gaps. If it is cost prohibitive to build a Fabens ground station, then leasing can still be a viable option.

7.4.1 RECOMMENDATIONS: BUILD OPTION

The primary criteria for judging the build option is price versus specifications—for ground stations, a major driving factor is gain. Larger antennas provide more gain, yet also can significantly drive up prices due to the limitations of the AZEL tracking mounts. While the antennas themselves are fairly cheap, AZEL mounts are a very costly component of a ground station system due to the requirement to have precision tracking. Due to this cost, expandability is also taken into consideration. If an AZEL can be reconfigured in the future to other frequency bands, such as changing from OF-II's MEO high-gain UHF antenna to a LEO medium-gain VHF antenna, then this is considered an advantage.

Out of the quotes and proposals received, M2 Antenna System's UHF-only option best meets OF-II's needs as it balances cost with performance (gain) of the antenna. Further, M2's AZEL can be reconfigured for other VHF, UHF, or S-band systems as long as care is taken not to

overload the mount. The downside to M2's quotation is that software development, licensing, installation, and support are not provided. However RBC Signals has stated that they can take care of these services at additional cost, while still providing the same hardware from M2. Further, RBC Signals can include UTEP in its revenue sharing program, where UTEP's ground station would be leased out to other users when not in use, allowing UTEP to profit. RBC Signals has stated that they have already identified a potential customer interested in having a ground station near El Paso.

7.4.2 Recommendations: Lease Option

For the lease option, not many companies are available for leasing to SmallSats. It is a fairly new business. Many companies exist which lease for commercial users, however these ground stations are not set up for most SmallSats. RBC Signals is ideal as they provide a variety of ground stations which could potentially receive OF-II's downlinks, and also at a low pay-as-you-go cost of $10/minute for UHF and $20/minute for S-band. It is additionally recommended to lease Morehead State University's 21 m tracking antenna as the very high gain would even allow OF-II's transmissions to be detected at apogee, which could provide 5+ hour communication windows per day. The only caveat is that the lack of attitude control would not guarantee the S-band patch antenna's ability to send a signal to Morehead.

7.4.3 Recommendations: Volunteer Option

Several universities have expressed interest in helping with OF-II by listening to the sky for down links. Even though not all volunteer universities are in ideal locations to see OF-II at perigee, every additional volunteer is helpful. It is recommended to keep in contact with volunteers who have expressed interest, as well as seek more volunteers at other CubeSat

developing universities. AMSAT is another organization that could be helpful in finding volunteers if OF-II is approved to use the amateur service.

7.4.4 Recommendations: Pricing Summary

The table below summarizes the total prices for the recommended options.

Build and Lease Option:

Table 21: Pricing summary for build and lease options

Company Name	Item	Price
RBC Signals	Hardware • AZEL and Control Unit • Dual Yagi antennas • Pipe mount kit • Non-penetrating mount • Software support	$30,000
RBC Signals	Installation Support • Phone support for site preparation • 4 days of on-site support	$5,000
GomSpace	GomSpace GS 100 Transceiver	$14,000
RBC Signals	Setup fee	$3,000

RBC Signals	UHF TT&C (Assume 7 stations @ 30 minutes per day, 5 days)	$1,050
RBC Signals	S-Band TT&C (Assume 7 stations @ 30 minutes per day, 5 days)	$2,100
Morehead State University	21 M Tracking Station S-Band TT&C (Assume 3 days)	$8,550
Total:		$63,700

Lease Only Option:

Company Name	Item	Price
RBC Signals	Setup fee	$3,000
RBC Signals	UHF TT&C (Assume 7 stations @ 30 minutes per day)	$1,050
RBC Signals	S-Band TT&C (Assume 7 stations @ 30 minutes per day)	$2,100
Morehead State University	21 M Tracking Station S-Band TT&C (Assume 3 days)	$8,550
Total:		$14,700

7.5 Ground Station Network analysis and Final Proposal

The following analysis provides a deep insight about the footprint area for OF-II.

OF-II footprint calculation:

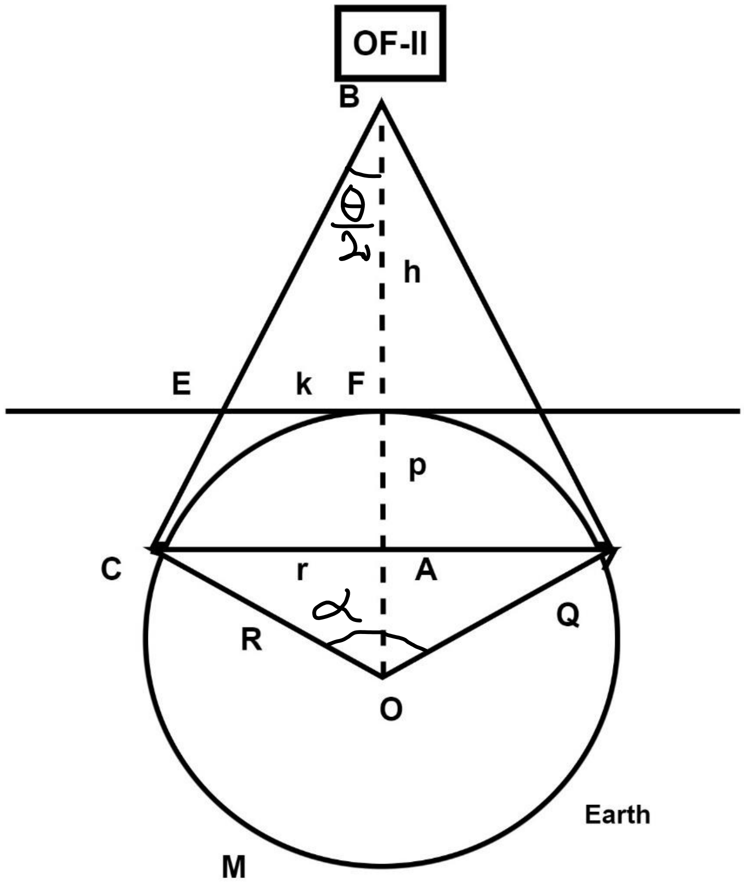

Figure 27: OF-II footprint

Let's Assume,

EF=k , CA=r, OC=R

In ΔBEF,

$$\tan\frac{\theta}{2}=\frac{k}{h}$$

So, k= $h \tan\frac{\theta}{2}$

Here, known values are h, θ, k, r, p

In ΔBEF,

$\tan\frac{\theta}{2} = \frac{r}{h+p}$

So, (h+p) $\tan\frac{\theta}{2}$ = r …………………….. (1)

Since, ΔBEF & ΔBCA are similar triangle, so their side lengths will be in a same ratio.

$\frac{\mathrm{EF}}{\mathrm{CA}} = \frac{\mathrm{BF}}{\mathrm{BA}}$

So, $\frac{\mathrm{k}}{\mathrm{r}} = \frac{h}{\mathrm{h+p}}$………………………….. (2)

From equation 1 and 2 we can write,

$\frac{k}{(\mathrm{h+p})\tan\frac{\theta}{2}} = \frac{h}{(\mathrm{h+p})}$

So, $k(h+p) = h(h+p)\,tan\frac{\theta}{2}$

So, $hk + kp = h^2\,tan\frac{\theta}{2} + hp\,tan\frac{\theta}{2}$

So, $p(k - h\,tan\frac{\theta}{2}) = h^2\,tan\frac{\theta}{2} - hk$

So, $\boldsymbol{p} = \frac{\boldsymbol{h^2\,tan\frac{\theta}{2} - hk}}{\boldsymbol{k - h\,tan\frac{\theta}{2}}}$……………………………… (3)

So, $r = (h + \frac{\boldsymbol{h^2\,tan\frac{\theta}{2} - hk}}{\boldsymbol{k - h\,tan\frac{\theta}{2}}}) + tan\frac{\theta}{2}$

Again, $CQ = 2r$

In, ΔCAO, $cos\alpha = \frac{OC^2+OQ^2-CQ^2}{2OC*OQ} = \frac{R^2+R^2-CQ^2}{2R^2} = \frac{2R^2-CQ^2}{2R^2}$

So, $\alpha = cos^{-1}\left(1 - \frac{CQ^2}{2R^2}\right) = [X]rad$

So, $Xdeg = \frac{\pi X}{180}$.

