

COSMO Fall 2020 Mission Overview

Chadd Miller¹, Majid Alhajeri², Siva Shankar³, Conner Neilsen⁴, Lea Chandler⁵, Alexei Smith⁶, Jett Moore⁷, Matt Weber⁸, Shabthakiri Rajasekaran⁹, Sam Holt¹⁰, Jash Bhalavat¹¹

1. Project Manager, 2. Systems Engineer, 3. Test Lead, 4. ADCS Lead, 5. FSW Lead, 6. COMMs Lead, 7. EPS Lead, 8. Interfacing Electronics Lead, 9. TCS/STR Volunteer, 10. STR Volunteer, 11. Solar Panel Volunteer

December 14, 2020

COSMO will take scalar and vector measurements of the Earth's magnetic field in Low Earth Orbit (LEO) in a CubeSat sized platform to provide a space-based solution for updates to the World Magnetic Field Model (WMM).



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Executive Summary

This report highlights the current status of and key decisions made on the COSMO CubeSat during the Fall Semester of 2020, whose team can be seen in Figure EX-2. Despite challenges faced due to COVID-19, the team was able to make significant progress on all fronts. Further mission refinement was made possible due to robust radiation and risk analyses, and CONOPs discussions between the ADCS, FSW, and SE teams. Manufacturing also approaches as analysis was performed on the updated structure, the EPS board saw structural and electrical modifications, and the solar panel PCB design is nearing completion. In response, test and test planning efforts increased for the XACT, radios, and overall mission integration. Finally, the addition of a electronics expert to the team has sped up the development of the CDH and the interfacing electronics. Each subsystem has a clear path forward and the project as a whole is moving towards PIR.

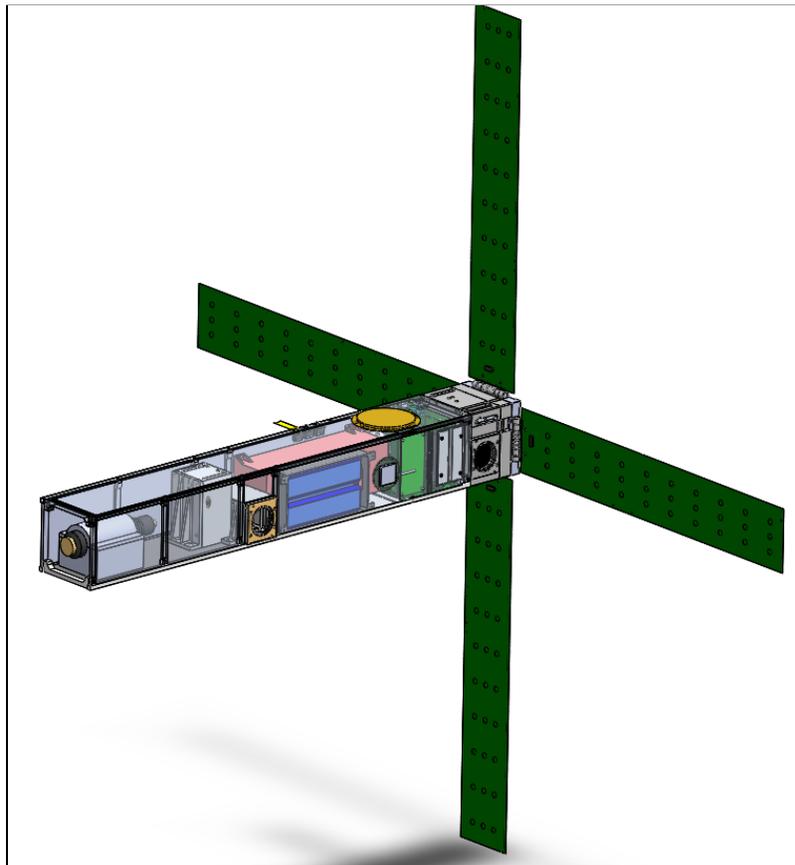


Figure EX-1. COSMO CubeSat Transparent Rendering

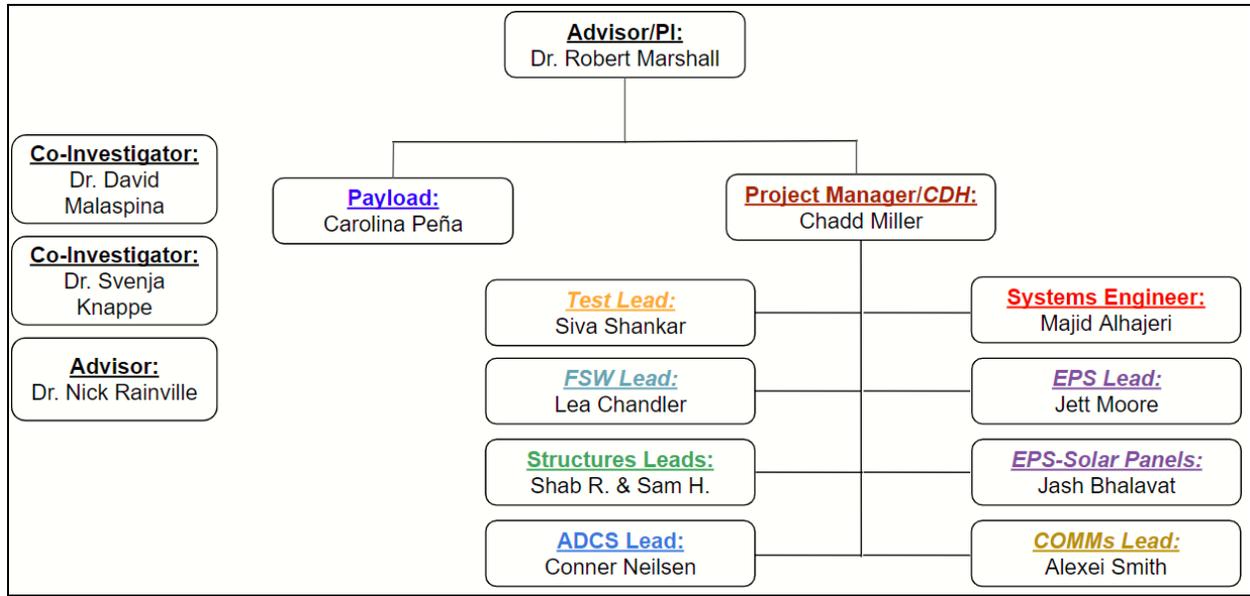


Figure EX-2. FA2020 COSMO Org. Chart

Project Background

The Earth produces a geomagnetic field that runs from its center to the space around it due to the dynamic currents within the core. Although it is often represented as a perfect dipole, perturbations from crustal fields and other anomalies distort this field. Furthermore, the geographic and magnetic poles are misaligned, and the magnetic poles continue to drift at an increasing rate.

Because navigation and control systems globally rely on knowledge of the Earth's magnetic field, a standard called the World Magnetic Model (WMM) was created and adopted by NATO, the DoD, and many civilian referencing systems. It is updated by the National Geospatial-Intelligence Agency (NGA) every 5 years, with the most recent in 2019.

The data for these updates is currently provided by a 3 spacecraft constellation operated by the European Space Agency (ESA). This mission, called SWARM, is set for decommissioning by 2024. COSMO's goal is to replace SWARM as the primary source of WMM geomagnetic data.

NGA also sponsored a competition, called MagQuest, to seek novel approaches for this data collection. COSMO was a competitor and the only university-led team, and took second place with a prize of \$225,000 at the conclusion this year. Due to this participation, COSMO has been designed to meet the MagQuest requirements, which ensures that the mission meets the needs of the WMM, even if it is not selected as NGA's ultimate solution.

Mission Design

Overview

Following the requirements of both the mission and MagQuest, COSMO plans to have a 3 year mission duration, which will consist of a polar orbit with an inclination of 98.6 degrees, nearly circular orbit with a period of approximately 95 minutes. This coincides with an altitude of 600 km, which will result in an average eclipse time of 35 minutes, with the remainder of the orbit being in sunlight. As COSMO will be designed to meet requirements for MagQuest, it will be fully operational by 2027 with a 20 year mission duration, with less than a one month gap every 12 months. However, COSMO's initial demonstration launch (unrelated to MagQuest) is scheduled to take place in 2022. Figure MD-1 shows the orbit of COSMO over the ground station at LASP. Table MD-1 summarizes the mission design details.

COSMO is designed to operate in the following modes:

1. Deployment and Commissioning Mode: Initial mode upon deployment from NanoRacks. The mode will activate the spacecraft, detumble, deploy solar panels and communication modules, and perform system health checks.

2. Safe Mode: Activated during time of low battery power or system failure, and prioritizes system survival. Only high priority components ensuring system survival and communications active.
3. Science Operations Mode: Nominal mode of operation of spacecraft. Defined by activation of data collection during eclipse portion of orbit, and battery recharging during sunlit portions of orbit.
4. Communications Operations Mode: Primary mode in which the spacecraft communicates with the ground. When in range of the LASP ground station, the spacecraft will downlink on-board memory via S-Band transmission.
5. Attitude Switching Mode: Mode when activating on-board reaction wheels to maneuver between different pointing states (magnetic field lines, Sun, ground station).

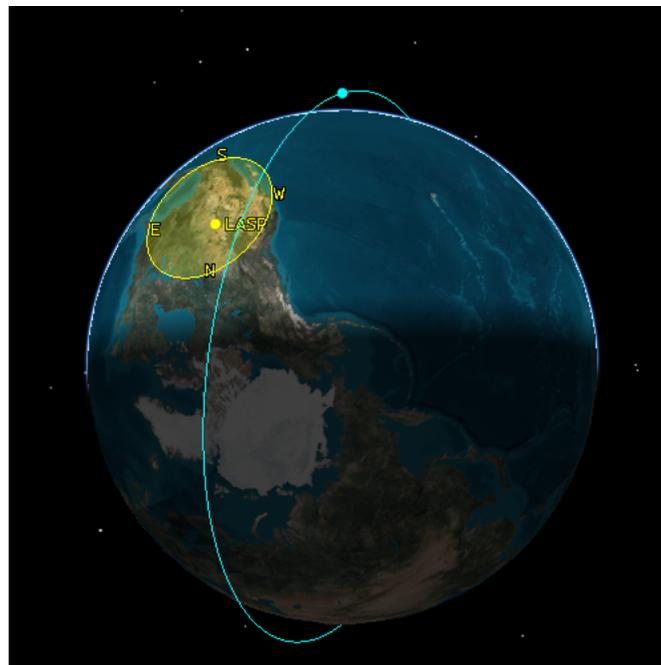


Figure MD-1. COSMO orbit as modeled on STK.

Table MD-1. Mission Design Summary.

Element	Value
Orbit Inclination	Polar Orbit (98.6 Degrees Inc.)
Eccentricity	≈ 0
Altitude	≈ 600 km

Period	≈ 95 minutes
Mission Duration	3 years per COSMO (1 year overlap)
Average Eclipse Time	35 minutes
Average Ground Time	10.3 min/day over multiple passes

Requirements and Constraints

The COSMO team defined a set of requirements, laid out in the Requirements Verification Matrix (RVM), that define the design of the COSMO spacecraft. The goal of these requirements is to define expectations that must be met to ensure the success of COSMO. All of these requirements defined below have been reviewed and accepted by the program sponsor. These requirements are set up so that higher level requirements flow down into lower level requirements, and each requirement is traceable back to the mission objectives. The highest level requirements are mission objectives, shown in Table MD-2, and are defined in collaboration with the science team. These requirements define the purpose of the mission and all other requirements flow down from these mission objectives.

Table MD-2. COSMO mission objectives.

Ref.	Mission Objective
MO-1	Demonstrate the capability of CubeSats to take precise and accurate magnetic field measurements in LEO.
Ref.	Mission Requirements
MR-1	COSMO shall measure the vector components of the Earth's magnetic field with an accuracy of less than 5 nT each.
MR-2	COSMO shall measure the vector components of the Earth's magnetic field with a precision of less than 5 nT each.
MR-3	COSMO shall measure the vector components of the Earth's magnetic field over the range of -70 uT to +70 uT for each component.
MR-4	COSMO shall measure these vector components at a minimum rate of 1 Hz.

In addition to these set of mission objectives, a number of constraints have been defined in collaboration with the project sponsor. These constraints set limitations on the design of the spacecraft based on available resources. Table MD-3 shows a list of all the constraints.

Table MD-3. COSMO mission objectives.

Req.	Requirement Statement	Rationale
CO-1	COSMO shall use the LASP ground station facilities for UHF communications	Required as the project is being done in conjunction with LASP (institutional constraint)
CO-2	COSMO shall use the LASP ground station facilities for S-Band communications	Required as the project is being done in conjunction with LASP (institutional constraint)
CO-3	COSMO shall use the NRCSD for deployment	Allows for the use of a 1x6 bus and sun-synch insertion (mission constraint)
CO-4	COSMO shall use the XACT ADCS from BCT.	The XACT has already been purchased
CO-5	COSMO shall use AzurSpace 3G30C solar cells.	The solar cells have already been purchased

In addition to the requirements and constraints shown on Tables MD-1 and MD-2, a set of mission design-specific requirements have been flown down from the aforementioned sets. Table MD-4 shows these requirements.

Table MD-4. COSMO mission objectives.

Req.	Requirement Statement	Rationale
MD-1	The orbit of COSMO shall have an orbital inclination between 81-99 degrees.	Requirement for MagQuest
MD-2	The orbit of COSMO shall be inserted into orbit at an altitude between 400-800 km.	Requirement for MagQuest
MD-3	The orbit of COSMO shall be limited to an eccentricity between 0 and 0.001.	Analysis is more accurate when spacecraft is in lower, consistent circular orbit.
MD-4	The COSMO mission shall have a lifetime of 20 years with gaps no longer than 1 month every 12 months.	Requirement for MagQuest
MD-5	COSMO shall be fully operational by 2027.	-
MD-6	COSMO shall complete an Orbital Debris Assessment Report (ODAR) that verifies compliance with NASA-STD-8719.14.	Required by the NCRSD.
MD-7	COSMO shall not be powered on within 30 minutes of deployment from the NCRSD.	-
MD-8	COSMO shall be powered on in Safe Mode after it leaves the dispenser once the batteries have reached greater than 80% charge.	-
MD-9	COSMO's deployables will be deployed once the spacecraft has detumbled (.5 deg/sec) (TBR) and been switched into Normal Operations Mode.	Reduces the risk of damage to the spacecraft or deployables by assuring it is detumbled.
MD-10	All COSMO spacecraft modes shall be defined in a concept of operations document	-

	(DOC ____)	
MD-11	The mission shall provide a ground segment to monitor and control COSMO.	The mission will need this in order to send commands and receive telemetry.

CONOPS Discussion

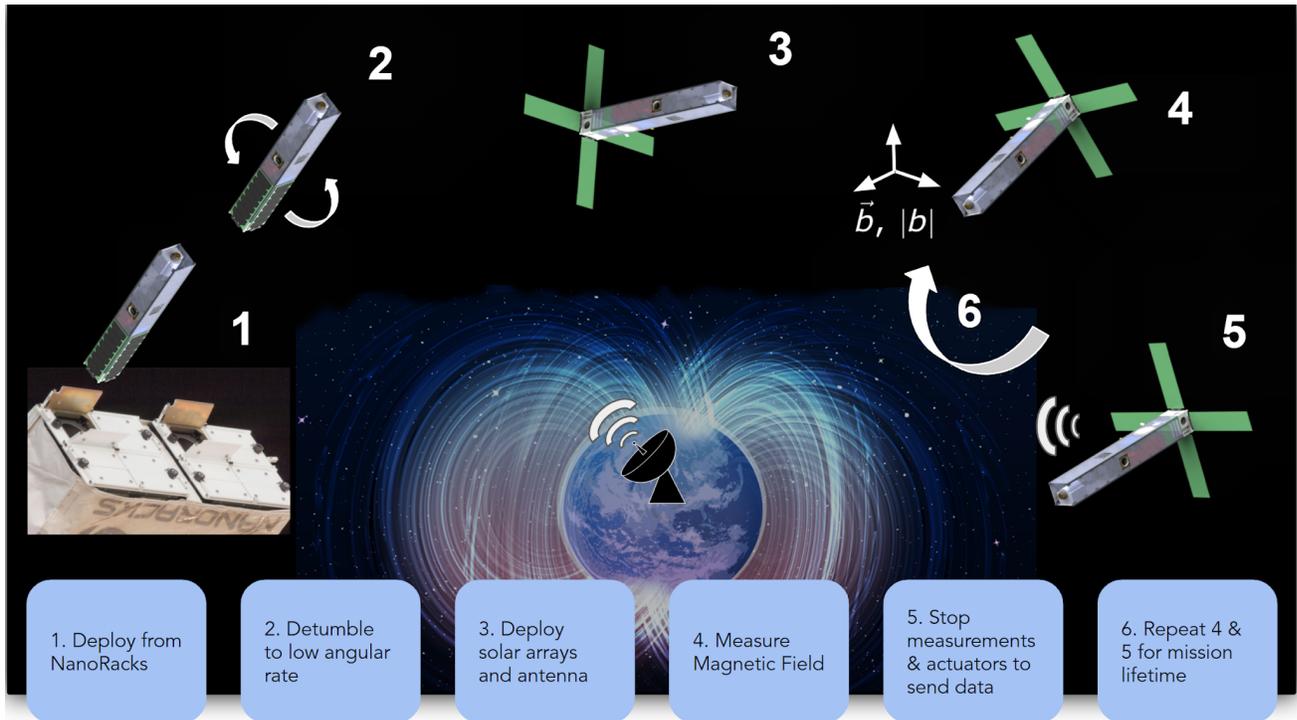


Figure MD-2. COSMO commissioning plan.

