York University
Faculty of Science and Engineering

ENG4000
Engineering Project

Critical Design Review Report

YuSend-1 Nanosatellite Communication Subsystem

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Abstract

YuSend-1 is a nanosatellite currently being developed by York University under the supervision of Dr. Regina Lee. The primary objective of the communication subsystem is to provide the design for a reliable communication link between YuSend-1 and the ground station. This includes transmitting telemetry and command sequences from the ground station (uplink) and receiving analog and digital data obtained from the payload and sensors onboard the cubesat (downlink) via RF transmission.

The YuSend undergraduate team is responsible for the design (the Space Segment only), implementation, building and testing of both the Ground Segment (GS) and Space Segment (SS) of the communication system.

The following document contains the critical implementation details of the communication subsystem of YuSend-1 developed by the YuSend undergraduate engineering team. The document provides a design overview and technical details on the various components of both the communication system on board the cubesat (SS) and the ground station (GS); progress to date; projected schedules; and current budget expenditures.

This document serves as a sequel to the Preliminary Design Review (PDR) Report and doesn't include certain technical details provided in the PDR document.

Acknowledgements

We would like to thank Professor Regina Lee for her continued support throughout this project. She has advised us of her hopes for the product, and pointed us toward appropriate documentation and requirements. We are also grateful to Professor George Zhu for pointing out proper report techniques and formatting, and to our PEO advisor Steven Coates.

Notation List

Acronym	*Definition*
AFSK	Amplitude Frequency Shift Keying
AM	Amplitude Modulation
AMSAT	Radio Amateur Satellite Corporation
AX.25	Amateur Packet-Radio Link-Layer Protocol
COTS	Commercial Off-The-Shelf
CW	Carrier Wave
FM	Frequency Modulation
GEO	Geostationary Orbit
GS	Ground Station/Segment
OBC	On Board Computer
RF	Radio Frequency
Rx	Receive
SS	Space Segment
SSB	Single Side Band
SSH	Secure Shell
TNC	Terminal Node Controller
Tx	Transmit
UHF	Ultra High Frequency
VHF	Very High Frequency

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1 Introduction

York University is preparing to design and construct its first spacecraft, a small 10x10x10cm cube (the Cubesat form factor) that contains the minimal set of components necessary for operation in space. What this group is attempting to do is design and construct a working prototype for the communication system of the spacecraft.

During the time of this project a suitable amateur ground station has also been constructed and tested by the YuSend team. It will be used to communicate with YuSend-1 and to support other satellite missions in the future.

Cubesat is a standard being developed by the national Science Foundation in the United States. It is a small form factor for a nanosatellite, designed for use in an educational environment. These nanosatellites are too small for more sophisticated science missions but are adequate for basic sensors and small cameras.

Thirty-one Cubesats have made it into space. Of these, about half have failed to transmit any data back to earth. Most transmitting Cubesats have only delivered about 100kB of data before failure. This has been due to power and communication failures that happened during or shortly after launch. Failure to deploy antennas, intermittent transmission, and lack of dedicated ground stations and electronics faults are all common causes of failure.

Most successful Cubesats have several traits in common. Firstly, the CW beacon of a successful Cubesat is almost continuously transmitting [Bryan & Kolas, 9, 14]. This enables ground stations to continuously track the satellite and easily download data. This continuous beacon contains system information and diagnostic data. A higher-throughput, high-power signal is then transmitted to dump images and other mission data that is requested on-demand. Another problem that has caused failure of a communications system is the lack of a reset command. Operators on the ground must be able to instruct the satellite to completely reboot itself.

This project aims to account for the most common sources of failure of the Cubesat communication systems and develop a working solution for the YuSend-1 mission.

In the past, designs for a Cubesat communications system have been done by Graduate students or large teams with substantial budgets, timelines and experience. Similar projects such as in the case of CanX-1, QuakeSat etc have primarily been undertaken by graduate students usually within two year timelines as part of their Master's thesis. This project attempts to recreate the achievements of other Cubesat design teams within the context of an undergraduate course, within a limited time and budget. These constraints are critical when making design decisions for this project, from the selection of TNC and Transceiver hardware, to the design and implementation of the antenna.

2 Theoretical Background

The main function of the communication system will be signal transmission and processing i.e. to encode digital information on an RF wave. For the Space Segment (SS), this will require converting digital information obtained from the payload such as a camera into an analog waveform. This waveform will then have to be modulated to a carrier frequency which is then transmitted as an RF signal. The Ground Segment (GS) will then receive and decode this information, readable by users. In order to better understand the above concept on two way radio communication certain important theoretical concepts are explained below.

2.1 Modulation

Communication between the satellite and ground station will take place on a given frequency using Frequency Modulation (FM). FM involves multiplying the signal to be sent by a sinusoid carrier frequency. The receiver amplifies the signal to compensate for signal strength lost in propagation, multiplies it by the carrier frequency, then puts the signal through a low pass filter to extract the original pre-modulated signal.

It is a simple, widely used standard in radio communications which, compared to alternatives such as amplitude modulation, is robust against noise, interference and amplitude fading.

2.2 AFSK

Audio Frequency Shift Keying (AFSK) is a digital modulation scheme in which a digital 0 is represented by one frequency, and a digital 1 by another frequency. This is the modulation that will be used for all communications between the ground station and satellite. Standard Frequency

Modulation (FM) will still be applied (the carrier frequency in the above figure) and the signal will be initially received by the radio as such. In the ground station, dissemination of the AFSK data will be done by the transceiver radio. On the satellite side the AFSK demodulation will likely be done by the TNC- as the smaller radio being used may not be capable of the task.

AFSK is not as power or bandwidth efficient as other modulation schemes, but is simple and can be tested against Environment Canada broadcasts.

2.3 Protocol AX.25

AX.25 is a data link layer (as in; just above the physical layer in the OSI model) protocol which is loosely based on the X.25 protocol. X.25 is an old packet switched networking protocol which has largely been superseded by TCP and IP, but provides the same function.

Generally, the Terminal Node Controller (TNC) handles the AX.25 packet assembly and disassembly. The Host, the 'computer' which has data to send, streams the raw data to the TNC. The TNC packages the data in AX.25 packets and sends those along to the transceiver, which will send those packets via AFSK on the radio waves.

It does not facilitate a broadcast system; calls have to take place between two nodes. The satellite will be put into a listen mode- waiting for a AX.25 call on a particular frequency. Calls will be initiated by the ground station to establish a virtual circuit to the satellite. At this point communication between the two devices will be trivial assuming the signal strength remains reasonable.

