CUBESAT GROUND STATION RADIO FREQUENCY CHAIN - ELECTRICAL SYSTEM

by

Ruhmaa B.
Sarah C.
Zoee F.
Alex T.
(Faculty Advisor: Dr. J. Sabarinathan)

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Department of Electrical and Computer Engineering
Western University
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1. Introduction/Background

1.1 Problem Statement

To design a ground station to communicate with the CubeSat while it is in space. The ground station will transmit, and receive information from the CubeSat that will need to be checked for errors and decoded. The ground station communication link is necessary to monitor the health, send commands to, and downlink payload data from the CubeSat.

1.2 Detailed Literature Review

The Canadian CubeSat project is 15 grants awarded by the Canadian Space Agency (CSA) to postsecondary institutions across Canada. The goals of this initiative directly align with the objectives of the University of Western Ontario and Nunavut Arctic College CubeSat Team: Ukpit-1. The mission statement is the following:

1) Provide an experiential learning and training opportunities for students in spacecraft development and operations, and in STEM outreach program development and delivery
2) Integrate and operate the Canadensys Nano VR camera in orbit for space and education

The CubeSat is a 10cm by 10cm by 20cm cube-shaped satellite, with major advantages such as readily available components, simplistic design, low cost. This allows it to be designed for various missions including research, technology demonstration, or for commercial use [1].

The CubeSat: Ukpit-1 is comprised of mechanical, electrical, and software engineering subsystems. These subsystems are underneath the umbrella of the Mission Control team and are listed below [2]:

- Structural
- Thermal
- Attitude Determination and Control (ADCS)
- Power
- Payload
- Radio Frequency Communications (RF Comms)
- Orbital
- On Board Computer (OBC)

Each system must work in a cohesive unit in order for the mission objectives to be reached. Mechanical Systems are responsible for the structural design of rails, cover plates, and antenna, as well as the mounting plates and solar panel plates. It is vital for students to understand the structural design to ensure their respective designs physically fit into or around the CubeSat. The Electrical Systems will be focused on power generation, signals, and monitoring status, for RF Comms, OBC, ADCB. The Software Systems must be able to decode and process the information coming to and from the CubeSat.

As stated in the Project Statement, the ground station will transmit and receive signals to and from the CubeSat. In order to understand the objectives and the overall Project Proposal, concepts of Filters, Power Amplifiers, and Second/Third Harmonic Output, must be clear [3].

There are multiple types of filters that will be used in this project, primarily bandpass and notch filters. A bandpass filter is used in a transmitter to limit the bandwidth of an output signal. The purpose of limiting the bandwidth is to avoid interference and noise from other stations with output signals. A notch filter is meant to reject signals in a specific frequency band called the stop band frequency range. It allows signals both above and below this band to pass through.

A junction circulator is a device that will prevent leakage between the transmitter and receiver. If leakage between the two components were to occur, the receiver could be damaged due to the high power signal being sent out by the transmitter. The junction circulator will function between 430-440MHz and will need to be placed between the transmitter and receiver, with a bandpass filter before it, to obtain the desired bandwidth.

Power amplifiers are devices used to amplify weak signals without modifying any of the information. A radio frequency power amplifier is used when transmissions are to be sent over long distances via air [4]. To design a power amplifier, the operation and output characteristics must be defined to choose one of two categories: A or B.

Finally, second and third harmonic outputs are undesirable frequencies within the desired bandwidth. Second harmonic outputs will affect both transmitted and received signals. However, third harmonic outputs are a result of the amplified transmitted signal at 1W.

In order to meet design goals it is important to create a link budget that will account for the gains and losses that a communication signal will experience while travelling through a communication system. Because of various losses such as atmospheric, path and polarization losses, the strength of the received signal will only be a fraction of the signal strength that was sent from the transmitter. Other than losses, link budget also takes into account other parameters such as frequency, altitude, and antenna polarization. The budget can then be used to calculate characteristics such as antenna gain, signal-to-noise ratio, beamwidth, and overall power received by the receiver. See Figure 1 in Appendix I for a visual representation.

1.3 Project Objectives

The overall objective of this project is to establish a means of communicating with the CubeSat. Communication will be performed through a ground station that must be designed, built and tested. The ground station will be modelled as an RF chain that includes an antenna, transmitter and receiver, junction circulator, power amplifiers, various signal filters and protective components. The transmitter will need to send out a 1W signal through the antenna at a frequency of 436.5MHz.

As the transmitter is sending out a high power signal, it will emit unwanted third harmonic frequencies. In order to eliminate these, a bandpass and multiple notch filters will need to be applied to the signal. The receiver will be also be functioning at 436.5MHz. A bandpass filter will need to be applied to the receiver in order to eliminate the noise and interference that will be received along with the desired signal.

Power amplifiers will be used to amplify both the transmitted and received signals. The transmitted signal needs to be amplified to about 1W in order to provide enough power for the signal to reach the CubeSat in space. The received signal will be very weak because of the distance travelled and the attenuation from the ionosphere during solar storms. It will need to be amplified in order to recover and process the information.

As mentioned above, objectives will also include the design of various filters that will be used on the signals. The two main types will be bandpass filters and notch filters. The bandpass filters will need to be designed to isolate a certain band of frequencies around the transmitted and received signals. This filtering will keep the transmitted signal in the allowable frequency band and will help to eliminate unwanted noise from the received signal. The notch filters will be designed to eliminate the unwanted third harmonic frequency components that will be emitted by the transmitted signal.

For the safety of the ground station, all of the RF chain components will need to be weather and lightning proofed, and a surge protector will need to be incorporated into the design. This way the ground station will be protected from any weather conditions, and power surges.