The Concept of Operations (CONOPs) for COSMO is shown in Figure MD-2. COSMO will be launched on a launch vehicle that meets the aforementioned orbit requirements and will be deployed via the NanoRacks deployer system. COSMO will remain unpowered for 30 minutes after the spacecraft is released from the deployer via a timer on the CDH. The spacecraft will then power on and begin to detumble itself to a maximum of $0.5^\circ/s$. Once the spacecraft is detumbled it will deploy its deployables, namely the solar arrays and the UHF antenna. Once the spacecraft appendages have been deployed the spacecraft will wait for contact with the ground station and then move into normal operations mode, via ground command. Whenever the spacecraft is over the LASP ground station the payload will be turned off and the spacecraft will slew point at the ground station. During this time, the spacecraft will downlink health and status (HS) data and payload data as well as receive commands to/from the ground station. This process will continue until the spacecraft deorbits into Earth's atmosphere, burning up on reentry.

Normal operations for COSMO will mean that the spacecraft will be taking science data throughout its orbit. In this mode the spacecraft will be sun-pointed on the day-side for power generation and will track Earth's magnetic field on the night-side. Where this transition between attitude states is still to be determined. This magnetic field tracking, to within 45 degrees, is required to take magnetic field data as the quality of data reduces as the magnetometer becomes perpendicular with the field. Initial analysis was done to determine if the spacecraft would be able to generate enough power if the magnetic field was tracked throughout the orbit. This was found to not be possible based on the current power budget. The team therefore moved to the above discussed operation plan, attaining data at around 2/3 of the orbit. COSMO also has a stringent magnetic noise requirement. The solar arrays have a large amount of current flowing through them, in turn causing magnetic noise. Further testing needs to be done to determine how much noise this will create and whether the day-side data is viable. On the night-side of the orbit the spacecraft will be able to take very clean data without the magnetic noise of the solar arrays and the potential to turn off the torque rods (TRs) for this portion of the orbit.

Radiation Analysis

A radiation analysis study was initiated in the Fall 2020 semester, in order to model the expected radiation environment that COSMO will endure over the course of 3 years in orbit. The radiation analysis is critical in determining the necessary shielding required to protect COSMO's radiation-sensitive components, such as the electronics, from all forms of radiation. The study was conducted on STK SEET and SPENVIS, two different software of different modeling approaches, for verification of results.

The primary objective of the radiation analysis was to determine the required shielding necessary to protect components prone to degradation due to exposure. The secondary objective was to model the SEU rates of COSMO at the intended orbit, in order to characterize the need for additional protective measures. Detailed analysis and results can be found in the Radiation Analysis folder in the Systems Engineering folder on Google Drive. The following tables provide a summary of the key outcomes of the analysis:

Table MD-5. Total Mission Radiation Dose.

Al Thickness (mm)	Trapped Electrons (rad)	Brems-Strahlung (rad)	Trapped Protons (rad)	Solar Protons (rad)	Total Dose (rad)
3.00	2.649E+03	3.112E+01	4.804E+02	2.485E+03	5.645E+03

Table MD-6. Mission SEU Rates.

Effect	Mission Total		
	bit ⁻¹	bit ⁻¹ sec ⁻¹	bit ⁻¹ day ⁻¹
Direct Ionization	1.257E+11	1.328E+03	1.1475E+08
Proton Induced	1.137E+01	1.202E-07	1.038E-02
Total	1.257E+11	1.328E+03	1.1475E+08

Current Status, Major Decisions, and Next Steps

The majority of the mission design is finalized. The only steps moving forward would be to use STK or the XACT EDU to calculate the duration that the magnetometer will be within 45 degrees of the magnetic field lines in order to determine the total amount of data we will receive per orbit. Future work includes, but is not limited to the following:

- investigating the reboot sequence
- Investing switching modes
- Verification of requirements through planned testing.
- Coordination between the SE, CDH, EPS, and STR teams be conducted in order to ensure that sufficient shielding is provided for sensitive components, due to the long duration of the mission.
- Investigating the effects of SEEs as well as mitigation strategies through coordination with CDH and FSW leads.
- Development of an appropriate reset concept.

Since most of the work has been completed in terms of Mission Design, no major decisions have been made this semester. A higher fidelity CONOPS model was developed and should continue to be maintained in order to align with the project's development. Additionally, the requirements document was revamped for proper tracking and development, and should be continued to be maintained as the verification process begins.

Payload (PLD)

Overview

The COSMO payload is made up of four components: an optical bench of material SupremEX 640XA, two Blue Canyon Nano Star Trackers (NSTs), a novel “Vectorized” Scalar Rubidium Optical Magnetometer, and the Magnetometer’s supporting electronics. The PLD is designed to minimize any deviation between the attitude measurement NSTs and the magnetometer. Thus, the NSTs are mounted to an optical bench of low thermal expansion and high thermal conductivity. This optical bench is then separately mounted to the spacecraft. A CAD rendering of the payload is shown in Figure PLD-1. This instrument payload is being developed separately from the COSMO spacecraft to meet the science requirements of the mission (Table MD-2). Therefore, significant detail is not presented here.

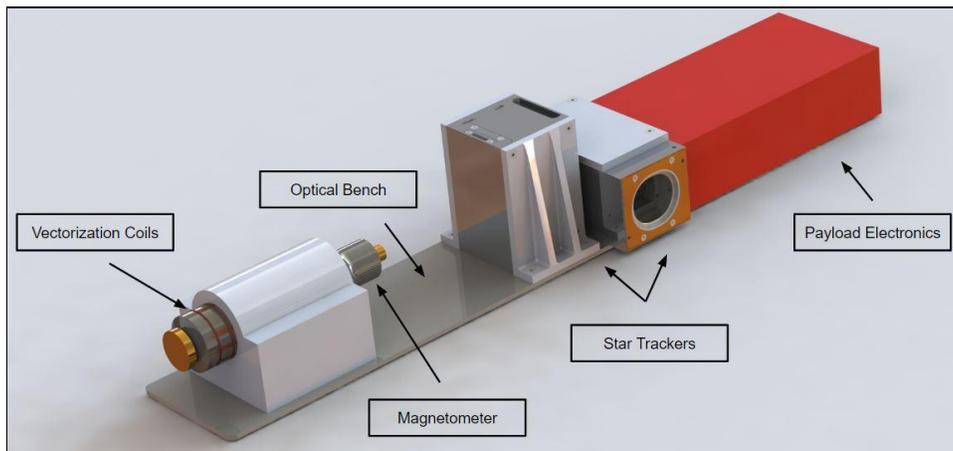


Figure PLD-1: Payload components and CAD rendering

Payload Interfacing

An instrument ICD is under development for the COSMO mission, and will provide further detail in interfacing with the spacecraft. However, as the spacecraft progresses in the meantime, the Size, Weight, And Power (SWAP) requirements in Table PLD-1 have been imposed on the Payload by the spacecraft. Interfacing with COSMO’s On Board Computer must also be done using UART (single ended or differential), and require no more than 20 pins total.

Table PLD-1: PLD SWAP Requirements

Component	NST(2)	Magnetometer	Electronics
Size (cm)	10x5x5.5	14x6.5x7.5	21x6.5x8
Weight (g)	700	350	1500
Power (W)	1.5 ea	3	3

Spacecraft PLD Interfacing Next Steps

While the PLD development is external to the spacecraft team, a number of steps can be taken to simplify and define spacecraft interfacing, as well as further the PLD subsystem as the spacecraft team is responsible for.

1. Optical bench material quote and purchase
2. Solidify optical bench mounting locations and NST mounting locations, specifying keep-out zones for magnetometer mounting
3. Specify keep-out zones for magnetometer electronics mounting
4. Continue Delrin investigation to reduce the effect of possible eddy currents on magnetometer measurements
5. Create a duty cycling plan to eliminate any loss of data over the LASP ground station

Spacecraft Overview

Description of Spacecraft Subsystems

This section will discuss the design of the COSMO spacecraft as well as each of the subsystems that make up the COSMO spacecraft.

- PLD - Payload: Consists of the magnetometer, star trackers, optical bench and payload electronics. The purpose of the payload subsystem is to conduct the science mission.
- EPS - Electrical & Power System: Consists of the solar arrays, batteries, and EPS PCB. The purpose of the EPS is to provide power to the rest of the subsystems.
- CDH - Command & Data Handling: Consists of the CDH PCB, which includes the on board computer (microcontroller) and memory.
- FSW - Flight Software: Exists in the CDH subsystem. Software used to operate subsystems and translate transmissions into commands.
- ADCS - Attitude Determination and Control System. Consists of the BCT XACT-15 unit to perform necessary pointing maneuvers, as well as a Coarse Sun Sensor and GPS slice.
- TCS - Thermal Control System. Contains TMP100 temperature sensors, battery temperature sensors (RTDs), battery heater(s), and thermal coatings. Used to regulate the temperature of COSMO components to within operational limits.
- COMMs - Communications Subsystem: Consists of two radios and antennas, an Astrodev Lithium-II UHF radio and tape measure antenna and a CydeSpace HSTX S-Band radio and patch antenna. Used for transmitting and receiving data.
- STR - Structures Subsystem. Consists of the structural components of COSMO, such as the chassis, hinges, rails, and subsystem mounts.

COSMO Layout

Figures SO-1, SO-2, and SO-3 show the COSMO coordinate plane used to describe COSMO's axes, the key components that make up the COSMO spacecraft. And COSMO's system block diagram, respectively.

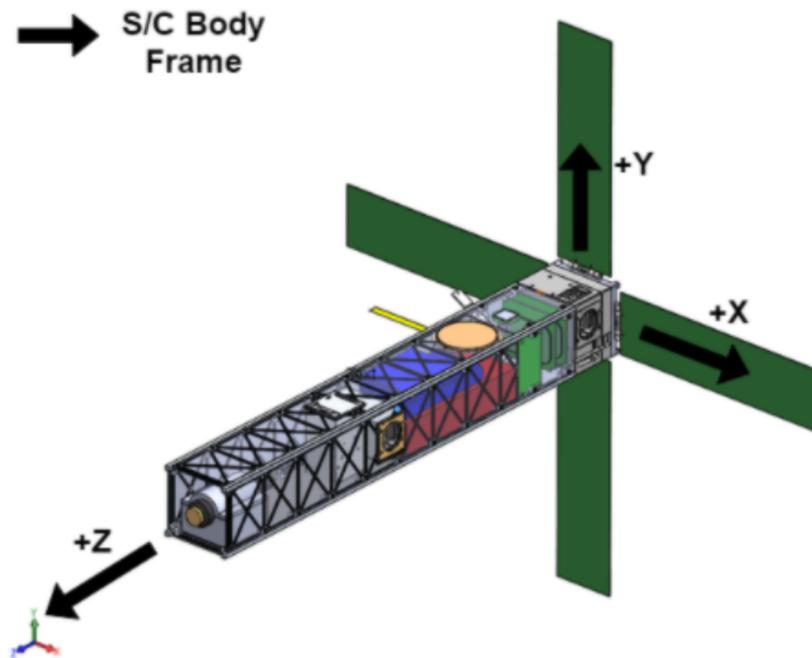


Figure SO-1. COSMO coordinate frame.

#	Equipment
1	Magnetometer
2	Star Tracker(s)
3	UHF Antenna
4	S-Band Antenna
5	Sun Sensor
6	Deployable Solar Panels
7	Aluminum Panels
8	Optical Bench
9	Batteries
10	UHF Transceiver
11	CDH Board
12	EPS Board
13	XACT ADCS Unit
14	XACT GPS Slice

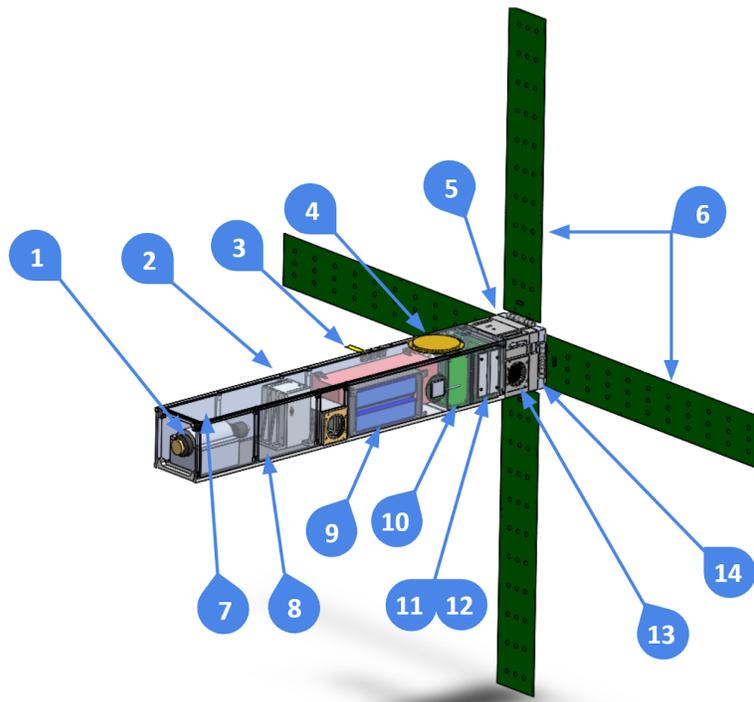


Figure SO-2. COSMO component overview.

Structures (STR)

Structure Overview

The structure for COSMO is 100x100x740mm and consists of four independent aluminum panels which are joined together along the rails using countersunk fasteners (see figure STR-1 below). Each of the panels includes weight relief cuts for mass reduction and through holes for externally mounted components. Additionally, an aluminum crown panel will be used on the -Z face of the spacecraft to allow for mounting of the solar panels and sun sensor.

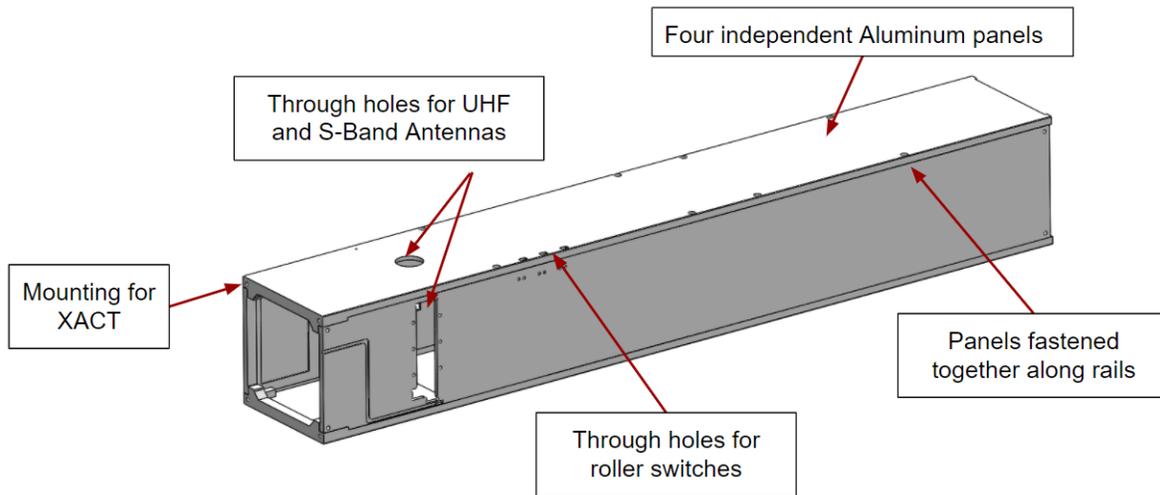


Figure STR-1. Structure overview.

Structure Key Driving Requirements

Figure STR-2 below provides an overview of the key driving requirements for the structure (a full list of requirements can be referenced in the RVM). The primary requirements for the structure are derived from the NanoRacks IDD which outlines the loading and dimensions that COSMO must adhere to. Through previous analysis of static loading, natural frequency, random vibration, and center of mass each of these requirements has been met. However, this analysis must be updated to incorporate recent design changes and improved constraints.

Figure STR-2. Key driving requirements.

KDR	Description	Reasoning
1	COSMO shall be deployed via the NRCSD system and adhere to all requirements laid out in the NRCSD Interface Definition Document (IDD)	We cannot launch if we do not meet the requirements set out in the NRCSD IDD
2	The CubeSat rail length (Z axis) shall be the following (+/-0.1mm): 6U rail length: 681 to 740.00mm	We cannot launch if we do not meet the requirements set out in the NRCSD IDD
3	The STR subsystem shall have a center of mass in the Z-axis that is +/- 12 cm from the geometric center of the s/c.	We cannot launch if we do not meet the requirements set out in the NRCSD IDD
4	The STR subsystem shall be capable of withstanding 1200N across all rail-ends in the z-axis.	We cannot launch if we do not meet the requirements set out in the NRCSD IDD

Structures Status

Over the course of this semester, the primary updates to the structure have focused on mounting, fastener selection, and investigating the feasibility of using Delrin panels around the magnetometer.

A majority of the updates to the structure have been minor changes to prevent interference and allow for wire routing. However, a few notable changes include the solar panel hinges and the star tracker mounting.

The hinges for the solar panel are finalized and are currently being manufactured. Initially just one set of the hinge is machined, to check proper functionality of the torsion spring mechanism and check if the solar panel PCBs are able to withstand the deployment torque.

Both of COSMO's NST star trackers will be mounted to the optical bench along with the magnetometer to ensure that their relative orientations remain stable despite thermal fluctuations. The NST's will be mounted using custom aluminum mounting brackets manufactured in house. For ease of assembly, through holes have been added to the -Y panel to allow for the mounts to be fastened or removed even after the panels have been joined (see STR-3 below).

