UCSP

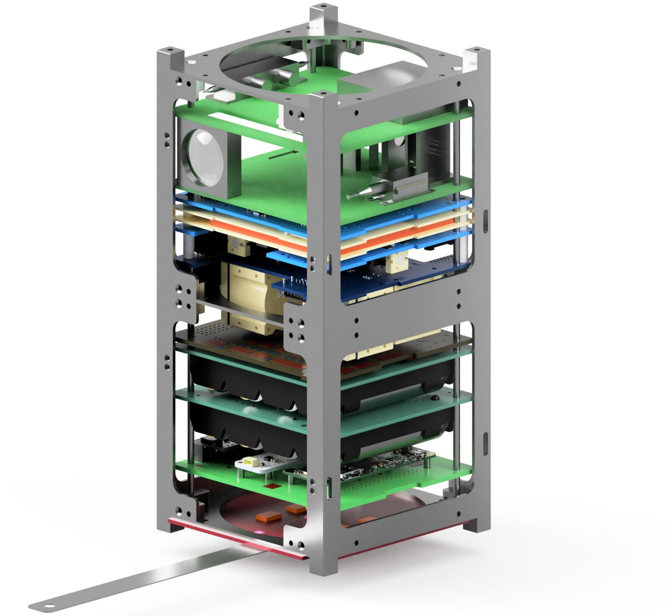
PULSE-A

$|\psi\rangle = \begin{pmatrix} \cos\theta \exp(i\alpha_x) \\ \sin\theta \exp(i\alpha_y) \end{pmatrix}$

THE UNIVERSITY OF CHICAGO

PULSE-A

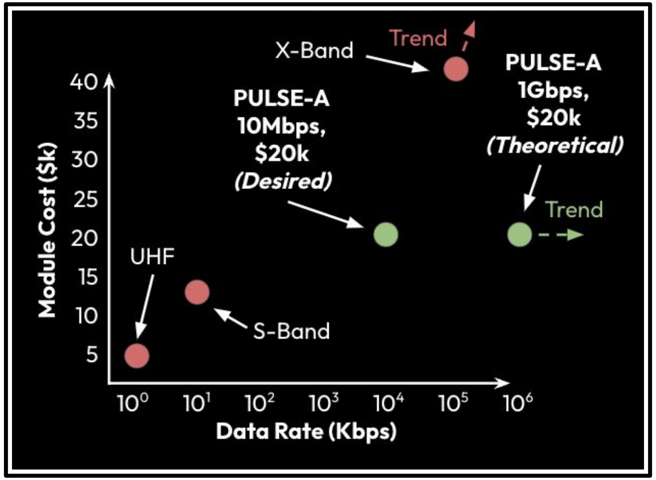
Polarization
Mod**U**lated
Laser
Satellite
Experiment



Principal Mission Objective

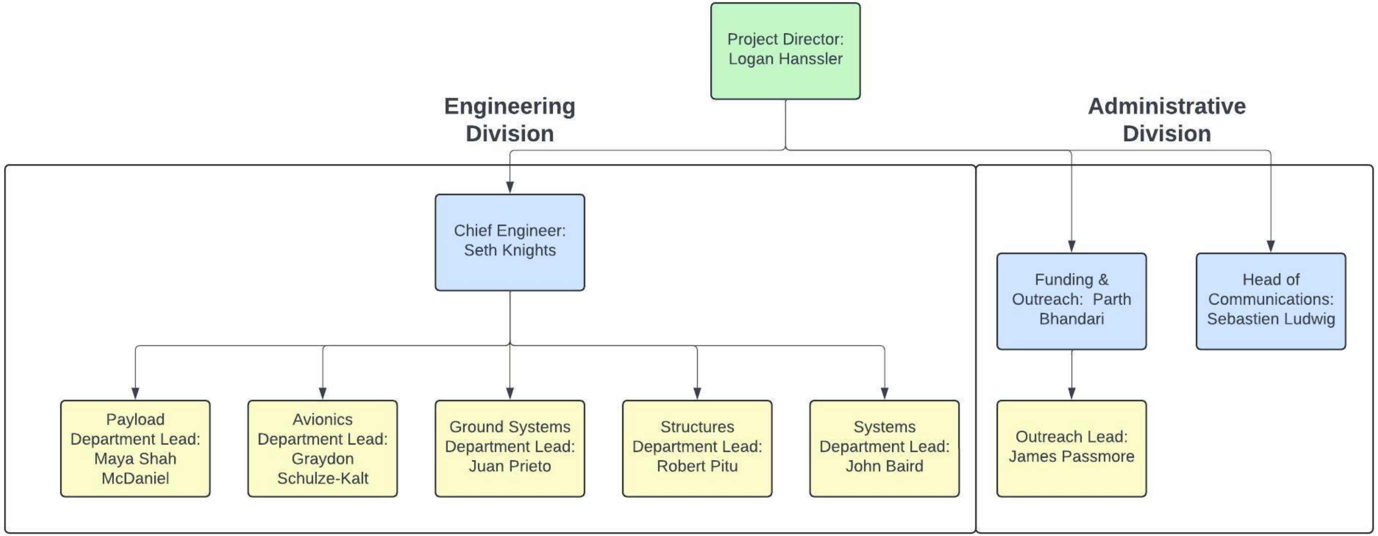
The principal mission objective of the PULSE-A CubeSat is to **demonstrate satellite-to-ground laser communications** using **circular polarization modulation** at a rate of **10 Mbps**, thereby developing and testing key systems that will be used in a **later QKD demonstrator**, PULSE-Q.