Now, From CQFM circle,

S= α*R

Using the above formula for 400km distance and assuming the value of theta as 30 degree, we get,

p=3541.871921

r=1056.221398, 2r=2112.442796

α= 0.33310959

From the CQM circle, S = αR = 0.33310959 * 6371 = 2122.24km.

So, the total area covered from the OF-II footprint is 2122.24kilometers.

RBC Signal Network has their coverages in the following area:

Table 22: Cities where RBC signals has their coverage

City	**Coordinates**
Deadhorse, AK	70.2002° N, 148.4597° W
Fairbanks, AK	64.8378° N, 147.7164° W

Honolulu, HI	21.3069° N, 157.8583° W
Los Angeles, CA	34.0522° N, 118.2437° W
Madison, WI	43.0731° N, 89.4012° W
Miami, FL	25.7617° N, 80.1918° W
San Juan, Puerto Rico	18.4655° N, 66.1057° W
Brest, France	48.3904° N, 4.4861° W
Valladolid, Spain	41.6523° N, 4.7245° W
Jos, Nigeria	9.8965° N, 8.8583° E
Milan, Italy	45.4642° N, 9.1900° E
Pomjan, Slovenia	45.4993° N, 13.7542° E
Kaunas, Lithuania	54.8985° N, 23.9036° E
Moscow, Russia	55.7558° N, 37.6173° E
Samara, Russia	53.2415° N, 50.2212° E
Perm, Russia	58.0297° N, 56.2668° E
Krasnoyarsk, Russia	56.0153° N, 92.8932° E
Irkutsk, Russia	52.2870° N, 104.3050° E
Magadan, Russia	59.5612° N, 150.8301° E
Jiaxing, China	30.7539° N, 120.7585° E

Distances between cities:

Table 23: Distances between nearby cities

Point A to Point B (Cities)	**Distances**
Deadhorse, AK to Fairbanks, AK	372.13 miles S (183°)
Fairbanks, AK to Honolulu, HI	3040.69 miles S (166°
Honolulu, HI to Los Angeles, CA	2563.14 miles NW (298°)
Los Angeles, CA to Madison, WI	1670.96 miles NW (300°)
Madison, WI to Miami, FL	1302.07 miles SW (206°)
Miami, FL to San Juan, Puerto Rico	1032.18 miles SW (243°)
San Juan, Puerto Rico to Brest France	3981.49 miles NW (316°)
Brest, France to Valladolid, Spain	465.44 miles S (178°)
Valladolid, Spain to Jos, Nigeria	2200.83 miles S (172°)
Jos, Nigeria to Milan, Italy	2449.60 miles N (0°)
Milan, Italy to Pomjan, Slovenia	221.72 miles E (87°)
Pomjan, Slovenia to Kaunas, Lithuania	788.70 miles NE (30°)
Kaunas, Lithuania to Moscow, Russia	543.20 miles E (78°)
Moscow, Russia to Samara, Russia	535.48 miles E (103°)
Samara, Russia to Perm, Russia	406.72 miles NE (33°)
Perm, Russia to Krasnoyarsk, Russia	1372.07 miles E (80°)
Krasnoyarsk, Russia to Irkutsk, Russia	529.31 miles SE (114°)
Irkutsk, Russia to Jiaxing, China	1704.52 miles SE (144°)
Jiaxing, China to Magadan, Russia	2429.96 miles NE (26°)
Magadan, Russia to Fairbanks, AK	378.92 miles N (345°)

This analysis helps to validate the final proposal where RBC signals has been considered as the primary ground station network. The final proposal is provided in the following section.

The scope of this proposal is to recommend a hybrid approach to the ground station development for OFII and future missions at the University of Texas at El Paso. The proposal contains two parts, first part is for UHF and second part is for S-Band. We highly recommend both as the solution for OF-II communication.

For UHF communication, the proposal approach will possess a turnkey cost of $45,250 USD. This option serves the purpose of receiving OF-II signals from 20 ground stations around the world and include a dual yagi antenna installation with receiver and tracking services. TT&C support will be received from RBC signals, Infostellar will be responsible for developing the station. As per our recommendation, this setup will be using a GOMspace radio. For a UHF comprehensive communication solution total cost will be $45250. A summary table is shown below. Later on reasons will be provided for selecting this option.

Service Name:	**Capabilities**	**Cost**
TT&C support from RBC signals	RBC Signals will provide access to their UHF antenna systems equipped with compatible ground radios at twenty locations all over the world to support communication requirements of OF-II.	Every pass costs $80 and a onetime $3000 service agreement. For 5days of OF-II mission the total cost will be $11000 for TT&C support.

	The final antenna locations will be confirmed at a future point	
Ground Station setup by Infostellar	Total hardware for ground station: - 395-405MHz Circular Polarized Yagi Antenna - 435-470MHz Circular Polarized Yagi Antenna Dual Yagi antenna's for receiving frequencies in range of lower and upper UHF bands - AZ/EL Motorized Mount (Rotator) - PC interface for AZ/EL Motorized Mount - Cables, other parts, etc. [Appendix 8]	$16000
Receiver from Gomspace	Nanocom GS100 radio	$8250
Installation support from Infostellar	Installation, set-up and service - Additional parts, cables and other hardware - Two on-site technicians for five days ** **does not include pre-approved travel expenses will be passed through at cost	$10000
Total costs		$45250

Background and reasons for the proposed options:

TT&C Support

There are several reasons for selecting the proposal options. For TT&C support we have selected RBC signals as our main service provider. RBC is a rapidly growing company who provides services such as real-time space communication technologies. RBC has a large ground station network containing more than 20 antennas all over the world. RBC could partner with UTEP to have us host an antenna and can help get it built if there is a building on campus to get it built. They can work with us to help offset costs. Trade time, to allow other entities to have time on the antenna (adding it to network). We have our STK analysis for RBC ground station location to predict the passes and we have observed adequate passing time for all their stations. RBC signals have experience working with GOMspace and ISIspace from whom we have purchased our transceivers. This will help to extract the data received from the satellite as RBC will be using same protocols that the transceivers use to send the data packets. Also, the prices quoted by them is reasonable and promising with regard to the OF-II service.

Building ground station

Infostellar is a Japanese company who has lot of experience in setting up ground stations. They will be using M2 436-CP42UG 436 MHz Yagi Beam antenna and a 144MHz antenna as well which can be used for the future missions as well. The UHF antenna Frequency Range is 430 To 438 MHz with a gain of 18.9 dBic and ellipticity of 1.5 db Typical which is capable of receiving OF-II signal with -120dBm of received power. The antenna provides nearly 18dB of gain and the

rest of 102 dBm can be achieved from the GOMspace receiver to close the link. It is estimated that at the FABENS-E35 location, assuming clear line of sight and minimal interference, an UHF carrier (f=436 MHz), a G/T (Figure of Merit) of -12.62K dB/K and C/N0 (Carrier to Noise Density ratio) of 65.48 dB-Hz can be achieved at data rates 1200 bps with good margins at. Infostellar also runs a network where other ground stations are connected. Infostellar can establish the connection between UTEP GS and their network so that the tracking of satellites can be more efficient in future using their network as well. Also, UTEP can have a contract with them to share the revenue by letting others use the UTEP station. Insfostellar technicians will be responsible for developing the whole turnkey system after integrating the additional GOMspace receiver. So, it could be highly effective for UTEP as it reduces complexity and also available at comparatively lowers cost. [24]

GOMspace receiver

The NanoCom GS100 (GS100) is designed specifically as a ground station radio for the NanoCom AX100 (AX100) radio board. The GS100 is a 19" rack mounted unit that contains two none flight qualified AX100 radio modules, placed on a special carrier board. If both the satellite and the GS100 use the AX100 radio to receive and transmit, it gives optimal performance, and minimizes the risk of implementation losses. An added benefit is full control of the ground station radio and eliminating the need for expensive FM/USB transceivers and custom hardware/software TNC solutions. The ground station radio will be an integrated component of the satellite, responding to CSP (CubeSat Space Protocol) requests, just like the satellite radio. This means that satellite monitoring and configuration software, can be used to control both satellite and the ground station. With both radios accepting the same message and configuration

format, the time spent on developing ground software is drastically reduced. Integrating a GOMspace radio with Infostellar setup is a comprehensive solution for the UTEP ground station.