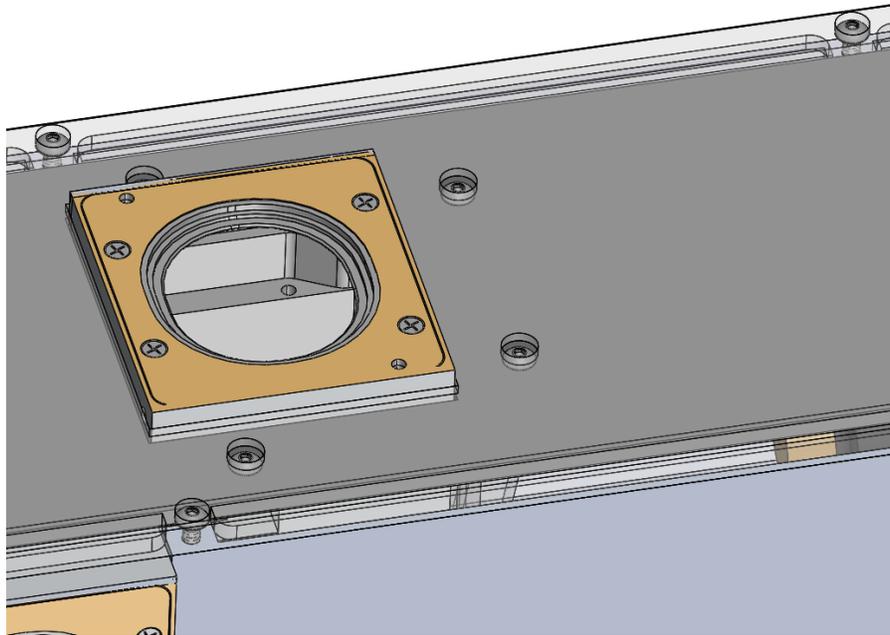


Figure STR-3. Through holes for NST mounting.

In addition to selecting fasteners and incorporating them in the CAD model, the previously selected flat head screws have been replaced with button head screws. This change was made to allow all fasteners (excluding fasteners along the rails) to sit flush with the aluminum panels and remove the need for countersinks. An example of this can be seen below in STR-4.

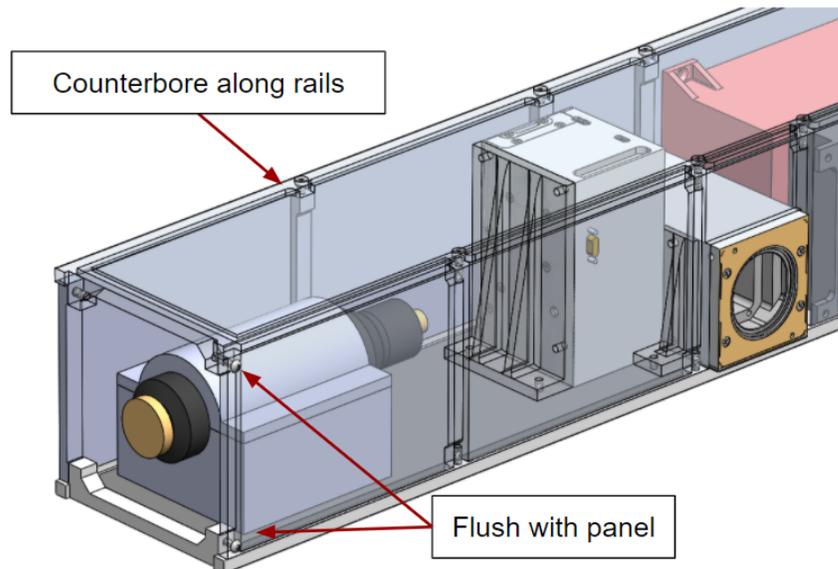


Figure STR-4. Fasteners.

In order to reduce eddy currents in close proximity to the magnetometer, the feasibility of using partially Delrin panels was investigated. STR-5 and STR-6 presents two approaches that were considered.

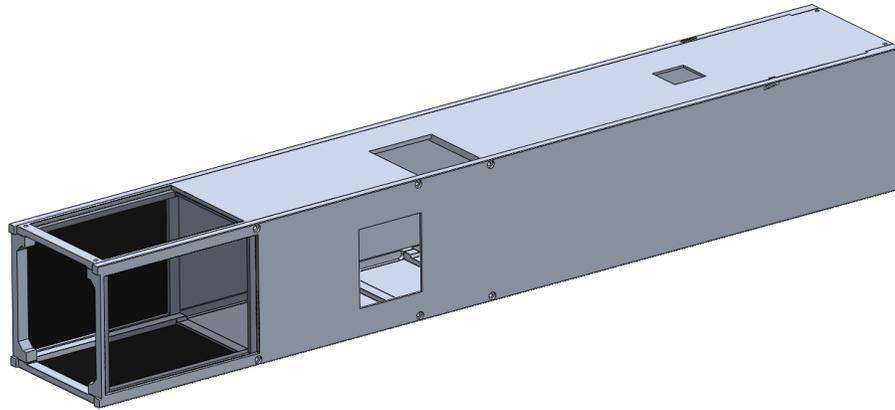


Figure STR-5. Solid Delrin panels.

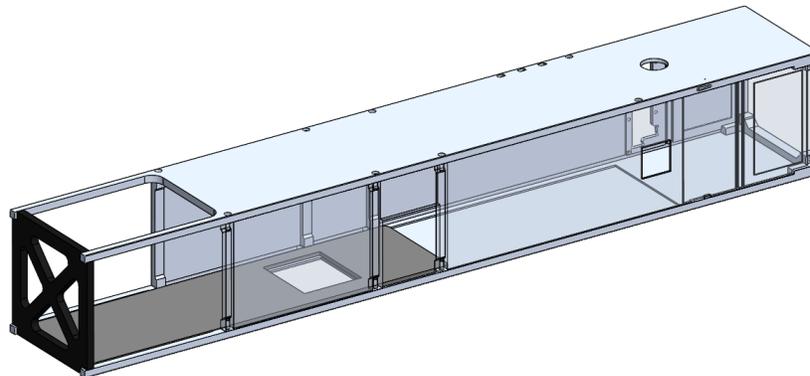


Figure STR-6. Delrin crown panel.

In the first case (STR-5), Delrin was added to fully surround the magnetometer and the aluminum skeleton was preserved for stiffness. As expected this change had very little effect on the overall stiffness, however, it did not greatly reduce the mass of aluminum surrounding the magnetometer. Therefore, to determine the extent to which the aluminum near the magnetometer could be reduced, the second case (STR-6) was considered. In this configuration all aluminum surrounding the magnetometer with the exception of the required aluminum rails was removed and a Delrin end piece was added. Using this as a bare minimum case, static loading and natural frequency analyses were conducted and can be seen below in STR-7 and STR-8.

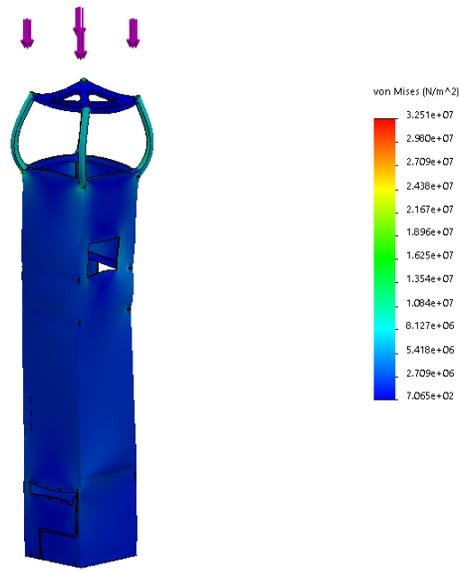


Figure STR-7. Static analysis.

Model name: Structure_Assembly_v4
 Study name: Frequency 1 (Default)
 Plot type: Frequency Amplitude
 Mode shape: 1 | Value: 165.45 Hz
 Deformation scale: 0.0164718

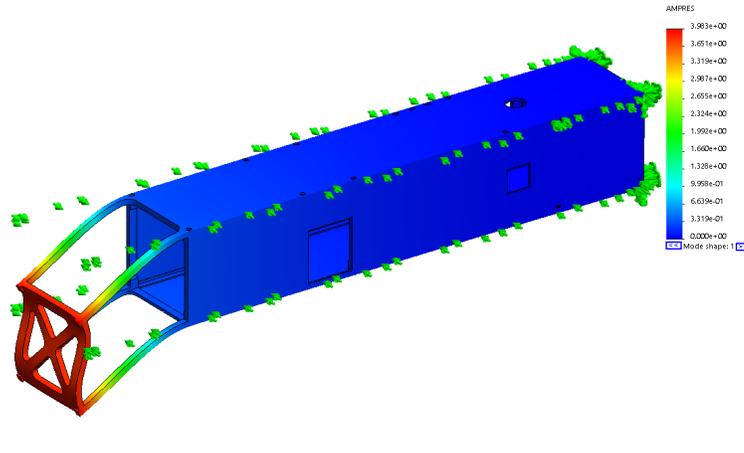


Figure STR-8. Natural frequency analysis.

From this analysis, it was found that the maximum stress during static loading reached $3.3 \times 10^7 \text{ N/m}^2$. While this result is still below the yield stress of the aluminum ($2.75 \times 10^8 \text{ N/m}^2$) it was nearly three times higher than the original fully aluminum design. Similarly, the first mode of this configuration (165 Hz) was much lower than the original design (1050 Hz) but still below the expected launch frequencies (20-25 Hz). As such, it appears that a partially Delrin design is indeed feasible but could benefit from minor modifications to improve the strength and stiffness.

Structure Steps to PIR

1. Update structural analysis to incorporate improved constraints from LASP
2. Complete any necessary revisions for manufacturing
3. Define the mounting interface for the optical bench and magnetometer electronics
4. Upon completion of the solar panel hinges, conduct deployment testing with FR4
5. Complete the Delrin design and analysis and the subsequent changes to the bus panels

Command and Data Handling (CDH)

CDH Overview

The Command and Data Handling (CDH) subsystem is responsible for storing payload data, communicating with all other spacecraft subsystems, and running the Flight Software (FSW). Figure CDH-1 shows some of these interfaces in a block diagram format. It is entirely composed of the CDH Printed Circuit Board (PCB) and its components. The main components include the Microchip dsPIC33EP512MU810 Microcontroller and 2 Single Layer Cell (SLC) microSD cards. Additional background information about the CDH Board components and design can be found in COSMO_CANVAS_CDH_Summer_2020.pdf and in the CANMO_Core_Avionics_ICD. This design has heritage on MAXWELL and MinXSS, but has been significantly modified for COSMO and CANVAS interfacing. This semester saw the move from a 4-6 layer board and the switch to a new GSE interface as major updates, and the subsystem is currently nearing manufacture-readiness.

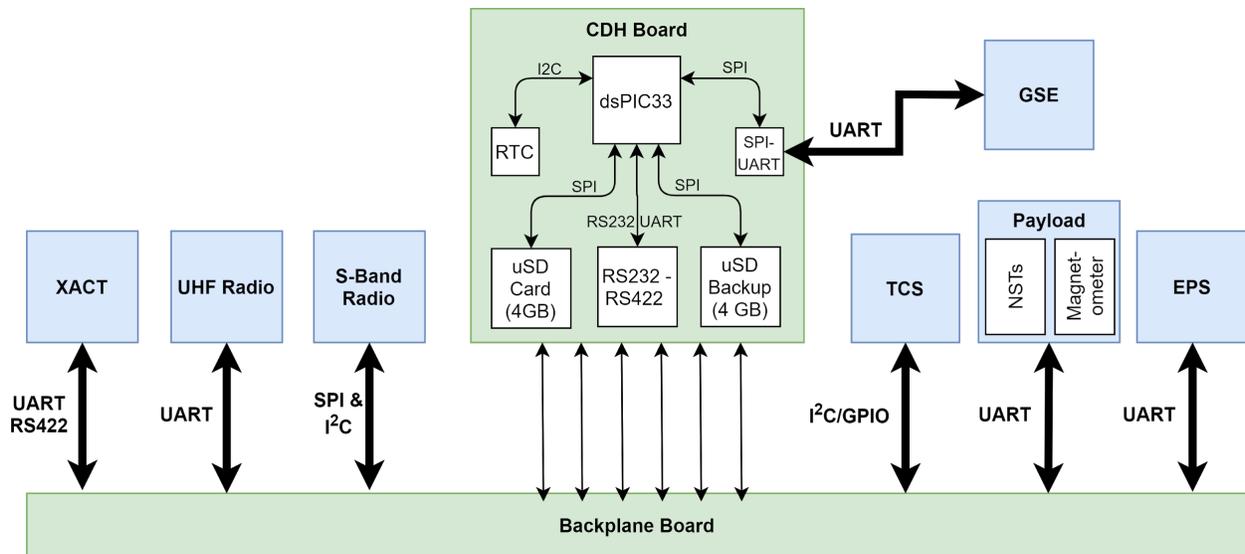


Figure CDH-1. COSMO CDH Block Diagram.

CDH Requirements

Table CDH-1 lists a few of the mission requirements that drive the CDH design. The full list of requirements can be found in the COSMO RVM.

Table CDH-1. Key Driving Requirements.

KDR	Description	Reasoning
-----	-------------	-----------

1	The COSMO CDH shall be capable of interfacing with all spacecraft subsystems and components (including STR)	The CDH must be able to interface to communicate commands and data.
2	The CDH shall be capable of operating in the radiation environment of Earth.	3 year mission duration over the poles presents a more significant radiation challenge, which must be addressed for mission success.
3	The CDH shall include a minimum of two weeks worth of on board data storage.	Should communications have a recoverable failure, the spacecraft will still be able to record data for a period while the recovery is executed.

CDH Status & Major Decisions

The CDH board has been redesigned to meet COSMO and CANVAS interfacing requirements and has undergone two layout revisions based on the changing project needs. The current revision is in a pre-reviewed state. The main schematic design has remained unchanged as of CDR, but several small changes have been made. The layout has changed significantly, however.

Many general electronics updates have been carried out since CDR with the assistance of CANVAS' Electrical Engineer. These include the implementation of Altium project version control, unified board design principles, common board shape and templates, and library control. Additional information on these principles can be found in the Electrical Engineering Principles document in the LAIR-Altium Shared Drive.

Schematic changes include mainly the addition of internal signal debug connectors and removal of the large Debug connector that can be found on previous CDH revisions and that of MAXWELL and MinXSS in favor of a new GSE design. Another schematic change was the significant re-assignment of pins on the PIC and backplane connector to promote routing ease. These pin assignment updates can be seen in this document: [CDH PIC Redesign Notes](#).

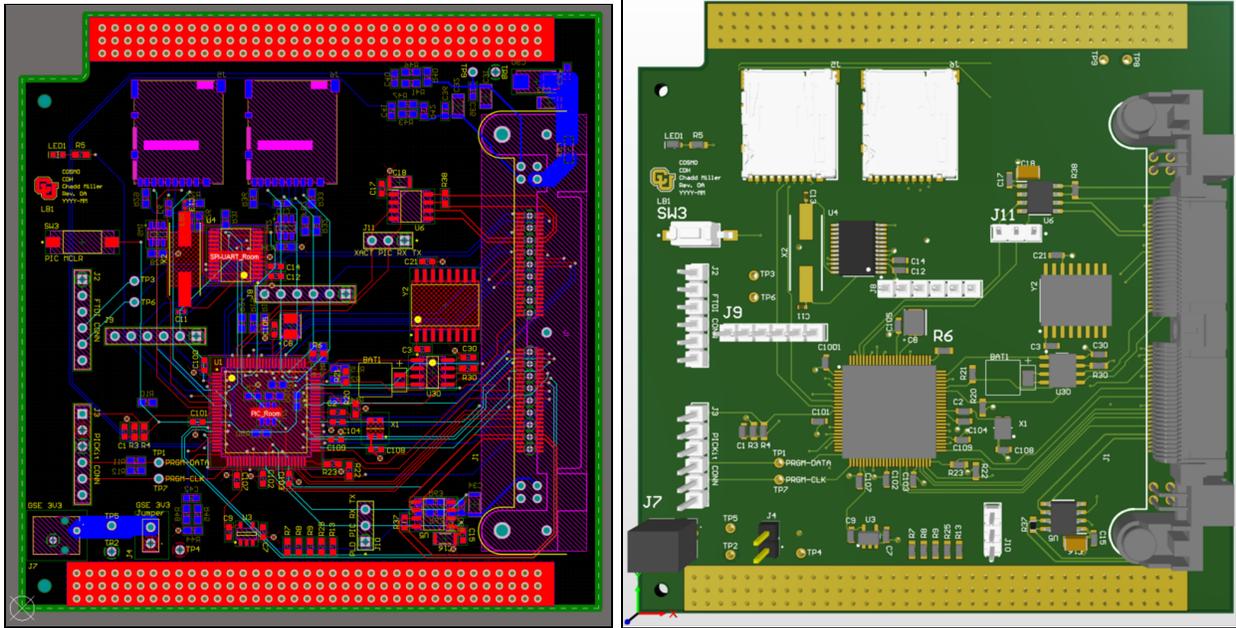


Figure CDH-2. Current CDH Layout.

Layout changes were considerable this semester, and included the move from a 4-layer to a 6-layer board. This allows an internal signal routing layer which increases the cost of the board, but allows for significantly easier routing and wider spacing between traces. This wider spacing was required upon implementing new unified Design Rules for CANVAS and COSMO PCB Layout, which include increased spacing between data signals, clock signals, and differential pairs.

