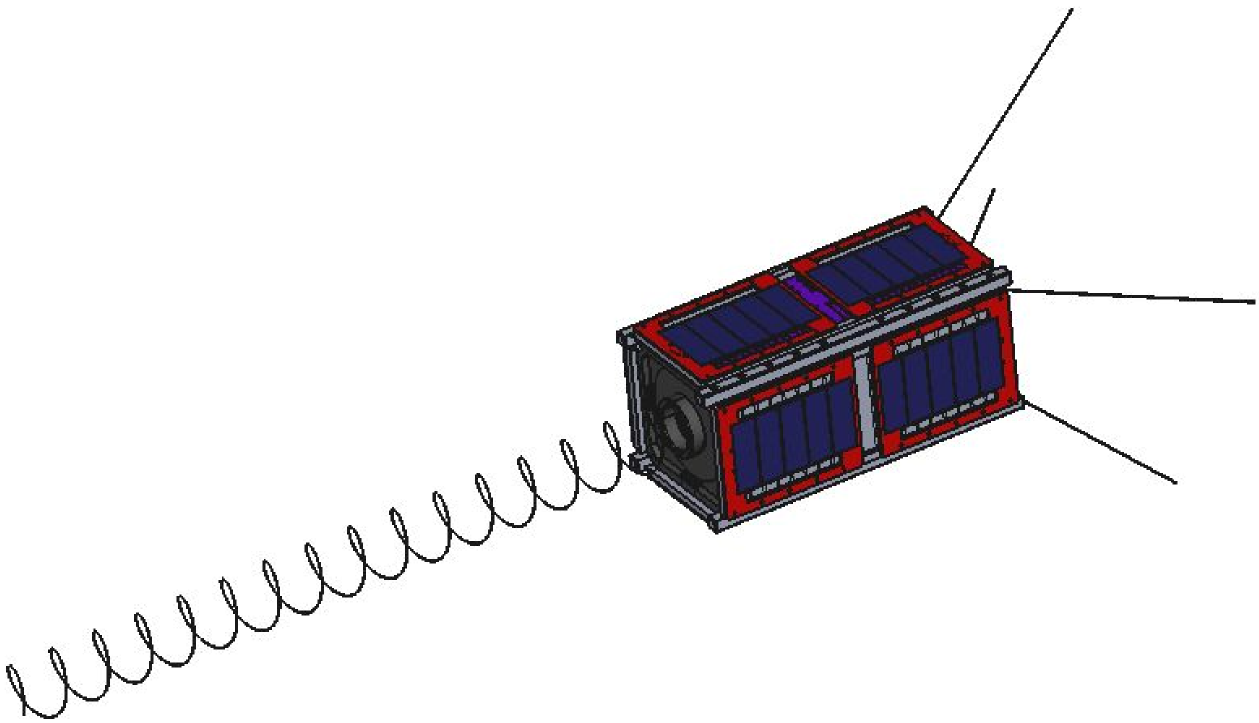
NASA CSLI Application

In Response to Solicitation NNH16ZCQ002O
For

OreSat: Oregon's First Nanosatellite

November 22, 2016



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Mission Parameters, Project Details, and Points of Contact

CubeSat Mission Parameters								
Mission Name	Mass	Cube Size	Desired Orbit		Acceptable Orbit Range	400 km @ 51.6 degree incl. Acceptable- Yes or No	Readiness Date	Desired Mission Life
OreSat	2.36 kg	2U	Altitude	400 km	325-450 km	Yes	Feb. 2019	1 Year
			Inclination	45°	45-75°			

CubeSat Project Details						
Focus Area(s)	Student Involvement- Yes or No	NASA Funding		Sponsoring Organization(s)	Collaborating Organization(s)	
		Yes or No	Organization		List	International- Yes or No
Education, Science, Technology	Yes	No	N/A	N/A	Portland State University, University of Oregon, Oregon State University	No

Points of Contact				
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Proposal Abstract

OreSat, Oregon's first small satellite, is a 2U CubeSat being built by a consortium of Oregon higher education institutions as an interactive space-based Science, Technology, Engineering, and Math (STEM) outreach program in the state of Oregon.

An Artisanally Handcrafted Satellite from the State of Oregon

At its core, OreSat is a vehicle for collaborative, interdisciplinary aerospace engineering education in the state of Oregon. University-based science and engineering students will, for the first time, be able to get hands-on nanosatellite engineering and operational experience in Oregon. OreSat will pave the way not just for this generation of engineers and scientists, but will also pioneer future collaborations and future Oregon-based missions.

"OreSat Live": Literally Space-Based STEM Outreach

OreSat's primary mission is to offer an innovative space-based STEM outreach to the entire state of Oregon. The "OreSat Live" system will stream live video directly from the satellite in low earth orbit to any Oregon school that builds an inexpensive, easy to assemble, simple to use ground station.

The OreSat Live space segment is based off the technology heritage of the DxWiFi project, a long distance WiFi-based (802.11b) 2.4 GHz amateur radio link pioneered at Portland State University. DxWiFi has been tested up to 125 km on small aircraft, and on a half dozen amateur rocket launches. By extending the reach of DxWiFi with higher gain antennas, OreSat will be able to directly transmit a 2 Mbps high-compression video stream from low earth orbit.

On the ground, students will hand-wind a helical antenna around a series of 3D printed forms, fasten the antenna to a laser-cut handheld plate, solder together a simple low noise amplifier board on a provided PCB, and add a $15 WiFi to USB converter. This < $50 system, which can be built from scratch, bought as a kit, or purchased as a complete unit, connects to any Windows, Mac or Linux laptop running OreSat's open source video streaming and decoding software. Students will hand-point the antenna at OreSat as it passes overhead using a freely available smart phone app made by Analytical Graphics, Inc. called "Satellite AR", which displays a real time satellite position in the sky. This fun, easy to build and use, "DIY" ground station will not only display real-time images transmitted directly from space, but also teach students about wireless communication, space, nanosatellites, orbits and give them hands-on experience with rapid prototyping technologies.

"Cirrus Flux Cam": OreSat's Science Mission

OreSat's secondary mission is to study the contribution of high-altitude cirrus clouds to global climate change. Dr. Greg Bothun and Eryn Cangi from the Department of Physics at the University of Oregon have developed the Cirrus Flux Cam (CFC), an inexpensive astronomy camera and optical filter wheel system designed to image the optical flux of sunlight reflected off high-altitude (>15 km) cirrus clouds. These clouds are often invisible to the naked eye but still absorb infrared radiation, a basic mechanism in global warming. The CFC will provide an estimate of the cirrus clouds' global coverage using a filter wheel to image the reflected light of cirrus clouds in 82a blue, 11 yellow, and LRGB bands. The data will be verified against ground-based studies in Oregon and later used to estimate the impact of cirrus clouds on climate change, which will help improve future climate models.

OreSat's Open Technology Mission

OreSat's tertiary mission is to demonstrate three innovative technologies for university-class CubeSats:

- **DxWiFi:** OreSat will demonstrate the functionality of DxWiFi, an inexpensive, long distance, open source S-band amateur radio communication technology with a 2 Mbps bidirectional data link.
- **Alta Devices Single-Junction CVD Solar Technology:** OreSat will demonstrate the space-readiness of a new type of chemical vapor deposition (CVD) Gallium Arsenide (GaAs) solar cell, manufactured by Alta Devices. Alta Devices is providing the cells in-kind for the OreSat mission.
- **The OreSat Bus:** The OreSat bus is an open source, modular card/backplane system that replaces standard CubeSat PC-104 stacks. The OreSat bus can scale from 1 to 3U CubeSats, and includes solar panels, battery packs, and radio systems. CAD files for the OreSat bus are already available on Github, a popular open source project site at https://github.com/oresat/.

More information can be found on the OreSat website at http://oresat.org/.