2. Design Approach

2.1 Concept Generation

Ground Station System Overview and Hardware Architecture

The main objective is to design and implement a CubeSat to Ground Station communication link that satisfies the requirements within the granted amateur radio frequency license. To accomplish this goal, the ground station will have to establish an up link, where commands are transmitted from the ground station to the Cubesat, and a downlink, where the Cubesat transmits collected data to the ground station. Figure 2 in Appendix I illustrates the communication link architecture of the ground station design. This design indicates the use a circular polarized antenna, analog front-end modules (polarization switch, surge protection, junction circulator, amplifiers, filters). The software defined radio takes care for the acquisition and decoding of the radio signals using digital processing software [5].

Link Budget

Generating a link budget is an important design aspect that will help quantify the losses and gains experienced in the ground station to CubeSat communication system. The link budget will consist of sections including inputs, ground station hardware, CubeSat orbit, antenna parameters, transmitter and receiver parameters, modulation and losses experienced within the communication system.

Some inputs in the CubeSat link budget will include uplink frequency, satellite altitude, elevation angle and satellite receiver bandwidth. These inputs will be chosen based off of design constraints, and they will be used to calculate other parameters within the link budget. The ground station hardware section will include data sheet information regarding the antennas, surge protector, antenna polarization switch, SDR transceiver, junction circulators and amplifiers. The section regarding the antenna will have information on both the uplink and downlink functionality of the ground station antenna which includes antenna frequency, wavelength, gain, beamwidth and polarization. Transmitter and receiver sections will both include information on cable lengths, and cable and connector losses. The transmitter section will have additional information on the transmitted and received power, and the receiver section will have additional information on receiver losses due to noise from antenna, feedline and component temperatures. The modulation section will quantify the required uplink bit error rate, data rate, modulation scheme and levels, and the signal-to-noise for the groundstation. The last section of the budget will highlight the many losses experienced throughout the ground station communication system. Some of the losses quantified in this section will be the atmospheric, ionospheric, polarization and antenna pointing losses.

Considering all of the parameters from the many sections listed above, the link budget will allow us to calculate critical values for the CubeSat communication system. Some of these critical values include transmitter and receiver power outputs, antenna gain, effective isotropic radiated power and signal to noise ratio [6].

Component Block Descriptions

Antenna

The antenna is arguably the most important component of the Ground Station. Some design requirements are having a large gain, VHF and UHF reception, long distance wireless communication and the least amount of interference/noise within itself. The Ground Station team proceeded to research the Yagi Uda antenna configuration, as the Western CubeSat Project Team recommended.

Polarity Switch

A polarity switch will be required in the Ground Station design in order to instantaneously switch the direction in which the electromagnetic waves propagate in a 3D pattern. The role of polarization is to give transmission signals a specific direction and it makes the beam more concentrated [7]. The polarization technique being used in this design is electrically controlled polarizers which can be integrated within a Low Noise Converter.

Surge Protection

The importance of surge protection is mainly to save costs from replacing components that could be damaged from power surges. This electrical device that protects equipment, also blocks voltage over a safe threshold. The surge protector works by shorting to ground voltage or blockly the voltage. In the application of the Ground Station, these power surges could occur from the power source or potentially from uncontrollable surges from lightning.

Band Pass Filters

The Ground Station cannot transmit any signal outside of the allocated frequency license. This filter is required to provide a general cleaning of all harmful, parasitic and spectral leakage that could damage hardware components or interfere with users around the 436.5MHz frequency band. The impedance of this filter will have to be matched with the impedance of the antenna to ensure optimal power transfer. With a center frequency around 436.5MHz, a 10MHz bandwidth is estimated to adequately clean up the desired signal. The bandpass filter must also meet the design restrictions set out in the link budget analysis, which requires low insertion noise. There are several widely used functions for designing filters, each with their own advantages and disadvantages:

1) *Butterworth*: Butterworth filter are characterized by a flat constant gain across the pass band, however the attenuation outside the pass band is typically low.

2) *Chebyshev*: Known for better roll off rate attenuation outside the passband but has ripples inside the passband.
3) *Elliptic*: The elliptic filter function has the sharpest roll-off attenuation, however there are ripples present in both the pass and stop bands

Notch Filter

Transmitters emit not only your desired frequencies but also undesired ones. The second and third harmonics are a way of characterizing nonlinearities. The third harmonic: $f_{3rd} = |2f_1 \pm f_2|$ and $f_{3rd} = |2f_2 \pm f_1|$ problem occurs if the power at IOP3 is high. Filtering is needed, specifically a notch filter is needed at $2f_1 - f_2$ and $2f_2 - f_1$, the filter will eliminate these frequencies and clean up the signal.

Several decisions regarding the notch filter were made, firstly, the team chose between building a filter or buying it. Building a notch filter would require placing zeros on the unit circle at the desired frequencies being looked at in order to eliminate them. Figure 3a in Appendix I shows the notch filter specifications. Figure 3b shows frequencies mentioned above that need to be eliminated. For this design, the pole-zero plot would look similar to Figure 3c in Appendix I and the transfer function would lead to the following MATLAB code:

```
NZ = [1 0 0 0 -1];
DZ = 1;
Freqz = (NZ, DZ,512,240)
```

After further discussion and sample simulations, it was decided to buy the notch filter. This led to another crucial decision of either purchasing a programmable filter or non programmable filter. Given that the project has a specified frequency range and bandwidth, the consensus was to purchase a programmable notch filter. After researching, it was found that there are no available programmable notch filters for the desired values. The notch filters are too tight for the application the team is designing for. This resulted in the team continuing to brainstorm other techniques to achieve the same elimination of frequencies without the availability of a notch filter. A few ideas that are currently being discussed in replacement is to add a low pass filters to act as a notch filter or include a guard band in the design.

Junction Circulator

The Ground Station will be acting as both a transmitter and a receiver which requires a junction circulator to be implemented in the design. The junction circulator will ensure the transmitted and received signals are kept separate, preventing leakage between the two systems. This separation will be important due to the high power (~1W) of the signal being transmitted uplink. If this highly powered transmitted signal were to leak into the receiver, it could potentially damage the entire receiver side of the ground station system.