A number of internal signal debugging headers were also added to the CDH board, as were an FTDI connector, PICKit connector, reset button, and external 3.3V power jack. These connectors allow integrated and non-integrated debugging and programming directly connected to the PIC. With the removal of the Debug connector, full CDH debugging and testing will now be done using the GSE board through the backplane connector in a “FlatSat” configuration. This frees up significant amounts of space on the CDH board, and does not require that signals be split from the PIC to the backplane and the Debug connector - as was required in the previous design.

The board shape was modified to adhere to the common board design and the board was re-routed with the above changes in mind. The current layout can be seen in Figure CDH-2. Additionally, suppliers were investigated for the parts on the CDH board using Altium’s ActiveBOM feature, so that the CDH board is ready for manufacturing as soon as possible.

In preparing for the semester Reviews, a number of unit testing protocols were also considered in slightly more detail for the first time, and these can be found in Table CDH-2.

Table CDH-2. Unit Testing Overview.

Test Name	Description	Resources Needed
Acceptance - Continuity	Check continuity between pins and their locations on the backplane, power, GND, etc.	Multimeter (GSE preferred), power supply
Acceptance - Basic Functionality	Ensure connection to required components, check output of OSC2, I/Os should be high-Z	Multimeter, oscilloscope, power supply (GSE preferred)
Acceptance - Programmable (LED)	Plug in PIC programmer to GSE connector, attempt to program device and make LED blink	PICKit4 Programmer, power supply, LED blink program
Functional-Digital Interfaces	Load tested program to toggle at least all digital interfaces (possible all pins), check high/low	PICKit4 Programmer, power supply, toggle I/Os program, multimeter (GSE preferred)
Functional - Peripheral Interfaces	Test UART, SPI, I2C lines for basic functionality, heavily test RS422 converters	PICKit4 Programmer, power supply, simple interface driver program, oscilloscope (GSE <i>strongly</i> preferred)
Functional - SD Card Memory Test	Read/write SD Card with dummy data, ensure access to specific areas of memory	PICKit4 Programmer, power supply, simple SD card read/write program, (GSE <i>strongly</i> preferred)
Functional - RTC Watchdog Reset	Test the watchdog's ability to reset the CDH in the event of a latchup	PICKit4 Programmer, power supply, program to cause reset, (GSE <i>strongly</i> preferred)

CDH Next Steps/Path to PIR

Pre-Integration Review readiness is defined here as having a fully manufactured and unit-tested CDH board that is functional and ready to begin integration and integrated testing. The steps to reach this point, in chronological order, are:

1. CDH Board Layout Review with CANVAS EE and make final revisions
 - a. Planned to be done over Winter 2020-2021
2. Altium Heritage/Radiation Tolerance analysis
 - a. Examine to ensure every component had flight heritage or has been cleared for space use - planned Winter 2020-2021, not critical path for Revision 1
3. CDH Board Revision 1 manufacturing preparation
4. Procure CDH board and components
5. Board manufacture by assembly of components onto PCB (internally or externally)

6. CDH Unit Testing (see table CDH-2)
 - a. Requires additional resources like simple FSW scripts and preferred access to functioning GSE board
 - b. Test procedures should also be written if possible
7. CDH EMI Testing
 - a. After unit testing is complete, the CDH board should be testing in its peak current mode to examine its EMI

At this point, the first revision of the CDH board should be ready for PIR. After PIR, the CDH component ratings should also be checked to ensure their maximum limits meet at least twice the expected operating conditions ([Parts Ratings Template](#)). Additionally a hard reset concept should be considered and implemented on Revision 2 of the CDH board. This reset method would help the CDH recover itself and the rest of the spacecraft from failures caused by Single Event Effect (SEE) radiation events. It is crucial, however, that this reset concept perform a full power removal from the CDH (as opposed to the current watchdog and reset button performing a “soft” reset by toggling the PIC’s MCLR pin). It is tentatively recommended to use the CDH RTC Watchdog as the master device and to edit its circuitry to be able to activate an enable line on the backplane or CDH board which completely severs the connection from the backplane power to the CDH power plane. The CDH, effectively reset, may then operate and work to individually reset additional subsystems (including the EPS PIC) as needed to attempt to recover from a SEE failure.

Electrical & Power System (EPS)

EPS Overview

The Electrical and Power Subsystem (EPS) is responsible for generation, storage, and distribution of power to all subsystems. The subsystem consists of three primary components: two 14.8 V 2600 mAh Tenergy Li Ion batteries, four solar panels and a power management printed circuit board (EPS board). The EPS board takes in a 17-24V solar panel voltage and converts it to a 16 V bus voltage to charge the batteries. Further, the EPS board bucks the bus voltage into three regulated voltage rails. One of the voltage rails is 3.3V and powers most spacecraft electronics and ICs. The other two rails output 12V with one of the 12V rails dedicated to the XACT due to its 3A inrush current. In addition to distributing power, the EPS monitors the battery state of charge and is tasked with efficiently optimizing solar panel power using the dsPIC 33 microchip. The chip also packages data for UART communication with the CDH. For ground testing and powering the EPS contains pin headers for programming and a DC jack for ground charging. The EPS also contains part of the inhibit circuitry required by Nano Racks. The physical deployment switches for this circuitry can be found on the backplane, or GSE board. Figure EPS-1 depicts the block diagram for EPS.

EPS Key Driving Requirements

Table EPS-1 displays the key driving requirements behind the Electrical and Power Subsystem. The requirements listed are not an exhaustive list of the requirements behind EPS, but they do capture what led to the design described in the EPS overview. Requirement EPS-2.1 is motivated by advice from LASP.

Table EPS-1. EPS Key Driving Requirements.

Req.	Description
EPS-1	COSMO shall be power positive on average over the course of an orbit.
EPS-2.1	The EPS battery shall not fall below a state of charge of 60%.
EPS-6	The EPS shall provide power to every subsystem at the appropriate voltage.
EPS-11	The EPS subsystem shall follow all electrical system requirements of the dispenser.

EPS Status

Power Management Board

Revision 0A of the EPS board has been procured from Advanced Circuits and is awaiting population. To get to this point, the EPS board has been significantly modified from the MAXWELL design. In order to meet structural requirements the board was constricted to a 90x94 mm footprint. To accommodate the limited surface area 2 more layers were added to the PCB, for 6 total, including an additional signal layer and an additional ground layer. With the extra signal layer the board was rerouted. The board also contains the necessary components for mounting in the cardstack including copper pours for the rails, a notch and removal holes. The copper pours are the primary interface with the rails. The rails provide thermal relief and prevent abrasions to the surface of the PCB. The notch enables external wire routing through boards on the cardstack. The removal holes allow the EPS board to evenly be pulled out of the backplane using allen wrenches.

In addition to structural changes, several electrical changes were made from MAXWELL's design. Instead of 12V regulated rails, MAXWELL's EPS board contained two 5V rails. To accommodate 12V, the peripheral components for the 5V buck

converters were modified to alter the output voltage. Similarly the peripheral components for the Solar Panel buck converters were exchanged to account for CANVAS input and output voltage requirements. Additionally, voltage dividers surrounding the dsPIC 33 were adjusted for 12V rail monitoring. In order to ease ground testing a physical program reset switch was added to the board in order to reset the dsPIC. Further, pin headers were added to the board for signal testing and microchip programming.

The current design follows the MAXWELL pseudo peak power tracking methodology for power conversion. The current peak power tracking is not functional and is instead replaced by a less efficient current limiting resistor. There are concerns about the lag time and compatibility of peak power tracking with the current EPS buck converters. The current limiting resistors could end up being sufficient for the design, but this will need to be verified through testing on Revision 0A.

Before ordering the board it was important to design rules specific to manufacturing and board requirements. Specifically manufacturing clearance tolerances were taken from Advanced Circuits and trace width rules were implemented for expected board current. In order to confirm the board's compatibility with these requirements a design rule check(DRC) was used to eliminate discrepancies. After the board was validated through the DRC, four boards were ordered from Advanced Circuits. Additionally, components for the board were found using Altium's Active BOM feature and they were ordered from Digikey and Samtec. A stencil is still needed for board production.

For more details on the EPS board functionality and interfaces please refer to the CANMO Core Avionics ICD for Fall 202

Power Budget

Spacecraft Subsystem, Unit, Quantity and Power Consumption									
Subsystem	Component/ Use Case	Max Voltage (V)	Max Current (A)	Peak Power (W)	Nominal Power (W)	Contingency (%)	Qty	Total Peak Power (W)	Total Nominal Power (W)
CDHS	Board/Wire	3.3		0.91	0.64	5	1	0.9555	0.672
COMMs	Astrodev UHF Radio TX	12		3	0.2	5	1	3.15	0.21
	espace HSTX S-Band Radi	12		5	0.9	5	1	5.25	0.945
ADCS	XACT/RW (25%)	12		2.47	0.00	5	1	2.5935	0
	XACT/RW+TR	12	2.53	2.82	0.00	5	1	2.961	0
	XACT/RW (10%)	12		1.92	0.00	5	1	2.016	0
EPS	Board/Wire	-	-	0.1	0	5	1	0.105	0
Thermal	Heaters	14.8 Batt		3	0	25	1	3.75	0
	Sensors	3.3		0.1	0	25	5	0.625	0
STR	UHF Antenna Deploy	14.8 Batt		1	0	25	1	1.25	0
	Solar panel burn wire	14.8 Batt		1	0	25	2	2.5	0
	E- Field burn Wire	14.8 Batt		1	0	25	4	5	0
	CTD Boom	12	0.1666	2	0	5	1	2.1	0
Payload	EF Pre-Amp	12		0.256	0.256	5	1	0.2688	0.2688
	BF Pre-Amp	12		0.015	0.015	5	1	0.01575	0.01575
	Analog Board	12		2.66	2.66	5	1	2.793	2.793
	Digital Board	12		1	1	5	1	1.05	1.05
GPS	Board/Wire	3.3	6	1	0	5	1	1.05	0

Table EPS-2. Current Power budget.

The current power budget meets design requirement EPS-2.1 that the battery shall not fall below a state of charge of 60%. This semester there was investigation into the buck converter loss and its effects on the power budget. Further investigation shall be done through EPS testing in the spring.

EPS MOVING FORWARD

Action items before PIR:

EPS Board

1. Procure stencil for solder paste placement.
2. Populate board using manual pick-n-place in electronics lab.
 - a. Initial continuity test to confirm board functionality.
3. Test signal noise and values.
4. Test solar panel brownout voltage by slowly lowering input voltage with a DC power supply.
5. Test battery charging capability using DC power jack.
6. Test board EMI.
7. Test peak power tracking capabilities using board pin headers.
 - a. Investigate other methods if needed through a trade study.
 - i. Direct Energy Transfer
 - ii. Current Limiting Resistors
 - iii. Dedicated/True Peak Power Tracking
8. Integrate EPS with other boards by utilizing the GSE board.
 - a. Test communication with CDH.
 - b. Test inhibit circuitry capabilities.
9. Modify board according to shortcomings discovered in testing.
10. Procure and populate Rev 1.
 - a. Automatic pick-n-place may be available through the EE department.

Power Budget

1. Review power budget code
2. Modify if needed
3. Implement discoveries from power conversion investigation

EPS - Solar Panels

SP Overview

The solar panel printed circuit board has the solar cells attached to it along with the burn wire resistors and is mounted on the outside of the satellite. The solar cells provide power to the spacecraft such that it can sustain flight operations. When the spacecraft is not in an eclipse, the board collects the power and charges the battery that

will be used during the eclipses. The burn wire resistors are hooked up to nylon wires and they will be powered in order to create heat and melt the wire to deploy the solar panels. For COSMO, the solar panels have 10 cells on each board totalling 40 cells for the satellite. The panel is rectangular in shape with a length of 482 mm and width 88 mm.

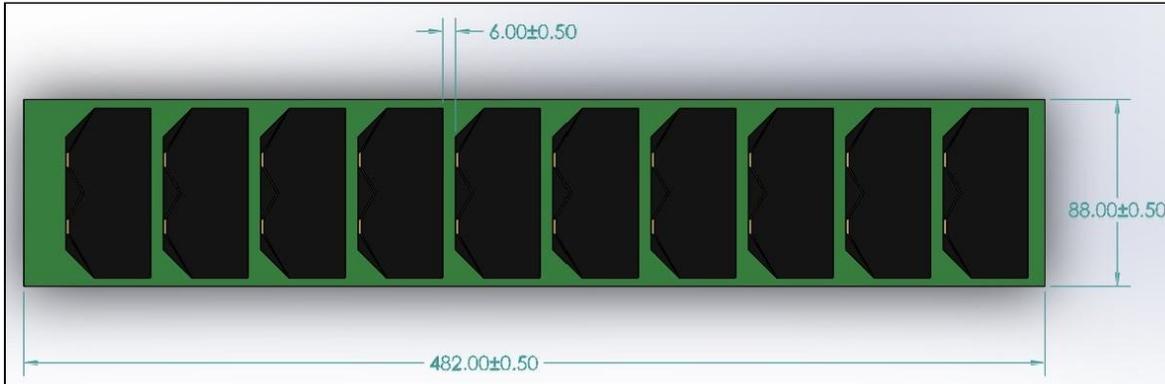


Figure EPS-3. Solar Panel 3D Preview with Dimensions.

SP Status

The solar panel components have been selected and the PCB design is 90% complete barring design rule check in Altium and a thermal relief issue with a connector. Along with that, the manufacturing plan is also in its initial revision. So, once parts arrive, we can quickly get to the next phase of production.

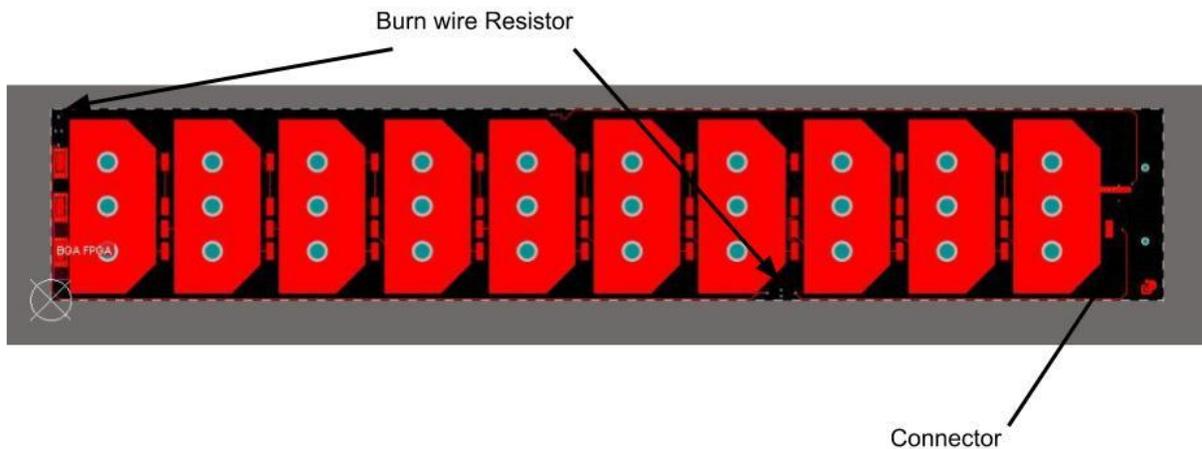
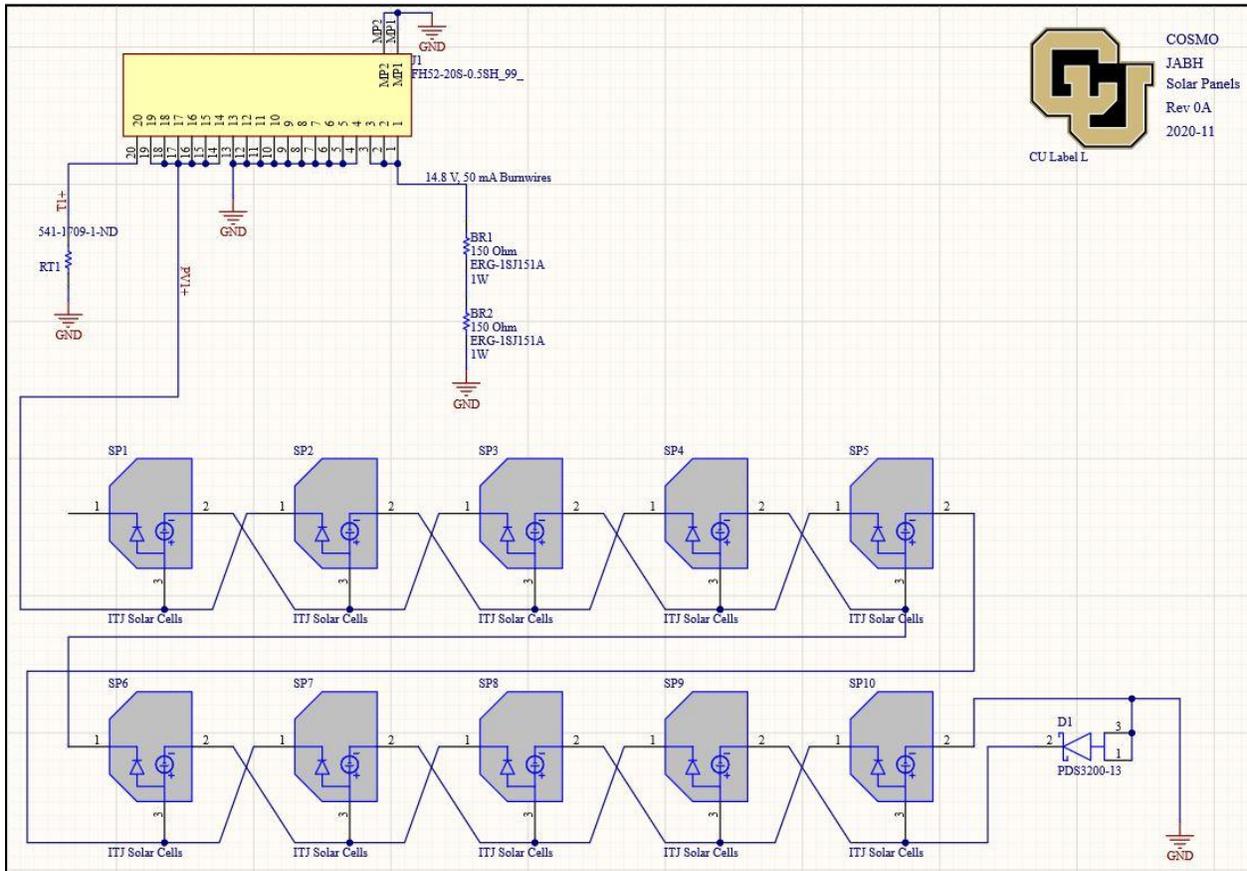


Figure EPS-4. Altium Solar Panel Layout with Burn Resistor and Connector locations highlighted.