Why PULSE-A?



- Use of optical frequencies enables order-of-magnitude faster communication than standard RF transmission.
- Trends towards more compact sensors means greatly increased on-orbit data collection, despite relatively mature RF technology.
- This presents a bottleneck on transmitting scientific research back to Earth – especially as high-speed RF technology rapidly grows in price.
- Nature of light means much narrower beam divergence, allowing for better physical security.
- Optical communications technology is the backbone of quantum key distribution, thus PULSE-A acts as flight heritage for a future mission, PULSE-Q.

Leadership



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Acronyms

ACS - Attitude Control System
CDH - Command and Data Handling
CDS - Cubesat Design Specifications
FPGA - Field Programmable Gate Array
FSM - Fast/fine Steering Mirror
LEO - Low Earth Orbit
MEMS - Micro-electromechanical System
OBC - On Board Computer
OGS - Optical Ground Station
RFGS - Radio Frequency Ground Station
SNR - Signal to Noise Ratio

Terminology

Satellite - Bus and Payload

Bus - Structural framework and essential systems that support mission operations

Uplink - RF transmission from ground to space

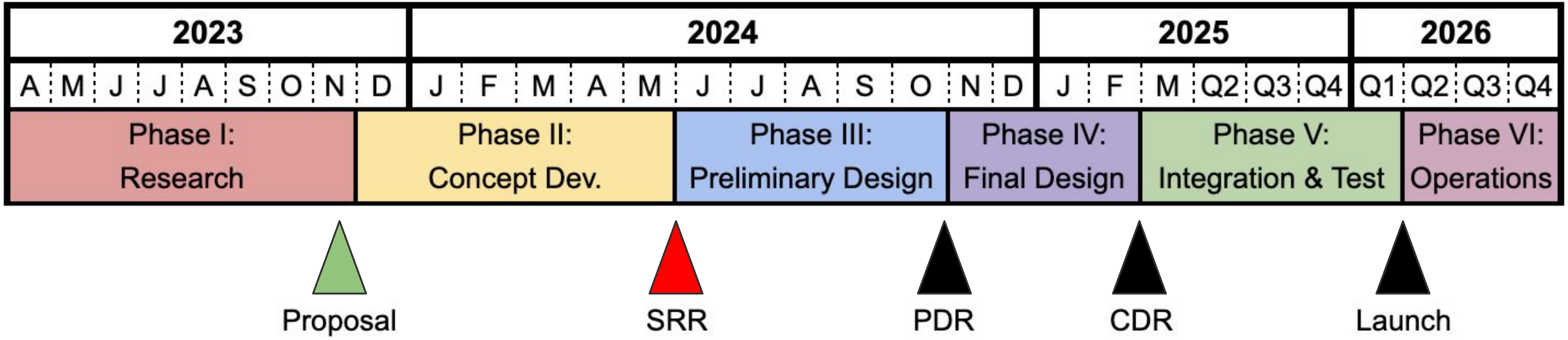
Downlink - RF transmission from space to ground

Payload Transmission Laser - The polarization modulated laser, from space to ground

Payload Beacon Laser - Continuous laser for tracking the Payload, from space to ground

Ground Station Beacon Laser - Continuous laser for tracking the OGS, from ground to space

Timeline


2023
2024
2025
2026
A M J J A S O N D
J F M A M J J A S O N D
J F M Q2 Q3 Q4
Q1 Q2 Q3 Q4
Phase I: Research
Phase II: Concept Dev.
Phase III: Preliminary Design
Phase IV: Final Design
Phase V: Integration & Test
Phase VI: Operations
Proposal
SRR
PDR
CDR
Launch

Funding

$75k raised from various sources so far:

- $25k via private donation
- $25k from five university departments
- $8k from annual allocations (from UChicago RSO office)
- $7.5k from SEDS-USA Space for All grant
- ~$10k in equipment from advisor Prof. Tian Zhong

~$80k budget gap to close

Concept of Operations

T-5m: On Board Computer (OBC) initiates Attitude Determination and Control System (ADCS) and feeds live GPS data to ADCS.

T-4m: GS and PULSE establish RF link.

T-3m: PULSE scans for uplink beacon using pattern originating at expected GS position using open-loop pointing.

