CUBESAT GROUND STATION RADIO FREQUENCY CHAIN - ELECTRICAL SYSTEM

by

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ECE4416 Electrical/Computer Engineering Project

Technical Project Proposal

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Proposal Summary

This document will cover the proposal of the CubeSat ground station radio frequency (RF) chain design. The scope of this project will be to design the necessary signal filters and determine appropriate specifications for all other ground station RF components. The design will include an antenna, polarization switch, surge protection, bandpass filter, notch filter, junction circulator to separate transmitting and receiving signals, power amplifiers, transmitter (TX) and receiver (RX). The objective of this project is to establish a means of communication to monitor the health, send commands to and downlink payload data from the CubeSat. Design constraints include; desired bandwidth of RX and TX signals, power amplifier gain, third harmonic output, software-defined radio (SDR) transceiver specifications and linked budget output power. This project will tackle the design of the Ground Station in a multi-phase V-Model design process over the next two terms.

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.

2. Background Information

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.

The CubeSat: Ukpit-1 is comprised of mechanical, electrical, and software engineering subsystems. These subsystems are under the umbrella of the Mission Control team and are as followed:

- 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.

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.

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. 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.

3. Project Objectives

The overall objective of this project is to establish a means of communicating with the CubeSat. That 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.

The 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 of 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 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 coming for space and 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.

4. Methodology

The planned architecture design of the ground station, *Figure 1*, is based on an SDR that satisfies the communication requirements in the Ultra High Frequency (UHF) band 300 MHz - 3 GHz. First, the antenna must be capable of receiving and transmitting in the UHF band. Second, the analog front end will provide amplification and filtering for both transmitted and received signals. Based on licensing requirements, the frequency used between the CubeSat and Ground Station will be 436.5 MHz with a bandwidth of 24 kHz. This design will make use of bandpass filtering techniques. When implementing this architecture there are strong restrictions [i.e., filter sampling rate, filter bandwidth, signal gain, SNR, etc.] in order to meet the link budget design requirements.

This project will tackle the design of the Ground Station in a multi-phase V-Model design process, *Figure 2,* as proposed below:

1) Conduct a literature review and research on RF bandpass/Notch filter or other solutions and finalize the ground station RF chain actitecure. Considerations include eliminating 3rd harmonic noise, sampling rate, SNR, etc.
2) Define Design Requirements - This will be broken down into (1) System level, (2) Subsystem level, and (3) Unit level design requirements.
3) Design a preliminary model of the ground station - This will occur for each system level with decisions on component selection, antenna model, filters, sampling rates, amplifiers, error vs SNR, etc. (note: limitations on hardware due to off the shelf components required, cost and time restrictions)
4) Design verification - This will occur during the development life cycle for all three levels. Ensure all unit level parts meet the desired specifications, ensure subsystems work together and system level design meets design requirements. This will include creating test plans, outlining all design requirements that will be tested, satisfied and documented.
5) Integration of components and in-lab setup.
6) Validation Phase & Acceptance Testing - Testing will occur in the opposite order of development (Unit level, Subsystem level, System level). Tools include; Matlab Simulink, oscilloscopes, spectrum analyzers, vector network analyzer

7) Create Ground Station Operations Guide for future use.

When using the V-Model design process, steps are followed in sequential order. Each stage must be complete before the next stage begins. Test plans are created in parallel with development steps. One of the benefits of this model is that design errors should not cascade down into later stages of the design process. If a system, subsystem, or unit level design requirement is found not met during parallel testing, this can be fixed by revising the design stage before processing.

The project phasing and process will be conducted in a multidisciplinary approach using skill and course based knowledge in:

- Communications: link budget analysis, modulation, filter design, RF stages, SNR, etc.
- Electronics: component selection, signal processing filters and amplifiers, safety oriented design
- Research and Development: Test plans and documentation, developing software based simulations for testing and design validation. Generate reports and documentation with high quality

5. Project Tasks and Responsibilities of Team Members

The Ground Station CubeSat project will be completed by all members of the team throughout the semester. Large tasks have been and 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 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.

Since choosing the Ground Station project, the challenge has been how to approach the problem set forth. This includes looking at previous work done by Western University and other CubeSat projects. The team is taking what has previously been done into consideration and looking for other methods to achieve the goal. Individuals have done research to educate themselves on the basic designs and principles of CubeSat projects. Resources have been found on the internet as well as provided by the graduate student.