SP Next Steps

Next steps for solar panels is to order the PCB, and other components such as the solar cells, resistors (burn wire) and a diode for the first cell. Then, test individual

components first. Then, practice attaching the solar cells to the PCB using mock solar cells. After some practice, we can start attaching the cells to the PCB. Meanwhile, test components together to make sure they perform well together. Then, attach all the components and then re test their entire Solar Panel in mission conditions.



COSMO
 JABH
 Solar Panels
 Rev 0A
 2020-11
 CU Label L

Figure EPS-3: Schematic of the Solar panels

Interfacing Electronics (Backplane, S-Band DB, GSE)

Backplane Overview

The Backplane board is responsible for providing an interface for spacecraft electronics as well as housing deployment and enable circuitry. Due to variations in mission requirements, the backplane is configured differently for COSMO and CANVAS. For both missions there is a card-stack that holds the other electronics boards. On COSMO, this card-stack contains the CDH, EPS and S-Band Daughter Board. Smaller connectors account for the payload, 4 Solar-Panels, UHF signals, temperature sensors, UHF burnout, XACT and battery voltage. Additionally, COSMO contains power enable circuitry for the UHF and payload. Also positioned on the backplane is burnout enable circuitry, that provides battery voltage to burnout resistors for the deployment of the UHF and Solar-Panels. The layout for the COSMO backplane can be seen in the figure below.

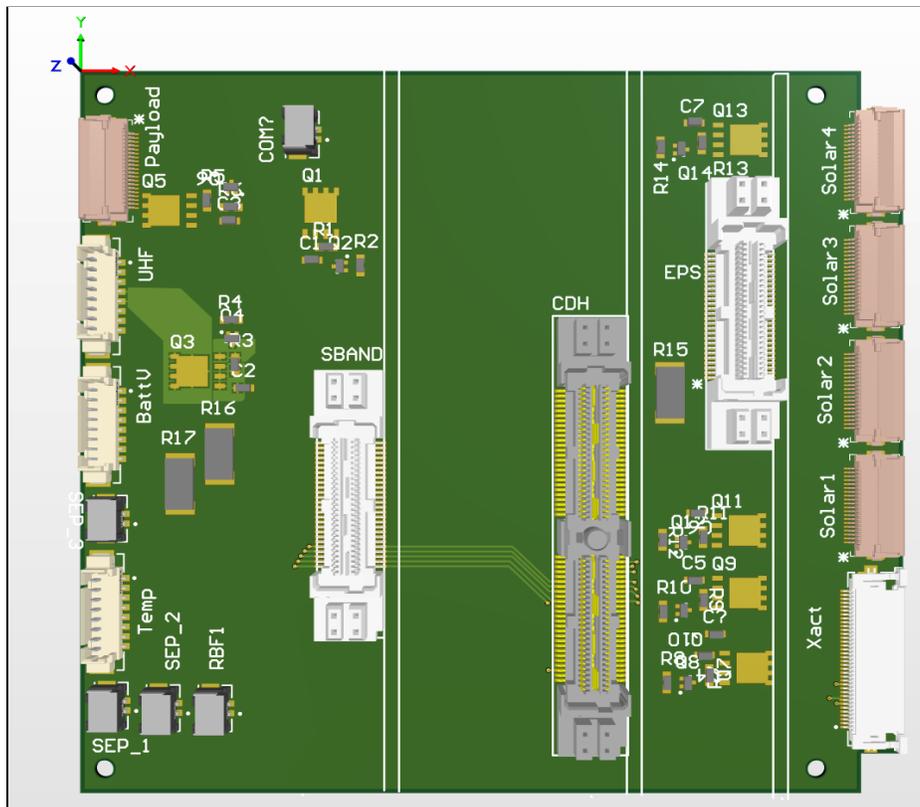


Figure BP-1. Backplane Layout.

Layout

Two factors were taken into consideration when determining the backplane layout, ease of routing and EMI (Electromagnetic Interference). The board anticipated to create the most EMI is the EPS. To account for this, the EPS is placed away from the analog board on CANVAS and the magnetometer on COSMO. For ease of routing, the surface mount connectors are placed along the edges of the backplane on the side closest to the instrument being connected. Rules for Advanced Circuit's 4-Layer Special are currently implemented in Altium in addition to Net specific width constraints. Routing is still needed on both backplanes as well as a design rule check. In order to adjust for the rules, the biggest anticipated obstacle is Silk Screen clearance constraints. Thermal considerations may also be needed for the backplane.

Wire Routing

The wire routing for COSMO is not as developed as the routing for CANVAS because there are not as many obstacles for cables in COSMO to run into. In CANVAS, the cables from the payloads need to be routed through the card stack to the analog board, but this is not the case for COSMO because the payload will be routed directly to the payload connector on the backplane. As for other cables throughout the COSMO structure, such as cables from the solar panels, batteries, UHF, and XACT to the backplane, these will be bundled and staked to the structure as needed. The wire bundling and staking methods will follow those used in the MinXSS mission, namely the use of ESD safe and low outgassing zip ties for bundling and Arathane 5753 + cabosil glue for wire staking. These methods of bundling and staking inside the structure have proven successful in past missions to prevent stray cables and wires from interfering with other components.

Deployment Circuitry

Power enable circuitry allows a controlled distribution of inrush current between spacecraft components. Inrush current is the current needed to startup a component. The XACT has a dedicated 3A line so it doesn't need a power enable switch. The UHF and payload enable circuitry, allows a multi stage power startup for the spacecraft, controlled by the CDH board.

Similar to the power enable circuitry, the burnout circuitry allows a controlled deployment of inertia altering spacecraft components. In the current state of the CDH and backplane all solar panels must be deployed at once. If a unified deployment is not structurally feasible, separate pins could be dedicated in order to deploy each Solar-Panel string individually. In addition to the Solar-Panels, burnout circuitry is included for the UHF antenna on both spacecraft.

RBF and Separation circuitry

Two of the key design requirements for the backplane are, “The subsystem shall adhere to all Electrical System Design and Inhibits outlined by NRCSD” (EPS-11) and “The RBF / ABF feature shall preclude any power from any source operating any satellite functions except for pre- integration battery charging”(EPS-11.6). The backplane contributes to these requirements by housing connections for physical deployment switches in addition to a RBF(Remove Before Flight) switch.

The backplane works in combination with the EPS board to ensure the NRCSD requirement is met. Deployment switches D1 and D2 are connected in series with the RBF switch to disable power between battery positive and load on the EPS board. D3 is only a physical switch on the backplane separating battery negative and ground.

Backplane Next Steps

1. Investigate thermal relief with TCS subsystem.
2. Confirm mounting with structures.
 - May need to alter mounting hole location.
3. Verify connector schematics with other electronics members.
4. Finish routing boards.
5. Make sure the board passes DRC(Design Rule Check).
 - Silkscreen will need to be altered.
6. Procure and populate first revision of COSMO Backplane PCB.
7. Perform continuity tests to confirm signals are connected.
8. Integrate with structure and other boards

S-Band DB Overview

The S-Band Daughter Board(DB) is intended to provide an interface between the Clyde Space HSTX-01-0073 S-Band Transmitter and the backplane of the spacecraft. On the CANVAS mission the S-Band DB will also provide an interface for the NovAtel OEM 719A GPS receiver, but on COSMO the GPS connector will be unpopulated. For the Clyde Space Transmitter interface there is a 104 pin through hole connector on the DB. The necessary signals from the transmitter are connected to testing headers and the backplane connector. The S-Band transmitter uses SPI and I2C lines to communicate with the CDH. Therefore, SCL, SDA, MISO, MOSI and CLK lines are accounted for on the backplane connector.

S-Band DB Status

The S-Band DB layout is complete on a 2 layer board. A brief reroute is still required before ordering. The board is built to be configurable in the cardstack. However, the width of the S-Band transmitter is slightly larger than the inner walls so slots will be utilized rather than the rails used on other boards. The headers allow easy access to board signals for continuity testing after board population.

S-Band DB Next Steps

- Add GPS power enable circuitry
- Order PCB
 - Output Gerber files
 - Advanced Circuits 2 layer special
 - Order components
- Populate boards
 - Manually apply solder paste
 - No stencil necessary
 - Manual pick-n-place
- Test signals using pin headers
- Integrate with flat sat using GSE.

GSE Overview

The Ground Support Equipment (GSE) board will be used for testing electronics and debugging COSMO's flight computer. This board will be similar to the backplane but it will not be integrated into the final COSMO structure. It will feature edge-mounted connectors for tabletop (FlatSat) integration with the EPS, CDH, and S-Band DB.

The GSE development has been favored over the backplane development toward the end of the Fall 2020 semester due to the need of a method of testing the first revisions of the PCB boards. The current state of the GSE board is under development in Altium. The schematics for connectors and pin assignments is being worked on.

Figure GSE-1 below shows the CANVAS FBD of the signal lines that will be used in the integrated GSE testing setup. This figure will be updated to create a separate version for COSMO's test setup that will exclude CANVAS' digital and analog board and will include the EPS board.

CANVAS Ground Support Equipment Board

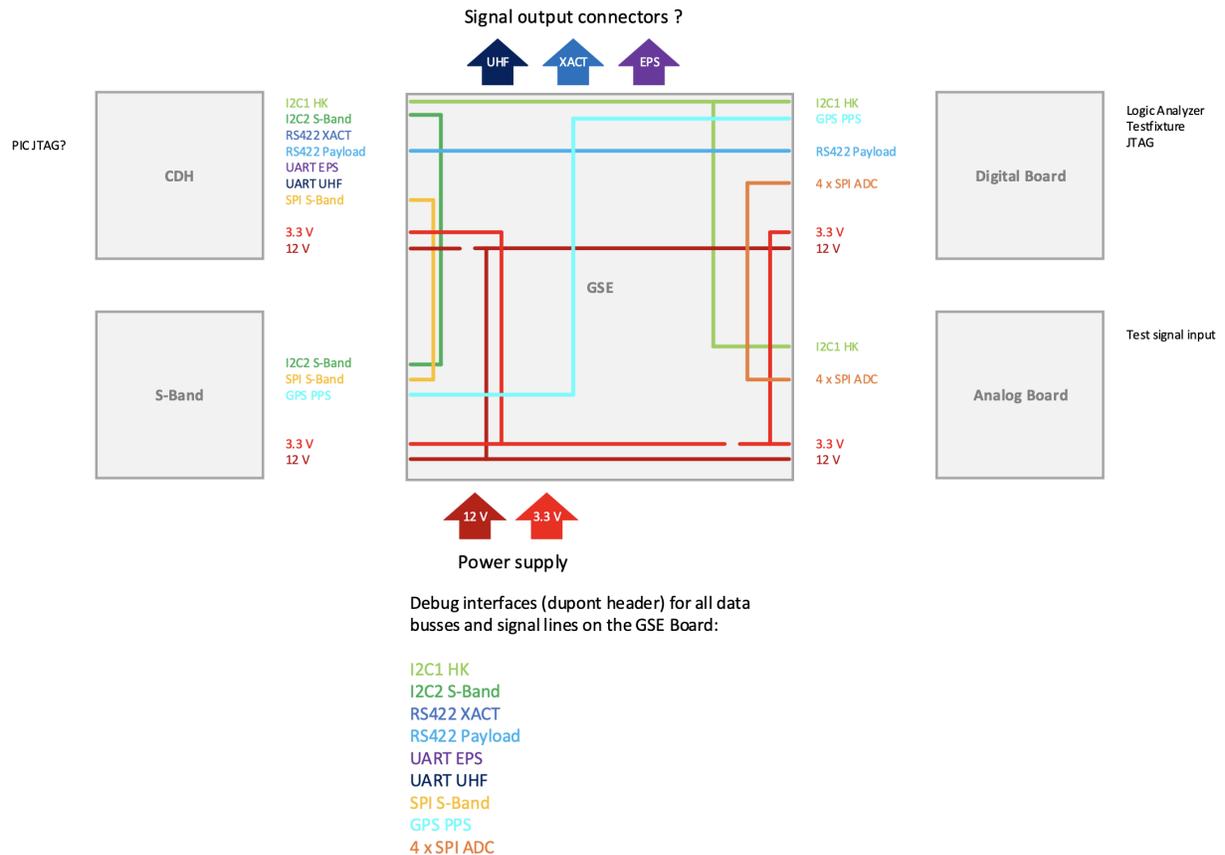


Figure GSE-1. CANVAS GSE FBD - Signal and Data Lines.

GSE Status

The GSE board began development in November 2020. It is still under development and is in the connector schematic phase in Altium. The development will likely be quick as it has many similarities to the backplane and most components can be copied over from the backplane projects.

GSE Next Steps

- Debugging connector definitions, external power supply design
- Schematic design completion
- Layout design complete and reviewed
- Procure and populate board
- Unit testing (continuity tests)
- Integrated testing

Communications (COMMs)

COMMs Overview

The COMMs subsystem will transmit payload data via amateur S-band (2402.5 MHz), transmit beacon and housekeeping data via amateur UHF (437.25 MHz), and receive uplinked commands via amateur UHF. This mission will use LASP’s ground station for all communications. All link budget calculations are based on a 20° elevation mask due to LASP’s current capabilities. This mission could use a 10° elevation mask in the future. LASP proprietary HYDRA commanding software will be used for test and operational commanding. Specs for radios can be seen below in the Status section.

The UHF system on CANVAS uses the AstroDev Li-2 radio with a tape-measure antenna. Commands and telemetry are sent over this system at a transmission rate of 9600 bits per second. The S-band system uses the Clydespace HSTX transmitter with a SANT patch antenna. This system has the capability to transmit up to 5 megabits per second, but until this can be confirmed with the ground station a transmission rate of 1 megabit per second will be assumed.

Table COMM-1 shows the specifications for the Li-2 and S-band radios.

Table COMM-1. UHF and S-band Radio Specifications.

	Radio	Manufacturer	Freq. (MHz)	RX?	TX?	Weight (g)	L (mm)	W (mm)	H (mm)
UHF	Li-2	Astrodev	130-450	✓	✓	30-52	64-65	32-33	0-10
S-band	HSTX	ClydeSpace	2402.5	X	✓	<100	86.06	91.72	14.55

COMMS Requirements

Table COMM-2 shows some of the key driving requirements for the COMMs subsystem. The requirements shown are based off of LASP as the choice of ground system.

Table COMM-2. COMMs Key Driving Requirements.

Req.	Description
COMM-1	The COMMs subsystem shall receive uplinked commands and downlink telemetry and system status in the UHF frequency range.
COMM-1.2	The COMMs subsystem shall have a minimum link margin of +6 dB on uplink and downlink.

COMM-2	The COMMs subsystem shall send science data in the S-band frequency range.
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COMMS Status

Much of the work done for the COMMs subsystem this semester was done in preparation for subsystem testing, which is scheduled to begin next semester.

Two prototypes of the PCB that interfaces with the Li-2 radio were populated, to be used in testing. These boards cannot be used in flight because they contain tin, which has whiskering properties in space. The layout is unlikely to change, so the prototype is fine to use in testing. The PCB will be temporarily wired to the Li-2 radio (this process must be done in the STlg lab, as the radio is flight hardware) for testing and removed once a tin-free flight board is obtained and populated.

The CAD model for the UHF antenna housing was updated for ease of manufacturing, and now more closely resembles the housing used in MinXSS. The housing now uses 3 U-brackets (Figure COMM-1) as opposed to two, and has fewer sharp edges. Before this change, the largest U-bracket was integrated into the main housing unit and would have required special drill bits to manufacture. It was also decided that the housing will be manufactured from Delrin (which was used for CSSWE and MinXSS) instead of windform (which MAXWELL is using). The CAD was updated to include these changes. In addition to this, the assembly plan and bill of materials were created so that the housing can be manufactured and assembled in the spring. The updated assembly is shown in figure COMM-2. This image shows the antenna stowed inside the housing. A prototype of the housing has been 3D printed, and fit-tested with a tape measure.

Table COMM-3. UHF Data Budget.

UHF		
Housekeeping channels	20	
HK bits per channel	8	bits
HK sampling rate	0.0625	Hz
total HK data rate	10.00	bits/sec
recording time per day	86400	sec
recording time of XACT	5400	sec
XACT Minimum HK Packet	254	bytes
Total data produced	0.28	MB/day
Ground station coverage	10.31	min
Downlink rate	9600	bits/sec

Data downlink capability	0.71	MB/day
Margin	153.33	%

Table COMM-4. S-band Data Budget.