Benefits and features of the proposal:

- ✓ Access to over 20 Ground stations around the world
- ✓ Professional assistance for setting up the passes at each GS location
- ✓ Getting settled with the legal issues
- ✓ Ensured five days TT&C support
- ✓ Reduced complexity as the same transceiver available at both ends
- ✓ Lower costs compared to the other options with increased benefits
- ✓ Both UHF and VHF setup for future missions
- ✓ Steerable antenna
- ✓ Contains two NanoCom AX100 for optimal
- ✓ Data reception (polarization diversity)
- ✓ Internal power amp, 25W
- ✓ Output for spectrum monitoring
- ✓ Externally controlled switchable RF bypass
- ✓ 19” rack-cabinet
- ✓ Priority access to our software platform StellarStation
- ✓ Consistent monitoring and scheduling transmissions
- ✓ Scope of generating revenue in future

8. TESTING OF COMMUNICATION SYSTEM

8.1 Testing description:

There are several testing processes, which have been planned to test the performance of the transceiver. At first, we would like to perform the current draw testing of the transceiver. Sometime due to the current and voltage fluctuations transceiver performance get hampered for example bit rates may vary. The mean and peak currents will be measured using the oscilloscope while the transceiver will be in three different states. Such as sitting idle, receiving and while it was transmitting. The test will show three distinct states of current draw for different data rates. Two current probes with the transceiver and a receiving device will be required for the test.

For career to noise testing, a test configuration will be developed to monitor the link quality and respective bit rates for the link. The purpose of this test is to verify that the transceiver could pass data in accordance with the link budget. A laptop will be connected to the transceiver and its development board inside a shielded chamber. A cable from the transceiver's antenna port will be connected to a connector on the inside of the shielded chamber. Another cable will run from the outside of the chamber on the same connector as transceiver's antenna cable inside the chamber and attached to an attenuator. Attenuators, filter, splitters, amplifiers, power supplies, a frequency generator, and a spectrum analyzer will be connected together. Configuration of attenuators, filter, splitters, amplifiers, frequency generator, and a spectrum analyzer provides a way for the noise of the system and signal power to be adjusted. The output of the setup will then be connected to another receiver with a development board, which was connected to a computer, completing the link. [1]

Radio continuously communicating and negotiating frequency hopping:

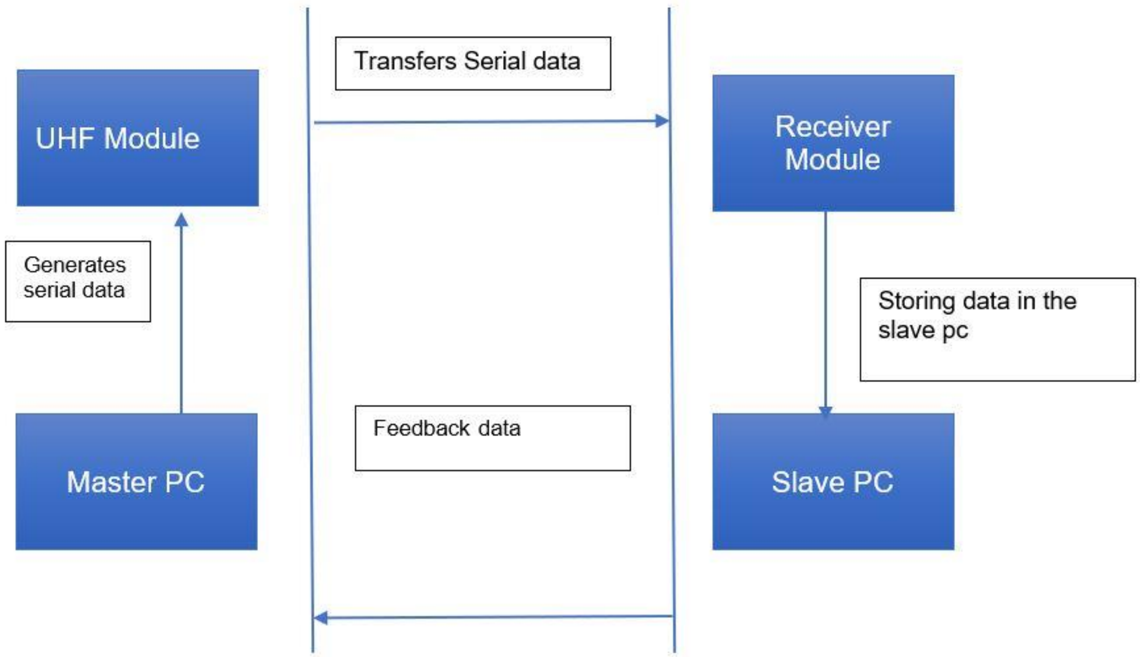

Figure 28: UHF module testing model

Test steps in brief:

- Connecting dummy load such as 20dB attenuator
- Connect physical wires
- Run python program
- Send data from Master to Slave PC
- Storing data in slave PC

Field testing is very essential in order to ensure successful operation of the transceivers. Flight modules with the flight antenna are being proposed for testing In the environment. This will allow us to get the actual idea about their performance.

Transceiver is needed to pass through a thermal test by which we can determine the suitability of operation at different temperature and also set the value for the internal sensor located inside the transceiver.

Signal interference is a very important issue for which the satellite signal transmission needs to be turned off. This is a strict legal restriction. So necessary tests have been planned to detect any interference and the uplink capability needs to be checked to stop the transmission at the time of interference. For this reason the sensitivity testing have been planned to ensure that the transceiver can be turned off at any moment while we send a command from earth. Error correction testing needs to be implemented for avoiding erroneous data transmission. This can be performed with protocol testing and checking error levels by aforenoted tests. Vibration and vacuum testing is optional as we already have these data available from the manufacturer. However, tests at our end can validate the data they have provided to us.

Here mentioned are some parameters which is needed to be ensured while performing the test.

- Temperature: 320K
- Lowest attenuation: 0dB
- Highest attenuation: 150dB
- Connection time: 30 seconds
- DC Power supply: +5V

Table 24: Components manufacturer and model number

Parameter	**Manufacturer**	**Model number**
UHF radio	GOMspace	Nanocom ax100
S-Band radio	ISISpace	ISIS TXS Transmitter
Master PC	Any	
Slave PC	Any	
Serial connection	Any	
Current probe	Any	
RF shielded chamber	Any	
Oscilloscope	Any	
Variable attenuator	Any	
Splitters	Any	
Function generator	Any	

Here is a list of potential hazards:

- Transceiver burning out
- Losing data
- Damage due to excessive heat
- Power supply interruption
- Link failure

Emergency procedures what should be done in the event:

- Checking power level

- Measuring heat
- Computer shutting down
- Connecting dummy load
- Checking stored data

Data storing and retention procedure:

- Data will be stored at the master computer
- Standards will be established beforehand for the data packets
- Secondary database will be stored at the slave computer
- Secondary data will be sent to master pc for comparison
- Received data from the slave pc will be compared with the data stored previously in the master pc

Sample Data table:

Table 25: Data table sample

Supply power	Current draw	Receive signal strength	Status of data packets	Connect time