AX.25 is the only choice here. The only alternative would be to create a new proprietary protocol from the ground up- the possible advantage would be less overhead, but this is not worth the time investment.

3 Technical Description

There are two parts to developing the communication system for YuSend-1i.e. the Space Segment (SS) and the Ground Station (GS). Central components required for basic two way UHF/VHF radio transmission are found in both segments. The main differences in component selection are dependent on the function and structural requirements and constraints of each segment such as budget, time, power, mass and space available.

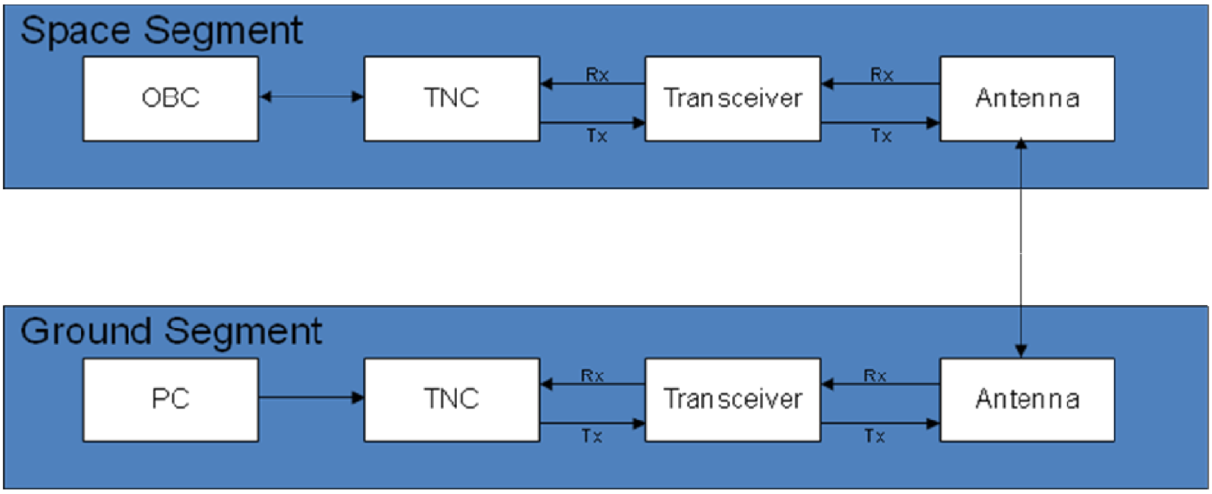


Figure 1: Communication Block Diagram

3.1 Ground Segment

Details on certain components can be found in the PDR but outlined below are details either on components on which the most progress has been made and/or are not found in the PDR.

Below we have a general design overview of the ground station. A more detailed diagram along with cabling information can be found in Appendix A.

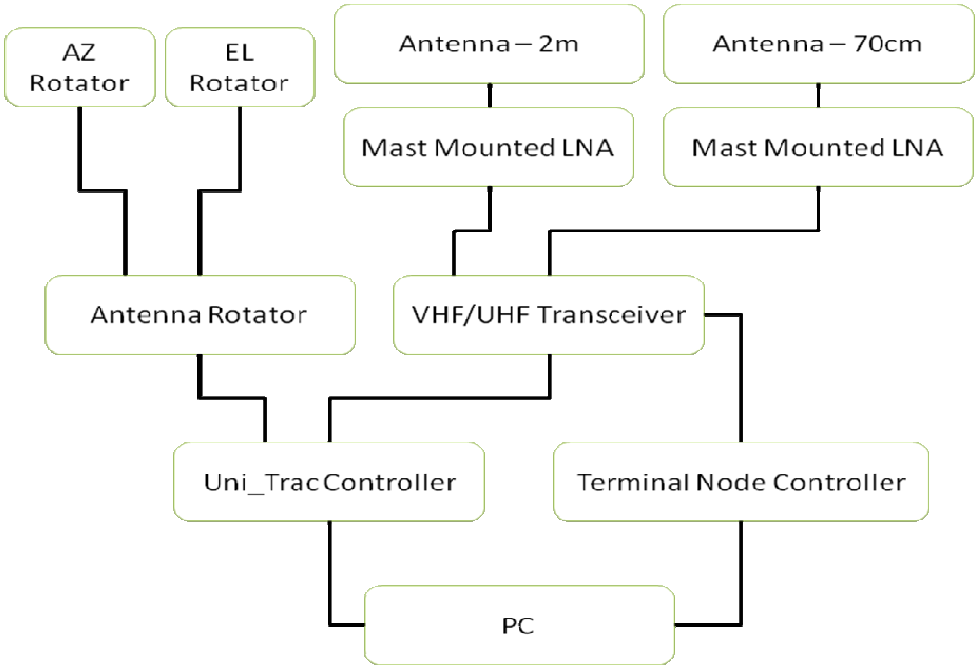


Figure 2: Ground Station Block Diagram

3.1.1 Antenna

The completed YuSend ground station uses a combination of two Yagi-Uda antennas for the bidirectional UHF and VHF communication with the satellite one of the reasons being due to its high gain. One is the M2 2MCP22 circular polarized antenna for 2 metres with an antenna system gain of 21.5 dBi at 145.9MHz and the other for 70cm is the M2 436CP42UG, setup based on an L configuration. These antennas are mounted on rotator motors to change antenna azimuth and elevation to allow tracking of the satellite for the duration of the pass.

Figure 3: UHF/VHF Yagi-Uda Antennas on the roof of Petrie

3.1.2 TNC

The TNC is the central point of the ground station. It acts as a modem and is responsible for modulating and demodulating the digital data packets sent to and received from YuSend-1. It controls the individual ground station components such as the transceiver and the antenna rotator. For our ground station we have decided to use Kantronics manufactured KPC-3 plus. It is able to provide satellite tracking information used for antenna pointing and it is also able to calculate the degree of Doppler shift and automatically adjusts the UHF/VHF radio frequency to compensate.

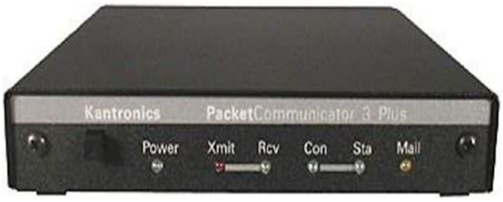


Figure 4: GS - Terminal Node Controller

3.1.3 Transceiver

Information between YuSend1 and the ground station will be transmitted and received utilizing ICOM's VHF/UHF All Mode Transceiver IC-910H. The frequency of communication will be on the amateur radio UHF/VHF band. We can eliminate the need for an external high power amplifier for satellite uplinks as the IC-910H contains a full 100 watts of power on VHF. For mode-J satellites, ICOM provides 75 watts of output on UHF. Unlike the transceiver on the satellite, power and weight are not limitations on the ground station transceiver.