Proposal Details

OreSat has three missions (focus areas):

1. OreSat's primary mission is to promote aerospace education and create an innovative Science, Technology, Engineering, and Math (STEM) education outreach opportunity in the state of Oregon.
2. OreSat's secondary mission is to study the contributions of high-altitude cirrus clouds to global climate change.
3. OreSat's tertiary mission is to raise the technological readiness of a suite of CubeSat technologies: the DxWiFi radio communication system, Gallium Arsenide solar cells manufactured by Alta Devices, and the open source OreSat CubeSat bus.

1. Primary Mission: STEM Educational Outreach

OreSat's primary mission is to transmit a live "selfie" video of Oregon K-12 students and their local area from low earth orbit. The K-12 students receive the video on simple equipment they build themselves, transmitted from a sophisticated satellite designed and built by only slightly older students at Oregon’s colleges and universities. This innovative and inspirational space-based educational outreach will motivate students to gain experience and explore new opportunities in STEM fields and careers in aerospace.

1.1 Educational Partners

To accomplish this educational outreach mission, the OreSat project is relying heavily on educational partners with deep experience in STEM outreach. A few of our partners include:

- Jim Todd, Directory of Space Education at the Oregon Museum of Science and Industry (OMSI), Oregon's premier science museum.
- Dean Walton, Science and Technology Outreach Librarian / Associate Professor at the University of Oregon
- Tamara DePue, Program Manager at the Math, Engineering, and Science Achievement (MESA) USA, which is a nationally recognized program to engage thousands of educationally disadvantaged students so they excel in math and science and graduate with math-based degrees.
- The Center for Science Education at Portland State University. The CSE focuses on enhancing teachers ability to teach science at both the primary and secondary levels.

1.2 Educational Materials and the OreSat Live Educational Ground Station

In collaboration with these educational partners, three different OreSat outreach kits are being created for high schools, middle schools, and elementary schools.

- **High Schools** are the main outreach target of OreSat. Directed at both high school science and technology teachers and directly to students, the high school outreach kit will have educational materials and activities covering space, orbits, satellites and nanosatellites, communication, and the impact these have on day-to-day life in Oregon. These materials will have the express purpose of inspiring high schoolers to build their own live video from space receiver: the OreSat Live Educational Ground Station. A single class, a groups of a few students, or even individual students can build their own ground station to receive live video from space on their own laptops. There are three different levels of kits for the ground stations to help with all student and teacher experience levels:

  - **Purchase a Fully Assembled Ground Station** from Crowd Supply, Inc. Crowd Supply (https://www.crowdsupply.com/) is an Oregon-based OreSat partner which distributes electronics and electronics kits to consumers. . This is the most expensive option (still projected to be well under $100), but requires no time or skills to assemble.
  - **Purchase a Component Kit** from Crowd Supply. Purchasing component kits should cost well under $50 per kit, and will enable students who have limited access to equipment to build their own receiver. For example, if the school has a 3D printer but not a laser cutter, then students could purchase the laser-cut components and print their own 3D forms. Since many high school have 3D printers, the expectation is that classes and/or students would purchase at least the electronics, which should cost under $20.
  - **Complete "DIY"**. This is the most exciting aspect of educational outreach: students can order their own circuit boards and components, 3D print their own helical fixtures, and lasercut their own panels. Students will learn about rapid prototyping, soldering, wireless and space communications, and get real world experience with cutting-edge manufacturing technologies that they may miss otherwise. All of the receiver's CAD is open source and available. Step-by-step instructions, including purchasing raw materials, assembling the components, and system testing, will be made available online.

- **Middle Schools** will also be given a similar, but more simple, set of materials. Middle school classrooms and students will be directed towards the complete Component Kit with all materials they'd need to build a ground station. This would make building a receiver just a few hours of simple, tool-free work. While more expensive than a "do-it-yourself" kit, these complete kits will enable middle school teachers, and possibly even groups of middle school students, to put together a ground station for their own use. We would expect one ground station per school, to be used by multiple classes or teams of students.
- **Elementary Schools** will receive educational materials targeted at elementary teachers in Oregon. Discussions and activities around space, orbits, satellites, and radios, and the impact of space in Oregon, will be available for elementary school teachers to show their students.

Elementary schools are not expected to purchase or build their own ground station. Instead, a secondary outreach program will match high school teams with their local elementary schools. High schools that have built an OreSat Live Educational Ground Station, and registered them online, will be connected with their local elementary schools. This will enable high school students to do STEM outreach, using the OreSat Live system to show off live video from space. This peer mentoring is an extremely exciting way of motivating young children to think and explore STEM fields, as they strongly identify with older students as role models. At the same time, high school youth are given an opportunity to develop leadership and mentoring skills which will serve them well in higher education and in their future careers.

While the live video will inspire students to think about the vantage point of space, there is also a tremendous amount of science to be done with multiple real time local observations of Earth from space. OreSat plans to work public science groups such as Public Labs, Inc (https://publiclab.org/) to enable this kind of "Citizen Science" outreach.

1.3 How the OreSat Live Educational Ground Station works

The OreSat Live Educational Ground Station is an inexpensive, simple to build, easy to use, open source 2.4 GHz receive-only system for capturing and displaying a real-time, live-from-space broadcast from the OreSat satellite (more technical details are available in the appendix). The ability to receive live video from space on a student's own laptop - essentially be able to take a selfie from space - is an exhilarating prospect that will hook students into building their own ground stations.

The ground stations' concept of operation (See Figure 1) is:

- Teachers and/or students purchase, assemble, or build their ground station from scratch.
- Students go to http://oresat.org/, check for avilable OreSat passes, and use an online form to request an OreSat Live "session" for their location.
- OreSat mission control receives the request and approves the session.
- OreSat is configured to point and transmit live video over that location at that time.
- On the ground, one student points the antenna, and tracks OreSat as it passes overhead, using a smartphone running a free app called Satellite AR ("Augmented Reality"), from AGI.
- Another student runs open source software on their Mac, Windows, or Linux laptop which downloads the datastream and displays live video of their location on the planet from ~ 400 km above them.

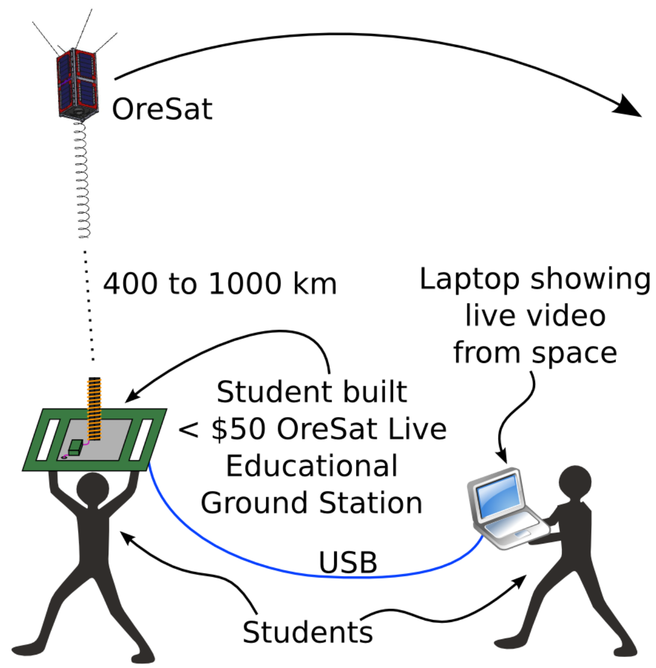

Figure 1: The OreSat Live system concept of operation. From left to right: Oresat with the helical antenna aimed towards ground (Top Left). High school or middle school student with hand-held helical antenna with smart phone used to locate satellite (Bottom Left). USB connection from hand-held antenna to laptop which will display live video (Right).