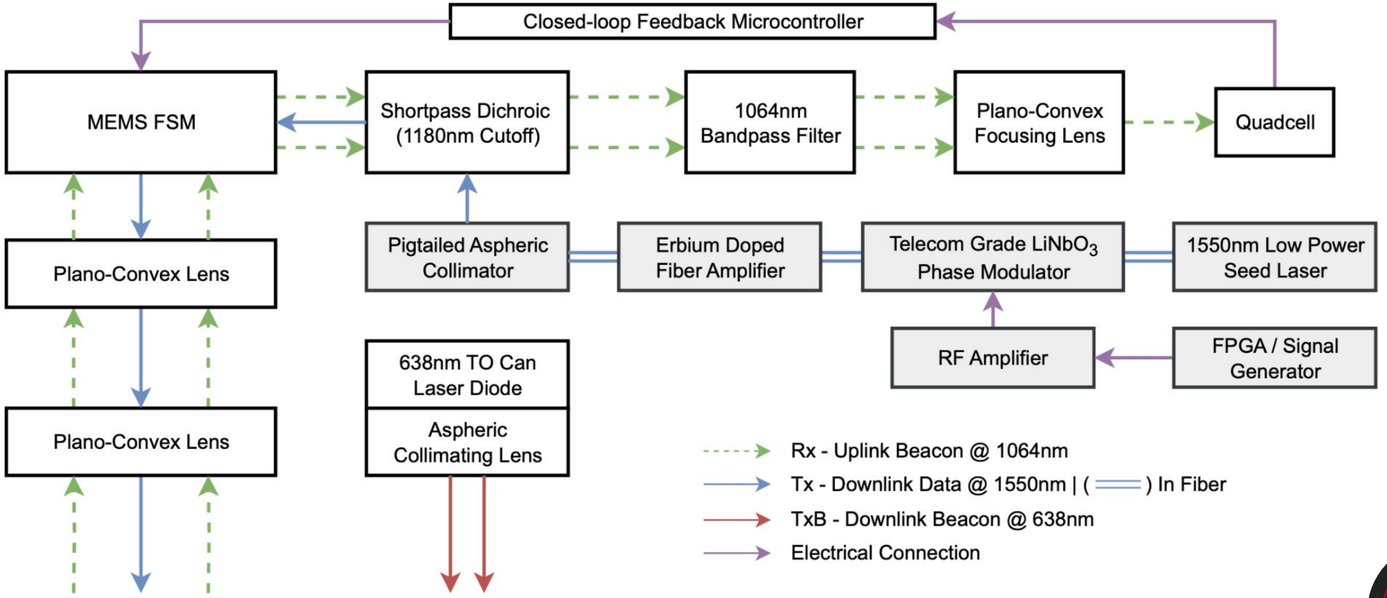
T-1m: Beacon acquisition on QC hands control to Payload. ADCS begins slewing. Closed-loop sequence initiated with QC and FSM, aligning uplink with center of QC. Downlink beacon enabled for GS fine pointing.

T-0: Transmission enabled with modulation controlled by FGPA.

< T+2m: Data is modulated and transmitted at the Payload, received at the ground station and decoded into bits at a rate specified by the mission requirements

Quick Payload Overview

Though slightly counter to the driving force of an SRR, we completed some preliminary payload design. Mostly based on previous work by both MIT and DLR, there are a few components that we know we will use, and for this reason they have made their way into our Payload requirements.



Mission Requirements

Top-level Mission Requirements

Req #	Requirement	Notes
MSN-01	The mission shall provide data transmission from satellite-to-ground using polarization-modulated laser communications.	
MSN-02	The mission shall execute data transmission at a rate of 10 Mbps ≤ Data Rate ≤ 25 Mbps.	25 Mbps is arbitrary but within reasonable range for both modulation and bandwidth. The transmission must be maintained for no less than 1 second for this requirement to be satisfied.
MSN-03	Nothing in the mission design shall preclude a mission life of ≥ 365 days.	Mission life is limited by initial orbital altitude and atmospheric drag. For PULSE-A, lifetime is expected to be approximately 6-14 months.

Satellite Requirements

Satellite Functional Requirements

Req #	Requirement	Notes
SAT-01	The Satellite shall be compliant with the most up-to-date revision of the CubeSat Design Specification (CDS).	The "Satellite" consists of the Bus and Payload. The current revision is CDS Revision 14.1.
SAT-02	The Satellite shall be compliant with the TBD launch provider's requirements.	
SAT-03	The Satellite shall be compliant with the TBD dispenser manufacturer's requirements.	The dispenser is expected to be NanoRacks CubeSat Deployer (NRCSD).
SAT-04	The Satellite shall be capable of maintaining an operational state after deployment.	Power will turn on immediately after deployment. Radio and ADCS will turn on 30 min after deployment (radio is bound by the deployer requirement, ADCS is our choice).

Satellite Functional Requirements

Req #	Requirement	Notes
SAT-05	The Satellite shall maintain a thermally controlled environment in LEO.	See Thermal Control Section
SAT-06	The Satellite shall transmit data to the OGS using polarization-modulated laser communications.	See Payload Section
SAT-07	The Satellite shall receive the ground station laser beacon from the OGS.	See Payload Section
SAT-08	The Satellite shall control pointing in three axes.	See Attitude Control Section

Satellite Functional Requirements

Req #	Requirement	Notes
SAT-09	The Satellite shall accept commands uplinked from the RFGS.	See RFGS Section
SAT-10	The Satellite shall process uplinked commands.	See CDH Section
SAT-11	The Satellite shall downlink data to the RFGS.	See Communications Section
SAT-12	The Satellite shall maintain time after being initialized by a valid time source.	
SAT-13	The Satellite shall be able to perform over-the-air firmware updates.	See CDH Section

Satellite Functional Requirements

Req #	Requirement	Notes
SAT-14	The Satellite shall provide data to the optical payload for downlink.	See CDH Section
SAT-15	The Satellite shall be able to determine its location through GPS.	
SAT-16	The Satellite shall be capable of activating all essential systems at deployment.	

Satellite Performance Requirements

Req #	Requirement	Notes
SAT-17	The Satellite shall be capable of activating all other systems [TBD] < time [TBD] minutes after deployment.	TBD is specified by the launch provider and deployer (for example, if we deploy from the ISS, we can't turn on RF until 30 min after deployment). OBC is involved, timer starts directly following deployment.