Figure 5: Ground Station Setup

3.1.4 Tracking Software

The main software being used in order to track satellites from the ground station are STK, NOVA and Unitrac. NOVA is compatible with the computer interface and the rotator controller software Uni_trac. Nova allows for CubeSat auto tracking and predicts the time, elevation and azimuth level for the satellite passes. It uses Keplerian elements to make all of the calculations. STK can be used to make Doppler Shift calculations.

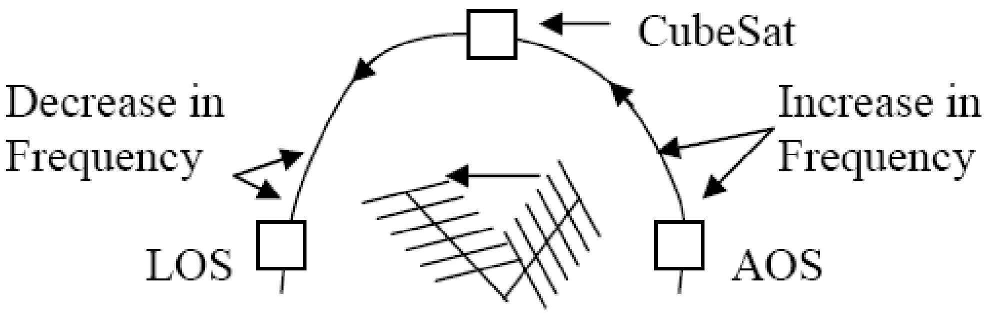


Figure 6: Diagram of Doppler Shift[1]

3.2 Space Segment

More details on components found here based on progress.

3.2.1 Antenna

YuSend-1 will be communicating with the ground station through the use of a dipole antenna. The dipole antenna's radiating element is designed to have cross-curved steel strips,

[1] (Ichikawa)

typically used in tape measure. Two antenna elements of a quarter-wave will realize the half-wave dipole. The antenna elements will have a 180° phase separation from each other and exhibit linear polarization.

During the launch of the satellite, the antenna elements will be tied down along the sides of the satellite. The antenna is designed such that the computer will switch on current to a loop of AWG 38 Nichrome metal wire surrounding some nylon wire, melting through it due to the high temperature. The natural tension in the tape-measure stock will cause it to flip up into the ready position. This is done once, after the initial release of the satellite into its orbit, and is irreversible.

A power divider/combiner will be used to balance the power to and from the input and output ports. It will also shift one of the output ports by 180°, which combines with the other output port to get a single mixed signal connecting to the radio.

The backplane side of the antenna board will be copper clad. The other side will contain line traces of a designed line width, which will connect the antenna components.

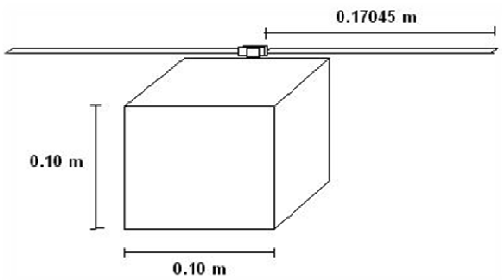


Figure 7: Dipole antenna model on YuSend-1

3.2.2 TNC

Since the PDR, the PacComm PicoPacket has arrived. We chose this based on its flight heritage and its small size and cost. The TNC operates at 1200bps, using 8 data bits, 1 stop bit, and no parity bit. We are now working on interfacing the TNC with the on-board computer. We encountered an unexpected issue when the TNC arrived with RJ-11 connectors instead of the RJ-45 connectors that the documentation told us to expect. But the problem has been resolved.

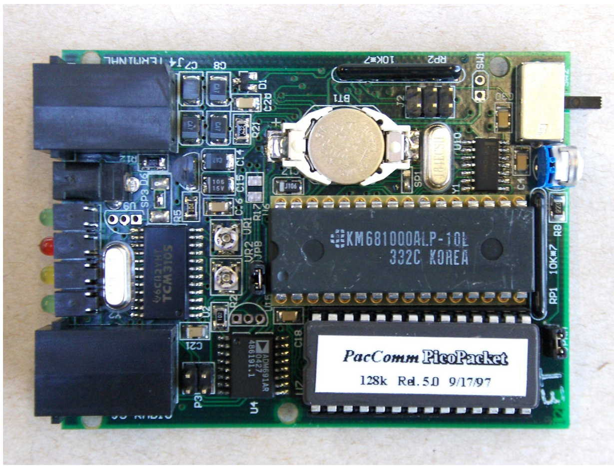


Figure 8: Space Segment TNC Pico Packet

3.2.3 Transceiver

The COTS transceiver being used on YuSend-1 is the Yaesu VX-3R miniature dual band transceiver. It has dimensions of 8.32cm by 4.20 cm. Thus it meets our size and weight constraints. It operates from a 3.7V Li-ion battery and has a current consumption of 150mA for receiving and 400mA for transmitting. It will be connected to the deployable antenna and will be receiving and transmitting and modulating/demodulating UHF/VHF frequencies.

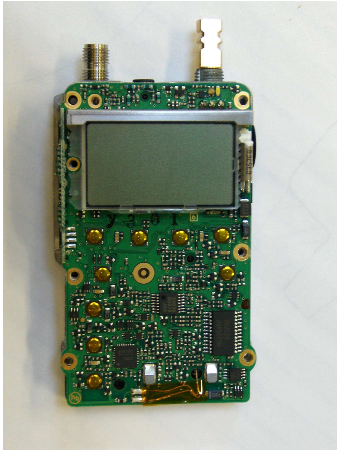


Figure 9: Space Segment Transceiver

4 Progress to Date

4.1 Ground Station

✓ Antenna True North alignment

- *GS Calibration and Testing:* Testing and calibration of the antenna pointing was completed as the azimuth rotator wasn't calibrated since it was repaired. Secondly the antennas orientation had to be corrected so as calibrate the antennas to be pointing to true North. This was done using an accurate site map and simple angle calculation relative to the HWY.