Some design characteristics that need to be considered for the junction circulator will be the frequency range, isolation loss, voltage standing wave ratio, and reverse and forward power requirements.

Power Amplifiers

There will be multiple power amplifiers in the Ground Station design as shown in the block diagram, Figure 2 - RF Chain. As there are many classes of amplifiers, different configurations were researched to meet the design requirements, including the amplification of both transmitted and received signals. Class A amplifiers have the highest linearity, low noise signal, and no charge storage problems but they have a high heat output. Class B amplifiers have a lesser heat output but require two transistors and 0.7 volts to reach operating status. Non-linearity takes effect when power is high, to drive antennas, and where frequencies are highly involved.

Software Defined Radio

Unlike traditional radios, software defined radio's (SDR) are a more versatile form of transceiver that allows for cheap and efficient use of signal standards a frequency bands. The hardware configuration of an SDR is under software control. Traditional radios offer limited processing and a fixed design for single communication frequency and bandwidth. This allows for flexible reconfiguration of multi-band signals and deploy more advanced algorithms, communication standards, and decreases time for communication systems development in the future [8].

2.2 Concept Evaluation and Selection

Antenna

A Yagi Uda antenna will be used for the Ground System. The team is reviewing the 436CP16 circularly polarized antenna which is optimized for Low Earth Orbit (LEO) satellite communications from M2 Antenna Systems, Inc. The gain matches the design requirements of the rest of the RF Chain components for the band between 432-440 MHz. The feed impedance is 50 Ohms unbalanced, however the team will conduct testing and analysis using Smith Charts to design a circuit to impedance match. Common characteristics of this antenna include super gain, fixed frequency operated, light weight, low cost, and superdirective [9]. A superdirective antenna is an antenna whose directivity is obviously larger than traditional antennas with similar size [10]. The 436CP16 has yet to be purchased and the CubeSat Project team needs to obtain a Radio License in order to transmit and receive.

Polarity Switch

The polarization switch that has been selected is the PS-70CM from M2 Antenna Systems, Inc. This specific model is a kit designed to work with the chosen antenna which ensures low insertion noise into the component itself. Since the switches were designed for NASA, they have a very good range, from 100 to 500 MHz.

Band Pass Filter

As mentioned in the concept generation Section 2.1, the bandpass filter will provide a clean up and eliminate undesired frequency components in the Rx and Tx signals. As a result, the design should consider as close to 0 dB attenuation as possible in the pass band region. Due to the design constraints of the link budget to keep insertion noise as low as possible, there should be minimal noise added by the bandpass filter. With the center frequency of 436.5MHz and a bandwidth of 10MHz, the filter is required to operate in a strict range. The Chebyschev and Elliptic filters both have a ripple in the pass band region, resulting in additional undesired noise figure. To achieve the desired bandpass filter characteristics, a Butterworth LC configuration using inductors and capacitors was chosen for preliminary analysis.

Power Amplifiers

One of the power amplifiers that will be used in the Ground Station design is a Low Noise power amplifier (LNA) which belongs to Class A. Other amplifiers will need to be selected to impedance match in order to provide maximum power transfer between the source and the load is in the output stages of amplifier circuits. Another consideration is cascading amplifiers to increase signal strength in the RX chain. In a cascading amplifier, the output of the first stage is connected to the input of the second stage which increases the overall voltage gain. Further details can be found in section 3.1.

Software Defined Radio

Software Defined Radio technology was chosen over standard radio hardware primarily due to the system flexibility. This selection will be beneficial for future CubeSat projects, reducing the need for redesigning demodulation hardware and upgrading system components as new protocols become available. The SDR receiver chosen for this project for the final design is likely the USRP B210 from Ettus Research. The criteria used for selecting the SDR included a balance between cost, simple interface method, noise performance, frequency selection, bandwidth and dual channel for additional future applications. Other SDRs considered include HackRF Jaw-breaker and the Beecube. However, for prototyping purposes cost is the main driving factor, therefore a BeeCube SDR will be used since they are readily available to Western Univerity's CubeSat Project.

3. Preliminary Analysis

3.1 Engineering Techniques/Software Tools

Band Pass Filter

In order to design the bandpass filter prototype with appropriate impedance matching and magnitude response, various engineering tools will be used. Micro-cap has been used to provide a preliminary analysis of the designed bandpass filter. This will include both magnitude and phase response to ensure the filter meets the design specifications. The input impedance of the bandpass filter will have to match the output impedance of the antenna, but first the antennas impedance at the frequency of 436.5 MHz must be determined. Impedance matching will be done using smith charts and simulation software. Once a reasonable bandpass filter prototype is made, the bandpass filter PCB will be designed using Autodesk EAGLE or Altium electronic design software.

Power Amplifiers

The engineering technique used to analyse the power amplifiers chosen is the Maximum Power Transfer Theorem. This theorem occurs when the resistance value of the load is equal in value to that of the voltage sources internal resistance allowing max power to be supplied to the system. Using the Link Budget excel sheet, the power through the entire Ground Station system will be approximated to ensure the TX and RX chain function according to the design requirements.

Regarding cascading amplifier configurations, a single stage amplifier is not sufficient to build a practical electronic system because although the gain of the amplifier depends on device parameters and circuit components, there exists an upper limit for gain to be obtained from single stage amplifier. To overcome this problem, the team needs to cascade two or more stages of amplifiers to increase overall voltage gain. The disadvantage is bandwidth decreases as the number of stages increases, shown in Figure 4 in Appendix I.

3.2 Preliminary Analysis

Band Pass Filter

Since the bandpass filter follows the antenna in the communication chain, the input impedance of the bandpass filter must match the output impedance of the antenna at the 436.5MHz frequency range. The output impedance of the antenna will be calculated using both smith charts and by simulating the antenna at 436.5MHz using software to ensure accuracy.

