This document explores the satellite in its entirety with respect to demonstrating the effectiveness of its preliminary design with considerations of risk, cost, schedule, and requirements

CougSat-1 PDR

Preliminary Design Review

Revision: 1.0.0



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# Introduction

Words

## Design Discussion

Question to address for each requirement:

1. How does this design fulfil the requirement?
2. Why was this design selected over other designs?
3. What is the confidence and maturity of this design?

# Subsystems

## Attitude Determination & Control Subsystem

## Command & Data Handling

## In-Orbit Communication Subsystem

The in-orbit communication subsystem (Comms) is responsible for the following functions:

* Transferring telemetry to the ground station
* Transferring payload data to the ground station
* Transferring commands from the ground station
* Transmitting a locating beacon

### Overall Design

The Comms is made up of three RF radios and two antennae in separate amateur radio bands. The primary antenna is bidirectional and low gain. The secondary antenna is downlink only and high gain. The RF radios are implemented as software defined radios.

Design Discussion:

1. The primary antenna is used for all four functions. The secondary antenna is used for transferring large amounts of data from the payload such as images from the camera.
2. Using a software defined radio allows full control over the radiated signal. Preliminary tests with a system on chip radio resulted in abominably slow data rates over a couple meters and could not be adjusted without expensive proprietary software.
3. Software defined radios have been used for CubeSat ground stations successfully. They also have significant support in the communities. The design being implemented has no flight heritage. Confidence in the design will have to be acquired through significant testing.

### Requirements

#### COMMS-001

Description:

*The Comms shall have a CW beacon during SAFE mode and only after the specified radio inhibit timeout*

Reasoning:

*CW is the most spectrum efficient, can get through the weakest link, and lowest power consumption transmission*

Design:

A low power RF clock generator feeds a low gain (low directivity) antenna through an adjustable amplifier. The entire Comms can be powered via the Electrical Power Subsystem and the Comms can turn each of its radios off.

Design Discussion:

1. The RF clock generator produces a CW wave and the low gain antenna will emit this nearly everywhere so with an ADCS failure, there is a high change of successful reception of the signal. The adjustable amplifier allows the power to be reduced to conserve resources during SAFE mode. The two power switches inhibit RF emission until both subsystems allow transmission to occur after the radio inhibit timeout.
2. Producing a CW wave is as simple as RF goes so there is not much room for design simplification.
3. There is confidence that this design can produced the required beacon. If the primary radio is damage, the secondary antenna can output a beacon albeit with a narrow antenna.

#### COMMS-002

Description:

*The Comms shall have a telemetry containing beacon during STANDBY and SCIENCE mode and only after the specified radio inhibit timeout*

Reasoning:

*The beacon will be used for tracking and will send telemetry to any ground station*

Design:

A RF chain with baseband signals synthesized by the Comms µController feeds the low gain antenna. The signals will be modulated using the telemetry data with a low data rate. The entire Comms can be powered via the Electrical Power Subsystem and the Comms can turn each of its radios off.

Design Discussion:

1. The low gain antenna will emit the signal nearly everywhere so with an ADCS failure, there is a high change of successful reception of the signal. The low data rate requires a lower signal to noise ratio than a high data rate which improves the chance of successful demodulation. The two power switches inhibit RF emission until both subsystems allow transmission to occur after the radio inhibit timeout.
2. This design was created to maximize the chance of successful reception of data as without telemetry, the satellite is useless.
3. Existing 1U CubeSats use a low gain antenna, similar power output, and similar modulation scheme and have high success. This allows us to test our receiver using existing satellites in orbit.

#### COMMS-003

Description:

*The Comms may have a high-speed downlink during TRANSMIT mode and only after the specified radio inhibit timeout capable of at least 500kbps goodput*

Reasoning:

*This will be used to transfer large files (payload images). A single photo will take 80s at this rate which is up to 30 images a day*

Design:

A RF chain with baseband signals synthesized by the Comms µController feeds the high gain antenna. The signals will be modulated using quadrature phase shift keying (QPSK) by the payload data with a high data rate. The entire Comms can be powered via the Electrical Power Subsystem and the Comms can turn each of its radios off.

Design Discussion:

1. The high gain antenna will concentrate the signal at the ground station to maximize signal to noise ratio. The high data rate requires a high signal to noise ratio to maintain successful demodulation. QPSK is fairly easy to modulate and demodulate; it also is fairly immune to changes in amplitude or frequency which will be incurred as the satellite orbits. The two power switches inhibit RF emission until both subsystems allow transmission to occur after the radio inhibit timeout.
2. This design was created to ease the software development as QPSK is fairly simple as opposed to other modulation schemes. Furthermore, the hardware to synthesize the baseband signal is simpler than the hardware to synthesize more arbitrary waveforms required by other modulation schemes.
3. Existing 1U CubeSats use a QPSK as a modulation scheme as well as larger weather satellites. This allows us to test our receiver using existing satellites in orbit.