1.4 The OreSat Live Space Segment

OreSat's primary mission is to support the OreSat Live video transmission from space directly to students on the ground. OreSat conforms to the 2U CubeSat satellite form factor, as described in Cal Poly CubeSat Design Specification (CDS). OreSat has three main subsystems:

1. The OreSat Bus, which takes care of power, telemetry, command, low bandwidth communication, and housekeeping,
2. the OreSat Live subsystem, which transmits live video from space down to the ground, and
3. the Cirrus Flux Cam system for Earth observation science, described in Section 2.

Figure 2 shows the Oresat CubeSat in its fully deployed state. Visible is the S-band (2.42 GHz) +16 dBi RHCP helical antenna for OreSat Live, the 70 cm (436 MHz) omni-directional turnstile antenna, and the Alta Devices solar modules. Detailed technical specifications on the OreSat satellite can be found in the appendices, including a block diagram, technical details on all subsystems, structure and mass budget, power budget, and the beginnings of a Failure Modes Effects Analysis.

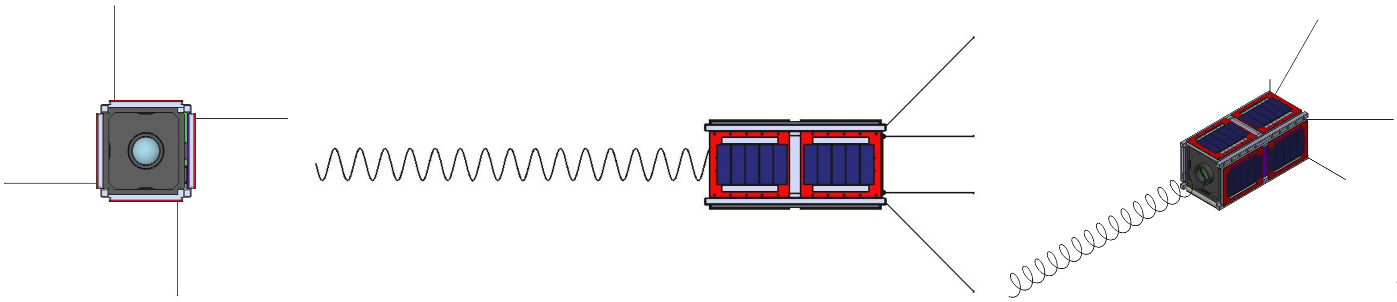

Figure 2: Left: top view, Center: side view , Right: orthonormal view

The **OreSat Live subsystem** is based on the extensive technology heritage of the Portland State Aerospace Society's amateur rocketry avionics system (see appendix). The system consists of:

- **OreSat Live Camera:** The OreSat Live camera is a simple 720p cellphone style camera that is streamed to the flight computer for video stream compression.
- **DxWiFi Communication System** has three parts:
    - A commercial, off the shelf IEEE 802.11b "WiFi" transceiver using the Atheros 9K chipset
    - A 30 dBm (1W) power amplifier
    - A 16 turn +15 dBi 2.4 GHz helical antenna made of nickel titanium (nitinol) wire that has a half-power beamwidth of ±20°. The antenna is stowed for launch in the +Z axis face of the CubeSat and uses a monofilament burn wire as a deployment mechanism.
- **Attitude Determination System:** The ADS uses six ±1° photodiode-based sunsensors to determine sun location. The SDR GPS project is used for precise vehicle ephemeris estimation, including position and time.
- **Attitude Control System:** The ACS uses three magnetorquers and a tetrahedral arrangement of four reaction wheels to control the satellite's attitude to within ±5°. Although already in process of being prototyped, the ACS represents the largest risk in the OreSat Live system.

Technical details of the OreSat Live system can be found in the appendix.

1.5 The OreSat Ground Station Infrastructure

OreSat "mission control" requires more than just the educational ground stations: The OreSat project has two full-capability (transmit and receive) automatic ground stations for operating the satellite based loosely on both the open source Satellite Networked Operational Ground Systems (SatNOGS) project (https://satnogs.org/), and the experiences of other university-based CubeSat projects. Each station has a 70 cm (UHF) uplink and downlink for Telemetry and Command (T&C) as well as up and down links on S-band (2.4 GHz) for the DxWiFi project.

Considerable effort has been put into collaboration on the OreSat ground station. The design is open source, and will be made available to other CubeSat projects as their CubeSats are in view of the Oregon-based ground stations. And, like the SatNOGS project, the OreSat Ground Station is generic enough to be useful to other university CubeSat projects. The end goal would be a collaborative network of university ground stations; the University of Illinois at Urbana-Champaign, Virginia

Polytechnic Institute and State University, and Portland State University have already taken the first collaborative steps on this project.

Technical details of the OreSat Ground Station can be found in the appendix.

2. Secondary Mission: Cirrus Flux Camera Science Package

OreSat's secondary focus is an Earth science mission to study the contribution of high altitude cirrus clouds to global climate change. Cirrus clouds often appear invisible to the naked eye, but nonetheless create significant negative feedback to amplify global climate change as a result of their large opacity in the infrared. The general consensus in the climate science community is that they are difficult to detect and estimates of their global coverage are difficult to make. While some new detection methods exist, such as satellite imaging in the 1.38 μm band, there may be a more effective and easier detection method. The imaging system will use an all-sky astrophotography camera and combinations of bandpass filters to collect survey data. Thin cirrus clouds, made almost exclusively of ice crystals, should directly reflect sunlight and therefore have the same filter flux ratios as the sun. Clouds with higher moisture content will have different filter flux ratios. Standard astronomical photometric techniques are applied to the images to determine flux ratios. Preliminary results show that good detection of cirrus clouds on bright, clear days occurs with use of the 82a blue, 11 yellow, or LRGB luminance filter alone or in combination. A detailed explanation of the Cirrus Flux Cam research can be found in the appendix. The primary investigators for this research are Dr. Greg Bothun and his student, Eryn Cangi, from the Department of Physics at the University of Oregon.

The Cirrus Flux Cam will make use of a low resolution astrophotography camera and a specially designed filter wheel to image the Earth's atmosphere. Although the camera and filters are still in preliminary design phase, the concept of operations is relatively simple. The nadir pointing camera will rapidly take several low resolution images using the monochromatic astrophotography camera, one image per available optical filter. The images and location data will be stored by the flight computer until either an OreSat Live pass, or the satellite passes over an OreSat Ground station (or other SatNOGS participating ground station), at which point the data can be send down the Low Gain Radio.

Figure 3: Prototype Astrophotography camera with filters used during ground testing

Once the images are received as data, the images will be sent to the University of Oregon group for analysis and publication.

3. Tertiary Mission: Technology Demonstration and Flight Heritage

There are three technology readiness level demonstration projects that OreSat hopes to pioneer:

- **DxWiFi**, the long distance Wifi technology in development since 2003. DxWiFi has functioned successfully on PSAS rockets up to 5km and on flight tests to 125km. By using 802.11b on the amateur radio band, extremely inexpensive COTS components can be used to implement this high 2 Mbps link. Demonstrating DxWiFi in space has potential to dramatically reduce the cost of high speed, amateur band Space-to-Earth data transmission.

- The **OreSat bus card cage** form factor was developed by an interdisciplinary team of mechanical and electrical engineering students at Portland State University. This flexible, modular system would demonstrate a new, open source bus for university class cubesats.
- OreSat has partnered with Alta Devices, a manufacturer of solar cells, to demonstrate the readiness of their **High Efficiency GaAs Solar Cells**. During its time in orbit, OreSat will broadcast valuable information on solar cell performance that will be recorded and given to Alta Devices to provide them valuable proof of their readiness to enter the field of spacecraft resource suppliers.

4. Project Organization

The OreSat Project is being lead by the Portland State Aerospace Society (PSAS), a well-established student aerospace engineering project based at Portland State University. Formed in 1997, PSAS has a number of innovative "firsts" in amateur rocketry and has developed a collection of sophisticated avionics for amateur rocketry, many of which are showcased in the OreSat project. Please see the appendix for more information on PSAS and OreSat's technology heritage. PSAS is managed by a "control board" of undergraduate students, graduate students, industry advisors, and PSU faculty advisors (names and resumes are in the appendix).