Figure 5a shows a 3rd order Butterworth filter for the center frequency of 436.5MHz and bandwidth of 10MHz. In order to prove the feasibility of the Butterworth bandpass filter, the frequency response of the prototype was conducted in MicroCap and can be seen in Figure 5b in Appendix I. Although this Butterworth bandpass filter design shows the desired frequency response, some capacitor values are less than 1pF, and some inductor value.s are below 1nH. That leads to difficulty in hardware implementation of this filter. As a result, furtn l, her research into other filter types and filter order needs to be conducted. Future work will include research into cascading low pass and high pass filters, and micro strip filters for high frequency narrow bandwidth bandpass filters.

Link Budget

Various input values and other parameters will be used to calculate the critical values needed for the CubeSat ground station design. Some critical equations that will be used in the CubeSat link budget are given below [11]:

<u>Uplink Budget</u>

Parameter Name	*Equation*	*Units*
Free Space Path Loss	$L_p = 20 * log_{10}(\frac{4\pi Sf}{v_p})$	[dB]
Slant Range	S= $r_e * \left[\sqrt{\frac{(r_e+A_s)^2}{r_e^2} - cos^2\theta} - sin\theta\right]$	[m]

Total Losses of Ground Station Transmitter	$L_{T(GS)} = L_{TxC(GS)} + connector\ losses + filter\ insertion\ losses + other\ in\ line\ device\ losses + antenna\ mismatch\ losses$	[dB]
CubeSat Receiver System Noise Temperature	$T_{sys(CS)} = (T_{A(CS)} * \alpha_{CS}) + T_{o(CS)} * (1 - \alpha_{CS}) + T_{LNA(CS)} + \frac{T_{2stage}}{G_{LNA(CS)}}$	[K]
Power Delivered to CubeSat Antenna	$P_{d(CS)} = P_{t(GS)} - total\ GS\ antenna\ \ losses$	[dBW]
Ground Station Antenna Pointing Losses	$L_{pl(GS)} = 12 * (\frac{P_e}{42})^2$	[dB]
Uplink Antenna Polarization Loss	$L_{up} = \frac{1}{2} * \left\{1 + \frac{\left[(1-AR_{Tx(GS)}^2)*(1-AR_{Rx(CS)}^2)*cos(2*\theta_p)+(4*AR_{Tx(GS)}*AR_{Rx(CS)})\right]}{(1+AR_{Tx(GS)}^2)*(1+AR_{Rx(CS)}^2)}\right\}$	[Linear units]
CubeSat Received Power	$P_{r(CS)} = P_{t(GS)} + G_{t(GS)} + G_{r(CS)} - L_p$	[dBW]
Effective Isotropic Radiative Power	$EIRP = P_{t(GS)} - L_{tl(GS)} + G_{t(GS)}$	[dBW]
Uplink SNR Power Ratio at Ground Station Receiver	$P_{SNR(GS)} = P_{LNA(CS)} + P_{N(CS)}$	[dBW]
Signal Power at CubeSat LNA Input	$P_{LNA(CS)} = G_{r(CS)} + isotropic\ signal\ level\ at\ CS - L_{pl(CS)} - CS\ receiver\ in\ line\ loss$	[dBW]
CubeSat Receiver Noise Power	$P_{N(CS)} = k_B + 10 * log_{10}(T_{sys(CS)}) + 10 * log_{10}(B_r)$	[dBW]

Downlink Budget

Parameter Name	*Equation*	*Units*
Total Losses of CubeSat Transmitter	$L_{T(CS)} = L_{TxC(CS)} + connector\ losses + filter\ insertion\ losses + other\ in\ line\ device\ losses + antenna\ mismatch\ losses$	[dB]

Ground Station Receiver System Noise Temperature	$T_{sys(GS)} = (T_{A(GS)} * \alpha_{GS}) + T_{o(GS)} * (1 - \alpha_{GS}) + T_{LNA(GS)} + \frac{T_{comRcvr}}{\left[\frac{G_{LNA(GS)}}{10} \frac{L_{RxC(GS)}}{10}\right]}$	[K]
Downlink Antenna Polarization Loss	$L_{dp} = \frac{1}{2} * \left\{1 + \frac{[(1-AR_{Tx(CS)}{}^2)*(1-AR_{Rx(GS)}{}^2)*cos(2*\theta_p)+(4*AR_{Tx(CS)}*AR_{Rx(GS)})]}{(1+AR_{Tx(CS)}{}^2)*(1+AR_{Rx(GS)}{}^2)}\right\}$	[Linear units]
Downlink SNR Ratio	$P_{SNR(CS)} = P_{r(GS)} + P_{N(GS)}$	[dB]
Actual Received Signal Power at Ground Station	$P_{r(GS)} = P_{t(CS)} + G_{t(CS)} + G_{r(GS)} - L_{T(CS)} - L_p - L_{pl(GS)} - L_{dp} - atmospheric\ losses - ionospheric\ losses - other\ in\ line\ losses\ of\ GS\ antenna$	[dBm]
CubeSat Receiver Noise Power	$P_{N(GS)} = 10 * log_{10}(k_B * T_{sys(GS)} * B_r)$	[dBm]

Uplink & Downlink Budget

Parameter Name	*Equation*	*Units*
Channel Capacity	$C = B_r * log_2(1 + SNR)$	[bits/ second]

*Undefined variables found in the above equations can be referenced in Appendix 2.

4. Prototype Validation Plan

4.1 Prototype Concept

The RF Chain block diagram is the first foundation of a physical prototype of the Ground Station. As parts are currently being specced out, once items are purchased, the testing plans will need to be confirmed and ready to validate the prototype concepts. Those testing plans have become more clear as the team understands how each component will affect the functionality of the rest of the RF Chain as this phase of the project. Please see Figure 2 in Appendix I. Below in the table, the team has created a sample testing plan with verification for the band pass filter.