✓ Tracking of cubesats through use of NOVA, STK, AMSAT, UniTrac

- *Satellite orbit prediction and tracking:* STK was used to be able to predict the Doppler shift. A complete list of operational amateur satellites was obtained from the AMSAT website: http://www.amsat.org/amsat-new/satellites/frequencies.php?opOnly . STK was used to create a scenario that employs most of the functioning amateur satellites was created obtained from the AMSAT website minus those not operational yet, adding the receiver on the ground station object and transmitters in each of the satellites. Once that is done, the Doppler shift can be predicted. This was then used in conjunction with NOVA which is compatible with the computer interface and the rotator controller software Uni_trac. Nova allows for CubeSat auto tracking and predicts the time, elevation and azimuth level for the satellite passes. It uses Keplerian elements to make all of the calculations.

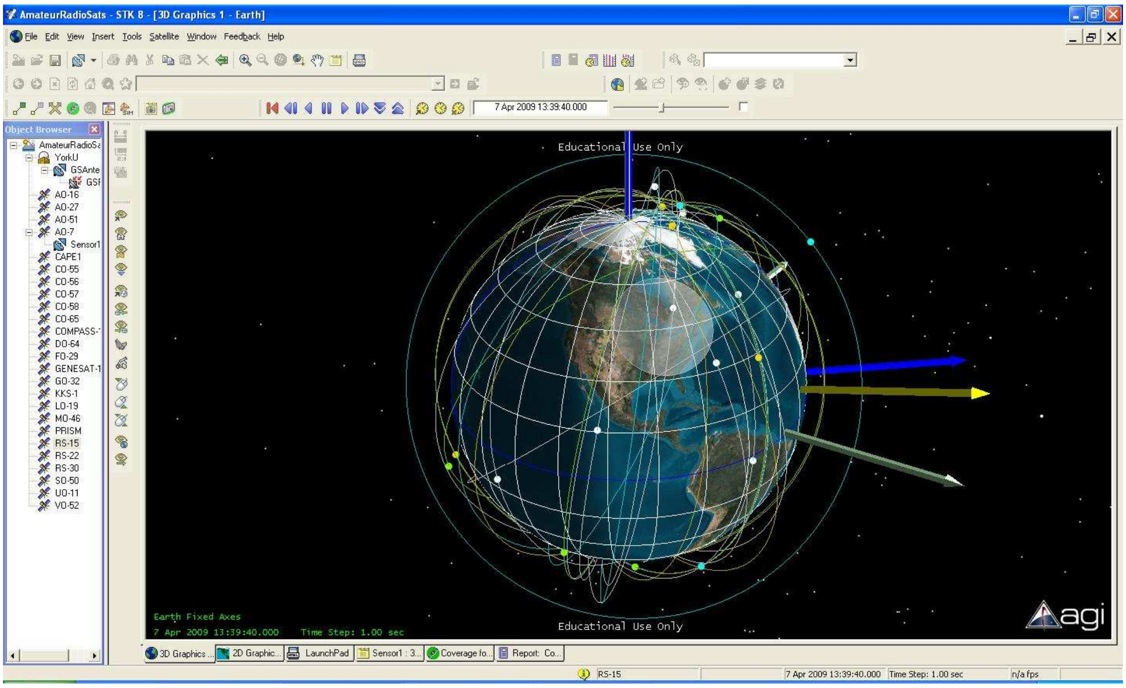


Figure 10: STK Scenario of all Operational Amateur Satellites

- ✓ Receive of beacon signal from CubeSat Oscar-58

  - As part of the ground station testing and a major milestone achievement was that we were able to receive the CW beacon signal from CubeSat XI-IV (Oscar-58) on April 3rd.

Figure 11: NOVA auto tracking of selected satellites

✓ Receiving commands from the Environment Canada broadcasts

- We were able to receive signals which were demodulated and de-encoded using the TNC and were able to receive text in the form of ASCII.

4.2 Space Segment

✓ Antenna finalization

- The Antenna for the Space Segment has been finalized and design details can be found in the Technical Description section of the report. The length of the antenna has also been calculated for as can be seen below:

- Antenna – Half-wave dipole, (ideal half-wavelength dipole)

$$\lambda = \frac{c}{f}$$

$$c = 3\ 10^8\ m/s$$

$$f = 440\, Mhz = 440 \;\; 10^6 \;\; 1/s$$

$$\lambda = \frac{300}{440}\; m = 68.18\; cm$$

$$\frac{\lambda}{2} = 34.09\; cm = 0.3409\; m$$

- Therefore, the elements in the antenna must each be 0.17045 m in length.

✓ Current measurements

- Using a handheld digital multimeter, the current measurements were taken for the Cubesat's TNC and Transceiver when powered with a 6V power supply. The measurements are shown below:

Table 1: Current Measurements

	Transmitting	**Receiving**	**Idle**
TNC	50mA	50mA	10mA
Transceiver	245mA	110mA	45mA
Total	295mA	160mA	55mA

✓ Volume measurements

- The volume of the communication system was a driving factor in this project. Now that all of the components have arrived, we were able to finalize the volume requirements for our subsystem. These measurements are shown below:

Table 2: Volume Measurements

mm^3	**Transceiver**	**TNC**	**Cubesat (internal)**
W	42.5	61.5	95
H	12.5	11.5	95

L	72.5	81.9	95
Vol	64.4 cm3	95.4 cm3	857 cm3

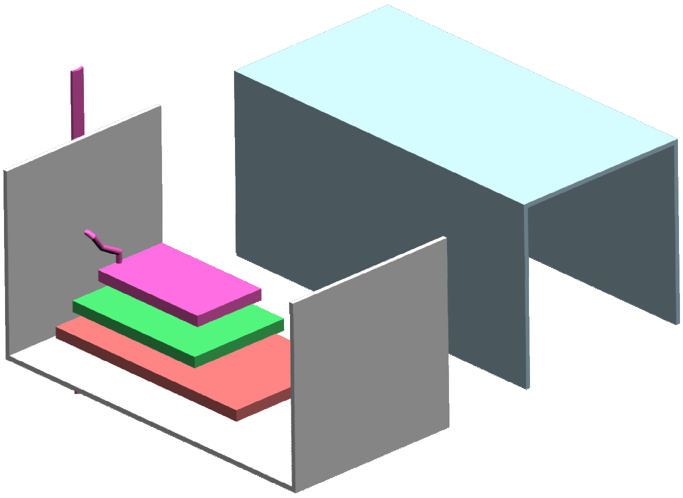


Figure 12: ProE drawing1 of CubeSat Structure Mounting

4.3 GS and SS Software Solution

Data collection is the primary objective of the satellite mission. Data collection will take the form of camera imagery since camera's can come in suitably small forms. For this project, the undergraduate ENG4000 project, a low resolution USB webcam is used in the prototype. Then the image file is transmitted to the ground station. This describes the complete software aspect of the project.