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 filter designs will be assigned to separate team members. Individual work will be done in the lab and then the team will come together in order to decide upon the final design for each filter. Two members will be assigned to focus on the receiver side of the signal and two will be assigned to focus on the transmitter. This will allow for smaller meetings between two members, opposed to four, giving the opportunity for collaboration and teamwork as well as optimizing semester time.

The power amplifier gain will connect the SDR transceiver to the low pass filter. The amplifier will need to be purchased, one member of the team will be responsible for researching online and within the department to decide upon which purchase should be made.

The third harmonic, as described in the background section is one of the main design issues. When the power is high at the power amplifier gain, very specific filtering is needed. This is an issue that only occurs at the transmitted side of the signal, so the two members working on the transmitter side will require two notch filters to filter out the third harmonic frequency. Additional research will be done on other methods to filter out the frequencies in order to ensure that the best solution is being applied to the Ground Station.

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, *Figure 3.* One member of the team will be 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. These tasks will be split between members as the project continues. Members who run into fewer problems, which will likely be the two working on the RX side will take on additional tasks for the project.

6. Preliminary Budget and Parts List/Software Tools

Preliminary Budget

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) Access to multiple SDR's. must choose one for the design
4) Junction circulator, $45.00 USD
5) Antenna, 436CP16: 432-438MHz, $295.95 USD
    a) Covered by Western CubeSat Project Team, not purchased yet
6) Polarization Switch, PS-70CM, 70CM. $245.99 USD
7) RF protector, Type N, $47.50 USD, not finalized yet
8) 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

7. Gantt Chart

The Gantt chart will be updated as new course tasks are assigned and individual roles are further split up.

(See Appendix II)