PSAS is managing the other participating Oregon Universities. Currently, other university participation includes researchers and students at the University of Oregon who are developing the Cirrus Flux Cam, OreSat's science Mission, and Oregon State University which will be running several undergraduate capstones projects in support of OreSat starting in the 2017 academic year.

Since OreSat is Oregon's first CubeSat, the OreSat team is actively recruiting experienced advisors to help with the project management and technologies. A few of OreSat's project and technical advisors include:

- Brian Sanders, Deputy Director of the Colorado Space Grant Consortium, is an experienced CubeSat project manager and has agreed to advise on OreSat management.
- Krunal Desai, senior avionics engineer at Planetary Resources Inc., has agreed to be OreSat's senior technical advisor.
- Dr. Alex Ghosh, adjunct research professor at the University of Illinois Department of Aerospace Engineering, is another experienced CubeSat program director who has agreed to be a technical and project advisor.

Finally, the OreSat management team is actively pursuing more formal training by attending technical conferences. These have so far included 2016 SmallSat conference at Utah State University, the 2015 and 2016 CubeSat Workshops hosted at California Polytechnic at San Luis Obispo, and the 2016 Oregon CubeSat Workshop hosted by the Oregon and Alaska Space Grant Consortium.

5. CSLI Applicability

The OreSat mission plan is in keeping with the 2014 NASA Strategic Plan and is directly applicable to objectives 1.7, 2.1, 2.2, 2.3, and 2.4. Specifically, OreSat mission objectives are aimed at inspiring the next generation of students through hands-on STEM education, studying the impact of global weather processes on the Earth, and developing new technologies for space systems.

NASA's strategic objective 2.4 specifically outlines the need to "Advance the Nation's STEM education and workforce pipeline by working collaboratively with other agencies to engage students, teachers, and faculty...". As a student run project, OreSat is committed to building a generational legacy that will educate and inspire young students to continue their STEM education and fully develop an appreciation of space and technology. By developing a space-based educational outreach mission (literally), a younger generation of students will be educated and inspired.

Earth Science represents one of the largest opportunities for CubeSat research while in orbit. In particular, the CSLI is in a unique position to facilitate climate modeling and OreSat is taking full advantage of this opportunity. Objective 2.2 states "[NASA's] assets in space and on Earth are giving us unprecedented insight into the Earth system and how we can minimize the impacts of environmental change." By delivering a science payload directed at monitoring cirrus clouds in the upper atmosphere and their relationship to climate change, the Cirrus Flux Cam mission fits the NASA Strategic Plan perfectly. Dr. Bothun's research and the OreSat mission will directly affect our knowledge of the Earth climate system and provide valuable insight into cirrus cloud contributions.

As an open source project, OreSat provides a useful resource for furthering the small spacecraft body of knowledge and for demonstrating innovative design and technology. This allows the OreSat project to meet NASA objective 2.3, which calls for NASA to "advance technology development in a flexible, 'on-demand' way, and lower mission design costs to leverage Government dollars for technological breakthroughs." OreSat will help with this goal by raising the technology readiness levels on key technologies for university-class CubeSats. The successful space demonstration of the DxWiFi communication system brings a previously unaccessible high-speed communication technology to the open source, amateur satellite community. The OreSat bus provides a new, modular and flexible CubeSat bus, and finally Alta Devices GaAs solar cells will enable enable a new solar cell manufacturer to claim space readiness.

6. Compliance Requirements

The OreSat design is in full compliance with:

- The Cal Poly CubeSat Design Specification (CDS) version 13.
- NanoRacks CubeSat Deployer Interface Control Document (NR-SRD-029) Revision 0.36
- Launch Services Program Requirements Document (LSP-REQ-317.01)

As part of the OreSat development schedule, a full complement of thermal, vibration, and vacuum testing will be implemented in accordance with Table 1 of the Launch Services Program Requirements Document (LSP-REQ-317.01). Testing is currently set to be performed at Cascade Tek in Beaverton, OR.

All known regulatory compliance documents have already been filled out and are awaiting the outcome of this application. These documents include:

- A NOAA waiver must be requested because of the Oregon Live camera and the Cirrus Flux Cam missions.
- An International Amateur Radio Union (IARU) Satellite Frequency Coordination Request will need to be submitted upon proposal acceptance. This coordination needs to be completed several months prior to the launch manifest. The coordination can take up to a year, so the request will be submitted once a response to this proposal is received.

- A notice of intent to operate will be submitted to the Federal Communications Commission (FCC) with the coordinated frequency and emission designation, after coordination with the International Amateur Radio Union (IARU).

Please see the appendix for more information, and the completed forms.

7. Merit and Feasibility Reviews

For each review, we gathered a group of subject matter experts and asked them to review our proposal and submit their feedback via a Google form. Each Google form was populated with questions specific to the mission it was covering. For each question we asked for a rating from 1 to 5 on the scale of "Does Not Comply" to "Fully Complies". Additionally, we asked for additional comments and concerns at the end of the questionnaire. A summary for each review and a list of reviewers is given below.

7.1 Merit Review of Primary Mission: "OreSat Live" STEM Outreach

The average rating for the OreSat Live merit review was 4.57 out of 5. Please see the appendix for a list of the questions posed and a breakdown of the average rating for each question. The primary mission merit reviewers were:

1. Jim Todd, Director of Space Science Education; Oregon Museum of Science and Industry (OMSI)
2. Tamara DePue, Program Manager; Oregon Math, Engineering, Science and Achievement (Oregon MESA)
3. Dr. Jason Motamedi, Senior Researcher, Education Northwest.
4. Fabian Mak, AP Physics Teacher; Westview High School.
5. Kristin Moon, Teacher and STEM Instructional Specialist; Portland Public Schools
6. Dottie Passmore, Science Teacher and Robotics Coach; Westview High School.

The general consensus among reviewers is that the Oresat Live mission of educational outreach is in keeping with NASA strategic goals and by that measure has merit. The concerns regarding this mission were centered around the educational outreach package to local schools and whether the cost of the educational ground station could be afforded for some of the local schools. We are busy addressing these concerns and will take the input into account as we begin to assemble our educational outreach packages. One of the more interesting pieces of advice was to offer professional development training for local teachers interested in participating in the OreSat program. This idea coupled with the possibility of presenting at the Oregon Science Teacher Association Conference next year has been adopted as vital pieces of the OreSat Live outreach program. The end consensus is that giving students access to a direct space-based educational outreach is both a worthwhile mission and a valuable tool for schools in the area given the right amount of foresight and planning.

7.2 Merit Review of Secondary Mission: "Cirrus Flux Cam" Science Mission

The average rating for the Cirrus Flux Cam merit review was 4.67 out of 5. Please see the appendix for a list of the questions posed and a breakdown of the average rating for each question. The secondary mission merit reviewers were:

1. Dr. Erik Bodegom, Physics Professor; Portland State University.
2. Professor Michael Fitzgibbons, Physics Professor; Portland State University.

3. Professor Morley Blouke, Physics Professor; Portland State University.

The consensus for the Cirrus Flux Cam mission is that the study of cirrus cloud contributions to global climate change is a worthwhile endeavor. There were no significant concerns regarding the merits of the Cirrus Flux Cam mission.

7.3 OreSat Feasibility Review

For the feasibility review we asked our subject matter experts to review each subsystem of OreSat and rate it on feasibility and also provided a comments section for each system to elaborate on any concerns they might have. The average rating for the feasibility review was 4.13. Please see the appendix for a list of the questions posed and a breakdown of the average rating for each question. The feasibility reviewers were:

1. Brian Sanders, Deputy Director of the Colorado Space Grant Consortium; University of Colorado at Boulder
2. Krunal Desai, Senior Avionics Engineer; Planetary Resources Inc.
3. Dr. Alex Ghosh, Adjunct Research Professor; University of Illinois Department of Aerospace Engineering
4. Glenn Richardson, Software Engineer; SpaceQuest, Inc.