Band Pass Filter Requirements	**Verification**
Successfully passes required signals (431.5-441.5 MHz)	• Connect signal generator to input of filter and use oscilloscope at output.

	● Conduct frequency response analysis by varying signal generator frequency between (431.5-441.5 MHz) and verify output magnitude is between 0 and -10 dB.
Successfully attenuates signals outside of (431.5-441.5 MHz)	● Connect signal generator to input of filter and use oscilloscope at output. ● Set signal generator to 430 MHz and verify output signal is attenuated by 20-30 dB for each frequency tested. Repeat for 443 MHz.

4.2 Budget/Parts list details

As Western University has provided $75 per team member, this gives the team a total of $300 to work with. The breakdown of this total is to be discussed with the entire Western CubeSat Project Team. The following lists in this section will contain many items that have the cost covered by the CubeSat Project. The prices are quoted as a point of information and the Ground Station Team acknowledges that the lists may be modified due to design, equipment availability and cost-reduction decisions.

Parts List and Software Tools:

1) Matlab Simulink Software
2) ANSYS Simulation Software
3) Micro-Cap 12 Evaluation Software
4) RF Mentor Tool, Smith Chart Software
5) Altium and EAGLE for PCB designs
6) SDR BeeCube (model to be decided)
7) Junction circulator, $45.00 USD provided by Western CubeSat
8) Antenna, 436CP16: 432-438MHz, $295.95 USD provided by Western CubeSat
9) Polarization Switch, PS-70CM, 70CM. $245.99 USD provided by Western CubeSat
10) RF protector, Type N, $47.50 USD
11) Unknown number of capacitors and resistors for testing and final design

List of Equipment:

1) Agilent N5812A 100K - 6GHz Signal Generator
2) Multimeter
3) Power supplies
4) Tektronix DPO 7354C Oscilloscope

5) Network/spectrum Analyzers
6) Vector Network Analyzer (VNA)
7) BeeCube (SDR) - Mini, Regular, Mega

5. Team Member Contribution

The Ground Station CubeSat project has thus far and will continue to be completed by all members of the team throughout the semester. Large tasks will continue to be broken down into smaller sections. Then, assigned to individuals of the team to complete and combine for the overall deliverable.

Weekly, the team meets to discuss tasks and progress, at this time, the team strives on being collaborative to share thoughts and ideas to further the progress of the project and/or help other members with their assigned tasks that week. Some weeks, the team meets twice, once with the members and another in the presence of the graduate student, Nicholas Mitchell, who provides a wealth of information and guidance for the progress of the ground station. At all meetings, individuals take their own notes and following the meeting, one member summarizes and posts the meeting minutes in a shared drive for all members to reference. Every week, it is each individual's responsibility to complete at least three tasks, which can be as simple as additional research, and provide those three tasks to the other members as well to the graduate student. This encourages members to teach each other about what they have learnt, reducing redundancy and contributing to proactive time management throughout the course of the year. The weekly task updates will ensure that the project will not stall for periods of time throughout the year. The team is extremely motivated to keep the project on a tight weekly schedule as the end goal is to have a working ground station before the capstone final deadline.

The main design choices that the team will be completing include: filter design, power amplifier gain, third harmonic output solutions, and Software Defined Radio (SDR) transceiver specifications.

Various filters will need to be designed for the project: bandpass, notch and passband. Alex has been working on the bandpass filter design and simulating it in microcap. He is completing work in the lab and presenting the team with the results in which the team is in the process of deciding upon a final design for each filter. Zoee is working on the notch filter which as discussed earlier in the report has been decided to be purchased. She is researching different programmable notch filters along with components needed for the other filters and amplifiers creating an order sheet for all materials. Once deciding upon a basic design Alex will focus on the receiver side of the signal and Zoee will focus on the transmitter.

The power amplifier gain will connect the SDR transceiver to the low pass filter. The amplifier is being specced out by Ruhmaa and added to the purchase list in which Zoee is responsible for. In addition to the power amplifiers, Ruhmaa has been working on the noise temperature theory and maximum power transfer through system. The noise temperature theory will ensure the design of the Ground Station has the correct power flowing through the system.

The SDR transceiver has a point in which the output of IP3 has to be less than the output of IP2. Filtering will need to be done and as the gain increases, that filtering will need to become tighter. Alex is responsible for testing how tight specifically this filtering will need to be and the specific SDR specs that will obtain an optimal output.

Additional tasks that the team will be working on include lightning proofing the outside of the electrical design, impedance matching, link budget, antenna modeling and weather proofing the design. Sarah has been responsible for researching and completing these additional tasks, working on the link budget and applying radiation and propagation knowledge to the Ground Station project. In addition, the team has been working together to understand and apply concepts such as Smith charts and impedance matching. As this is a group project, tasks are divided and assigned to member, however, the team is encouraged to help one another with their tasks in order for the success of the project and solidify understanding overall.

6. References

[1] J. Sabarinathan *et al.*, “Western University – Nunavut Arctic College CubeSat Mission – Overview,” p. 12.

[2] J. Sabarinathan, M.Cross, *et al.*, “Preliminary Design Review,” pp. 1-170, 2019

[3] N. Mitchell, “Electrical Capstones Definitions,” pp. 1–20, 2019.

[4] What is a Power Amplifier? Types, Classes, Applications. (2018, February 5). Retrieved from www.electronicshub.org

[5] Cappiello, A. G., Popescu, D. C., Harris, J. S., & Popescu, O. (2019). Radio link design for cubesat-to ground station communications using an experimental license. ISSCS 2019 - International Symposium on Signals, Circuits and Systems, 1–4. https://doi.org/10.1109/ISSCS.2019.8801767

[6] N. Mitchell *et al*, “UHF-LinkBudget-Western,” pp. 1–12, 2019.