Payload Requirements

Payload Functional Requirements

Req #	Requirement	Notes
PAY-01	The Payload shall transmit data to the OGS using a circular polarization-modulated laser.	Flowdown from MSN-01
PAY-02	The Payload shall store data to be transmitted via laser.	All data to be transmitted will first be handled / stored by the Payload.
PAY-03	The Payload shall modulate the transmission laser to encode stored data via polarization.	Here we define encoding as transforming the data to be transferred (in the form of binary 0/1s) into separate polarization states of light, in our case LH and RH circularly polarized light.
PAY-04	The Payload shall collect the laser beacon from the OGS along an optical path.	By collect we mean recieve, condense, and collimate for detection.

Payload Functional Requirements

Req #	Requirement	Notes
PAY-05	The Payload shall detect the laser beacon from the OGS.	After the beacon is received, it must be detected for fine pointing feedback. (Dependent on PAY-04)
PAY-06	The Payload shall perform fine pointing to align the downlink transmission laser with the laser beacon from the OGS.	This flows down from the ACS pointing requirements, which are expected to be insufficient for the required transmission accuracy. Fine pointing in the payload is required.
PAY-07	The Payload shall transmit a laser beacon to the OGS parallel with the downlink transmission laser.	

Payload Performance Requirements

Req #	Requirement	Notes
PAY-08	The Payload shall modulate the transmission laser at a frequency of $10 \leq$ Frequency ≤ 25 MHz.	Flowdown from MSN-02
PAY-09	The Modulator shall create left handed circularly polarized light to an accuracy of [TBD].	Imperfect circular polarization refers to either an imperfect phase shift (not pi/2) or a difference between the amplitudes of the x and y axes. This should give us a set of numbers depending on these two variables.
PAY-10	The Modulator shall create right handed circularly polarized light to an accuracy of [TBD].	
PAY-11	The Payload shall align the ground station laser beacon with the center of the detector within an angular margin of 0 +/- TBD°.	Most likely, the detector will be a quadcell.

Payload Performance Requirements

Req #	Requirement	Notes
PAY-12	The Payload shall detect the ground station laser beacon when body pointing error is 0 +/- 1 deg.	This requirement is derived from the interface between the ACS and the FSM. 0 is defined as the pointing vector from the ground station.
PAY-13	The Payload shall be capable of operating the payload transmission laser continuously for 150 ≤ time ≤ TBD seconds.	150 seconds is somewhat arbitrary, but is closely related to the time of 1 pass. The TBD is essentially the time of the longest possible pass.
PAY-14	The Payload shall be capable of operating the payload beacon laser continuously for 150 ≤ time ≤ TBD seconds.	150 seconds is somewhat arbitrary, but is closely related to the time of 1 pass. The TBD is essentially the time of the longest possible pass.
PAY-15	The Payload shall maintain structural alignment within +/- [max angle ° TBD].	This result is TBD because it depends on vibration testing (or Zemax analysis) which will determine how much the lenses can shift while continuing to satisfy PAY-11 and PAY-12.

Payload Performance Requirements

Req #	Requirement	Notes
PAY-16	The Payload shall be capable of continuous operations at 18.5 W +/- 3 W.	Added approximate input powers of EDFA, modulator, seed laser, beacon laser, FSM, FPGA & RF Amplifier, and added about a watt. +/- estimate is somewhat arbitrary, but informed from maximum energy storage in battery and current design power draw.
PAY-17	Detector shall detect the ground station laser beacon at an SNR no less than 5.	The math behind this requirement is closely related to OGS-15. Most likely, the detector will be a quadcell.
PAY-18	Optical assembly shall produce a transmission laser beam with power TBD +/- TBD W.	This minimum power is dependent on NEP and desired SNR and can be calculated by Pmin=SNR*(NEP*(f)^0.5 + E)/ e where f is our bandwidth frequency (10^7 for 10 Mbit/s), E is the external noise from sources including but not limited to IR emission lines, atmospheric glow and light pollution, and e is an efficiency factor dependent on the loss due to the OGS's optical path.

Payload Performance Requirements

Req #	Requirement	Notes
PAY-19	Optical assembly shall produce a beacon laser beam with power TBD +/- TBD W.	Optical Ground Station drives the minimum power required over irradiated area for adequate signal to noise ratio for detection of photons from the optical payload at 10 Mbps. The limiting factor is, similarly to above, the noise equivalent power generated by the beacon detectors in the ground station. These are intrinsic to the camera, and may be measured in other units rather than NEP. The camera's frequency of detection is much lower than that of the detectors for the transmission laser, suggesting a lower power requirement for the same SNR, depending on the intrinsic noise equivalent power of the camera.

Thermal Requirements

Thermal Functional Requirements

Req #	Requirement	Notes
THRM-01	The thermal subsystem shall maintain an operational thermal environment for the bus.	Subcomponents include power systems, energy capture systems, and ACS systems.
THRM-02	The thermal system shall maintain the payload system at a temperature range within the maximum and minimum operating temperature range of the most thermally sensitive components.	This will primarily be accomplished via passive control.

Thermal Performance Requirements

Req #	Requirement	Notes
THRM-03	The thermal subsystem shall maintain the bus system within a temperature range of TBD K < Temperature < TBD K.	Individual subcomponent requirements may spawn additional requirements for the thermal subsystem.
THRM-04	The thermal subsystem shall maintain the Payload within a temperature range of TBD K < Temperature < TBD K.	In the current design, certain components in the payload have an operating temperature ranging from -40 to 60 degrees Celsius, while other components can be more sensitive to temperature and others more resistant, suggesting that thermal control designs will have to be very specific to each component, and the temperature of each payload component may vary significantly at a given time.