S-band		
Magnetometer data production	3296	bits/sec
Star tracker data production	256	bits/sec
GPS data production	160	bits/sec
Total data production rate	3712	bits/sec
recording time per day	86400	sec
Total data produced	40.09	MB/day
Ground station coverage	10.31	min
Downlink rate	1000000	bits/sec
Data downlink capability	73.74	MB/day
Margin	83.95%	
Link to full budget	https://docs.google.com/spreadsheets/d/1LUr7ooAkxF07o878EtZxf5gVS22kwttbOHB/EHJsbebl/edit#gid=1502927381	

Table COMM-5. S-band Downlink Budget.

S-band (Downlink)		
<i>Spacecraft:</i>		
Spacecraft Transmitter Power Output:	1.0	watts
S/C Connector, Filter or In-Line Switch Losses:	0.0	dB
Spacecraft Antenna Gain:	8.3	dBiC
Spacecraft EIRP:	7.3	dBW
<i>Downlink Path:</i>		
Spacecraft Antenna Pointing Loss:	-0.5	dB
Antenna Polarization Loss:	-1.0	dB
Isotropic Signal Level at Ground Station:	-159.7	dBW
<i>Ground Station:</i>		
Ground Station Antenna Pointing Loss:	-0.50	dB
Ground Station Antenna Gain:	40.1	dBiC
Ground Station Transmission Line Losses:	-0.5	dB

Ground Station LNA Noise Temperature:	289	K
Ground Station Transmission Line Temp.:	290	K
Ground Station Effective Noise Temperature:	355	K
Ground Station Figure of Merit (G/T):	14.1	dB/K
G.S. Signal-to-Noise Power Density (S/No):	82.5	dBHz
Telemetry System Eb/No:	32.5	dB
Telemetry System Required Eb/No:	9	dB
System Link Margin:	23.5	dB
Link to full budget	https://docs.google.com/spreadsheets/d/1vgPhleV_fozlZW_CyOMAPtnxWMrULm0TeL2fSMnR7vyU/edit#gid=55289108 <u>9</u>	

Table COMM-6. UHF Uplink and Downlink Budgets.

UHF			
	Downlink	Uplink	
	<i>Spacecraft:</i>	<i>Ground Station:</i>	
Spacecraft Transmitter Power Output:	2.0	500.0	W
Spacecraft Antenna Gain:	-6.0	19.0	dBiC
Spacecraft EIRP:	-4.0	41.9	dBW
	<i>Downlink Path:</i>	<i>Uplink Path:</i>	
Spacecraft Antenna Pointing Loss:	-0.5	-1.0	dB
Antenna Polarization Loss:	-1.0	-4.0	dB
Isotropic Signal Level at Ground Station:	-156.1	-115.2	dBW
	<i>Ground Station:</i>	<i>Spacecraft</i>	
Ground Station Antenna Pointing Loss:	-0.03	0.0	dB
Ground Station Antenna Gain:	40.1	-6.0	dBiC
Ground Station Transmission Line Losses:	-0.5	-1.0	dB
Ground Station LNA Noise Temperature:	398	1163	K
Ground Station Transmission Line Temp.:	290	270	K
Ground Station Effective Noise Temperature:	563	1449	K
Ground Station Figure of Merit (G/T):	12.1	-38.6	dB/K

G.S. Signal-to-Noise Power Density (S/No):	84.5	74.8	dBH
Telemetry System Eb/No:	44.7	35.0	dB
Telemetry System Required Eb/No:	9	17.0	dB
System Link Margin:	35.7	18.0	dB
Link to full budget	https://docs.google.com/spreadsheets/d/1vgPhleV_fozlZWCyOMAPtnxWMrULm0TeL2fSMnR7vyU/edit#gid=552891089		

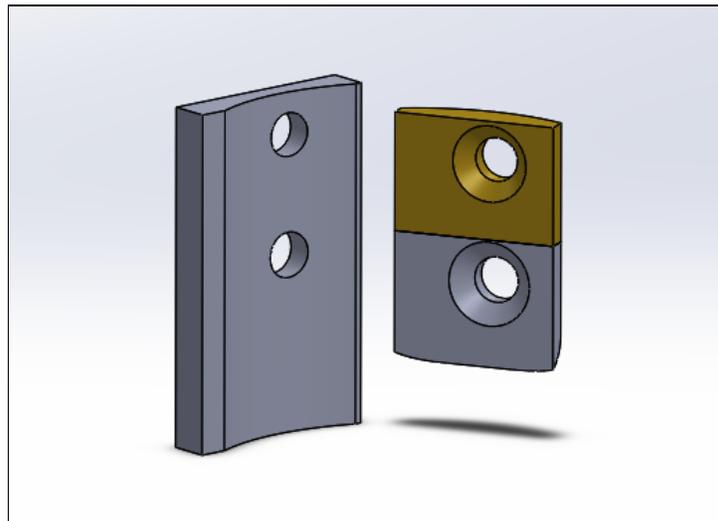


Figure COMM-1. U-brackets for UHF Antenna Housing.

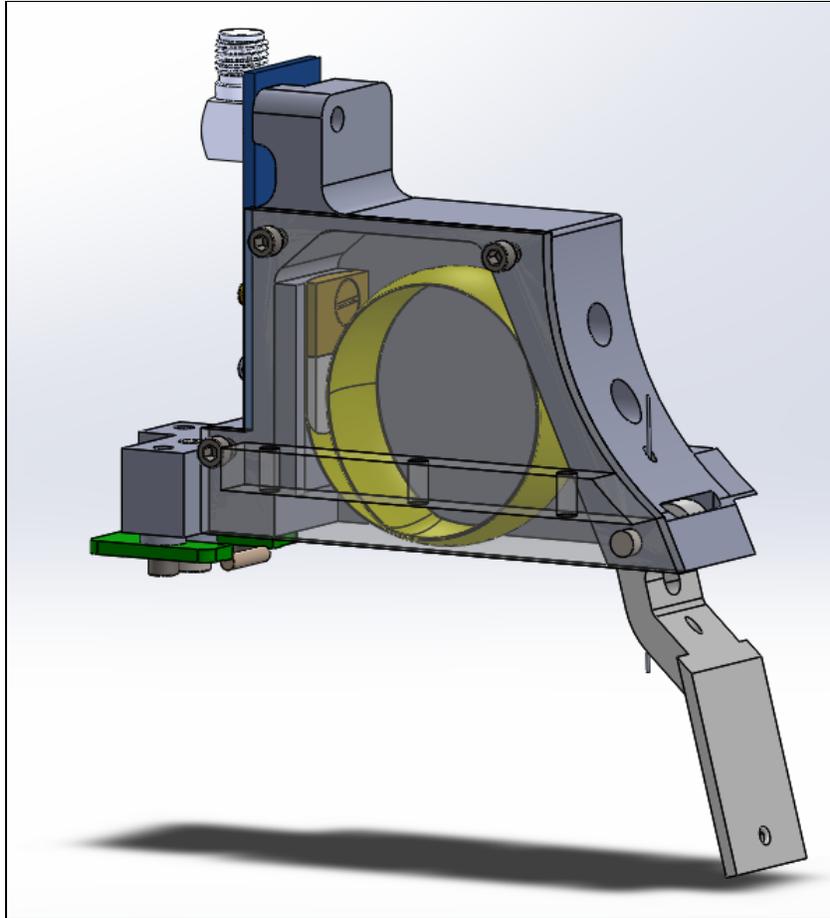


Figure COMM-2. Updated UHF Antenna Housing CAD - Stowed Assembly.

COMMS Major Changes

The major changes to the COMMs subsystem have been in adjusting the potential downlink rate in the link and data budgets. Previously it had been assumed that a downlink rate of 2 Mbps was achievable. This number has been adjusted to 1 Mbps to be more conservative and to be reflective of current conditions reported by other LASP missions. The HSTX can theoretically transmit at up to 5 Mbps, but until this can be confirmed via testing the lower downlink rate is being used. This lower rate does decrease the data margin, but the margin is still positive. This margin is almost guaranteed to change, however, due to increased knowledge of the radio capability through testing, new choice of ground station, and/or through LASP improving their elevation mask.

The other changes to the COMMs subsystem were in the UHF antenna housing. As mentioned above, the housing can now be manufactured with standard tools and will be manufactured from Delrin.

COMMs Next Steps/Path to PIR

The immediate future for the COMMs subsystem mainly involves testing. The current schedule has testing beginning in mid-January with completion in April. Both radios will first be inspected to ensure they match the physical properties specified in each of the respective ICDs. The Li-2 will then be temporarily integrated with the prototype PCB, and the HSTX will be integrated with the S-band Daughter Board. The radios will undergo individual configuration tests and command tests, to ensure that both can power on and send/receive simple commands. There are additional unspecified tests that must be performed on each radio; there is room in the schedule for these tests to occur in mid-to-late February. After the initial radio testing is completed, the UHF antenna housing can be manufactured and assembled. After the assembly, antenna deployment testing can begin. Finally, both the UHF and S-band systems will undergo uplink/downlink capability testing with the LASP ground station. Table COMM-7 shows the testing schedule for the UHF system, and table COMM-8 shows the testing schedule for the S-band system.

Table COMM-7. UHF Testing Schedule.

Names	Description	Start	End	Status
UHF Prototype PCB	Populate prototype PCB for use in testing	10/8/20	10/8/20	Completed
Li-2 Radio Inspection	Inspect for physical damage and compliance	1/18/21	1/19/21	Not started
Temporary PCB Integration	Wire Li-2 Radio to PCB prototype for testing	1/19/21	1/20/21	Not started
Li-2 Configuration	Radio powers on/off; RX/TX telemetry test	1/21/21	1/25/21	Not started
Li-2 Command Test	Ensure radio can send/receive simple commands	1/25/21	1/29/21	Not started
Flight UHF PCB	Flight version of UHF PCB	2/4/21	2/5/21	Not started
Permanent PCB Integration	Integrate flight PCB with Li-2 radio	2/1/21	2/15/21	Not started
Additional testing	TBD testing	2/5/21	3/1/21	Not

				started
UHF Antenna Deployment	Test burn wire deployment process	3/6/21	3/11/21 1	Not started
Uplink/Downlink Capabilities	Determine uplink and downlink capabilities with GS	3/11/21 1	4/9/21	Not started

Table COMM-8. S-band Testing Schedule.

Names	Description	Start	End	Status
HSTX Inspection	Inspect radio for physical damage and compliance with specified properties	1/19/21 1	1/20/21 1	Not started
Daughterboard Integration	Integrate daughterboard with S-band radio	1/21/21 1	1/26/21 1	Not started
HSTX Configuration	Radio powers on/off; TX/TX telemetry test	1/27/21 1	1/31/21 1	Not started
HSTX Command Test	Ensure radios can send/receive simple commands	2/1/21	2/5/21	Not started
Additional testing	TBD testing for both radios	2/6/21	3/1/21	Not started
Downlink Capabilities	Determine downlink capabilities with GS	3/11/21 1	4/9/21	Not started

The UHF antenna assembly must also occur before PIR. The manufacturing and assembly are scheduled for later February to early March, to allow for deployment testing in early to mid March. Manufacturing is planned to take place in the aerospace department machine shop, and assembly will be done in the BASIL lab if non-flight components are used, and in the STIg lab if flight components are used. The tape measure for the antenna has already been purchased, as has some Delrin that can be used to manufacture parts of the housing. Before manufacturing, the rest of the materials outlined in the bill of materials must be purchased. There are also two circuit boards that must be populated - an impedance board and a deployment board. The layouts for these boards have been completed, but the components have not yet been

ordered. The boards should not need to be professionally populated.

Attitude Determination and Control Subsystem (ADCS)

ADCS Overview

The Attitude Determination and Control System (ADCS) that will be used on COSMO is the XACT-15, a commercial off the shelf package from Blue Canyon Technologies (BCT). The XACT-15 was chosen due to its high pointing accuracy capabilities and heritage from other missions like the MinXSS cubeSat here at CU Boulder. The flight unit was delivered from BCT in October of 2020 and is currently located in the STIg lab. It is a fully integrated ADCS subsystem that is capable of attitude determination (with onboard Kalman filtering) and attitude/momentum control. The XACT-15 contains three reaction wheels for attitude control, three orthogonal torque rods for momentum dumping, a star tracker (w/ star catalog), a coarse sun sensor, an internal magnetometer, and an inertial measurement unit (IMU). The primary focus of the ADCS subsystem this semester was on testing in order to verify the key driving requirements (KDRs).

ADCS Requirements

The key driving requirements (KDRs) for the ADCS subsystem are given below in table ADCS-1. These requirements are defined to ensure the spacecraft can successfully detumble upon tip-off from nanoracks, maintain control during mission operations, collect power with the solar arrays, collect data from Earth's magnetic field, and downlink the data to LASP.

Table ADCS-1. ADCS Key Driving Requirements.

Req.	KDR	Description
ADCS-4	1	The ADCS shall be capable of desaturating the reaction wheels
ADCS-5/6	2	The ADCS shall be capable of three-axis stabilization of the spacecraft from a tip-off rate of $10^\circ/s$
ADCS-8.1	3	The ADCS shall be able to point the solar arrays within ± 15 deg of the Sun vector during normal operations
ADCS-8.2	4	The ADCS shall have a pointing accuracy during downlink equal to $\pm 22.5^\circ$

ADCS-8.4	5	The ADCS shall be capable of slewing the spacecraft at a minimum rate of 0.36 °/sec.
ADCS-8.5	6	The ADCS shall have a pointing accuracy during magnetic field tracking equal to $\pm 22.5^\circ$

ADCS Status

The focus of this semester for the ADCS subsystem was on testing. From previous semesters' work, the key driving requirements for the ADCS subsystem were defined. Based on these requirements, the XACT-15 (figure ADCS-1) was determined to be the best choice for COSMO's ADCS subsystem, and was then ordered. Again, the XACT-15 flight unit arrived this semester (October 2020) and is located in the STig Lab. Although the XACT-15 has heritage from previous missions, it is necessary to verify the XACT-15 is capable of meeting the COSMO specific requirements.



Figure ADCS-1. XACT-15 ADCS.

Currently the ADCS subsystem is in the testing phase to verify the aforementioned KDRs. This testing is being done using an Engineering Development Unit (EDU) of the XACT-15 and a Real-time Dynamics Processor (RDP). The EDU (figure ADCS-2) is a plastic copy of the XACT-15 (without the actuators) and contains the same electronics as the flight unit. The RDP (figure ADCS-2), also from BCT, models the dynamics of the CubeSat and contains nonlinearities and disturbances to accurately simulate the orbital and attitude behavior of COSMO. For more information on the EDU and RDP, see their ICD's and user guides which are located on the secure Kingston USB drive in the STig Lab. COSMOS software, from Ball Aerospace, is used as the interface for command and control of COSMO. This program, along with the RDP, allows commands to be sent to the EDU to control the spacecraft. It also provides telemetry from the simulated spacecraft which can be visualized in real time and/or exported to MATLAB for processing. For instructions on how to set up and interface

between the EDU, RDP, and COSMOS, please see the instructional guide we created ([CANMO ADCS RDP/EDU/COSMOS Installation and Set-Up Guide](#)). For instructions on how to export telemetry from COSMOS please see the telemetry extraction guide we created ([CANMO ADCS COSMOS Telemetry Extraction Guide](#)).



Figure ADCS-2. XACT-15 EDU (left) and RDP (right).

This semester testing with the EDU was done. The beginning of this semester was spent on gaining STIg lab access and becoming familiar with setting up and running simulations using the EDU and RDP. Some time was also spent on learning how to use COSMOS and extract telemetry. As mentioned before, we formally documented these steps and created instructional documents for these tasks. This was done as these tests are repeatable, and will be done again for CANVAS. While testing for COSMO took an entire semester, CANVAS testing could now be done within a few weeks. The next part of the semester was spent on working on KDR verification. This required us to figure out what telemetry data from the EDU could be used to verify the various KDRs, and then write testing plans. After writing the testing plans, a simulation of the mission was created in COSMOS. This simulation was designed based on the mission CONOPS, and the timing of the orbital maneuvers was established using the current STK model for COSMO. The simulation that was created runs for 3+ orbits with a total duration of around 5.5 hours. The simulation is scripted in one single Ruby script and is saved in the COSMO ADCS google drive. While this report does not contain the test results, an example of some telemetry plotted over the entire simulation can be seen below (figure ADCS-3). This plot depicts the reaction wheel speeds during the 3+ orbits and indicates when the pointing modes switch during the mission. As shown, the spacecraft switches between sun pointing, magnetic field pointing, and LASP pointing.

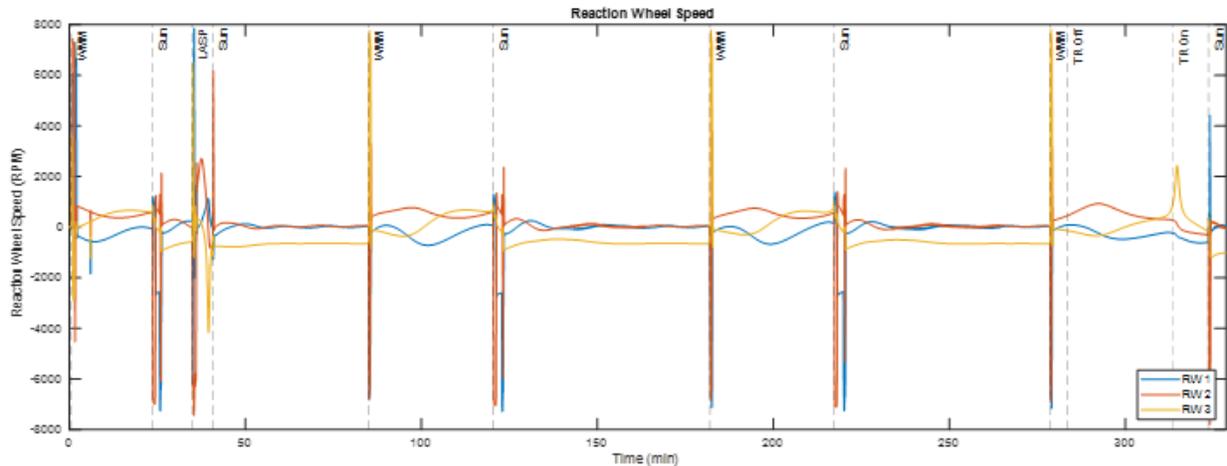


Figure ADCS-3. Reaction Wheel Speeds During Simulation.