[7] Introductory Consumer Electronics Technology Series - Philips/Magnavox Electreference: Satellite Reception (2010). Retrieved from http://repairfaq.cis.upenn.edu/sam/icets/index.htm

[8] Maheshwarappa, M. R., & Bridges, C. P. (2014). Software defined radios for small satellites. Proceedings of the 2014 NASA/ESA Conference on Adaptive Hardware and Systems, AHS 2014, 172–179. https://doi.org/10.1109/AHS.2014.6880174

[9] Stutzman and Thiele, Antenna Theory and Design, John Wiley, 2012.

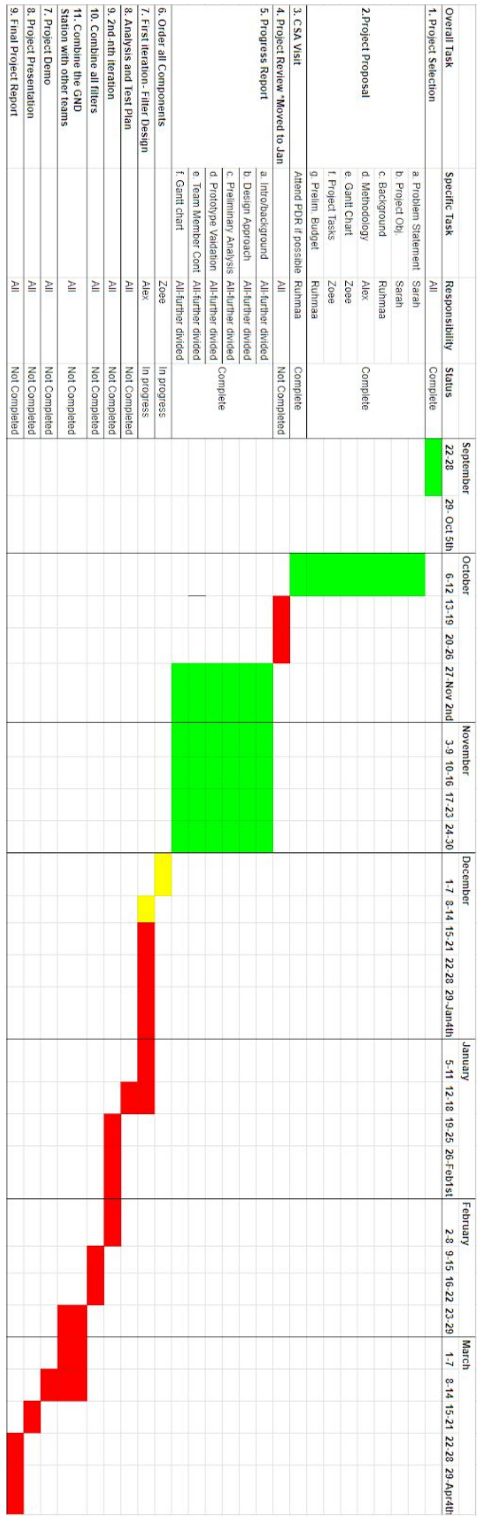
[10] Morris M. L. *et al.,* (2005) IEEE Trans. Antennas Propag. 53 pp. 2850

[11] J. Sabarinathan *et al., “*SATCOM 101”. (2019, October 28). Retrieved from https://uwoca.sharepoint.com/sites/SabarinathanLaboratory

[12] Khan A. R *et al.,* Five-nations CubeSat Constellation; An Inexpensive Test Case for Learning and Capacity Building 3rd IAA Conference on University Satellite Missions and CubeSat Workshop J. project Members

[13] B.A Shenoi, “Introduction to digital signal processing and filter design,” p. 120, 2006.