8.2 Proposed test plan

Table 26: Proposed Test Plans

	Type of Test	Proposed Test Plan	Data to Collect (purpose for test)	Other Components needed
1	Current draw testing	Currrent draw testing is essential for monitoring the current consumption by the transceiver. Two transceivers, current probes with oscilloscope will be required with power supply.	Mean and peak current consumptions will be measured for three states. Three states are Transceiver idle, Transceiver transmitting and transceiver receiving	Secondary transceiver, Multimeter, Probes for current and voltage measurement, Oscilloscope
2	Bit rate testing	Vibrating bit rates might be a problem for communicating with the satellite. Python serial data flow test with master and slave pc for observing the	Transmitted and received data packets will be compared. Number of bits received from the slave pc will be observed.	Python program for serial data, RF shielded chamber, Multimeter,

		data transmission and reception capability is proposed.		
3	Career to noise testing	A configuration of attenuators, two transceivers, filter, splitters, amplifiers, frequency generator, and a spectrum analyzer will be used to measure the amount of noise occuring in the link	The purpose of the test is to ensure that the transceivers can pass the data in accordance with the link budget. Received power, Noise power, C/N, and baud rates will be observed.	Python program for serial data, RF shielded chamber, Multimeter, Variable attenuator, Splitter, Function generator, Oscilloscope
4	Field testing	This is a simple test that will be performed in an open environment. Transceivers will be turned on at transmitting state with the flight antenna connected to it.	External receivers will receive the data and store it in a computer. Data rates and data quality will be monitored for different distances.	Dummy antenna, flight antenna, receiver, Distance calculator, Signal attenuator, Storage device.

		Receivers will be kept at a certain distance.		
5	Thermal testing	This test is for getting the data of the heat generated by the transceiver while it's transmitting or receiving. Two transceivers, computers and heat sensors will be used.	A table containing temperature data, time duration and data bits will be created. This will help to take the right decision of when the transceivers need to turn on or off.	Heat sensor, Transceiver, Dummy antenna, Computer
6	Transmit power testing	This testing if for measuring the transmit power produced by the transceiver. Transmit power will be set by commands and performance will be observed while transmitting.	Data will be collected for different levels of transmit power, respective data rates and signal attneuation.	Spectrum analyzer, Receiver, Computer
7	Signal interference testing	Signals will be interferred deliberately by using same	Time duration, number of frequencies, detection	Spectrum analyzer, Receiver, Computer,

		frequency and detection capability will be tested	time & transceiver turning off capability will be monitored at the time of interference.	secondary transceiver
8	Sensitivity testing	The test will be performed in radio frequency shielded chambers. Signal reception capability will be tested for both satellite and antenna for variable attenuation.	This test will be performed to ensure that satellite and ground station can hear from each other.	Primary and secondary transceiver, spectrum analyzer, computer, RF shielded chamber, receiving antenna
9	Error correction testing	For this test, data packets will be transmitted from the transceivers and number of errors will be monitored at the receiver end	Number of transmitted and received data packets will be monitored and compared to figure the number of errors.	Software, Computer, Serial data flow, Storage device
10	Doppler shift testing	This test is to verify the transceivers	Transceiver and receiver's relative	Transceiver, dummy antenna,

		capability of automatic frequency control to reduce the effect of Doppler shift. Transmitters and receivers will be moved simultaneously to observe the frequency drift.	motion, frequency and wavelength will be monitored.	Automatic frequency controller
11	Protocol testing	This test is to ensure that the transceivers are receiving command from the OBC and performing the tasks accordingly.	List of commands and their execution capability for transceiver will be monitored	Software, CSP, computer
12	Vibration testing	This test is to monitor the performance of the transceiver while it will be at a vibrating environment. Shaker table will be used perform this test	Data will be collected for vibration levels and for each level performance of the transceivers will be monitored.	Transceiver ,Shaker table, Receiver

13	Vacuum testing	This test is to verify the performance of the transceiver in vacuum which will validate it's use in space.Vacuum chamber will be used to perform this test.	Transceiver performance will be observed while keeping it in the vacuum.	Vacuum chamber, Transceiver, Receiver

8.3 Failure modes analysis:

Different failure modes have been analyzed and their potential risks have been assessed. Based on the effect of failures recommendations to avoid the risks have also been provided. Each of the failure modes are assigned with risk score to identify the impact of the risks.

8.3.1 RISK ASSESSMENT:

Risk scores are determined by considering the severity and probability of occurrence. Final risk scores are the multiplication of severity and probability value.

Table 27: Risk Assessment Criteria

Severity of Occurance		
Value	Description	Criteria
1	Irrevelant	No Impact to System or Mission
2	Slight	Little Impact to System, But No Harm to Mission
4	Important	Possible risk to mission
8	Critical	Definite Risk to Mission Success
16	Disasterous	Certain Mission Failure
Probability of Occurance		
Value	Description	Criteria
1	Very Unlikely	Theoretically possible, but extremely unlikely
2	Remote	Very unlikely during the mission life, however given enough time or cycles a failure is expected to occur.
3	Occassional	Low risk, but possible failure during planned mission timeline, or # of cycles
4	Moderate	Fairly likely chance of failure during mission timeline.
5	High Probability	Evidence of failure in testing, or obvious weakness in design.

8.3.2 FAILURE MODES:

Table 28: Failure Modes Analysis table

Failure Mode	Description of Failure Mode	Effect of Failure (focus on impact to the mission)	Recommendations to Reduce Failure Mode	Test Plan (include document reference numbers once known)	Risk Score (Refer to Sheet 2)	Assessment Criteria (Reason for Risk Value Assignment)
Change of Bit Rate	Bit rates are going to change due to the amount of current flowing to the communication module.	1. Receiving devices will not be capable of decoding the signal. 2. Telemetry data will be incomplete	EPS needs to send sufficient and constant amount of current	1. Current draw testing can be performed to check EPS is providing constant amount of current.	12	Severity 4, Probability 3 Will lead to loss of data that will be received. Ground Station need to be synchronised

						continuously
Low Sensitivity	Satellite and ground station fail to receive signal from each other	1. Grounds station will not hear from the satellite 2. Satellite will not hear from the ground station	Field testing could be suitable for checking the performance of the devices	1.Testing performance in different types of weather condition	20	Severity 4, Probability 5 Ground station and satellite will not be able to get signal from each other
Signal interference	OF II signal interferes with any other radio operator's signal	1. Receiving devices will sense noise while getting the data 2. Loss of data due to noisy channel	According to the FCC regulations, at the time of any interference the transmission needs to be stopped by the user	1. Sending a "STOP" command to transceiver and check if it can stop the transmission	16	Severity 4, Probability 4 Will lead to noisy data reception. Telemetry data will not be retrieved.

Error correction	Receiving devices will get erroneous data. Telemetry, housekeeping data will be interrupted	Housekeeping data such as the printing information can not be retrieved	Error correcting methods needs to be implemented in the software	Software testing (Low density parity check)	16	Severity4. Probability 4 Erroneous data will cause loss of satellite houskeeping information.
Load management	Transceiver can be burnt if it's not connected to sufficient amount of load	COM modules stop operation	Connection of a dummy load	Testing the performance of the transceiver with a 20dB attenuator	4	Severity 4, Probability 1 Transceiver can be burnt if not connected to a proper load before turning on.