#### COMMS-004

Description:

*The Comms shall have sufficient preamble for receiver synchronization*

Reasoning:

*A preamble allows the receiver to wake up and recover the clock from the signal*

Design:

The Comms’ frame[[1]](#footnote-1) begins with seven bytes of alternating 1 and 0 bits. The last bit will be the same as the bit before to delimitate the start of the frame.

Design Discussion:

1. The preamble, with alternating bits, allows the receiver to decode the clock frequency and have time to prepare for reception of data. The start frame delimitator indicated when the frame’s body is being received.
2. The preamble is a simple way to synchronize the radios albeit with some overhead but the overhead is small when a full sized packet is transmitted.
3. The preamble and start frame delimiter were taken from the design of an ethernet frame which works very well.

#### COMMS-005

Description:

*The Comms shall have a receiver continuously on and only after the specified radio inhibit timeout*

Reasoning:

*Communication from the ground may occur at any time*

Design:

The receiver radio is low power and will continuous search for a signal expect when transmitting as the primary antenna can only perform one operation at a time. The entire Comms can be powered via the Electrical Power Subsystem and the Comms can turn each of its radios off.

Design Discussion:

1. The low power receiver allows it to not significantly impact the energy budget of the EPS when operated continously. The two power switches inhibit RF emission until both subsystems allow transmission to occur after the radio inhibit timeout.
2. The primary antenna’s downlink and uplink signals are identical, so the software only has to be written once. This also decreases the amount of testing required.
3. The confidence in this design is the same as the transmitter as they are effectively identical, see Comms-002.

#### COMMS-006

Description:

*The Comms may have a voice message audible during the telemetry beacon*

Reasoning:

*Listener can be informed of our website which will have instructions for decoding the telemetry encoded in the transmission*

Design:

The primary downlink radio’s baseband signals can be arbitrary waveforms. This includes an audio message. The Comms µController will take the audio stored in Flash memory and add the telemetry data outside of the audibly range.

Design Discussion:

1. Storing the voice message reduces the burden to synthesize the audio waveforms. Replaying the audio is not difficult and encoding the telemetry is already performed for Comms-002 so combining these features is straightforward.
2. The software defined radios allow easy manipulation of the algorithm if there is difficulty in embedding the data under the audio message.
3. Existing 1U CubeSats successfully use data under voice to transmit telemetry while performing transponder operation. This allows us to test our receiver using existing satellites in orbit.

#### COMMS-007

Description:

*The Comms shall have at least a low gain antenna*

Reasoning:

*If the ADCS malfunctions, data still needs to be capable of transferring to the ground (low gain is low directionality)*

Design:

The low gain antenna is a dipole which is the simplest antenna and has a nearly isotropic radiation pattern.

Design Discussion:

1. A nearly isotropic radiation pattern will reduce the effects of a malfunctions ADCS.
2. The simplest antenna and the lowest gain makes a dipole the best choice for a low gain antenna.
3. Existing 1U CubeSats successfully use dipole antennae.

#### COMMS-008

Description:

*The Comms shall communicate to the IHU*

Reasoning:

*The Comms needs to receive commands from the IHU and transfer data back*

Design:

The IHU and Comms µController shall have a standard SPI interface.

Design Discussion:

1. SPI is a simple and robust bus that provides bidirectional communication.
2. SPI requires few pins, operates at a fast data rate, and does not suffer from bus lock up like I²C.
3. SPI is fully supported by every electronics engineer and has been used on many CubeSats.

#### COMMS-009

Description:

*The Comms shall send telemetry to the IHU upon request*

Reasoning:

*The IHU logs the data and sends it to the ground for analysis*

Design:

The Comms will monitor various voltages, current, and temperatures for telemetry and transfer it to the IHU using the SPI bus described in Comms-008.

Design Discussion:

1. Voltage, current, and temperature gives a good idea of the status of the Comms.
2. The data is flexible so adding more information is easy.
3. Measure voltage, current, and temperature is not difficult and many of our prototypes already have this functionality.

## Environmental Control Subsystem

## Electrical Power Subsystem

## Ground Station

The ground station subsystem (Ground) is responsible for the following functions:

* Transferring telemetry from the satellite
* Transferring payload data from the satellite
* Transferring commands to the satellite
* Receiving a locating beacon

### Overall Design

The Ground is made up of three RF radios and two antennae in separate amateur radio bands. The primary antenna is bidirectional and high gain. The secondary antenna is downlink only and high gain. The RF radios are implemented as software defined radios.