The feasibility reviews of the OreSat systems were varied in their feedback, but the general consensus is that each system is feasible. This said, clearly more explanation and a more thorough systems analysis needs to be addressed prior to launch. Examples of concerns are: a lack of detail about power systems, concerns on the attitude control system control loop, questions about software encryption, and concerns over the radiation tolerance of mission critical systems. We are in the process of addressing the issues raised during the feasibility review. A majority of these concerns surround the need for more information within the proposal document, rather than a weakness in the system design. In terms of feasibility, the weakest system is the Cirrus Flux Cam. This is expected since this is a late addition to the OreSat mission. The current plan is to run undergraduate capstone projects at Oregon State University in electrical and mechanical engineering to develop the Cirrus Flux Cam system in 2017.

8. OreSat Development Schedule

OreSat progress is being managed on a weekly basis, with a routine status meeting held every week. The current project management software being used is an open source online Gantt chart tool (GanttProject) that tracks the OreSat critical path. Project management at PSAS has been handled by students, with guidance from industry mentors with over 50 years of experience (please see appendix for resumes). This successful model of student-led project organization will continue throughout the lifetime of OreSat.

Development schedules are notoriously difficult to get right. Please see the appendix for a detailed Gantt chart of our current schedule, including slippage factors, design review milestones and concluding with completion of OreSat and subsequent on-orbit operations. A summary of our critical dates are:

Task/Event	Start	End
Design, Prototype, write application	Now	Feb 2017
CSLI Announcement	-	Feb 2017

Preliminary Design Review	**-**	**Feb 2017**
Full system FlatSat build with integration testing	Feb 2017	Feb 2018
Critical Design Review	**-**	**Feb 2018**
Engineering Model build, integration, balloon/rocket tests	Feb 2018	May 2018
Flight Hardware Build and Test	May 2018	Nov 2018
Environmental testing on Flight Hardware	Nov 2018	Dec 2018
Secondary Flight Hardware Build and Test	Nov 2018	Feb 2019
Ready for Launch	-	**Feb 2019**
Launch	**Feb 2019**	**Feb 2020**
In Orbit Operations	**Launch**	**Launch + 12m**

OreSat will be ready to launch February of 2019, after two years of hard work commencing at the CSLI announcement in February 2017.

9. Budget

This budget is based on building 3 complete units of OreSat, with 1 component spare. The first unit is the integration and test model, scheduled for first build and flight testing on amateur rocket launches and high altitude balloon flights. The second unit is the flight test model, scheduled for pre-flight environmental testing. The final unit is the flight model.

System	Subsystem	Qty	Price	Ext.
OreSat Bus	Structure, power, control, etc.	4	$5,000	$19,900
Oresat Live	Flight computer, ADS, ACS, DxWiFi, etc.	4	$9,000	$35,950
Cirrus Flux Cam	Camera plug filter wheel	4	$950	$3,800
Ground Station	Primary and secondary ground stations	2	$2,500	$5,000
Testing	Environmental, thermal vac, rocket, balloon	1	$11,500	$11,500
Misc	Contingency	1	$10,000	$10,000
	TOTAL			**$86,150**

For a more detailed budget, please see the appendix.

10. Funding

OreSat is being enthusiastically funded by multiple Oregon institutions, organizations and companies. Please see the appendix for the list of current funding sources. These funding sources total **$88,000** worth of in-kind service donations and proceeds, which exceeds our projected budget of $86,150.

Proposal Appendix

A. Resumes

Resumes for projects leads at Portland State University and the Portland State Aerospace Society (PSAS):

- Aaron Baker, Electrical lead, PSAS Control Board and ECE Undergraduate Student
- Andrew Greenberg, ECE Adjunct Faculty, PSAS Faculty Advisor
- Marie House, Mechanical lead, PSAS Control Board and MME Undergraduate Student
- Glenn LeBrasseur, PSAS Industry Advisor for Communications Systems
- Erin Schmidt, PSAS Control Board and MME Graduate Student
- Ed Steinberg, PSAS Industry Advisor for Project Management

Resumes for University of Oregon:

- Dr. Greg Bothun, Physics Professor
- Eryn Cangi, Physics Undergraduate Student
- Dr. Dean Walton, Associate Professor of Library Science

B. Compliance Documentation

The OreSat team understands the importance of dealing with regulatory requirements as early as possible. Detailed here is the current state of our regulatory compliance for the OreSat project.

B.1 National Oceanic and Atmospheric Administration (NOAA)

The OreSat mission plan calls for two camera systems, one for OreSat Live mission and one for the Cirrus Flux Cam science mission. Because of these cameras, OreSat will require a NOAA License which is contingent on CSLI approval and launch manifestation. We have started this process by submitting a NOAA initial contact form, which can be found attached below.

B.2 International Amateur Radio Union (IARU)

OreSat has already filled out the IARU Amateur Satellite Frequency Coordination Request form for the S Band DxWiFi communication system and for OreSat Live and the 70 cm Low Gain Radio. Once a flight opportunity has been announced, the form will be submitted to the IARU Satellite Advisor to request an amateur frequency coordination.

B.3 Federal Communications Commission (FCC)

The Notice of Intent to Operate will be filed with the FCC as soon as the IARU has coordinated OreSat's frequencies and OreSat has been manifested.

C. Letters of Support

- Dr. Ren Su, Dean of the Portland State University Maseeh College of Engineering and Computer Science
- Dr. Jack Higginbotham, Director of the Oregon Space Grant Consortium
- Josh Lifton, CEO of Crowd Supply, Inc.
- Tamara DePue, Program Manager of Oregon MESA
- Dr. Dean Walton, Associate Professor of the University of Oregon Science & Technology Outreach LIbrary
- Krunal Desai, Senior Avionics Engineer at Planetary Resources, Inc.
- Rich Kapusta, Chief Marketing Officer at Alta Devices

D. Additional Project Documentation

D.1. Technical Details: OreSat Live Educational Ground Station

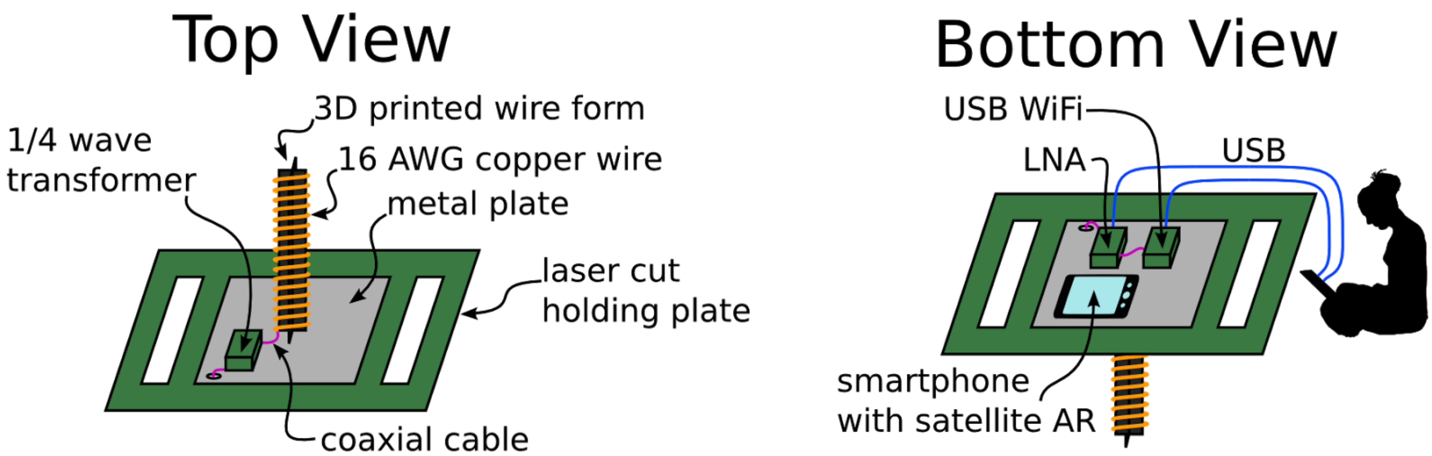

Figure D1-1: The Oregon Live Educational Ground Station in detail.