Antenna deployment	Radiation pattern will be adversely affected or diminished	Tracking will be difficult. Gains of the transmitting and receiving antenna will be adversely affected.	Antenna deployment tests need to be performed	1. Antenna deployment test 2. Feedback test	8	Severity 8, Probability 1 Will lead to loss of mission objective.
Doppler shift	Change of the frequency and wavelength due to the relative motion of the satellite and the earth	Signals will be interrupted	Preforming tests using STK simulations	Validating the simulated results with the performance of the COM system	6	Severity 2, Probability 3 Will cause frequency drifting and loss of signal
Tracking and pointing	Satellite may not be tracked if the orbital information is	Loss of signal from OF II	Orbital parameters need to be verified	1. Looking for the methods of orbital	16	Severity 4, Probability 4 Will lead to loss

	not available. Ground station antenna can not be pointed			determination 2. Relying on the information received from ULA		of data received.
Thermal imbalance	Transceiver may be turned off if it reaches the threshold temperature	Loss of signal from OF II	Temperature ranges should be set properly in the transceiver's internal temperature sensor.	1. Temperature threshold value will be set by command. 2. Performance needs to be verified by controlling the temperatur	17	Severity 4, Probability 4 Will lead to loss of mission objective.

				e externally		
Low transmit power	Signal may not be reached from the satellite if enough transmit power is not available	Loss of signal from OF II	Transmit power needs to be verified at sprectrum analyzer at different EPS conditions.	1. Testing signal in spectrum analyzer 2. Setting up different power level of EPS	18	Severity 4, Probability 4 Will lead to loss of mission objective.
Error in protocol	Transceiver will fail to excute command received from OBC	Loss of telemetry data	Data packets need to be transmitted from the transceivers and number of errors will be monitored at the receiver end	Transceiver performance need to be veified at different condition while sending commands.	19	Severity 4, Probability 4 Will lead to loss of mission objective.

9. CONCLUSION & FUTURE WORKS:

9.1 Transceivers:

Transceivers for OF-II communications have been selected based on the preliminary link analysis that have been performed by the OF-II communications team. Due to the orbital parameters it was quite difficult to select the proper transceiver module that could be a perfect fit for the mission. Due to limited space inside the satellite, two frequency operations by single module was highly encouraged. But since, no module was found with the anticipated feature of operating two frequencies simultaneously, we had to include two different transceivers with two frequency operations. The UHF module needs to be integrated with the circuit board that will be developed in-house at UTEP as it contains only the transmitter. The testing procedures proposed for the communication module are some basic tests which should be able to verify the performance of the transceivers. Test is primarily based on the current draw and power consumption of the radio. The form factor of the device is ideal for the requirements of a CubeSat and a radio of similar capabilities, with a similar form factor, and lower current draw would be an excellent candidate for future CubeSat implementation. Until a better radio is introduced, the best option for the program is to procure Gomspace NanoCom ax 100 for operation in the satellite. The radio has been tested and documented by GomSpace and would provide the means to complete the Orbital-Factory II mission until better products are available. A valuable lesson learned during the communication system development of the Satellite is that the frequency allocation process should begin at fundamental level, for the deep space missions the radio’s need to be developed with more transmission power compared to the radios which are available off the shelf for LEO missions.

9.2 Antenna:

The primary radio antenna selection process worked out well. The antenna that was purchased was a good fit for the program and the form factor. Endurosat has worked with us dedicatedly to ensure that their antenna works well for our mission. The primary need from the antenna was to have the capability of transmission at UHF center frequency with more transmit power. Currently the antenna can transmit at 3.5 watts. Radiation pattern was the difficult portion of the antenna development. The antenna vendor has tried to create an omnidirectional radiation pattern as there is no altitude control in the satellite pointing towards the ground station is not possible for many passes. Selecting and installing a proper antenna for a telemetry radio involves selecting a suitable style of antenna for your installation, properly mounting the antenna, cabling the antenna to the radio connection. One of the most important considerations is ensuring that the antenna works well for operating frequency. The antenna will be cut and tuned for our designated frequency. The antenna deployment will be tested which includes the burn-wire mechanism.

9.3 Ground Stations:

The ground station remains to be built and integrated. The fundamental structure for the ground station is in place. The ground station proposal has been prepared and submitted to the authority for review. It includes both build and renting options for receiving OF-II mission data. There is a significant amount of work to integrate a Gomspace radio, integrate and testing the High-Power Amplifier and Low Noise Amplifier, develop an automation of operations scheme, develop a database management plan, and test the completed system. Proper analysis and researches have been performed to ensure the suitability of these options. Recommendations have been provided based on the analysis which can be very helpful for making a decision.

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APPENDIX 1

Budgetary Quote

Quote No: W052517-04B

Date: June 2, 2017

Associate Email:

M2 Antenna Systems, Inc. 4402 N. Selland Ave. Fresno, CA 93722 Phone: (559) 432-8873 Fax: (559) 432-3059 www.m2inc.com

Customer Id:	**N/A**
Company:	**The University of Texas at EL Paso**
Address:	**500 W. University of Ave. EL Paso, TX 79968**
Contact:	**Mike Everett**
Email:	mleverett@utep.edu
Phone:	**(915) 203-1006**
Fax:	

M2 Associate: Wyatt Lyzenga

wyatt@m2inc.com We are pleased to quote the following per your request.

Qty	Part Number	Product Description	Unit Price	Discount	Line Total
1	FGAE1000	AZEL1000, PEDSTAL BOX FRAME	$11,225.00		$11,225.00
1	FGAEPMK6	PIPE MOUNT KIT, 6 5/8" O.D.	$925.00		$925.00
1	FGRC2800PRKX2SU	RC2800PRKX2SU, ACU AZ/EL CNTRL UNIT	$2,950.00		$2,950.00
400	FGRCS1812	RCS-1812, CONTROL CABLE (PER FOOT)	$1.01		$404.00
1	FGPRI627F	DISH, 6' (1.8M) .375 F/D RATIO COMPOSITE	$4,950.00		$4,950.00
1	FGAEDAK6	DISH ADAPTER KIT, 6'	$105.00		$105.00
1	FGAEFLFK	FEED LEG FOOT KIT, 3'-10' DISH	$850.00		$850.00
1	FGSF239245	SEPTUM DISH FEED, 2.39-2.45 GHz	$4,250.00		$4,250.00
1	FGCRSBMEXT	CROSSBOOM EXT, 2"X.125 W/HDWR	$395.00		$395.00
1	FGLBKAM	L-BRACE KIT, UNIVERSAL (AM)	$121.99		$121.99
1	FG2MCP14	2MCP14, 143-148 MHz CP YAGI ANTENNA	$335.99		$335.99
1	FGCRTCHG	CRATING CHARGE, ISPM-15 COMPLIANT	$680.00		$680.00
		****OPTIONAL ITEM BELOW****			
1	FGNPRM107X107	NON-PENETRATING MOUNT, 10.7' X 10.7'	$2,600.00		$2,600.00
			Discount	**$0.00**	
Comments:	***TOTAL DOES NOT INCLUDE SHIPPING OR HANDLING CHARGES.**			**Subtotal**	$29,791.98
				Sales Tax	
				Total	**$29,791.98**

The lead time to manufacture the products for you would be 8-10 weeks upon receipt of your order.

We accept Visa, MasterCard, American Express and Discover as forms of payment. A NET-30 Account may be set up based upon a completed Credit Application. Shipping charges are prepaid and billed to your invoice.

Thank you for the opportunity to quote for your needs.