Design Discussion:

1. The primary antenna is used for all four functions. The secondary antenna is used for transferring large amounts of data from the payload such as images from the camera.
2. Using a software defined radio allows full control over the radiated signal. Preliminary tests with a system on chip radio resulted in abominably slow data rates over a couple meters and could not be adjusted without expensive proprietary software.
3. Software defined radios have been used for CubeSat ground stations successfully. They also have significant support in the communities. The design being implemented has no flight heritage. Confidence in the design will have to be acquired through significant testing.

### Requirements

#### GND-001

Description:

*The Ground shall receive all forms of transmission from the Comms*

Reasoning:

*The Ground is the other side of the communication system*

Design:

Software defined radios will connect to antennae of both bands. The antennae will be mounted on a two-axis tracking system in combination with being high gain. Both antennas are circularly polarized.

Design Discussion:

1. Once the orbit of the satellite has been identified, the tracking system will continuously aim the antenna at the satellite to maximize the received signal.
2. Being circularly polarized does impact the signal when it is linear polarized, but this impact is constant as opposed to having the polarization completely off and not receiving any signal.
3. Many amateur radio operators have tracking systems for satellites and use circularly polarized high gain antennae. This system can easily be tested with existing satellites already in orbit.

#### GND-002

Description:

*The Ground shall transmit commands up to the Comms*

Reasoning:

*The Ground is the other side of the communication system*

Design:

A software defined radio will transmit on the same primary antenna described in GND-001.

Design Discussion:

1. The software defined radio allows complete control over the RF signal and its software can be duplicated from the Comms transmitter as they are almost identical.
2. Reusing the radio design and software from Comms reduced development efforts and increases likeliness of success.
3. Existing 1U CubeSats can receive at the same frequencies the Ground will transmit. This allows us to test our receiver using existing satellites in orbit.

#### GND-003

Description:

*The Ground shall be capable of autonomous reception for up to 10 days*

Reasoning:

*Having the Ground with an operator for every pass is too much time and effort*

Design:

The antenna has a tracking mount that will not require operator interaction. The software will automatically decode and store all data it receives.

Design Discussion:

1. The tracking antenna software is already written from various tutorials online. The automatic decoding of data is already a planned feature as the operator won’t be able to decode the RF signal anyways.
2. There is effectively only one way to enable autonomous reception on the Ground station.
3. Existing 1U CubeSats transmit telemetry nearly continuously. This allows us to test our receiver using existing satellites in orbit.

#### GND-004

Description:

*The Ground may use cross-platform software*

Reasoning:

*Minimum is it must operate on Windows 10*

Design:

The ground software is written in Java which is cross-platform. Interfacing with the software defined radio might require platform specific software.

Design Discussion:

1. Java provides an easy environment to produce great cross-platform programs and is relatively easy to create a graphical user interface.
2. Other languages would require significantly more effort to create a cross-platform application and a graphical user interface.
3. Existing CubeSats successfully use Java for their ground station and it works cross-platform.

#### GND-005

Description:

*The Ground shall transmit received data to a common repository*

Reasoning:

*This archive will have all of the data of all of the satellites*

Design:

The individual ground stations may transmit their received data via the internet to a server that will collect the data into a database.

Design Discussion:

1. Automatically collecting the data is much easier than asking individual ground stations to email the data over.
2. Having clients transmit data to a database is standard web programming operation and there are not many alternatives to this.
3. See above.

#### GND-006

Description:

*The Ground may have a website with the latest telemetry*

Reasoning:

*Websites are an easy way to show the current status of the satellite to the general public*

Design:

The website will fetch the latest data in the database described in GND-005 and display it using standard web languages. The website could also display graphs to show the change in data over time.

Design Discussion:

1. Browsers are really good at displaying HTML and CSS consistently across platforms without any fuss from the end user and thus are effective to convey the status of the satellite to the general public.
2. Reading from a database and updating a webpage is standard web programming and there aren’t many alternatives to this.
3. See above

#### GND-007

Description:

*The Ground shall have a RX only and a TX/RX version*

Reasoning:

*Only ground stations authorized by Cougs in Space will have TX capabilities for security*

Design:

The ground station software with require a licensing file to unlock the transmitting capabilities.

Design Discussion:

1. Licensing file allows the software to remain the same between the versions.
2. Using a file is not the most secure way to implement this but the intent is not to prevent but to deter those with bad intentions. The software is publicly available so one could build their own ground station but there is significant effort in this to just gain control over a button. The wrong doer would also need the specific uplink frequency which is unknown unless they stand in front of our antenna whilst it is transmitting.
3. Some CubeSats don’t have any security and they work fine. Plus there isn’t much wrong doers can do if they have access.

## In-Flight JTAG Reprogrammer

## Payload

## Structure

1. See Open Systems Interconnection (OSI) model [↑](#footnote-ref-1)