7. Gantt Chart



Appendix I

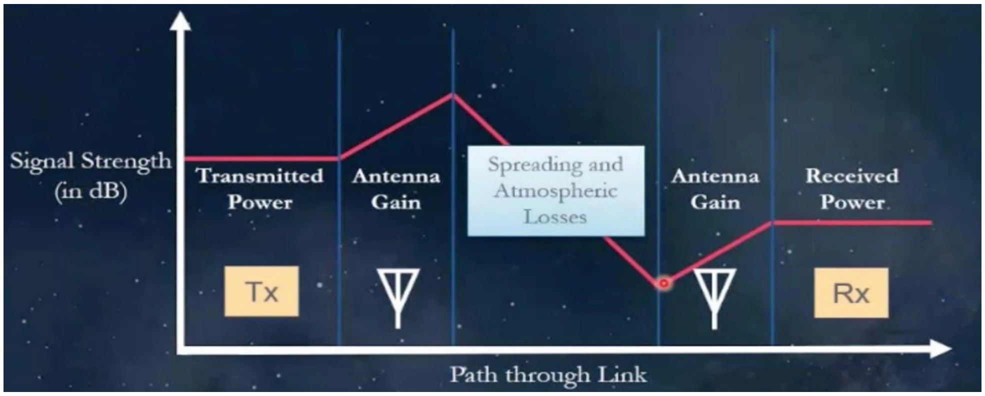


Figure 1: Link Budget Representation

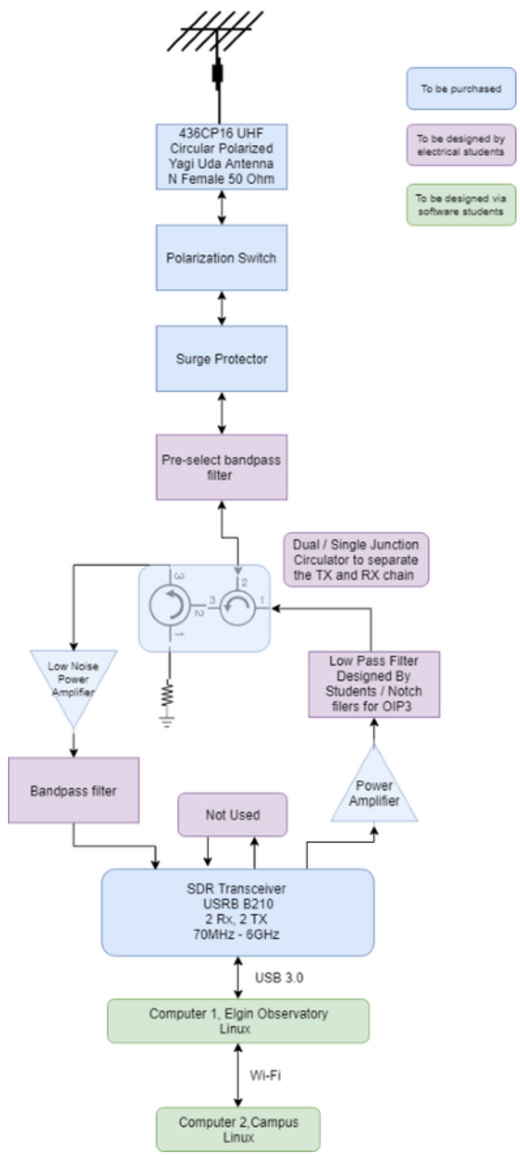
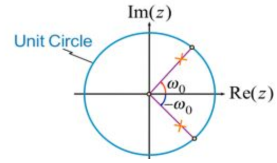


Figure 2. RF Chain

Figure 3a. Notch Filter Impulse Response

FIR: $H(z)=b_0(1-e^{j\omega_0}z^{-1})(1-e^{-j\omega_0}z^{-1})=b_0[1-(2\cos\omega_0)z^{-1}+z^{-2}]$

IIR: $H(z)=b_0\dfrac{(1-e^{j\omega_0}z^{-1})(1-e^{-j\omega_0}z^{-1})}{(1-re^{j\omega_0}z^{-1})(1-re^{-j\omega_0}z^{-1})}=b_0\dfrac{1-(2\cos\omega_0)z^{-1}+z^{-2}}{1-(2r\cos\omega_0)z^{-1}+r^2z^{-2}}$