8. References

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

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

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

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

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

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

Appendix I

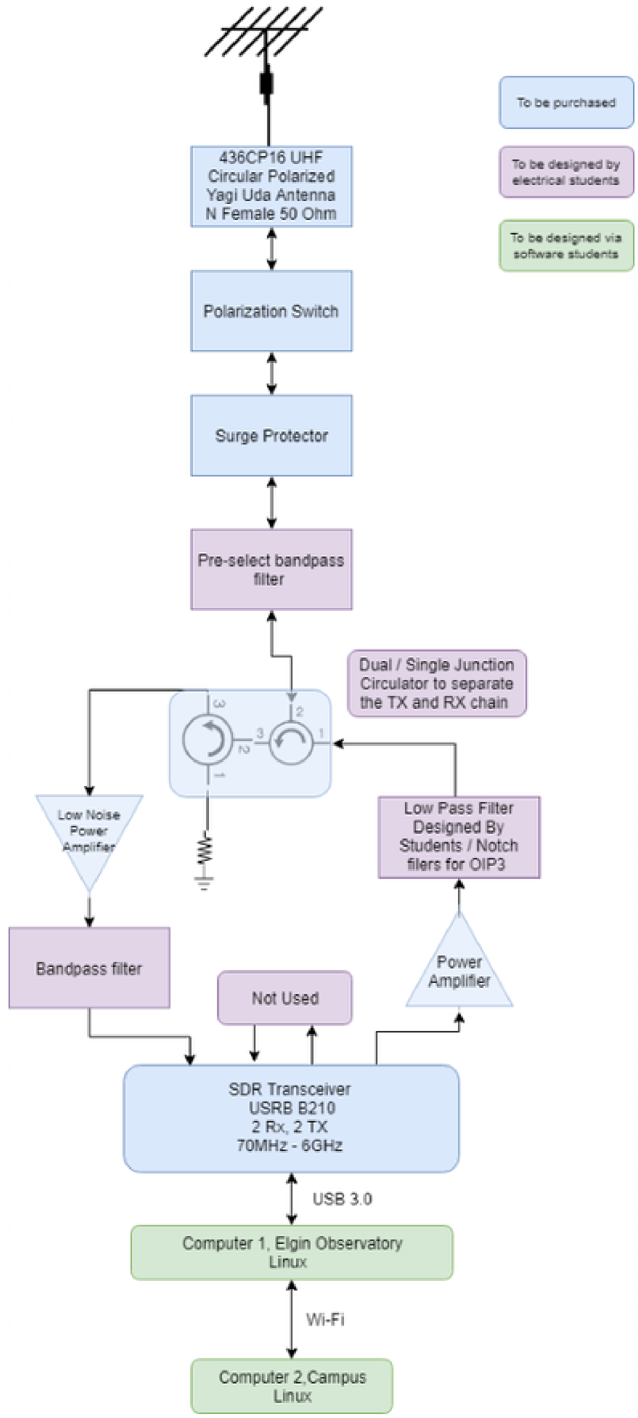

Figure 1: Preliminary Ground Station Radio Frequency Chain Architecture

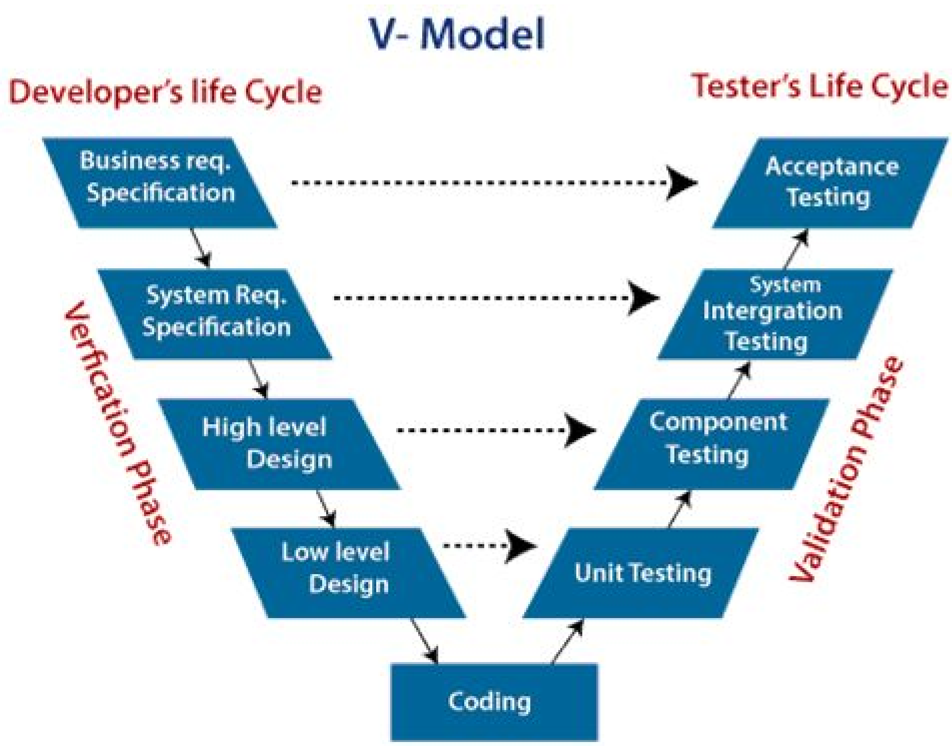

Figure 2: V-Model Design Process

Figure 3: SDR Transceiver

Appendix II

Overall Task
Specific Task
Responsibility
Status
Sept
22-28
29-5th
Oct
6-12
13-19
20-26
27-2nd
Nov
3-9
10-16
17-23
24-30
Dec
1-7
8-14
15-21
22-28
29-4th
Jan
5-11
12-18
19-25
26-1st
Feb
2-8
9-15
16-22
23-29
March
1-7
8-14
15-21
22-28
29-Apr4th
1. Project Selection
All
Complete
2.Project Proposal
a. Problem Statement
Sarah
b. Project Obj.
Sarah
c. Background
Ruhmaa
d. Methodology
Alex
e. Gantt Chart
Zoee
f. Project Tasks
Zoee
g. Prelim. Budget
Ruhmaa
Complete
3. CSA Visit
Attend PDR if possible
All
Complete
4. Project Review
All
Not Completed
5. Progress Report
All
Not Completed
6. Order all Components
All
Not Completed
7. First iteration- Filter Design
All
Not Completed
8. Analysis and Test Plan
All
Not Completed
9.2nd-nth iteration
All
Not Completed
10. Combine all filters
All
Not Completed
11. Combine the GND Station with other teams
All
Not Completed
7. Project Demo
All
Not Completed
8. Project Presentation
All
Not Completed
9. Final Project Report
All
Not Completed