Attitude Control Requirements

Attitude Control Functional Requirements

Req #	Requirement	Notes
ACS-01	The ACS shall provide pointing control in three axes.	The ACS will have sensors and actuators allowing it to point at the OGS.
ACS-02	The ACS shall provide pointing knowledge in three axes.	The ACS will have sensors and actuators allowing it to point at the OGS.
ACS-03	The ACS shall be able to send data to the OBC.	
ACS-04	The ACS shall be able to receive data from the OBC.	The OBC will communicate with the GPS to provide pointing information.
ACS-05	The ACS shall be able to track the OGS coordinates.	The OBC will interface with the GPS to provide pointing information.

Attitude Control Performance Requirements

Req #	Requirement	Notes
ACS-06	The ACS shall provide three-axis pointing control with a radial accuracy of ±1° 3-sigma.	±1° 3-sigma accuracy is standard for high-end COTS ACS units for CubeSats (source CLICK). ACS-05 implies a flow-down requirement for the optical path to create minor adjustments.
ACS-07	The ACS shall provide three-axis position knowledge to a radial accuracy of TBD m ≤ Radius ≤ TBD m.	The upper bound comes from the OGS laser's beam divergence.
ACS-08	The ACS shall provide three-axis velocity knowledge to a radial accuracy of TBD m/s ≤ Velocity ≤ TBD m/s.	This will be primarily be determined by requirements for the beacon and orbital propagation.

Structure Requirements

Structure Functional Requirements

Req #	Requirement	Notes
STR-01	The structure subsystem shall be compliant with the most up-to-date revision of the CubeSat Design Specification (CDS).	The current revision is CDS Revision 14.1.
STR-02	The structure subsystem shall be compliant with the TBD launch provider's requirements.	
STR-03	The structure subsystem shall be compliant with the TBD dispenser manufacturer's requirements.	The dispenser is expected to be NanoRacks CubeSat Deployer (NRCSD).
STR-04	The structure subsystem shall provide an external aperture for the OGS laser beacon and downlink transmission laser.	Both lasers will use the same aperture.

Structure Functional Requirements

Req #	Requirement	Notes
STR-05	The structure subsystem shall provide an external aperture for the Payload laser beacon.	This is a different aperture from the aperture described by STR-04.
STR-06	The structure subsystem shall provide support for an external communications antenna.	This includes mounting, stowing, and electrical communication capabilities.
STR-07	The structure subsystem shall provide supporting surfaces for solar cells.	
STR-08	The structure subsystem shall secure any appendages prior to deployment.	

Structure Performance Requirements

Req #	Requirement	Notes
STR-09	The structure subsystem shall be compatible with loads of TBD N ≤ Load Force ≤ TBD N.	This accommodates loads on the Satellite during launch and will be determined by the TBD Launch Vehicle user guide.
STR-10	The structure subsystem shall be compatible with vibrations of TBD dB ≤ vibration ≤ TBD dB.	Vibration units are decibels as per SMC-S-016.
STR-11	The structural panel in front of the Payload primary lens shall provide a circular lens aperture of radius (27.5 ± 2.5) mm.	The aperture's dimensions are derived from the Payload requirements to receive the laser beam from the OGS.
STR-12	The structure shall maintain the Payload optical path alignment to an angle of ± TBD°.	Depends on vibration because vibration can affect alignment.
STR-13	The structure shall maintain the payload optical path alignment within a margin of ± TBD μm.	Depends on thermal expansion, alignment error to which light pathway is significantly compromised

Power Requirements

Power Functional Requirements

Req #	Requirement	Notes
POW-01	The power subsystem shall be compliant with the most up-to-date revision of the CubeSat Design Specification (CDS).	The current revision is CDS Revision 14.1.
POW-02	The power subsystem shall generate energy from the sun.	
POW-03	The power subsystem shall provide energy storage.	
POW-04	The power subsystem shall distribute power to all Satellite subsystems.	

Power Functional Requirements

Req #	Requirement	Notes
POW-05	The power subsystem shall inhibit power to the Satellite while contained within a deployer.	Most likely, we plan to use 2 levels of inhibition while stored in the deployer.
POW-06	The power subsystem shall be capable of providing power to the bus using only solar generation.	The system should be able to bypass the energy storage device, with solar-generated power being supplied to other critical subsystems.
POW-07	The power subsystem shall have an external charging port for its energy storage device.	

Power Performance Requirements

Req #	Requirement	Notes
POW-08	The power subsystem shall generate TBD ± TBD Wh of energy during each orbit.	Energy generation requirement is derived from Payload and ACS energy consumption requirements which require refinement.
POW-09	The power subsystem shall be capable of storing TBD Wh ≤ Energy ≤ 80 Wh of energy.	Maximum energy is derived from NanoRacks deployer standard. Minimum requirement depends on Payload and ACS duty cycle and power consumption.