An application designed and coded by this team, will run on the OBC and control camera operations. This program will also handle application level communications; linux AX.25 drivers handle the transport layer. Addressing and connection state are handled by the Linux OS running on the OBC, so it is reasonable to say that Linux is the network layer for our system. The information to be transmitted will be encoded in RS232, although it is the TNC that maintains the node-to-node connection, a function of the data-link layer. RF Transmission is the physical layer, obviously.

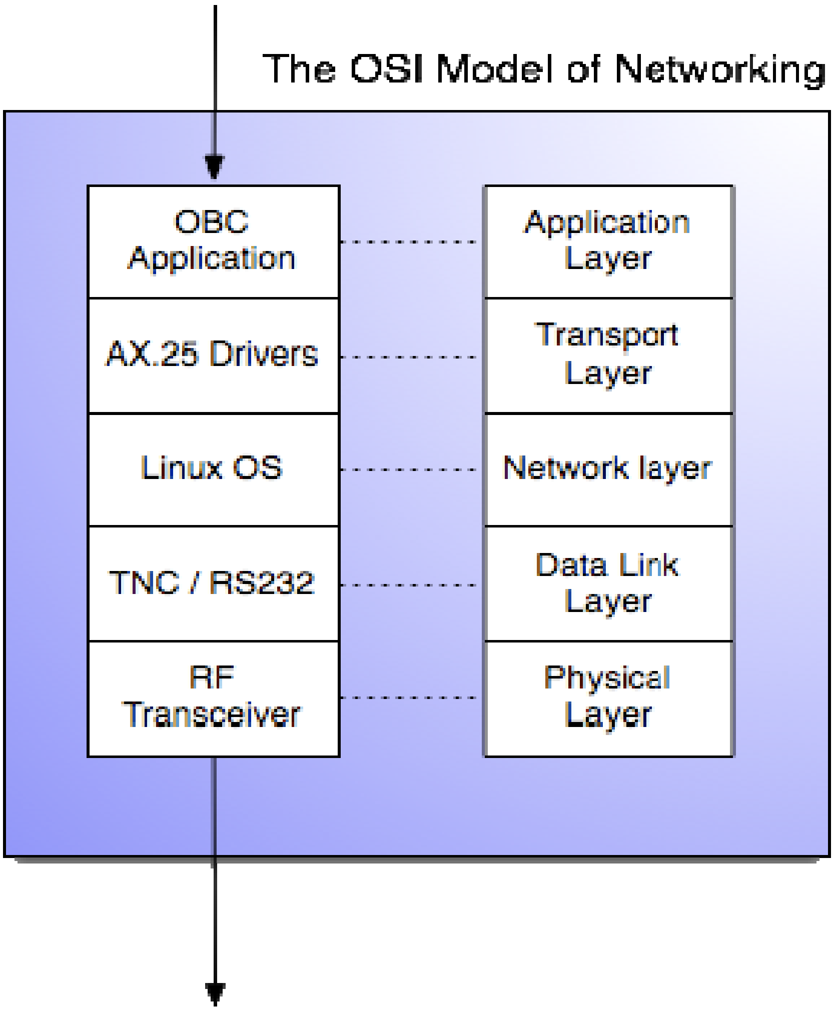


Figure 13: OSI network Model

A similar process is followed on the ground stations end, by its own software. Connections will be initiated from the ground station. The standard operating mode of the satellite communication system will be to listen for an incoming connection on a selected frequency. When the ground station antenna within broadcast range of the satellite, a connection can be initiated by the station's TNC.

Once a connection has been made to the satellite it can be sent commands. The station will interpret incoming data as commands. The only command of interest is one which initiates a picture to be taken and sent back as a stream of data to the ground station.

The ground station confirms the presence of a satellite in it's broadcast range by way of a beacon. In ground based nodes, a beacon is a periodic signal that is sent out that advertises your station as available for connections. Satellites employ a similar procedure with an added twist; the beacon is transmitted continuously as a tone. If listened to on a transceiver set to CW (Morse code) it will sounds like a series of beep that will get further apart if the satellite is traveling away from your location, and vice versa for traveling towards.

The bulk of ground station software operations will be handled by third party software. Our plan allows for a unified graphical user interface to be coded and implemented, but this is a low-priority issue subject to time constraints. Nonetheless, the existing interfaces have gone through several development cycles, are straight-forward and easy to demonstrate to users.