The components of the educational ground station are relatively straightforward, and have all been tested in previous technology demonstration tests for the DxWiFi project. Please see Figure D1-1 for a diagram of the educational ground station. They are:

- **2.4 GHz Helical Antenna**: Based off the standard design from the Antenna Engineering Handbook, this antenna is a 16 turn, roughly +16 dBi high-gain 2.4 GHz RHCP antenna and has a ±20 degree ½ power beamwidth. CAD files for 3D printers ("STL" files) are available for students to 3D print a stackable fixture that helps them carefully wind commonly available 18 gauge copper electrical wire around the stacked fixtures.
- **Custom Quarter Wave Transformer and Low Noise Amplifier:** Students will most likely purchase the PCB and components of these two parts of the antenna, and solder the components on themselves. A few simple tests using the antenna and WiFi adapter will let them know if their antenna is working correctly.
- **WiFi to USB to Adapter:** The ZCOM ZCN-722M is a commercial, off-the-shelf USB to WiFi (IEEE 802.11b/g/n) adapter based on the Atheros 9K chipset, and is generally available for $15. Drivers are available for all common operating systems.
- **Mounting Plate:** The mounting plate is a laser-cut piece of bamboo or other plywood with hand holds and holes for mounting the antenna and PCBs. While a student could easily make this by hand, the CAD files are meant for students using a laser cutter as part of their rapid prototyping experience.
- **Smartphone running Satellite AR:** Satellite AR ("augmented reality") is a free smartphone app produced by Analytical Graphics Inc (AGI). The user chooses any satellite in its database (based on the JSPoC database), and the app overlays the location of the satellite on the image from smartphone's camera. The orientation of the smartphone is calculated by Satellite AR based on the smartphone's accelerometer and magnetometer. Pointing accuracy of Satellite AR is roughly 10° or better, which works well with the helical antenna's ±20° ½ power beamwidth.
- **Laptop running OreSat Software:** Any Windows, Mac or Linux laptop with two free USB ports (one for the WiFi adapter, and one to power the Low Noise Amplifier) will work. Students download and run the open source video packet decoding software posted on OreSat's

download page, and the software displays current satellite status, packets being received, and the live video from the satellite.

Crowd Supply, Inc (https://www.crowdsupply.com/) is an Oregon-based company that will be stocking and distributing parts of the Oregon Live Educational Groun Station. There are three different ground station kits, with individual components also available separately:

- **Complete Ground Station:** All components, including antenna and PCBs, assembled and tested and ready for usage.
- **Complete Kit:** All components necessary to build your own ground station. No 3D printer or laser cutter necessary.
- **Maker's Kit:** PCBs, components, wires, and miscellaneous helpful parts only. The students build their own 3D printed antenna fixtures and laser-cut their own handheld plate.
- **Individual Components:** Each component will be available for individual purchase as necessary.

D.2. Technical Details: OreSat Structure and Mass Budget

OreSat's structure is a 2U CubeSat design using a four piece machined 6061-T6 hard anodized aluminum structure (see Figure D2-1). The structure has "card cage" slots to hold subsystem components, specially spaced to support printed circuit board (PCB) "cards" (described below in the OreSat Bus section). For the latest status of the OreSat Structure, please see the relevant GitHub Project Site.

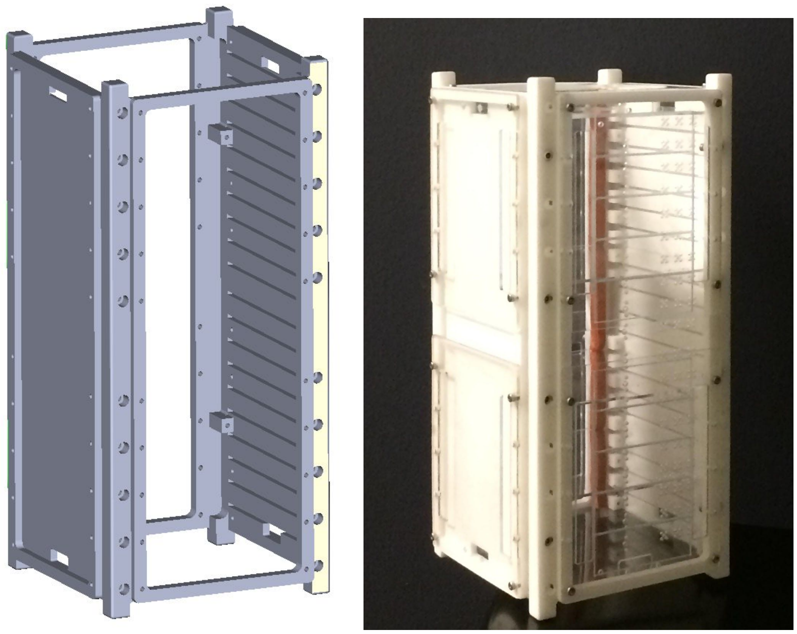

Figure D2-1: Left, CAD render of OreSat Structure. Right, 3D printed and lasercut acrylic mockup

Preliminary thermal analysis was run on the structure in Thermal Desktop by C&R Technologies, to understand the thermal peaks and valleys in a variety of orbits and internal power consumption cases (Figure D2-2).

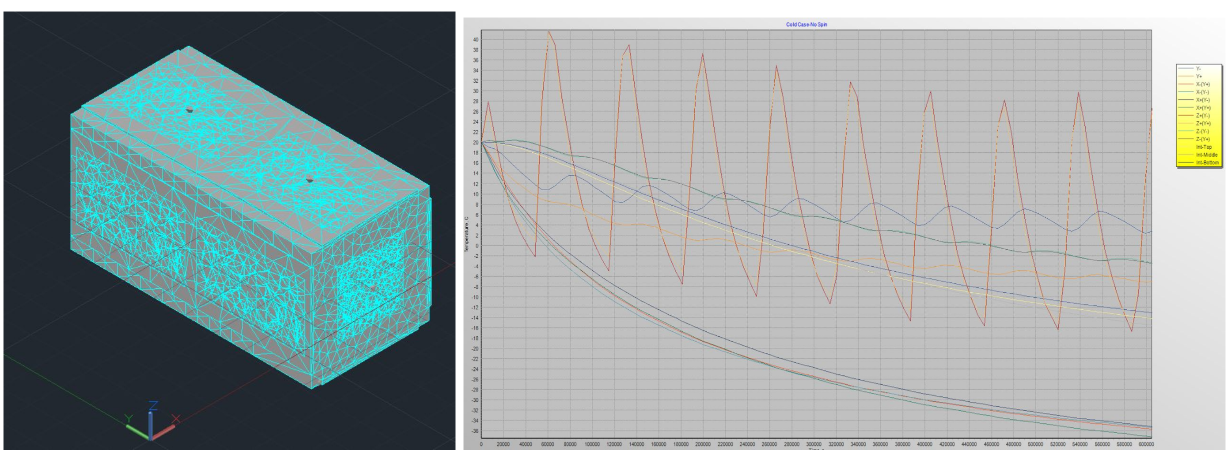

Figure D2-2: Left, FEA mesh of the OreSat Structure. Right, temperature over time graph of non-spinning 2U structure

The vehicle's mass is currently estimated to be 2.36 kg, which has a 12% margin over the 2.66 kg maximum for a 2U CubeSat. The detailed mass budget is as follows:

System	Qty	Subsystem	Mass (g)	Ext. Mass (g)	Susbystem (g)	Notes
Structure					**465.5**	
	1	+X aluminum Frame	96.5	96.5		Based on CAD model
	1	-X aluminum frame	113	113		Based on CAD model
	1	+Y aluminum Frame	125	125		Based on CAD model
	1	-Y aluminum Frame	125	125		Symmetrical with +Y
	40	Frame fasteners (M2.5x8 Hex socket)	0.58	23.2		Overstimate; number of needed fasteners still preliminary.
	80	Solar module fasteners (M2x6 Torx round head)	0.2	16		Overstimate; number of needed fasteners still preliminary.
	8	Backplane fasteners (M2x6 Torx round head)	0.2	1.6		Overstimate; number of needed fasteners still preliminary.
	2	Z axis deployment springs	5	10		CPSLO-sourced Z axis deployment springs
OreSat Bus					**911.5**	
	8	Solar Modules	31.5	252		Preliminary estimate. Solar Module PCB = 21.5 g
	4	Battery modules	104	416		Preliminary estimate. OreSat Card PCB = 27 g
	1	Low Gain Radio	40	40		Based on prototype
	1	LGR 70 cm canted turnstyle antenna assembly	62	62		Based on prototype
	1	System Controller	41	41		Based on prototype
	1	OreSat Backplane	100.5	100.5		Preliminary estimate. OreSat Backplane PCB = 50.5 g
OreSat Live					**824.0**	
	1	Flight Computer	57	57		Preliminary estimate.
	1	OreSat Live camera	25	25		Preliminary estimate.
	1	DxWiFi: Transciver + LNA + PA	57	57		Preliminary estimate based on existing components
	1	DxWiFi: helical antenna (structure + antenna)	77	77		Preliminary estimate.
	2	DxWiFi: Backup S-band patch antennas	25	50		Based on prototype
	6	ADS: Sun sensors	25	150		Preliminary estimate based on existing components
	1	ADS: SDR GPS	42	42		Based on prototype
	2	ADS: SDR GPS: L1 patch antennas	25	50		Based on prototype
	4	ACS: Reaction wheels	49.75	199		Preliminary estimate based on existing components
	3	ACS: Magnetorquers	39	117		Preliminary estimate based on existing components
Cirrus Flux Cam					**157.0**	
	1	Astrophotography camera	57	57		Based on the Orion StarShoot All-In-One Astrophotography Camera
	1	Filter Wheel assembly	100	100		Preliminary estimate
TOTAL MASS					**2358.0**	

D.3. Technical Details: OreSat Bus

OreSat uses the "OreSat Bus", an innovative card-cage / backplane approach to flexibly and rapidly building satellites (Figure D3.0-1). This approach has many advantages:

- Cards can easily be pulled and replaced.
- Cards, in some circumstances, can be moved between positions without significant consequence.
- Cards with tall components can be easily accommodated by "skipping" slots as necessary.
- The cards are designed to have large copper runs on the very outside edges where they are held by the hard anodized aluminum rails. This allows the rail walls to be used as a thermally conductive, but electrically insulating, connection.

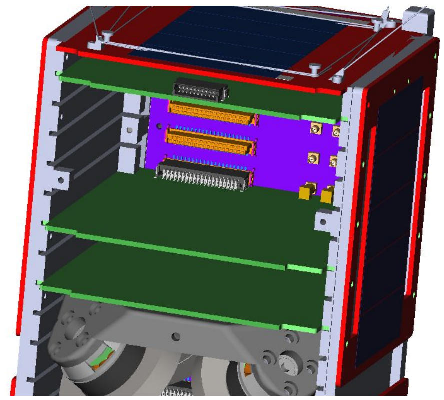

Figure D3.1-1: OreSat Card-cage system. Cards are green, backplane is purple. 20 pin backplane connectors (orange) and MMCX RF connectors (gold) are visible.

D.3.1. OreSat Bus: Solar Power System

Eight identical 1U solar modules provide roughly 1.15 W each, covering the four elongated sides of the satellite, for a maximum combined output power of approximately 2.3 W when illuminated. The cells are manufactured and donated in-kind by Alta Devices of Sunnyvale, CA, a new solar cell manufacturer that specializes in chemical vapor deposition (CVD) Gallium Arsenide cells with roughly 26% efficiency in AM0 conditions. The cells are arranged in a 5 x 1 module with PET cover sheet provided by the manufacturer. The cells are bonded to the solar module PCBs using silver epoxy.

The solar module PCBs have the solar array bonded to the "outside" of the module's PCB, and the power conditioning Maximum Power Point Trackers (MPPT) on the "inside" of the PCB. The MPPTs boost the cell output voltage to 5.5V for distribution to the batteries and to other emergency power systems. A 6 x 12 female 1.27 mm spaced pin header then connects the modules to the top and bottom cards in the satellite, which then connects to the backplane. An extremely small and extremely low power 32-bit ARM Cortex-M0 microcontroller reads solar panel outputs and every few seconds outputs the power on OreSat's Controller Area Network (CAN)-based power telemetry bus.

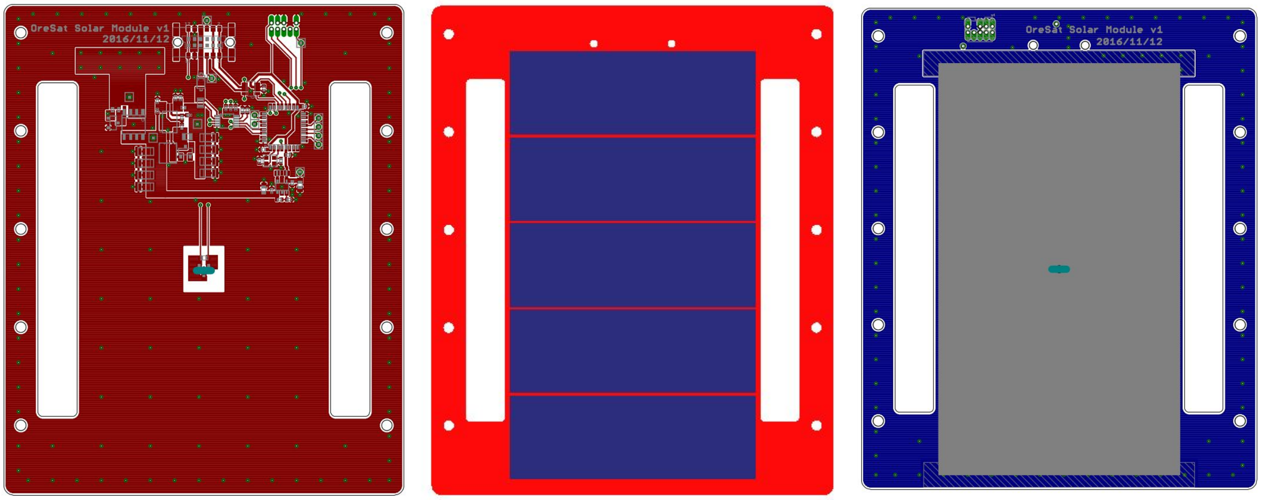

Figure D3.1-2: 1U Solar Module. Left: "bottom" of the module with Maximum Power Point Tracker circuitry. Center: 3D model of array. Right: "top" of array with cells marked out as gray.

The in-orbit insolation values are obviously highly dependant orbit, including beta angle. C&R Technologies Sinda Fluent Thermal Desktop simulations of 0 to 75 degree beta angles lead to acceptable temperature and power generation outcomes, although at a 0 degree beta angle, the number OreSat Live runs may need to be limited to one every few days in order to keep the batteries at acceptable charge levels. For a current status of this component please see the relevant GitHub Project Site.

A simple power budget analysis can be found in Section D15.