Power Performance Requirements

Req #	Requirement	Notes
POW-10	The power subsystem shall be designed to provide TBD W ≤ Power ≤ TBD W continuous power during entire mission operations after initial boot-up.	Minimum continuous power is driven by the ACS's passive pointing power draw.
POW-11	The power subsystem shall be designed to provide 18.5 W ≤ P ≤ TBD W continuous power to the Payload subsystem for 2.5 min ≤ Time ≤ 5 min during transmission.	18.5W lower bound is taken from PAY-14, 2.5 min lower bound is taken from PAY-12, and 5 min upper bound is somewhat arbitrary but is roughly double the time of 1 pass.

Communications Requirements

Communications Functional Requirements

Req #	Requirement	Notes
COMM-01	The communications subsystem shall receive data uplinked from the RFGS.	A means of accepting data from Ground Control is required.
COMM-02	The communications subsystem shall receive commands uplinked from the RFGS.	A means of accepting commands from Ground Control is required.
COMM-03	The communications subsystem shall transmit downlink data to the RFGS.	A means of transmitting data to Ground Control is required.
COMM-04	The communications subsystem shall transmit the Satellite's GPS data to the RFGS.	A means of transmitting GPS data to Ground Control is required for the OGS to point at the Satellite.

Communications Performance Requirements

Req #	Requirement	Notes
COMM-05	The communications subsystem shall be capable of transmitting data to the RFGS in a downlink at a rate of 1 Kpbs ≤ Rate ≤ TBD Kbps.	Typical low-cost systems have data rates of up hundreds of Kbps; however, Artemis found that reliability was far greater for a rate of 2 Kbps. We estimate the rate should be ≥ 1 Kbps as a result given telemetry constraints with a currently undetermined upper bound.
COMM-06	The communications subsystem shall be capable of receiving uplinked data from the RFGS at a rate of 1 Kbps ≤ Rate ≤ TBD Kbps.	Typical subsystems can handle up to 100 Kbps. Artemis found that reliability was far greater for a rate of 2 Kbps. We estimate the rate should be ≥ 1 Kbps as a result with a currently undetermined upper bound.

Command and Data Handling Requirements

CDH Functional Requirements

Req #	Requirement	Notes
CDH-01	The CDH subsystem shall provide dedicated memory for payload downlink data.	Payload downlink data refers to data that will be dowlinked through the payload transmission laser.
CDH-02	The CDH shall send commands to the ACS subsystem.	
CDH-03	The CDH subsystem shall receive data from the ACS subsystem.	Includes commands and subsystem state information.
CDH-04	The CDH subsystem shall be able to process data from Payload instruments.	Payload instruments include Quadcell, FSM, FPGA, etc.

CDH Functional Requirements

Req #	Requirement	Notes
CDH-05	The CDH subsystem shall be able to command Payload instruments.	Same note as CDH-04.
CDH-06	The CDH subsystem shall provide storage for data received from the RFGS.	Includes commands, data files, and programs.
CDH-07	The CDH subsystem shall store telemetry data for radio downlink to Ground Control.	Telemetry refers to subsystem status/state data.
CDH-08	The CDH subsystem shall perform computations on stored data.	Includes processes that store, compress, or alter data, such as orbit propagation calculations.

CDH Functional Requirements

Req #	Requirement	Notes
CDH-09	The CDH subsystem shall synchronize the CDH real-time clock with a time standard.	Possible requirement satisfaction by synchronizing CDH with an external time source, ie GPS clock. Time standard in UTC.
CDH-10	The CDH subsystem shall execute flight software.	Flight software includes onboard tasks to be executed by the CDH system as required to operate the satellite.
CDH-11	The CDH subsystem shall be re-programmable by external sources.	Includes via access ports and over-the-air updates.
CDH-12	The CDH subsystem shall provide a mechanism to restart the CDH processing elements in the event of a recoverable failure.	Intended for application of a watchdog timer. Recoverable failures include those caused by errors in flight softtware or resettable hardware.

CDH Functional Requirements

Req #	Requirement	Notes
CDH-13	The CDH subsystem shall sign radio downlink data.	
CDH-14	The CDH subsystem shall verify signed uplink data.	
CDH-15	The CDH subsystem shall discard unsigned uplinked data.	
CDH-16	The CDH subsystem shall maintain redundant systems for data storage.	Refers to primary flight software.

CDH Performance Requirements

Req #	Requirement	Notes
CDH-17	The CDH subsystem shall reserve TBD Mb ≤ memory ≤ TBD Mb of memory for optical downlink.	TBD will be determined with further analysis.
CDH-18	The CDH subsystem shall be able to access optical downlink data at a rate of 10 Mbps ≤ Data Rate ≤ 25 Mbps.	
CDH-19	The CDH memory shall provide TBD Mb ≤ storage ≤ TBD Mb of nonvolatile storage for flight software.	Constrained by developed software. Will be determined by CDH budgets.
CDH-20	The CDH processor shall support an execution speed of TBD ≤ speed ≤ TBD [DMIPS].	Constrained by developed software. Likely to be constrained by the pointing, acquisition, and tracking (PAT) sequence.
CDH-21	The CDH memory shall provide TBD ≤ storage ≤ TBD Mb of nonvolatile storage for commands.	Refers to primary flight software.

CDH Performance Requirements

Req #	Requirement	Notes
CDH-22	The CDH memory shall be able to read data from storage at TBD ≤ speed ≤ TBD bits/sec.	Memory speed will be determined through trade study analysis.
CDH-23	The CDH watchdog timer shall reset processing elements after an elapsed time of TBD [sec] ≤ time ≤ TBD [sec] of not being reset.	Properly executing flight software is expected to continuously reset the watchdog timer before it times out.
CDH-24	The CDH clock shall have an accuracy of TBD [sec] +/- TBD [sec]	Clock accuracy will be determined through analysis of execution accuracy to meet mission objectives, such as during the PAT sequence.
CDH-25	The CDH watchdog timer timeout setting shall be determined by hardware	Electrical components will determine CDH watchdog timeout to avoid software-induced failures.