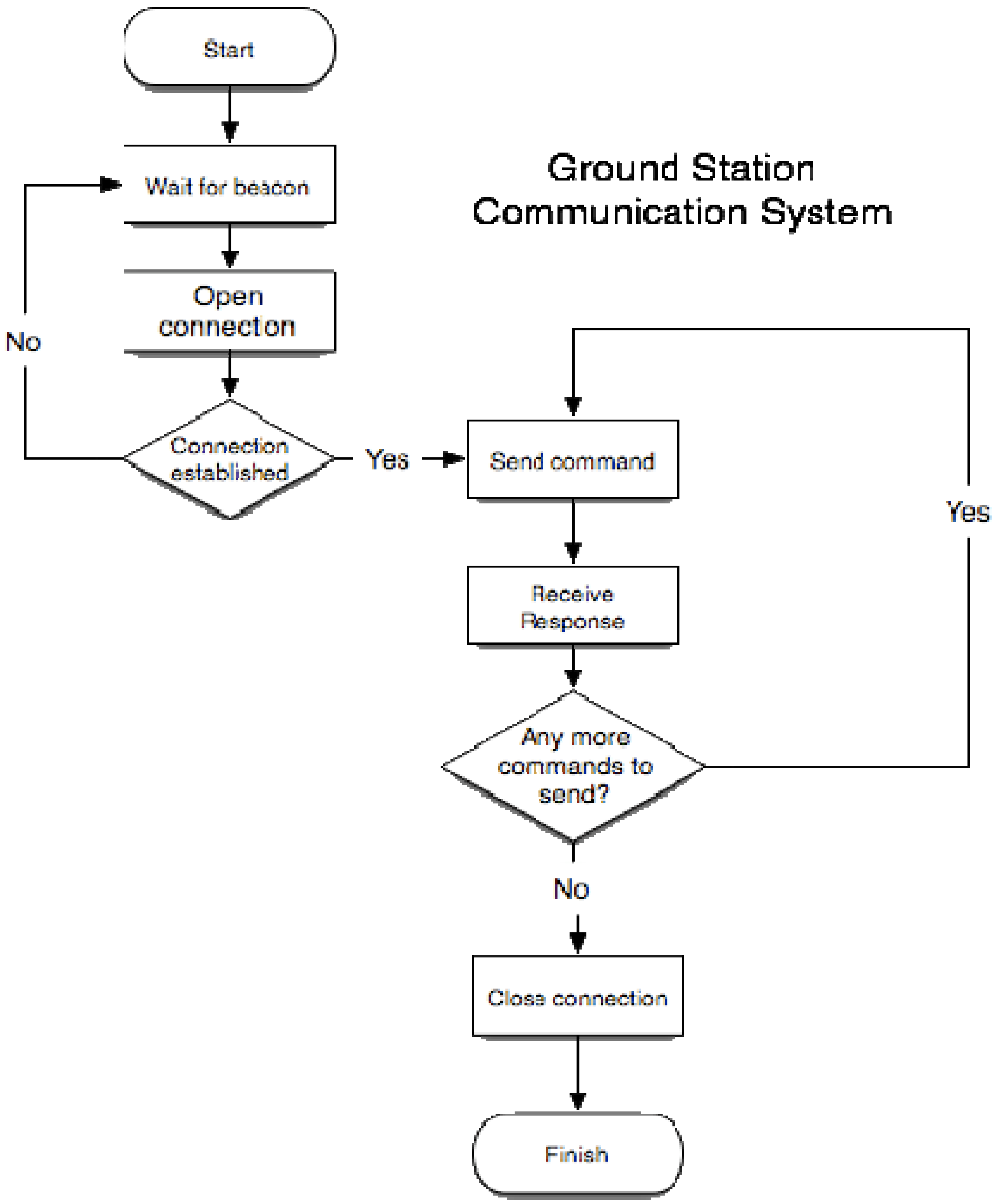


Figure 14: Ground Segment Communication Software Flowchart

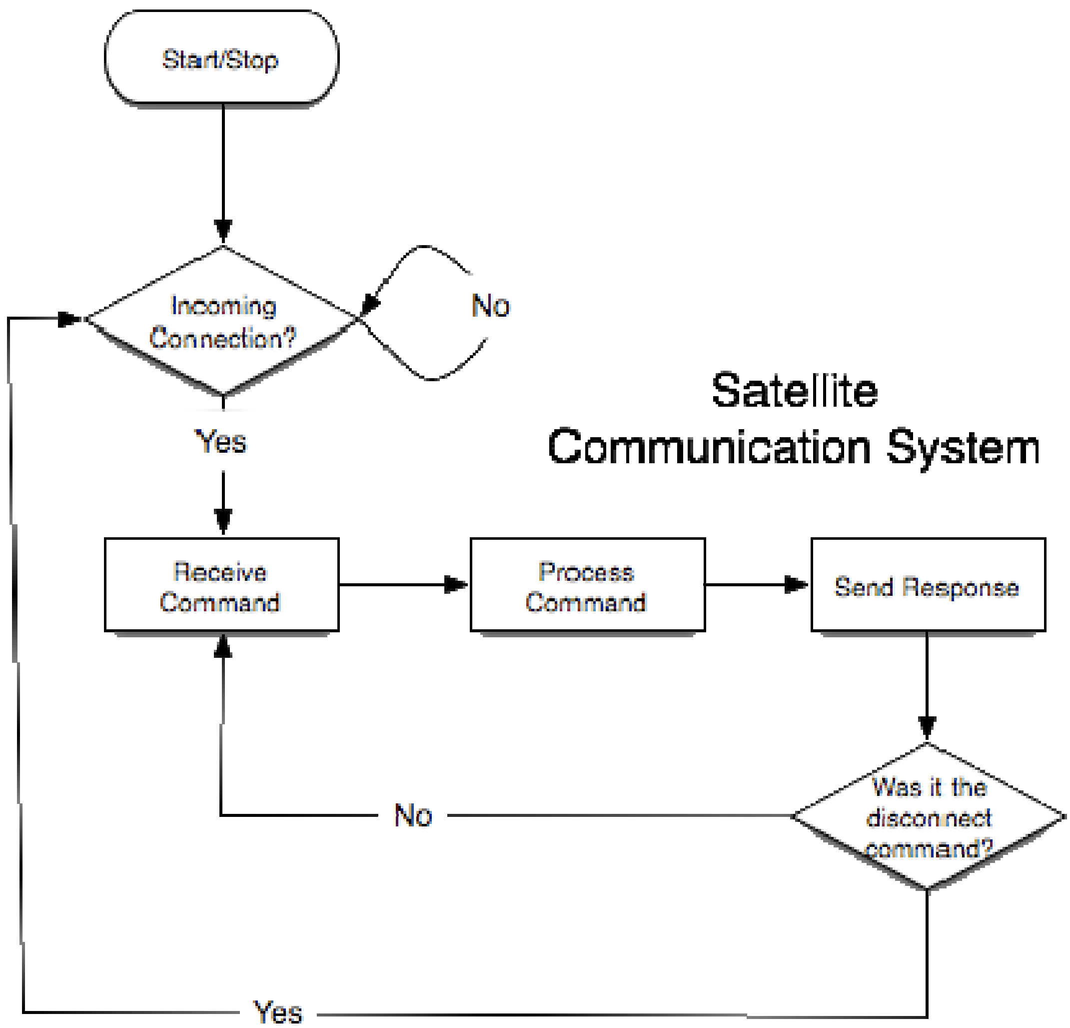


Figure 15: Space Segment Communication Software Flowchart

5 Projected Schedules and Future Tasks

5.1 Future Tasks

With the ground station mostly complete we can give more of our attention and time to our second part and focus on the Space Segment of the project. Thus the following tasks will be the main focus for the following few weeks.