APPENDIX 2

MOREHEAD STATE UNIVERSITY

Ronald G. Eaglin
Space Science Center

Morehead State University Space Science Center
21 Meter Space Tracking Antenna
(Latitude: 38° 11 30.773 N,
Longitude: 83° 26 19.948 W) U.S.A

FUNCTION	PERFORMANCE
Antenna Diameter	21 Meter
Receive Polarization	RHCP,LHCP,VERT,HORZ
Travel Range	AZ +/- 275 degrees from due South (180 deg) EL -1 to 91 degrees POL +/- 90 degrees
Velocity	AZ Axis = 3 deg/sec EL Axis = 3 deg/sec POL Axis = 1 deg/sec
Acceleration	AZ = 1. 0 deg/sec/sec min EL = 0.5 deg/sec/sec min
Display Resolution	AZ/EL = 0.001 deg POL = 0.01 deg
Encoder Resolution	AZ/EL = 0.0003 deg (20 Bit)
Tracking Accuracy	<= 5% Received 3 dB Beamwidth (0.028 deg RMS L-band) (0.005 deg RMS Ku-Band)
Pointing Accuracy	<= 0.01 deg rms

21 M Space Tracking Antenna

The Space Science Center at **Morehead State University** has developed a full motion 21-meter class antenna system which is engaged in a rigorous research program in radio astronomy and also serves as an Earth Station for satellite mission support as well as a test bed for advanced RF systems. The instrument is staffed by university faculty and students and is available for a wide variety of TT&C services. Performance Characteristics are provided below:

21 M Mission Operations Center

Control Room at 21 M

21 M Antenna System Radio Frequency Operating Regimes

Radio Frequency (RF) Band	Bandwidth	
	Low End	High End
L-Band	1.4 GHz	1.7 GHz
S-Band	2.2 GHz	2.5 GHz
X-Band	7.0 GHz	8.4. GHz
Low C-Band	4.8 GHz	5.0 GHz
Ku-Band	11.2 GHz	12.7 GHz

Radio Frequency Performance at L-Band and Ku-Band

Radio Frequency (RF) Performance Criterion	Measured Parameters	
	L-Band	Ku-Band
Frequency	1.40 GHz	11.2 GHz
Antenna Gain	47.80 dBi	65.50 dBi
LNA Temperature	25 K	70 K
System Temperature, T_{sys}	83.8 K	139.0 K
G/T at 5° Elevation	28.6 dBi/K	44.1 dBi/K
HPBW	0.62°	0.08°

Radio Frequency Performance at S-Band and X–Band

Radio Frequency (RF) Performance Criterion	Theoretical Parameters	
	S-Band	X-Band
Frequency	2.4-2.7 GHz	7.1-7.6 GHz
Antenna Gain	52.8 dBi	62.0 dBi
System Temperature, T_{sys}	215K	215K
N_o	-175dBm/Hz	-175dBm/Hz
G/T at 5° Elevation	29.5dBi/K	38.7dBi/K
HPBW	0.37°	0.13°

For Scheduling or Cost Structure contact:
Dr. Ben Malphrus (606) 783-2212 b.malphrus@moreheadstate.edu

APPENDIX 3

SIGNALS

Proposal To

for

UHF TT&C Services

SIGNALS

August 24, 2017

www.rbcsignals.com

Confidential

Executive Summary

RBC Signals is pleased to present this proposal for TT&C Ground Station Network Services to UTEP. Our goal is to make it simple to access data from your spacecraft whenever and wherever needed. We're confident you will find our solution cost-effective and flexible to your business and operational needs, and our service reliable.

Our experienced and talented team is ready to assist you by taking on the hassle of deployment and maintenance of your ground station network. In addition, we are pleased to offer (for your consideration) engineering and regulatory support services that allow you to focus on the most valuable aspects of your project.

WHAT WE'RE PROPOSING

We propose that UTEP contract with RBC Signals to provide TT&C services including implementation of all communication infrastructure necessary to support your upcoming OF2 and potential follow on missions. We have also included an option to support UTEP in the deployment of a UHF Ground Station in Fabens, Texas.

WHAT'S IN OUR PROPOSAL

In this proposal, we address our understanding of your requirements, and explain how our team can meet those requirements in a cost effective, reliable and timely manner. We are flexible to discuss any business model that make sense for you and we are ready to start a technical and business discussion.

If you have any questions or concerns, please feel free to contact me directly.

Christopher Richins
CEO, RBC Signals
+1.404.803.7734

RBC Signals Company Information

Company Overview

RBC Signals was founded in 2015 with the goal of creating a global network of satellite ground stations to serve the unique needs of today's commercial satellite operators. Our mission is to improve life on Earth by providing affordable access to real-time data from space.

RBC Signals is a leading multi-national satellite data services company headquartered in Redmond, WA, USA with offices in Tel Aviv and Moscow. RBC Signals is focused on helping satellite operators receive and deliver data to their end users with the lowest possible latency and cost. The company uses a flexible, cost-effective model that can easily scale to meet your needs.

We are a VC-backed company with 5 customers currently on contract. We provide daily ground station services to existing satellite operators, as well as communication architecture engineering and licensing support to pre-launch customers.

Our seasoned team has many decades building, operating and maintaining ground stations for direct reception and processing of Earth Observation satellite data.

Leadership Team

Christopher Richins – Co-Founder and CEO – Boeing Sea Launch, SpaceX, Planetary Resources, Bain & Company; BS EE (BYU), MS Astronautics (USC), MBA (UVA).

Olga Gershenzon – Co-Founder and CSO – 25+ years as a founder and executive at ScanEx, providing satellite communication infrastructure and data analytics services; MS Engineering-Meteorology, GIS department Moscow State University

Rani Hellerman – VP Sales/International Business – Experienced satellite executive. 30 years managing R&D and satellite operations in Israeli Army, 16 years managing sales and technology for ImageSat; BS EE, MBA

Alex Shumilin – Director of Engineering – 20+ years of experience in satellite communication software development, earth observation data processing and distribution; BS Physics, Moscow State University

Our Understanding of Your Needs

UTEP was the winner of the ULA sponsored CubeCorps launch competition. The Orbital Factory 2 (OF2) spacecraft will demonstrate on-orbit repair of solar cells using 3-D printing technology.

Launch: TBD

Orbit: GTO

Mission Duration: 5 days

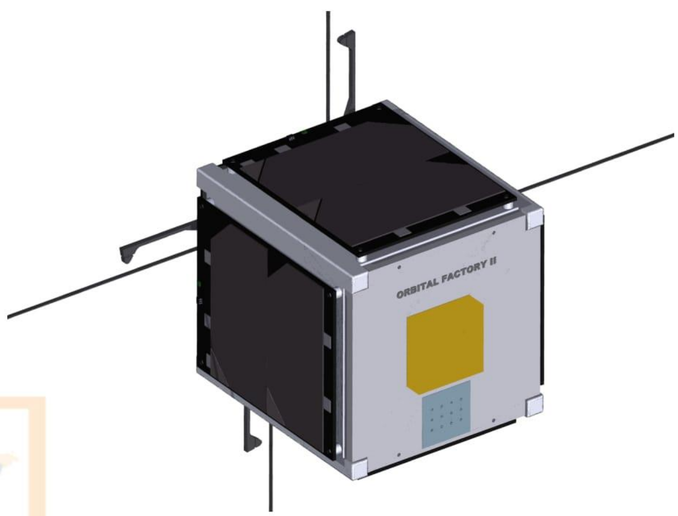
TT&C UHF Radio: GomSpace AX100

UHF Frequency: 437 MHz

TT&C S-Band Radio: ISISpace

S-band Frequency: 2441 MHz

Desired communication volume: As much as possible, at least every perigee pass



Our Approach

Communication Services

The RBC Signals Ground Station Network consists of infrastructure around the globe providing low-latency, low-cost communication services to spacecraft operators. We leverage the excess capacity of dozens of antennas to provide a reliable communication network at prices compatible with commercial business models. Additionally, RBC Signals is building our own network of highly capable systems to meet specific customers' requirements and to deliver the highest service level possible. We provide a single convenient interface for ground station scheduling and operations across our network.

RBC Signals will provide UHF and S-band antenna systems equipped with compatible ground radios to support communication requirements. The final antenna locations will be confirmed at a future point.

RBC Signals is also proposing to support UTEP in the installation of a UHF/S-band ground station in Fabens, TX.

RBC Operations Support System (ROSS) Platform

The ROSS platform provides a powerful interface for viewing and scheduling available communication resources across the RBC Signals Network. This proprietary system makes any compatible ground station in the RBC Signals Network accessible as if it were a custom-built part of your dedicated network.

You may choose between using the web-based platform or integration with our APIs for automated operations via your mission control software. The ROSS platform also provides a portal for customer account management, including usage tracking and support requests.