Optical Ground Station Requirements

OGS Functional Requirements

Req #	Requirement	Notes
OGS-01	The OGS shall point to the Satellite.	The OGS pointing facilitates reception of the downlink beacon and downlink transmission, as well as transmission of the uplink beacon.
OGS-02	The OGS shall receive the payload beacon laser and payload transmission laser from the Satellite.	
OGS-03	The OGS shall split the payload beacon laser and payload transmission laser into separate optical paths.	Notionally, the separation will occur via a dichroic lens.
OGS-04	The OGS shall decode the downlink transmission laser into packageable data.	

OGS Functional Requirements

Req #	Requirement	Notes
OGS-05	The OGS shall track the payload laser beacon.	Enables operation of feedback loop for satellite pointing.
OGS-06	The OGS shall tag each data packet according to the specific time it is received.	This should be accurate to the bit rate modulated at the payload. See OGS-15.
OGS-07	The OGS shall transmit the ground station laser beacon.	
OGS-08	The OGS shall decode the downlink transmission laser into bits based on polarization state.	

OGS Performance Requirements

Req #	Requirement	Notes
OGS-09	The OGS shall split the payload laser beacon and the downlink transmission laser by wavelength; the payload laser beacon shall be sent to the tracking camera and the downlink transmission laser shall be split by polarization state and detected by 2 detectors.	(Will probably use APDs - avalanche photodiodes)
OGS-10	The OGS shall decode data at a transmission rate of 10 Mbps ≤ Data Rate ≤ 25 Mbps.	The transmission rate is determined by the Mission Requirements.
OGS-11	The OGS shall tag each data packet at a rate of one tag per 40 ns ≤ Time ≤ 100 ns.	Rate of tagging determined by mission requirements for bit rate.

OGS Performance Requirements

Req #	Requirement	Notes
OGS-12	The OGS shall maintain the telescope pointed at the satellite during the optical pass for 1 second ≤ Time ≤ TBD seconds accurate to [TBD +/- TBD] degrees	More generally, this TBD value would be determined by the minimum accuracy of the "lowest field of view receiver", which references the telescope and tracking camera in the current design, but could reference any receiver setup. Mission requirement says achieve data rate for no less than 1 second, so then our requirement should be taken from that
OGS-13	The OGS shall implement a feedback loop using sub-second updates of the position of the satellite.	The camera can only update the position of the payload laser beacon with a certain time interval. Our telescope will only have a certain degree of accuracy, meaning the uncertainty in pointing for the telescope will result in a pointing offset. The position updating interval should be smaller than the time in which the pointing uncertainty would result in a loss of tracking.

OGS Performance Requirements

Req #	Requirement	Notes
OGS-14	The OGS shall analyze tagged photons and convert to digital information to a degree of accuracy no less than TBD %.	
OGS-15	The OGS shall be capable of decoding the laser transmission at a signal to noise ratio of 5 +/- TBD.	With our current setup, (using low NEP detectors, and with a data rate of 10 Mbit/s), our signal to noise ratio is given by SNR = e*P/[(NEP*(f)^0.5 + E)] where f is our bandwidth frequency (10^7 for 10 Mbit/s), E is the external noise from sources including but not limited to IR emission lines, atmospheric glow and light pollution, P is the power received at the telescope, NEP is an intrinsic noise equivalent power of the detectors, and e is an efficiency factor dependent on the loss due to the OGS's optical path.

RF Ground Station Requirements

RFGS Functional Requirements

Req #	Requirement	Notes
RFGS-01	The RFGS shall command the Satellite.	Only valid commands received from the RFGS shall be executed by the Satellite.
RFGS-02	The RFGS shall uplink commands and data to the Satellite.	Commands and data will be uplinked via RF.
RFGS-03	The RFGS shall accept downlinked data from the Satellite.	The communications subsystem will downlink data via RF.
RFGS-04	The RFGS shall ensure the integrity of uplinked commands.	This implies the use of encryption and checksums in sent data.

RFGS Functional Requirements

Req #	Requirement	Notes
RFGS-05	The RFGS shall ensure the integrity of downlinked commands.	This implies the use of encryption and checksums in received data.
RFGS-06	The RFGS shall be capable of uplinking system updates to the Satellite.	System updates will be uplinked via RF.
RFGS-07	The RFGS shall track the Satellite in orbit.	This will primarily use GPS coordinates and secondarily use optical feedback.

RFGS Performance Requirements

Req #	Requirement	Notes
RFGS-08	The RFGS shall be capable of accepting downlinked GPS data from the Satellite every TBD sec ≤ Time ≤ TBD sec.	A consistent interval between GPS data reception is necessary for the OGS to track the Satellite. We roughly estimate an upper bound of 1 second intervals for tracking, although we plan to investigate this figure more.
RFGS-09	The RFGS shall be capable of receiving downlink data from the Satellite of TBD Kpbs ≤ Rate ≤ TBD Kbps.	
RFGS-10	The RFGS shall be capable of uplinking data at a rate of TBD Kbps ≤ Rate ≤ TBD Kbps.	