- ✓ Antenna Fabrication
  - Based on the decided design the half dipole antenna has to be fabricated and tested.
- ✓ Component mounting
  - Since the various components have been stripped down to the vital parts we will start mounting them into a CubeSat structure. Although making sure it fits into the structure is secondary to our main objective of just producing a working communication design.
- ✓ Thermal Vacuum chamber testing
  - A thermal vacuum testing of the various subsystems of YUSend-1 including the communication system has been scheduled to be tested on April 20th. We will be testing for space environment conditions such as sunlight heat and single surface heat input to ensure that the various components such as the antenna, TNC and transmitter function satisfactorily.
- ✓ Software Completion
  - The software code to be able to send and receive telecommands and telemetry information and final overall system testing needs to be done.
- ✓ ProE drawings refinement

- The current ProE drawings though are accurate and is to scale, a more detailed drawing needs to be made based on the design specifications.

✓ Antenna deployment testing

- Once the antenna has been fabricated we need to test the deployment mechanism, completion of which will be the completion of a major milestone.

✓ Final Testing

- Final testing will involve transmitting images from the SS to the YuSend ground station.

5.2 Schedule

Week of	Sept 15	Sept 22	Sept 29	Oct 6	Oct 13	Oct 20	Nov 3	Nov 10	Nov 24	Dec 15	Jan 5	Jan 19	Jan 26	Feb 2	Feb 9	Feb 16	Feb 23	Mar 2	Mar 9	Mar 16	Mar 23	Mar 30	Apr 6	Apr 13	Apr 20	Apr 27	May 4	May 11	May 18	May 25
Tasks																														
Project Proposal	■																													
Contract Proposal		■																												
Ground Station Assembly & testing	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■								
Basic radio operator's qualification				■																										
Design Specification review					■																									
Software development begins					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
1st design update presentation														■																
Antenna design and modeling													■	■	■	■	■	■	■	■										
Preliminary design review																		■												
Antenna fabrication																					■	■	■	■	■					
2nd design update presentation																				■										
1st communication link test																							■							
Critical Design review																						■	■							
Final design report																											■	■	■	■

6 Obstacles and Risks

➢ *Ground Station Fabrication and Testing*

Some of the initial cause for concerns was the amount of time being consumed in the assembly of the ground station which was our secondary mission objective.

- However, this was averted by adding the Ground Station to our mission objective to developing the communication system as the GS is an important part to establishing communication with YuSend-1 and any other future York University led satellite missions.

- It also required certain changes to our schedule to include more time for Ground Station building and inclusion of simultaneous works on the Space Segment.

- Overall working on the Ground station helped us learn a lot about the Space Segment components which consist of the same main components as the GS. Thus reducing the amount of time required to spend on the Space Segment.

Figure 16: GS Fabrication

There were also other issues with the cablings and various component compatibility issues.

- This was resolved various black box testing and reading up on the manuals of the different components.

- ***Potential Risks with Space Segment***

The potential risks to the project that could arise in the following few weeks would be the failure of the antenna design and deployment mechanism fails

- The antenna design will have to reevaluated and re designed as the antenna is a vital component to the success of the mission requirements for the Space Segment
- However if time doesn't allow the redesign of the antenna then for demo purposes a non deployable make shift antenna will have to be used.
- If the deployment mechanism fails once again the design will have to reevaluated but if time doesn't allow for that the final design will be demoed minus the deployment of the antenna and the report will contain a detailed report for the reasons of failure.

Failure of other internal components

- The TNC and Transceiver will be tested within the next two weeks in the T-Vac Chamber for Space readiness.

7 Budget Expenditure

In the following subsections is a detailed report of the full costs to date as well as expected costs.

7.1 Donated

The GS components were provided for by Dr.Regina Lee and were purchased prior to the start of the project.

Table 3: Donated Equipment

Segment	Item	Provided by
Ground Segment	Ground Station Components	Dr.Regina Lee
Space Segment	On-board computer	Dr.Regina Lee
Demo Presentation	Weather balloon	Dr. Ben Quine
Ground Segment and Space Segment	Power supply and other test equipment	Dr.Regina Lee

7.2 To Date and Expected Expenditure

Table 4: Expense Report

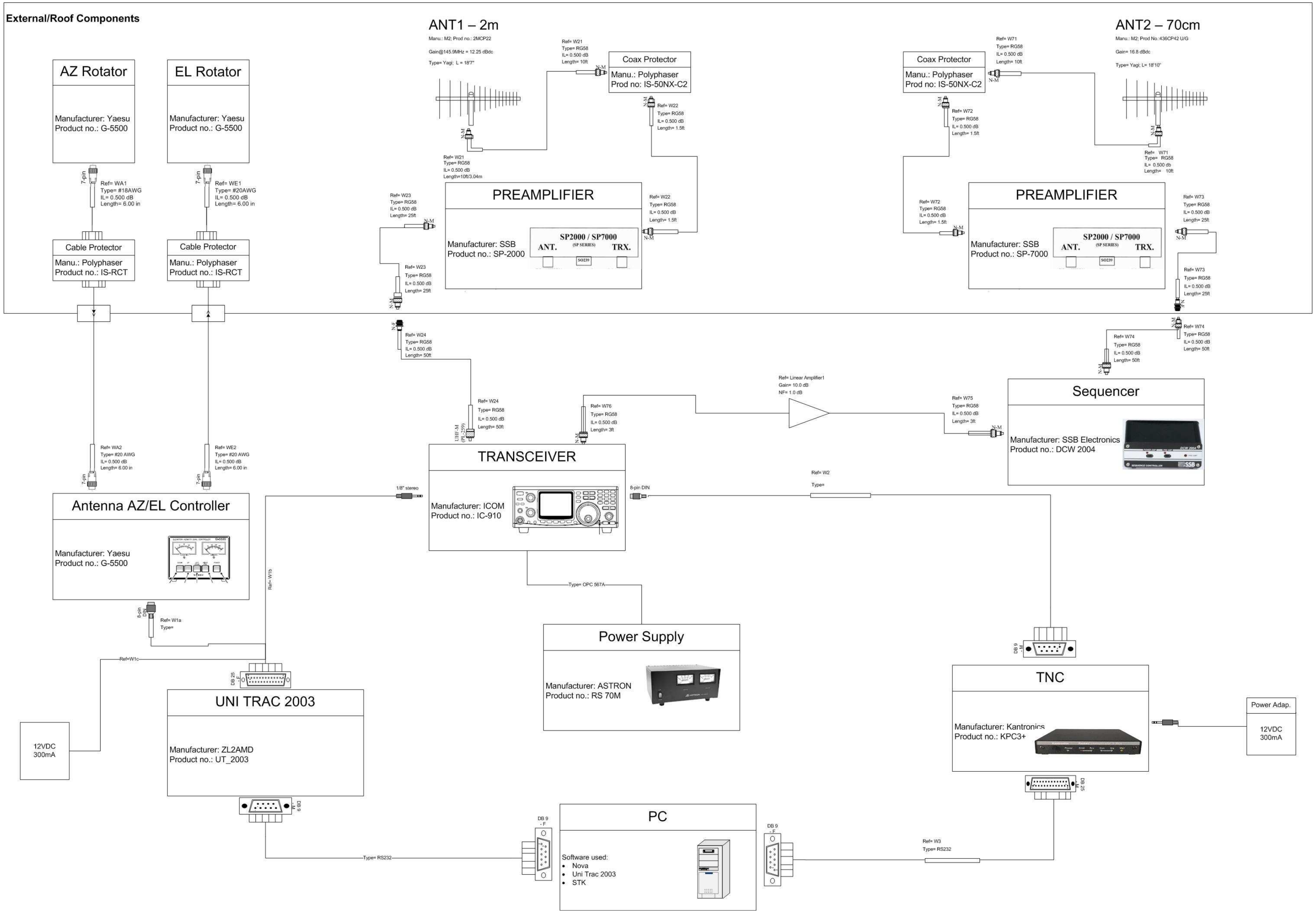
Item	Change since Feb.	Cost
Antenna assembly and deployment mechanism		$150.00
Yaesu VX-3R		$239.00
PicoPacket TNC		$320.00
Wires and other materials	+$16.00	$36.00
Presentation Supplies		$150.00
Subtotal	**+$16**	**$895.00**