For the full results and analysis of our tests please see the ADCS testing document ([COSMO ADCS KDR 1, 3-6 Test Procedure and Results](#)). This document also includes the procedures for these tests which is intended to allow anyone to duplicate these tests with minimal effort. Again, similar tests will be completed for CANVAS and this will allow for quick and smooth testing to be done. In summary, the results from our testing are promising and we expect every KDR to be verified. Currently, the ADCS team has verified KDRs but formal verification will come from the SE. The pointing accuracy KDRs for sun and magnetic field pointing (3,6) have been verified. The KDRs for LASP pointing and slew requirement (4,5) currently meet the criteria for success, but we need to run another simulation with a different primary axis defined during LASP pointing. These KDRs are expected to be verified again. Desaturation (KDR 1), has been verified but again we want to run another simulation, but this time set the reaction wheel max speed to 6000 rpm (rather than leave it default). We expect to verify this KDR again, but want to look at the effect this has on the maneuver times. Also regarding desaturation, we looked at the effects of turning the torque rods off during the night side of the orbit. These results were promising, as the reaction wheels did not saturate and the spacecraft maintained control during this time. Again, we want to look at this once more in the next simulation. KDR 2 (3-axis stabilization) is the only KDR that we have not run a test for. Currently, we are working on the test plan and plan on running another simulation to get telemetry to verify this KDR. While every KDR has not been verified this semester, we plan on running another simulation early Winter Break to re-verify some of the KDRs with these small changes implemented. KDR 2 is the only requirement that we have some real work to do, but expect to have it completed by the start of the Spring semester. By the start of spring semester, we also will have updated our testing document with the updated results and then can get them formally verified.

Flight software ADCS commands were also worked on this semester. Completing EDU testing informed us what FSW commands are needed to be sent to the XACT-15 during the mission. Lea, the FSW lead, created a document in the Spring 2020 semester with a list of ADCS flight software commands. The ADCS FSW commands can be found in the google drive ([ADCS Software Commands](#)). This semester, the FSW command structures in RUBY were translated to the FSW language. Some of this was already done in the Spring semester, but we updated some of those commands and added some new ones that will be used. Regarding FSW, we still have a lot of work to do with the FSW lead next semester. A process needs to be developed on how FSW/CDH will communicate with the ADCS subsystem and what required telemetry packets/definitions will be used.

ADCS Major Changes

No major changes were made to the ADCS subsystem this semester. Although, some changes in documentation were made. The previous ADCS lead has some experience with the test set-up and wrote some instructions on how to get it up and running. These instructions were helpful to newcomers (like ourselves), but were minimal and were missing some key information and steps. We had some difficulty getting the test set-up running this semester. There were about 3 different instances we got stuck and how to reach out to BCT for guidance. These hurdles pertained to installing COSMOS correctly, configuring the RDP testing software, and configuring the computer to work with the EDU and RDP. This took up almost a month of our time. There was also no information on how to extract the telemetry from COSMOS for processing in MATLAB. To address these challenges and help prevent this from happening again with others, we created two instructional documents for EDU/RDP/COSMOS set-up, interface, and telemetry extraction (documents mentioned and linked in the previous section). We also applied this idea of documentation to our testing procedures. The goal of all this documentation is of course to provide the necessary information for others to repeat these same tests but with ease and minimal effort.

ADCS Next Steps/Path to PIR

There are some immediate smaller action items that need to be done for the ADCS subsystem. These are tasks that we plan on completing in December and January:

1. Re-run testing simulation with updated axis defined to re-verify KDRs 4 and 5 (December 18, 2020).
2. Re-run testing simulation with reaction wheel speeds defined (December 18, 2020)
3. Update testing document with new results (January 5th, 2020)
4. Complete testing plan and run simulation for KDR 2 (January 15th, 2020)

5. Get KDR testing results formally verified - i.e. signed off on (January 10th, 2020)
6. Work with SE to update CONOPS and STK with maneuver times from EDU testing (January 20th, 2020)

A lot of important tasks need to be done for the ADCS subsystem before PIR. These are larger broad-level tasks that will ready the ADCS subsystem for PIR and will be our focus for the Spring 2021 semester:

1. Work with FSW/CDH to develop processes and plans for communication between CDH and ADCS subsystems (Early-Mid Spring 2021)
2. Develop flight hardware testing plan for the XACT-15 (i.e. what needs to be done in order to ready the flight unit for tests? What subsystems will be involved? What testing will take place?) (Early-Mid Spring 2021)
3. Perform flight hardware testing of the XACT-15 (Mid-Late Spring 2021)
4. Develop plans for flight hardware integration and EMI testing that will take place post-integration (Late Spring 2021)

Thermal Control System (TCS)

Overview

The purpose of thermal analysis for a spacecraft is to ensure that all subsystem components will stay within their defined operational and survival temperature limits during any point of the mission. Apart from the subsystem components the main payload science instruments may also require to stay within a strict temperature range and in thermal stability throughout the mission.

Requirements

The key driving requirements for the thermal subsystem are listed below in Table TCS-1. Notably, the Thermal Control System (TCS) must be commanded by the CDHS and be capable of monitoring the temperature of each subsystem. Additionally, conduction pathways will be provided to ensure that components do not overheat and patch heaters will be used to safeguard components from falling below their minimum operational and survival temperatures.

KDR	Description	Reasoning
1	The TCS shall measure temperature of components and send the data to CDHS.	This is to assure that each subsystem remains in its operational temperature limits when it is on and its survival limits when the sensor is off.
2	The TCS shall provide heating for components that are below their operational (if they are on) or survival (if they are off) limits.	Due to the temperature fluctuations in space we want to assure none of the spacecraft components get too cold and leave their temperature limits.
3	The thermal control system shall provide thermal conduction paths for all subsystems such that they do not exceed temperature limits during operation.	Due to the temperature fluctuations in space we want to assure none of the spacecraft components get too warm and leave their temperature limits.
4	The TCS shall be commanded by the CDHS.	The CDHS will apply control logic and power toggle the heating elements to assure the components stay within their temperature limits.

Table TCS-1. Thermal subsystem key driving requirements.

Current Status

In order to keep internal components within acceptable temperature ranges patch heaters and conduction pathways will be used. For sensitive components such as the batteries it will be imperative that temperature is closely monitored and that heating is provided when needed. Additionally, the aluminum structure will be used as a heat sink and as a radiative surface to prevent components such as the EPS and CDHS from overheating. As the solar panels are expected to heat up significantly, the spacecraft will

also be designed to minimize heat conduction from the panels to the main chassis. Each subsystem component has their own operational and survival temperature. For components like the CDH board which has multiple components, the most tightest temperature range component was chosen. Table TCS-2 shows all the subsystem components operational and survival temperatures in COSMO spacecraft.

Subsystem	Component	Operating Temperature(C)	Survival Temperature(C)
<i>ADCS</i>			
	XACT	-20 to 60	-20 to 60
	GPS	-40 to 85	-40 to 85
<i>CDH</i>			
	CDH Board	-25 to 85	-40 to 85
<i>EPS</i>			
	EPS Board	-30 to 70	-40 to 85
	Battery	0 to 40	-20 to 70
	Solar Panels	-75 to 100	-75 to 100
<i>Payload</i>			
	Star Trackers	-40 to 70	-40 to 70
<i>Telecom</i>			
	UHF Board	-30 to 70	-40 to 85
	Sband Board	-25 to 61	-40 to 85
	Antenna	-40 to 85	-40 to 85

Table TCS-2. Thermal subsystem Operating Temperatures.

Thermal Analysis was performed in thermal desktop for 3 different orbital cases which are Worst case cold, Actual reference case and Worst case hot. Figure TCS-1 show the COSMO thermal model analyzed in Thermal Desktop. The results obtained from the initial analysis were satisfactory and matched the expected results.

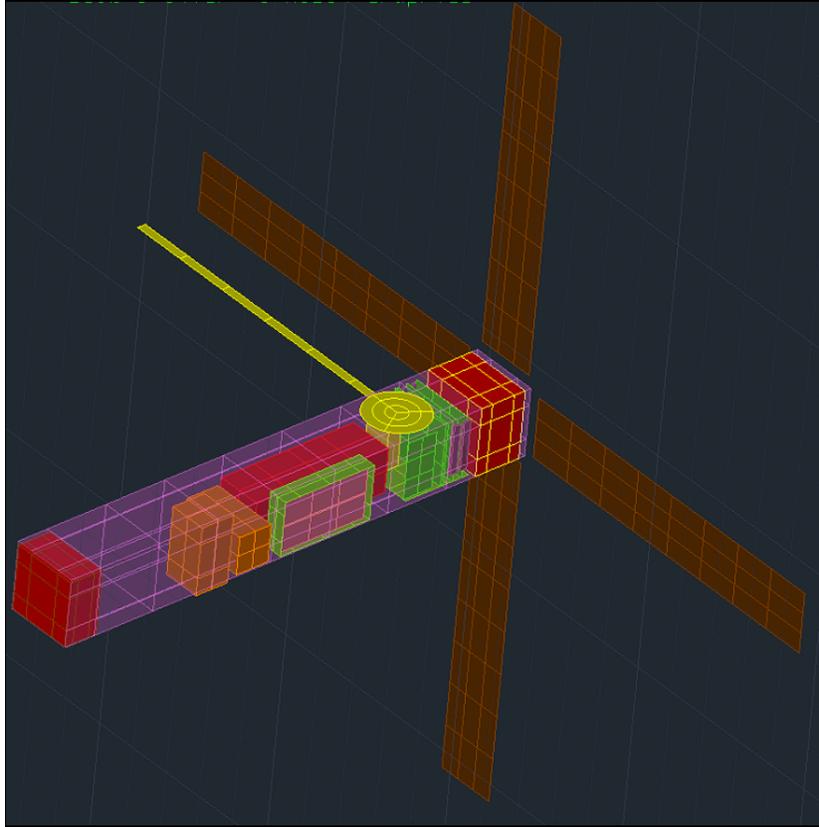


Figure TCS-1. Thermal Model.

The battery heaters were analyzed for their duty cycle and it was found that the heaters were used only during the worst case cold scenario with a maximum duty cycle of 7.1% per day. Based on the heater wattage 29 used during thermal analysis, the battery heaters were chosen. The chosen heaters have flight heritage from MINXSS. It was also found that every subsystem component has a temperature sensor except the batteries. Hence, a RTD type temperature sensor was chosen which was MINXSS flight heritage too. The results are depicted in Table TCS-3.



Table TCS-3. Thermal subsystem Results.

Major Decisions This Semester

Heatload for EPS board is now specified separately for dayside and nightside conditions. This seems to be the most accurate way of depicting the heat load from the EPS board since it's generating much more heat during the day side, when the solar panels are tapping energy, compared to the night side.

Board modeling is updated based on thickness of the copper layer instead of the actual thickness of the board. This method of modelling multilayer PCBs in thermal desktop has been tested by MINXSS and proven to be accurate.

Next Steps

Some of the major steps for thermal subsystem in the upcoming semester have been listed below in table TCS-4.

Task	Est. Completion Date
Heatloads/Materials properties are unknown for some of the payload components. The model has to be updated once those are known.	Jan 2021 (or as early as it is known)
Determine exact positions of battery RTDs and Heaters	Feb 2021
Testing Procedure document for thermal testing	Feb 2021

Table TCS-4. Thermal subsystem steps forward.

Flight Software (FSW)

FSW Overview

The flight software subsystem is composed of the embedded code running on the CDH and EPS computers. Due to the choice to use MAXWELL heritage designed for the CDH and EPS boards, the team has decided to modify the flight software developed for MAXWELL for use on both subsystems. The MAXWELL code is still in development and has heritage on the QB-50 mission. In addition, the CDH software references MinXSS heritage code to interface with the BCT XACT, as the ADCS component selected for COSMO differs from that on MAXWELL.

Because there will be no onboard operating systems, the software must define its own tasks and scheduler. The CDH code is responsible for managing the spacecraft modes and subsystems, executing commands from ground, and handling and downlinking data. The EPS code is responsible for peak power tracking, calculating the state-of-charge of the batteries, and collecting EPS telemetry.

FSW Requirements

The driving requirements for the COSMO FSW are shown below in Table FSW-1. These requirements were selected as they dictate the core autonomous functionality of the software required for mission success.

Table FSW-1. FSW Key Driving Requirements.

KDR	Description
1	The software shall autonomously manage a set of spacecraft modes and command each of the spacecraft subsystems
2	The software shall authenticate, process, and route ground commands to the appropriate subsystem.
3	The software shall support error handling.
4	The software shall control the deployment of all satellite extensions.

FSW Status

The CDH FSW responsibilities are separated into "tasks" and a scheduler is defined to execute these tasks at a certain frequency depending on their urgency. The tasks and scheduler are shown in Figure FSW-1. The high rate task consists only of the watchdog timer reset, the mid-rate tasks include interfaces and spacecraft operations, and the low-rate tasks consist of deployments and spacecraft monitoring. Again, because there's no onboard OS, there's no enforcement of the timing so the task

designs themselves must take into account the 1 ms limit. Each task must handle operations that may take multiple cycles to complete and perform correctly based on the spacecraft mode.

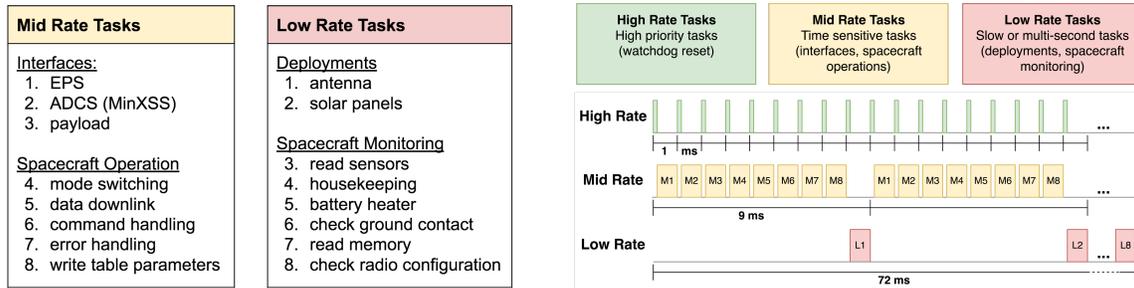


Figure FSW-1. An overview of the CDH task architecture design.

The software interface design for packets and data between the subsystems is shown below in Figure FSW-2. Note that the S-band is not included here because it transmits pre-packetized data as is. In general, the CDH will receive commands from ground, and send them to the appropriate subsystems. It will then receive data and telemetry back from the subsystems, and route it to ground. CCSDS packets will be used between CDH & ground for both data downlink and command uplink. The packet types for the COTs components are defined by the supplier for the XACT and HSTX respectively. Finally, the internally defined interfaces will use a simple opcode and checksum packet.

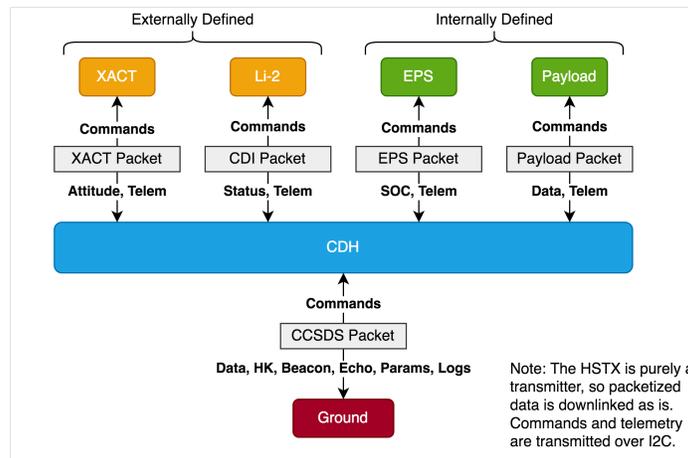


Figure FSW-2. Packet types and data across software interfaces.

The code is also designed with the ability to test. Using global defines, test code can be run and errors can be injected into the code. Debugging messages can then be sent over GSE port for an operator to read. Finally, the code is designed to be modular to facilitate unit testing.

FSW Semester Major Decisions

Development at the current stage of the project has been challenging for two reasons. Firstly, the MAXWELL inherited code is incomplete and changes are relevant to the COSMO project. Secondly, hardware development was delayed due to COVID-19, so no board exists to run the code. Because of this, work this semester focused on laying the foundation for future software development as remaining subsystem decisions are finalized. The current design and previous work is outlined in the Flight Software Handbook.

A top priority of the project is to implement and test our mode switching strategy. As the ADCS and SE teams have both been working to refine and verify our CONOPs, the software must implement the final design into the software. In order to provide input into the design from a software perspective, mode switching and mode operation flow diagrams were created to identify areas where more refinement or additional error handling is necessary. The diagrams are also helpful to visualize how the strategy ultimately is to be implemented into code. The mode switching diagram for COSMO is shown in Figure FSW-3. While the conditionals in the blocks use a high level perspective, it can be seen that further consideration will be needed in order to define criteria such as “errors occurred”.