TT&C Pricing

TT&C Support	Price per minute
UHF	$10
S-band	$20

Notes:

- A one-time set up fee of $3,000 will be invoiced at contract signing

Antenna Deployment	Price
Hardware • Az/EL Antenna Rotor with Antenna Control Unit • Dual Yagi 436 MHz 15.5 dBi (RHCP/LHCP) Antennas • 2m S-band Antenna with feed and LNA • Pipe mount kit • Non-penetrating roof mount system	$40,000
Installation Support • Phone support for site preparation • 4-days on-site support with 1 technician	$5,000

Notes:

- Approved travel expenses for installation support will be passed through at cost.
- Antenna cost does not include ground radios/receivers, servers
- Installation support does not include site preparation work

Duration of Quote

This price quote is effective for 45 days.

Thank You

Christopher Richins
CEO & Co-Founder
crichins@rbcsignals.com
+1.404803.7734

Olga Gershenzon
CSO & Co-Founder
olga@rbcsignals.com
+7.985.727.7630

Rani Hellerman
VP, Marketing & Sales
rani@rbcsignals.com
+972.54.481.8483

Seattle • Moscow • Tel Aviv

APPENDIX 4

Cut Along This Line

UNITED STATES OF AMERICA
FEDERAL COMMUNICATIONS COMMISSION

AMATEUR RADIO LICENSE

KG5UAK

Licensee: This is your radio authorization in sizes suitable for your wallet and for framing. Carefully cut the documents along the lines as indicated.

The Commission suggests that the wallet size version be laminated (or another similar document protection process) after signing. The Commission has found, under certain circumstances, laser print is subject to displacement.

RAHMAN, ASHIQUR
716 W YANDELL DR APT 16
EL PASO, TX 79902

FCC Registration Number (FRN): 0026659433

Special Conditions / Endorsements

NONE

Grant Date	Effective Date	Print Date	Expiration Date
07-06-2017	07-06-2017	07-07-2017	07-06-2027

File Number	Operator Privileges	Station Privileges
0007843697	Technician	PRIMARY

THIS LICENSE IS NOT TRANSFERABLE

(Licensee's Signature)

FCC 660 - May 2007

Cut Along This

Cut Along This

Cut Along This

Cut Along This

Call Sign / Number	Grant Date	Expiration Date	File Number	Print Date	Effective Date
KG5UAK	07-06-2017	07-06-2027	0007843697	07-07-2017	07-06-2017

Operator Privileges
Technician

Station Privileges
PRIMARY

RAHMAN, ASHIQUR
716 W YANDELL DR APT 16
EL PASO, TX 79902

AMATEUR RADIO LICENSE

FCC Registration Number (FRN): 0026659433

FCC 660 - May 2007

Fold Here

THIS LICENSE IS NOT TRANSFERABLE

Special Conditions / Endorsements:
NONE

(Licensee's Signature)
FEDERAL COMMUNICATIONS COMMISSION

Cut Along This

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APPENDIX 5

EnduroSat AD

33 “Tsar Osvoboditel” Blvd. 1504 Sofia, Bulgaria
Phone: +359 893 333 424 Email: stan@endurosat.com

Custom CubeSat VHF Antenna Option Sheet

1. Specifications

No	Parameter	Value
1	Center frequency	145 MHz
2	Bandwidth	5 MHz
3	Polarization	Circular
4	Weight	< 100 g
5	Height (excluding connector)	< 6 mm
6	Deployment system	Burnwire mechanism with individual rod deployment and feedback
7	Interface	IIC (Details in dedicated IIC User Manual)
8	Max RF output power	3.5 W @ 3kbps continuous
9	Horizontal dimensions	98 mm x 98 mm with extrusions for rails 8.5 mm x 8.5 mm in each corner (1U CubeSat Z side compatible)
10	RF connector	TBD – SMA / MCX / MMCX
11	Typical deployment consumption	Up to 300 mA @ 5V

2. Included in the shipment

- ✓ Flight model Custom VHF antenna
- ✓ Antenna deployment tester – useful for testing the deployment without deploying the flight model antenna and in Software development for commanding the antenna and receiving feedback from the switches. It features the same power consumption realized with the help of resistors on the bottom side and buttons for providing feedback that each rod has been deployed.
- ✓ 2 Coaxial cables 50 Ohm
- ✓ 2 Power and command cables
- ✓ USB stick with user manual
- ✓ Custom metal box packaging

Please send filled-in page 2 to email: stan@endurosat.com

APPENDIX 6

ISIS – TXS Small Satellite S-Band Transmitter

CubeSatShop.com

Overview

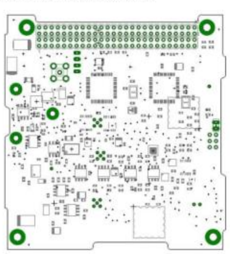
The ISIS TXS is a CubeSat standard compatible transmitter module designed specifically for nanosatellite applications. The TXS transmitter is very flexible and thus works at S-band frequencies from 2100 MHz to 2500 MHz and supports BPSK, or GMSK modulation schemes. TXS can provide downlink data rates up to 100 kbps, while featuring low power consumption.

Features

- Specifically designed for LEO applications
- Excellent performance versus size
- High data rate downlink capability
- Low power consumption
- BPSK or GMSK downlink modulation scheme
- Wide frequency range (commercial / scientific / ISM / amateur S-band)
- Data rate and power agile
- Flexible modulation schemes / bit shaping
- Available from Q2 2012

Included with shipment

- TXS S-band transmitter
- User Manual
- Two 52 pin SAMTEC ESQ-126-39-G-D or ESQ-126-21-G-D connectors



Available Configurations

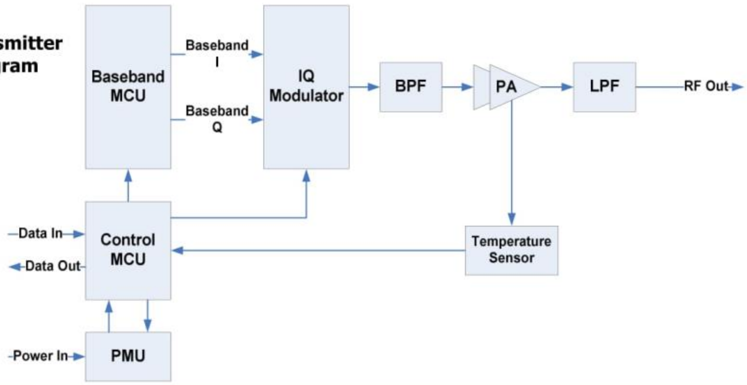
- Higher RF output power
- Custom form factors / connector interfaces
- I^2C interface
- Version for sounding rocket applications

Compatibility

- Compatible with standard CubeSat components available from ISIS and other suppliers
- Compliant with CubeSat standard

ISIS - TXS
Small Satellite S-Band Transmitter

S-Band Transmitter Block Diagram



Specifications	
Frequency agile (PLL controlled)	
RF frequency range	2100 MHz – 2500 MHz
RF output power	Controllable up to +28 dBm
Data rate	Selectable up to 100 kbps
Modulation	BPSK or GMSK available
Power consumption	≤ 4 W
Power supply	Single 6.5 – 30 VDC or 5V and 3V3 from EPS
Frequency accuracy	± 10 KHz
Frequency stability	20 ppm
VSWR	1.5
Operational temperature range	-20° to +60°C
Mass	62g
Form factor	90x96 mm (104 pin CubeSatKit bus compatible)

Telemetry Outputs (over I^2C)

- Power amplifier & board temperature
- Current consumption & bus voltage
- Lock status of frequency synthesizers

Interfaces

- 104 pin CubeSat Kit stackthrough connector carrying:
  - 6.5-30V DC power supply or 5V/3V3
  - I^2C bus interface
- RF output: SMA or MCX 50 ohm

Qualification and Acceptance Testing

Test	QT	AT
Functional	✓	✓
Vibration	✓	-
Mechanical Shock	✓	-
Thermal Cycling	✓	✓
Thermal Vacuum	✓	-
Total Ionizing Dose	-	-