8 Conclusion

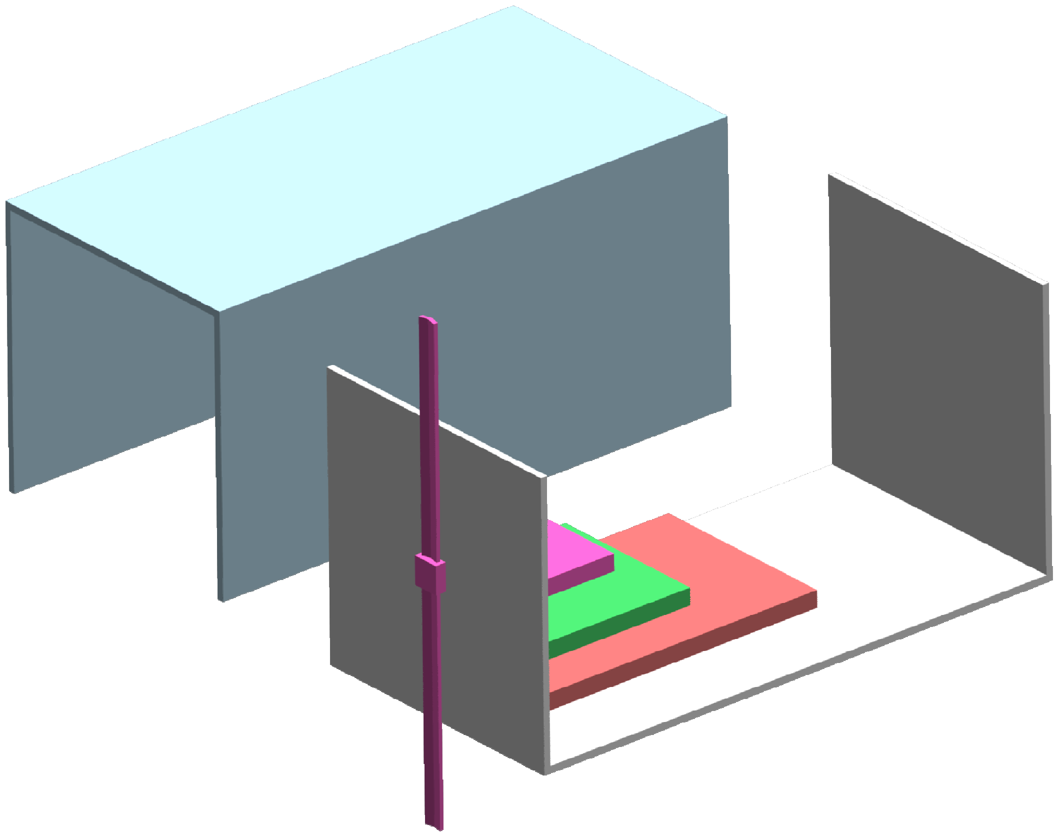
Apart from the initial unexpected time consuming fabrication and testing of the ground station which once we added to our project requirement and took account for with regards to time allocation, we are relatively on schedule. The significant progress made with the ground station testing after being able to successfully track and receive signals from amateur cubesats marks the crossing of a big milestone. This now allows the team to focus on the Space Segment side of things. The implementation of the Antenna design and deployment mechanism will be the most difficult hurdle on the Space Segment side.

To date YuSend has managed to stay within budget but this is largely due to support from Dr. Regina Lee and her lab. This last phase will be crucial to the overall success of the project. But overall the design, construction and testing processes are providing invaluable experience to the YuSend team.

Appendix A: Ground Station Cabling Diagram



Appendix B: ProE drawing of Mounted components and Antenna Design



References:

[1] George Hunyadi, D. M. (2002). A Commercial Off the Shelf(COTS) Packet Communication Subsystem for the Montana EaRth-Orbiting Pico-Explorer (MEROPE) CubeSat. *IEEE Xplore* , 473-478.

[2] Ichikawa, D. *CubeSat-to-Ground Communication and Mobile Modular Ground Station Development.*

[3] Krishnamurthy, N. (August 2008). *Dynamic Modelling of CubeSat Project MOVE.*

[4] Luke Stras, D. D. (2003). *The Design and Operation of the Canadian advanced Nanospace eXperiment (CanX-1).*

[5] Miranda, M. O. (2007). *Design of ground station antenna for a double CubeSat student project.*

[6] Polaschegg, M. (2005). *Study of a CubeSat Mission.*

[7] Smith, J. *Antena Tutorial.* AEROCOMM.

[8] Tarun S. Tuli, n. G. (2006). *Low Cost Ground Station Design for Nanosatellite Missions.*

[9] Tarun S. Tuli, N. G. (2006). *Low Cost Ground Station design for Nanosatellite Missions.*

[10]Traussnig, W. (2006/2007). *Design of a Communication and Navigation Subsystem for a CubeSat Mission.*

[11] http://cubesat.ece.uiuc.edu/Comm.html

[12]http://www.amsat.org/amsat-new/satellites/frequencies.php?opOnly