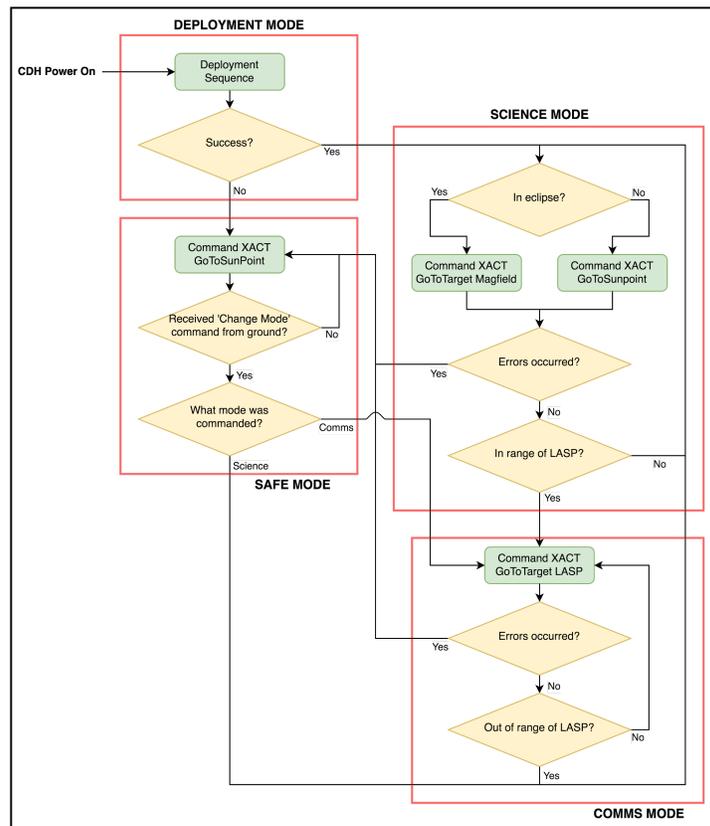


Figure FSW-3. The high level mode switching diagram for COSMO showing the criteria for entry into and exit from each mode.

There was much discussion on the CANVAS team this semester regarding the CDH and payload software, and concerns regarding the SD card operation for both missions were brought up. The team had hoped to use the MAXWELL test setup to verify the current understanding of the current SD card code and the test modifications; however, the team was unable to negotiate time on the setup. Considerations such as downlink priority, retransmit address lookup, and virtual channel ID (VCID) selection must still be addressed, and some recommendations have been provided by Magnus Karlsson of LASP. Ultimately, as memory is plentiful on the mission, decisions regarding memory allocation and priority will primarily be based on the number of packet types to be stored and their frequency of generation.

Additionally, new information arose from Dr. Nicholas Rainville this semester regarding the robustness of the current MAXWELL EPS peak power tracking (PPT) strategy and battery state-of-charge (SOC) calculations. PPT aims to find the “sweet spot” on the solar panel IV curve that maximizes power draw by controlling the current drawn from the panel. The existing MAXWELL design uses a hybrid of software and hardware strategies to control the current that results in a delayed reaction. A purely software based strategy would reduce this reaction time and increase efficiency, but require additional development and thorough testing, as there would be no recovery in the case of a software fault. A purely hardware design in the form of current limiting resistors is robust but inefficient. Further investigation by Jett Moore of the EPS subsystem will be conducted next semester and the results will influence the final software implementation. For the SOC calculation, a coarse method is being implemented on MAXWELL that results in errors of up to 5% and large swings in calculation outputs. However, this method can likely be used for COSMO with minimal modifications, as the error is tolerable for our mission and the output swing can be accounted for with a hysteresis band for decisions based on SOC.

Finally, the software documentation and knowledge has been condensed primarily into two living documents to be shared with the CANVAS project. Firstly, the Software Development Guide provides instructions for the development environment setup and standard coding strategies. Future additions to the document will include robust integration procedures as the software team grows, and instructions to program and run code on the dsPIC. Secondly, the Flight Software Handbook details previous design decisions, the current status, and all future work of the COSMO and CANVAS Cubesat flight software. The document must be updated as additional decisions are made. Both documents are listed and linked in Table FSW-2.

Table FSW-2: Reference Documents.

Document No.	Title	Author(s)
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1	Software Development Guide	Lea Chandler
2	Flight Software Handbook	Lea Chandler

FSW Next Steps

Software design often follows a design, implement, and test development flow, and this flight software is no different. However, it is unclear what the future of the software team will be in the upcoming semester. Design work for the CDH software is still necessary to specify the data downlink and command uplink packet contents, select the housekeeping data for the real-time and full housekeeping packets, and to define the SD card store and fetch operations for all packet types. Necessary design work for the EPS software is the telemetry packets to and commanding packets from the CDH, and the aforementioned PPT and SOC implementations. Because much of these decisions primarily involve mission operation, they can be made with little input from a software perspective and can be completed within the next semester.

Implementation of the finalized CONOPs, packet structures and parsing, and additional hardware drivers for new components will require software manpower. These tasks can likely be completed within a semester, even accounting for time to come up to speed with the project.

However, testing and modifying the design and implementation will take much longer and should be started as soon as possible. Unit testing of modules should occur as those modules are being implemented, followed by end-to-end functionality testing. Verification of the software KDRs should be completed within a year of the initial implementation of a majority of the code. Finally, day-in-the-life testing can occur once the hardware has been finalized and components have been connected in-the-loop. Following this timeline, the bulk of the software should be in the testing stages with few modifications necessary by the end of 2021 or early 2022.

Integration and Testing (I&T)

I&T Overview

Integration and Testing is a major part of any engineering project. In this section we will discuss what goes into the testing phases of COSMO, what is required from a testing plan, as well as delve into the integration plan and what went into the thought process for making it.

To begin, testing of COSMO is essential, as it enables us to understand the problems we may face, risks we may encounter, and how the spacecraft will perform when faced with the problems we anticipate. As such, individual subsystem testing is essential before we integrate the spacecraft. Each subsystem has met with the testing

team to confirm what tests will be performed and when to create the testing timeline, as listed in the next section of this report. In addition, testing plans were created for any tests the subsystems would need to perform, as well as for any testable KDR.

In addition to testing plans, an integral part of the I&T process is integration; combining all subsystems of the spacecraft efficiently to create a well organized, functioning satellite. An integration plan consists of an order in which to integrate each of the subsystems, as well as steps to be taken in each part of integration to ensure a well functioning spacecraft.

I&T Testing Timeline

With the beginning of testing this semester, the team wanted to create a centralized document to show a timeline of testing, so as to understand how much testing we should be doing, as well as the consequences of delaying certain tests. Unfortunately, the initial testing timeline we created was too optimistic, as such, the timeline was updated post end of semester presentation to represent these changes. A snapshot of the timeline can be view below, while the entire timeline can be found at the following link: [COSMO Testing Timeline](#)

equipment used, and who will be performing the test. In addition, each plan has a table where each step of the testing process should be written out with its description and date completed to be able to recreate the test if/when needed. Testing plans are currently located in the google drive at the following link: [COSMO Testing Plans](#)

Also as aforementioned, we wanted to create an integration plan as we move forward with the integration of COSMO. This plan goes into detail of the initial Integration overview we created last semester ([Integration Overview](#)), while also giving steps to the tester as to what the process of integration should accomplish. Though it is not filled out yet, the plan also gives space for the actual integration procedure, which will be filled out when integration actually takes place. The goal for this document is that all aspects of integration will be documented properly, and stored in one location. The document is currently housed in COSMO's google drive, at the following hyperlink: [COSMO Integration Plan](#).

I&T Next Steps and Path to PIR

Tasks for Next Spring 2020 Testing Team

- i. Moving into next semester, the new testing lead will first have to familiarize themselves with the documents we've created. Go over the testing and integration plans, and most importantly, the testing timeline
- ii. Next, the testing lead will have to reach out to the other subsystem leads, and understand what stages they're at in the testing process. Once they have had subsystem meetings, the testing lead will have to update the [COSMO Testing Timeline](#).
- iii. The lead should then look over and update the [COSMO Integration Plan](#). This is going to be vital going into Spring 2020, as there is a good chance COSMO begins the integration process by March.
- iv. Once those steps are completed, the lead should just keep updated on what tests are being run, and make sure the testing plans and other documentation are being updated as the tests are completed.

Path to PIR

- i. Major step in getting to PIR is going to be completing the integration plan. Though testing plans will need to be updated as testing progresses, those may take a backseat as we move into integration. Integrating the spacecraft is going to be a massive task the new testing lead will have to take up and essentially lead.
- ii. The new lead should also consistently be updating the plans for both integration and test in the google drive as changes are made on both those fronts.

Project Management

Schedule Overview

COSMO is currently in post Critical Design Review (CDR) design finalization and at the beginning of the manufacturing phase. We are preparing for or conducting individual subsystem manufacturing and unit testing in advance of Pre-Integration Review (PIR), which is defined here as having each subsystem completely manufactured, with unit testing and EMI testing complete (as needed). The COSMO schedule can be found as a Microsoft Project Gantt Chart on the LAIR-PM computer which is most commonly used via remote desktop with access by Dr. Marshall. The schedule stretches from the project's inception to the launch date. Past dates are not guaranteed to be updated to be correct, as the focus in updating this document has been on preparing and accurately scheduling for the future. Fall 2020 dates have been updated to the best of the PM's current knowledge, however.

The current estimated PIR date is 4/27/21, which aligns well with the Spring end-of-semester Review that is normally conducted as part of the graduate projects class. It is estimated that integration and FSW development will require roughly another year, putting Pre-Environmental Review (PER) at roughly the mid-semester review of Spring 2022 on 2/27/22. After PER, environmental and comprehensive spacecraft performance testing will be completed. With 120 days of current margin for any last-minute revisions and a month of shipping time to the launch site, this puts COSMO's launch date at 10/21/22.

Subsystem Schedule Highlights

Structures

The STR subsystem is fairly advanced on COSMO. This semester, manufacturing progress was delayed by the start of the investigation into use of Delrin for bus material near the magnetometer. This investigation requires additional analysis, and the STR components require some modifications for manufacturability. The Delrin investigation is expected to be complete with appropriate design modifications made by 3/1/21, with all structural components manufactured shortly thereafter on 3/30/21. This date assumes that we only have access to the AERO machine shop with limited employees available, but it also assumes we are able to use the employee's full time each week.

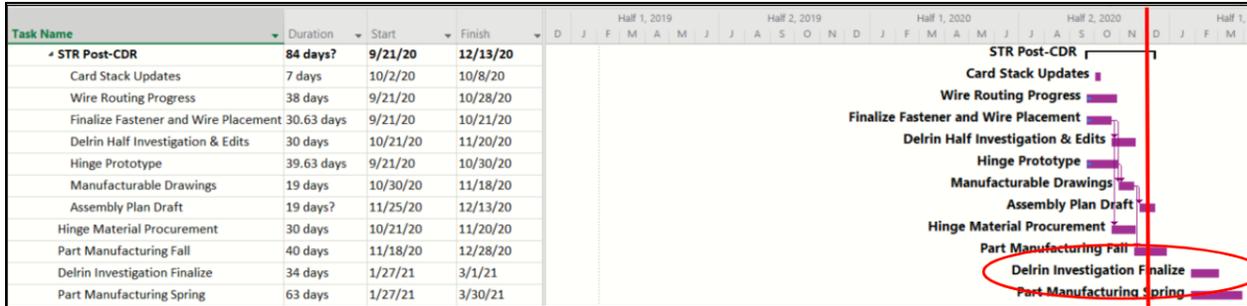


Figure PM-1. STR schedule with critical task circled and current time denoted with red vertical bar.

Electronics

The CDH PCB is nearly ready for a first revision, and is expected to be procured and ready for assembly by the beginning of the Spring 2021 semester with unit testing completed by 3/2/21. The GSE board is also expected to be ready by this time to assist in unit testing, and, as CANVAS' Electrical Engineer has started work on it, its progress should be significantly expedited. The backplane board has been delayed to focus on GSE board development, but, because the GSE board is expected to be functionally equivalent to the backplane board, backplane unit testing can be initially performed on the GSE board, meeting the PIR requirement.

The initial revision of the EPS PCB (denoted Revision 0 or Rev0) has been procured along with the components and is awaiting assembly. This will be done internally using the equipment in AERO150. It is expected that this initial revision will be full tested by the middle of the Spring 2021 semester. However, significant investigation must also be done in the Spring to redesign the EPS power conversion. If this redesign is set as a requirement for PIR, it may push the date back significantly. Currently, it is assumed that this investigation concludes with revisions made by PIR, but this estimate is fairly optimistic if major changes need to be made. An example of the current EPS schedule can be seen in Figure PM-2 (this schedule has been delayed by approximately 2 weeks at the time of writing). The EPS subsystem is of significant concern for schedule delays.

The Solar Panels are also concerning. While the PCB design for the panels is almost complete, the manufacturing process for the Solar Panels is complex, and must be planned and performed with extreme caution. To mitigate this, additional practice Solar Cells will be ordered, and a volunteer has already committed his time for the Spring semester.

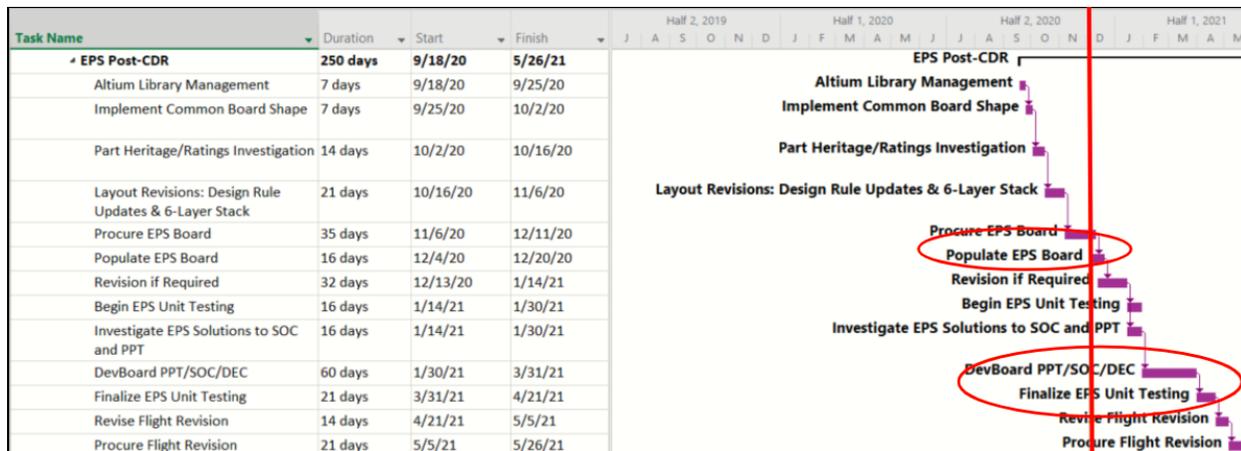


Figure PM-2. EPS schedule with critical tasks circled and current time denoted with red vertical bar.

COMMs

UHF and S-Band Radio testing has been impacted this semester with a variety of priority tasks that arose, and, due to the complexity of the radio interfacing required for testing, this presents another serious schedule concern. However, much of the testing has been planned out and is scheduled to begin in the Spring semester (if possible). Additional assistance from LASP for S-Band radio testing has also been acquired. Thus, COMMs unit testing is scheduled to be complete by PIR with a dedicated student in the Spring semester.

FSW

Flight Software is always of concern for CubeSat mission development schedules. The current flight software is based on MAXWELL and MinXSS heritage, which removes a great deal of development time. However, significant modifications need to be made to both the CDH software and EPS software (depending on the results of the power conversion study). It is estimated that the FSW will take at least an additional year from the Spring semester to be ready for comprehensive performance testing (PER entrance criteria). As dedicated students are extremely hard to find in this area, it is highly recommended that the project search for dedicated FSW resources. Much of the design and preparation work has been completed by the current FSW lead, Lea Chandler, who has laid significant groundwork for the future. However, implementation and significant unit and integrated testing of this design will be required.

Budget Overview

A number of small purchases were made this semester, and significant re-evaluation of the budget was done for electronics subsystems. The purchases included the manufacture of the EPS board as well as material for the first revision of the SP hinges and solar panel fracture testing, and can be found in the [FA2020 Budget](#).

The budget reevaluation can also be found in this document under the tab “PCB Costing.” With the transition from 4-6 layer EPS and CDH boards, new quotes for the manufacturing, components, and assembly of all boards were evaluated. The cost increase was found to be significant. To mitigate this, COSMO and CANVAS will share the manufacturing, component, and assembly cost of shared PCBs. Additionally, the number of revisions per board has been reduced to 3 (Rev1, Rev2 Flight) with the exception of the EPS board, which may require additional development. While 4 boards will be ordered each revision to maintain cost effectiveness, components will only be ordered to populate two of these boards each revision. Table PM-1 shows the current budget status with these updated estimates.

Table PM-1: Current Budget

Remaining Cost Total:	\$117,064.85
Running Total:	\$250,320.39
Expected + Running:	\$367,385.24
Budget:	\$380,000.00
Margin:	3.32%

PM Next Steps

The COSMO schedule requires frequent updates, and especially requires attention in the PLD development schedule as well as the integrated testing flow. Recommendations were made this semester to change the integrated testing to the desired flow: EMI Unit Test → Integration → Integrated Testing → Integrated EMI test. While this flow may take slightly longer, it is not expected to surpass FSW development time. However, every attempt should be made to parallelize this and other tasks as much as possible.

The COSMO budget also requires updates, including purchase of the latest quote of solar cells with additional mechanical and B-class cells in addition to requiring new quotes on thermal subsystem components and creating BOMs for structural components.