QT is performed on the design/qualification model
AT is performed on the unit to be shipped

This document is subject to change without notice. The latest technical information and price information is available on www.cubesatshop.com

ISIS - Innovative Solutions In Space

Molengraaffsingel 12-14, 2629 JD, Delft, The Netherlands • T +31152569018 • F +31152573969 • info@isispace.nl • www.isispace.nl

APPENDIX 7

ISIS - Innovative Solutions In Space B.V. • Motorenweg 23 • 2623 CR Delft • The Netherlands • www.isispace.nl
info@isispace.nl • T +31 15 256 9018 • F: +31 15 257 3969 • IBAN: NL57RABO0118953524 BIC: RABONL2U • Reg.nr. 27293068 • VAT-nr. NL817198611B01

ISIS

Quotation

The University of Texas at El Paso
attn Ashiqur Rahman
500 W University Ave,
EL PASO, TX 79902, USA

Quotation no.	: 170081	Date of quotation	: 08-06-2017
Page	: 1 / 1	Valid until	: 08-06-2017
Customer no.	: 31384	Delivery terms	: EXW (ex works)
Our ref.	: Visweswaran Karunanithi		
Email	: arahman2@miners.utep.edu	**Currency**	: **USD**

Item	*Product no.*	*Product description*	*Qty.*	*Unit price*	*Discount*	*Total*	*Lead time*
1	100012	ISIS TXS S-band Transmitter	1	9,518.48	$	9,518.48	6 weeks after order confirmation
		Includes: *- Transmitter Board PC/104 form factor with* *- RF frequency range 2400 - 2500 MHz* *- Data rate selectable up to 100 kbps* *- Modulation scheme: BPSK or GMSK* *- User Manual*					
2	100074	Ground Station Kit, 3 meter S-band dish.	1	52,071.67	$	52,071.67	22 weeks after order confirmation
		Complete turnkey ground station solution, pre-assembled and tested, including: *- S-band dish: 3-meters.* *- Feed LNA with a very low noise figure: ~ 0.7 dB.* *- Easily mountable support structure* *- Heavy duty azimuth/elevation rotors* *- Lightning protection system* *Rackmount PC with tracking SW and control electronics:* *- S-band, SDR receiver. Noise figure: <15 dB.* *- Frequency range:* *2400 - 2450 MHz*					
3	99991	Ground station installation + training.	1	13,437.85	$	13,437.85	
4	100058	RF checkout Box [S-band RF ground support equipment]	1	3,247.48	5.0% $	3,085.11	4 weeks after order confirmation
		S-band RF ground support equipment with software GUI					
				Total excl VAT	**$**	**78,113.11**	

* All prices in this quotation are excluding VAT, customs fees, duties, taxes, commissions, bank charges or withholdings, unless specified otherwise.
* Lead times in this quotation are an indication. Actual lead times will be confirmed in our Order Confirmation following your Purchase Order.
* Delivery and lead times may be affected by any applicable export documentation.
* Certain items offered require an option sheet to be returned for specific configuration settings, which may influence pricing and lead time.
* Unless specified otherwise in this quotation, the default payment milestones of 50% on order and 50% on delivery, based on the total price, apply.
* Delivery terms are defined according to INCOTERMS 2010 conditions.

This quotation is subject to our General Terms and Conditions. A copy is available online through www.isispace.nl or can be forwarded upon request.

APPENDIX 8

INFOSTELLAR PROPOSAL FOR UTEP

Regarding StellarStation for UTEP Mission

OVERVIEW

Infostellar is pleased to submit this proposal for services to support UTEP's upcoming satellite mission. Based on our understanding of UTEP's objectives, Infostellar is committed to providing access to our premier offering: StellarStation for UTEP's use in academic testing and monitoring of its launched satellite. Additionally, Infostellar is committed to help design and implement a new ground station for UTEP which could be included in the StellarStation network in the future.

Proposed Offering

- UTEP seeks a reliable ground station network to ensure consistent data transmission from its satellite scheduled for a 5-day mission
- Infostellar will provide ***priority access*** to our software platform StellarStation to allow UTEP to consistently monitor and schedule transmissions throughout the scheduled mission
- Infostellar can provide design, hardware and set-up for a complete ground station set-up in UTEP's location of choosing.

OUR PROPOSAL

Based on UTEP's orbital parameters and frequency bands that include amateur bands, Infostellar will provide priority access to our StellarStation platform that will include access to scheduling and monitoring for data transmissions. With priority access, UTEP will be able to step in front of currently scheduled transmissions (with adequate notice), to ensure continuous collection of mission and HK (house keeping) data

StellarStation is the on-demand delivery service of distributed satellite communication antenna access via the internet with pay-as-you-go pricing. As a proprietary platform for satellite operators, StellarStation enables continuous communication link with a network of ground stations. StellarStation allows communication with various satellites, and transfers data among satellite operators. Antenna owners provide antenna's idle time to the StellarStation scheduling platform in exchange for use 'credits. Antenna owners with owned satellites can use the credits to access OTHER antennas in the StellarStation network for their operation/service.

StellarStation can provide UTEP with five ground station points in Japan, Taiwan, Singapore, South Africa and United Kingdom. If UTEP would like to provide Infostellar updated information on its orbital parameters, as well as mission launch timing, Infostellar can provide an updated number of accessible ground station points. These access points may be subject to change.

Prior to launch, Infostellar will provide a period of compatibility testing for UTEP of StellarStation. Based on the timing of UTEP's mission launch, Infostellar expects to perform compatibility testing of UTEP's transceiver with a ground station site in North America (details to be confirmed).

Following greater input from UTEP, Infostellar is prepared to provide a complete ground station set-up and site installation, including the necessary hardware (antenna, rotator, RF components, tower cables, etc.). UTEP will provide a minimum 5 meters x 5 meters for the ground station, rack space for equipment, power and internet access to the site.

PRICING

The table below details the pricing and fees for the proposal outlined above:

Mission Connectivity	
Access to StellarStation platform	$5,000.00
Connection charge ***per pass - UHF***	$20.00
Connection charge ***per pass – S-band***	$200.00
Ground Station Set-up	
Total hardware costs for ground station: - 395-405MHz Circular Polarized Yagi Antenna - 435-470MHz Circular Polarized Yagi Antenna - Transceiver - AZ/EL Motorized Mount (Rotator) - PC interface for AZ/EL Motorized Mount - Cables, other parts, etc.	$20,000.00
Installation, set-up and service - Additional parts, cables and other hardware - Two on-site technicians for five days** ***does not include pre-approved travel expenses will be passed through at cost*	$10,000.00

Disclaimer: The prices listed in the preceding table are an estimate for the services discussed. Estimates are subject to change if project specifications are changed before a contract is executed. This pricing quote is valid for 45 days from the date of this proposal.

CONCLUSION

Infostellar is very excited to partner with UTEP on its upcoming satellite mission. Based on UTEP's academic testing needs, Infostellar is well positioned to support this critical research opportunity.

We are confident that we can meet the challenges ahead, and stand ready to partner with you in delivering an effective IT support solution.

VITA

Ashiqur Rahman was born in Dhaka, Bangladesh. He has attended his high schools and colleges there. He completed his undergrad from American International University-Bangladesh (AIUB) in Electrical & Electronic Engineering (EEE) in the Fall of 2015. In the Fall of 2016 he enrolled in the Graduate studies in Systems Engineering at The University of Texas at El Paso. He has been working as a Graduate Research Assistant for NASA MIRO Center for Space Exploration & Technology Research (cSETR) from Fall 2016. He has been responsible for developing the Tracking, Telemetry & Control system of UTEP's first Cube Satellite known as Orbital Factory-II.

Permanent address: 812 Margaret Dr

McKinney, TX 75071

This thesis/dissertation was typed by Ashiqur Rahman