Launch Vehicle Requirements

Launch Vehicle Functional Requirements

Req #	Requirement	Notes
LV-01	The Launch Vehicle shall transport the Satellite to LEO.	
LV-02	The Launch Vehicle shall maintain the Satellite in specified nonoperational ambient environment conditions.	
LV-03	The Launch Vehicle shall deliver the Satellite into orbit at $42.5° \leq$ Inclination $\leq 90°$.	

Launch Vehicle Performance Requirements

Req #	Requirement	Notes
LV-04	The Satellite shall be maintained by the Launch Vehicle within an ambient temperature range of TBD [deg C] ≤ Temp ≤ TBD [deg C].	
LV-05	The Satellite shall be maintained by the Launch Vehicle within an ambient humidity range of TBD [%] ≤ Humidity ≤ TBD [%].	
LV-06	The Satellite shall be deployed with a rotational rate of 0 rads/s <= rotational rate <= max TBD such that the ADCS is capable of detumbling.	

Assembly, Integration and Test Requirements

AIT Functional Requirements

Req #	Requirement	Notes
AIT-01	AIT shall test the satellite to verify compliance with all testing requirements as specified by SMC-S-016.	Acceptance testing shall be performed on all units, subsystems, and systems, and qualification or protoflight testing shall be performed as required or needed on a unit, subsystem, system and satellite level.
AIT-02	AIT shall test the satellite to verify compliance with all testing requirements as levied by the dispenser provider.	The dispenser provider is expected to be NanoRacks CubeSat Deployer (NRCSD).
AIT-03	AIT shall test the satellite to verify compliance with all testing requirements as levied by the launch vehicle service provider.	The launch vehicle service provider is unknown; the SpaceX Falcon 9 may be used as a temporary estimate for expected launch environment including maximum expected vibration, acoustic and shock levels.

AIT Functional Requirements

Req #	Requirement	Notes
AIT-04	AIT shall directly access the CDH subsystem command interface.	Direct access to the CDH bypasses the communications subsystem for ground testing.
AIT-05	AIT shall directly access the CDH subsystem data interface.	Direct access to the CDH bypasses the communications subsystem for ground testing.
AIT-06	AIT shall provide a dynamic Satellite simulation for closed loop ACS performance verification.	Closed loop testing significantly improves the chances of mission success. Closed loop testing provides an orbital dynamics simulation used to stimulate ACS sensors while monitoring ACS actuator responses for proper behavior. - from Darkness
AIT-07	AIT shall provide a compatible ambient environment for the Satellite.	The Satellite must be maintained in suitable temperature and humidity environment.

AIT Performance Requirements

Req #	Requirement	Notes
AIT-08	AIT shall test the satellite and all relevant units, subsystems and systems to verify that these withstand vibration testing of 6 dB above the Maximum Predicted Environment (MPE) for three minutes.	Vibration testing shall include random vibration, sinusoidal vibration, acoustic and pyroshock testing. The MPE is TBD and shall be determined by the launch provider. This is from SMC-S-016, as are all of the next few performance requirements following it.
AIT-09	AIT shall test the satellite and all relevant units, subsystems and systems to verify that these withstand thermal testing of +/-10°C above the Maximum Predicted Environment (MPE) for eight cycles.	Thermal testing shall be primarily comprised of thermal vacuum testing, although thermal cycling and thermal balance testing may be performed in place of or in combination with thermal vacuum testing as needed. The MPE is TBD and will likely come from simulating in ANSYS. Thermal testing is expected to be performed at UIUC LASSI.

AIT Performance Requirements

Req #	Requirement	Notes
AIT-10	AIT shall test the satellite to verify that it will withstand load testing to a level of TBD N ≤ Load Force ≤ TBD N as per the launch provider.	SMC-S-016 says 1.25x the limit load for unit level - limit load for each unit is TBD.
AIT-11	AIT shall EMC test the satellite and all relevant units, subsystems and systems to levels of 12 dB for 20 +/- TBD min at each space vehicle transmitter frequency.	From SMC-S-016. Used to verify that it will not be susceptible to or cause electromatic interference which results in malfunction. - I'm guessing it is mostly intended to test our radiation shielding and the functioning of the RF antenna. EMC test = electromagnetic compatibility test

AIT Performance Requirements

Req #	Requirement	Notes
AIT-12	AIT shall static load test all relevant units and subsystems to 1.25 times limit load for TBD +/- TBD duration.	From SMC-S-016.
AIT-13	AIT shall perform mode survey tests on the Satellite and/or relevant systems and subsystems as needed to develop a structural dynamic model for load analyses to an accuracy of TBD.	The methodology of mode testing is described in SMC-S-004.
AIT-14	AIT shall burn in all relevant electrical and electronic units for TBD hours to test for latent defects.	SMC-S-016 says unit thermal cycling + unit thermal vacuum + burn-in testing shall exceed 200 hours, and the final 100 hours shall be failure free.

AIT Performance Requirements

Req #	Requirement	Notes
AIT-15	The Satellite shall be maintained by AIT within an ambient temperature range of TBD [deg C] < Temp < TBD [deg C].	During integration, the Satellite must be kept in a clean and temperature-controlled environment.
AIT-16	The Satellite shall be maintained by AIT within an ambient humidity range of TBD [%] < Relative Humidity < TBD [%].	During assembly, the Satellite must be kept in a clean and humidity-controlled environment.

Questions