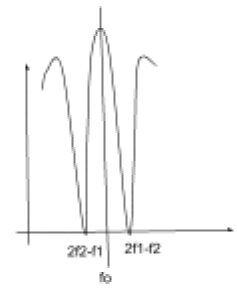


Figure 3b. The Ground station frequencies to be filtered out

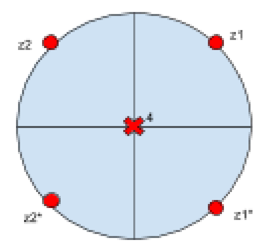


Figure 3c. The specified pole-zero plot

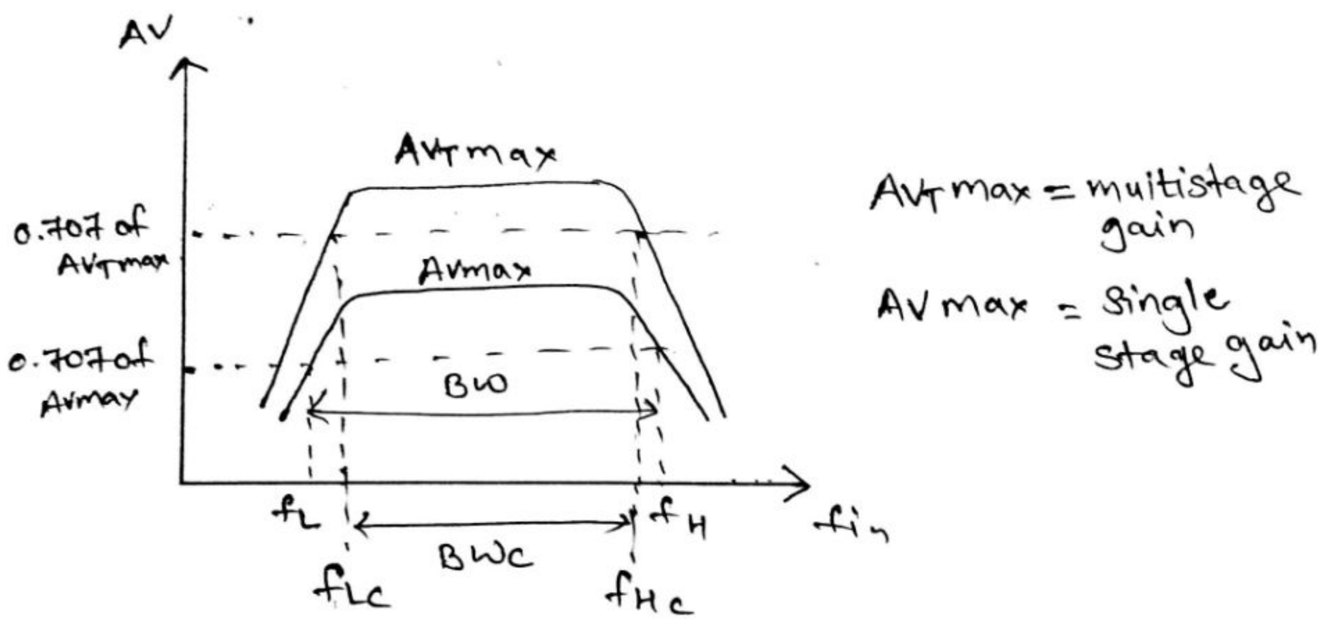


Figure 4 - Frequency Comparison of Multistage and Single Stage Gain

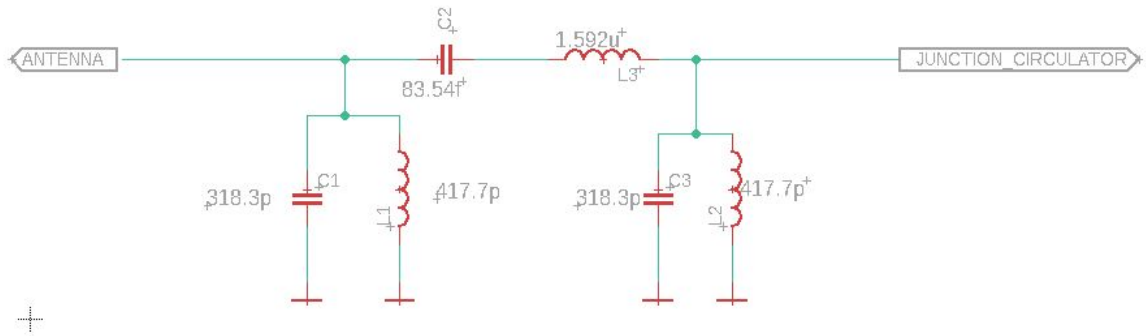


Figure 5a - Bandpass Filter

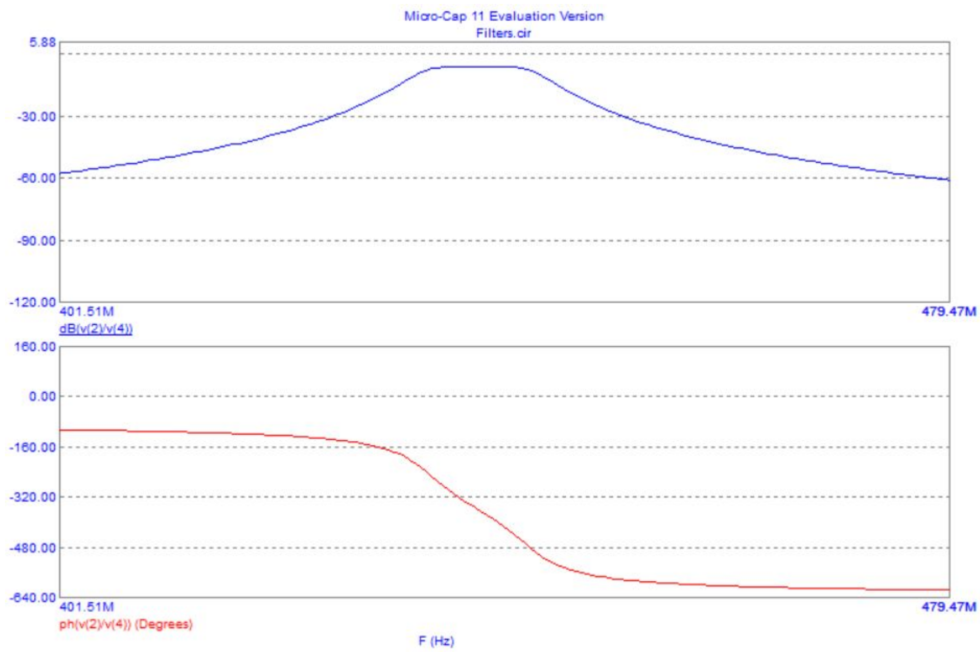


Figure 5b - Band Pass filter Frequency Response

Appendix II

Parameter Name	*Variable*	*Units*
Frequency	f	[Hz]
Boltzmann constant	k_B	$[\frac{m^2 * kg}{s^2 * K}]$
Speed of Light	v_p	$[\frac{m}{s}]$
Radius of Earth	r_e	[m]
Satellite Altitude	A_s	[m]
Antenna Elevation Angle	θ	[degrees]
Polarization Angle b/w Antennas	θ_p	[degrees]
CubeSat Transmission Line Coefficient	α_{CS}	No units
Ground Station Transmission Line Coefficient	α_{GS}	No units
Satellite Receiver Bandwidth	B_r	[Hz]
Ground Station Antenna Temperature	$T_{A(GS)}$	[K]
CubeSat Antenna Temperature	$T_{A(CS)}$	[K]
Ground Station Feedline Temperature	$T_{o(GS)}$	[K]
CubeSat Feedline Temperature	$T_{o(CS)}$	[K]
Ground Station Low Noise Amplifier Temperature	$T_{LNA(GS)}$	[K]
CubeSat Low Noise Amplifier Temperature	$T_{LNA(CS)}$	[K]
Comms Receiver Front End Temperature	$T_{comRcvr}$	[K]
CubeSat Receiver 2nd Stage	T_{2stage}	[K]

Temperature		
Ground Station Receiver Cable Loss	$L_{RxC(GS)}$	[dB]
Ground Station Transmitter Cable Loss	$L_{TxC(GS)}$	[dB]
CubeSat Transmitter Cable Loss	$L_{TxC(CS)}$	[dB]
Ground Station Transmitter Antenna Axial Ratio	$AR_{Tx(GS)}$	No units
CubeSat Transmitter Antenna Axial Ratio	$AR_{Tx(CS)}$	No units
Ground Station Receiver Antenna Axial Ratio	$AR_{Rx(GS)}$	No units
CubeSat Receiver Antenna Axial Ratio	$AR_{Rx(CS)}$	No units
Estimated Pointing Error	P_e	[degrees]
Power Transmitted from CubeSat	$P_{t(CS)}$	[dB]
Power Transmitted from Ground Station	$P_{t(GS)}$	[dB]
Ground Station Low Noise Amplifier Gain	$G_{LNA(GS)}$	[dB]
CubeSat Low Noise Amplifier Gain	$G_{LNA(CS)}$	[dB]
Ground Station Receiver Antenna Gain	$G_{r(GS)}$	[dB]
CubeSat Receiver Antenna Gain	$G_{r(CS)}$	[dB]
Ground Station Transmitter Antenna Gain	$G_{t(GS)}$	[dB]
CubeSat Transmitter Antenna Gain	$G_{t(CS)}$	[dB]