D.3.2. OreSat Bus: Battery System

The OreSat battery system consists of four battery "cards", each with one 3.3 AHr Lithium Polymer cell manufactured by PowerStream Batteries bonded directly to the card's PCB. Each of these "cell modules" has its own battery charger (bq24158) and battery protection circuit and fuel gauge (bq27742), and battery heater circuit. Like the solar modules, each battery pack has an extremely small and low power 32-bit ARM Cortex-M0 microcontroller which interfaces the battery charger, cell fuel gauge, and heater to the OreSat Controller Area Network (CAN)-based power telemetry and control bus.

All four battery modules, located near the center of mass of the satellite to reduce the moment of inertia of the satellite, will provide a whopping 13.2 AHr (47.52 WHr at 3.6 Vnom) of storage. At roughly 2.5 WHr per OreSat Live pass, this large battery pack provides up to 2-3 passes between charge cycles. For a current status of this component please see the relevant GitHub Project Site.

A simple power budget analysis, including battery charge calculations, can be found in Section D15.

D.3.3. OreSat Bus: System Controller

The System Controller (SC) is the high reliability heart of OreSat. The SC uses the radiation hardened Atmel (now Microchip) AVR ATMegaS128 processor as the main telemetry and control computer. The ATMegaS128 has the same package, pinout and API as the extremely inexpensive ATMega128 processor, making it easy to inexpensively build multiple engineering models. Designed by a Portland State University ECE Capstone team, the SC parses incoming commands from the Low Gain Radio (OreSat's T&C radio; see below) and acts as the watchdog and power controller for all other systems. For a current status of this component please see the relevant GitHub Project Site.

D.3.4. OreSat Bus: Deployment Switch and System Shutdown

OreSat has a system-wide "hard power down" interlock that disables all power sources in the CubeSat. This line is wired into the deployment switch, the Remove Before Flight (RBF) pins, and can be actuated by the System Controller (SC) as well. The SC can thus power cycle potential latch-up events on all boards, including itself: with a certain operational sequence, the SC can temporarily turn off its own power, letting the watchdog be its own watchdog.

Figure D.3.4-1: Left: OreSat System Controller prototype, with ATMegaS128 Right: Low Gain Radio Board

D.3.5. OreSat Bus: Low Gain Radio

The Low Gain Radio (LGR) system is a low bandwidth, high reliability communication system to link the satellite to OreSat mission Control. The LGR, used for for telemetry, commands, and control, was prototyped in a 2015 PSU ECE Capstone project (See Figure D3.4-1). It uses a NXP MKW01Z128 ARM Cortex-M0 processor with an integrated Semtech XE/SX1200 RF sub-GHz transceiver. The LGR operates in the 70 cm band at 436 MHz, with 1 W output via a monolithic power amplifier. The receiver noise temp is 35 K by use of a front end low noise amplifier.

Operating in half duplex mode, the NXP processor uses two main modulation modes: a simple beacon that uses on-off keying (OOK), as well as a Gaussian Frequency Shift Keying (GFSK) modulation at 9600 bps. The OOK will be used to send the satellite callsign, and basic telemetry data in Morse code at a rate of 5 wpm during periods of time that the satellite is idle. This simple, internationally accepted modulation scheme can be tracked and interpreted by international amateur radio operators in order to track the satellite for the first few hours and days of deployment. Using a university-class tracking ground station built here at PSU (see section below), sending GFSK packets will kick the LGR into T&C mode where commands can be uplinked and telemetry downlinked. Essential to the operation of the LGR is an omnidirectional canted turnstile antenna providing close to isotropic RHCP RF propagation, such that the LGR will function with the ground station regardless of spacecraft attitude. For a current status of this component please see the relevant GitHub Project Site.

Since the LGR is OreSat's command and control radio, security protocols have been implemented to make sure that only authorized users gain control of the satellite

D.4. Technical Details: OreSat Live

The OreSat Live system consists of the systems necessary to transmit live video from space. This includes the Flight Computer, Software Defined Radio GPS receiver, Attitude Determination System, Attitude Control System, Camera system, and the DxWiFi S-band communication system.

D.4.1. Flight Computer

The central core of the OreSat Live system is the Linux-based Flight Computer (FC). The FC is based on the AllWinner 1.2 GHz dual core A20 processor, as featured on the open source A20-OLinuXino-MICRO from Olimex, Inc. The FC controls image and video capture and processing, drives the 802.11b DxWiFi system, calculates its position and orbital parameters using SDR GPS, determines the spacecraft attitude using the ADS, and controls the attitude using the ACS. The software for the FC is based on the successful real-time, data-flow model "Flight Computer Framework" project from PSAS' amateur rocketry flights.

D.4.2. Software Defined Radio GPS Receiver

Another piece of technology heritage from Portland State University is the SDR GPS project. Based on the Maxim MAX2769 SDR GPS IC, SDR GPS streams raw I/Q data from the L1 band to the flight computer for processing. Standard algorithms on the FC then correlate GPS satellite signals and calculate receiver position and velocity. In conjunction with JSPoC tracking of the satellite, SDR GPS will enable precision on-orbit determination of position and velocity.

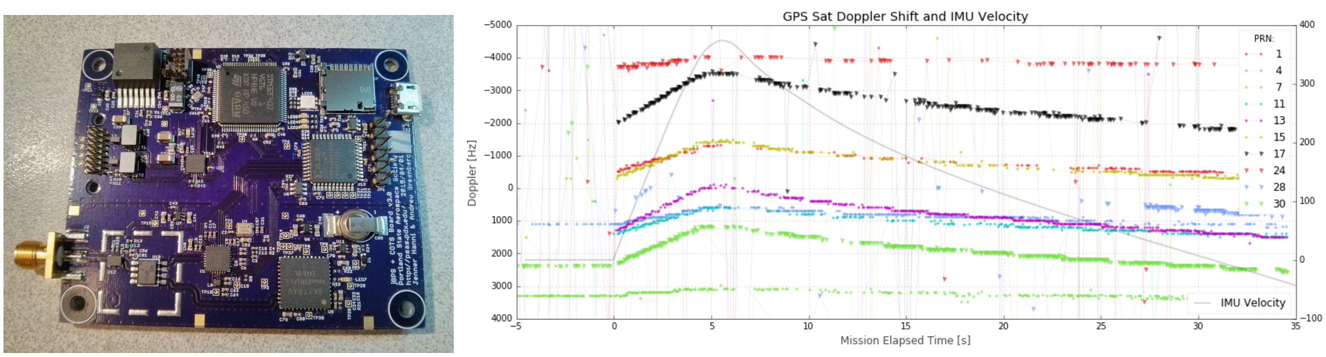

Figure D4.2-1: Left: SDR GPS receiver board. Right: doppler shift on satellites during amateur rocket flight.

SDR GPS will use two L1 band patch antennas mounted on the +X and -X surfaces that are phased together to provide an omnidirectional receive pattern. This should provide GPS reception regardless of the spacecraft's attitude and ability to control attitude.

D.4.3. Attitude Determination System

The OreSat Live and Cirrus Flux Camera payloads require only ±5° of pointing accuracy and are only operational in view of the sun. This allows OreSat to do attitude determination solely by six sun sensors, one mounted on each face of the CubeSat. Although OreSat is developing it's own sun sensor, the SolarMEMs Nano-SSOC-A60 analog sun sensor is an inexpensive COTS alternative with ±1° of accuracy. To compliment the sun sensor, OreSat also has a high precision Analog Devices ADIS16375 six degree of freedom IMU and a custom Honeywell HMC4003 magnetometer board.

D.4.4. Attitude Control System

OreSat will use magnetorquers and reaction wheels to control its attitude. Built into one 3D printed module, the magnetorquers and tetrahedral arrangement of reaction wheels are at the center of the

OreSat structure. For OreSat Live, the ACS must keep OreSat pointed to < ±5° in order for the helical antenna to achieve its maximum gain. For the Cirrus Flux Cam, pointing accuracy is reduced to < ±10° but there may be bounds on angular velocity that have not been specified yet.

The ACS will use the on-board magnetometer and the magnetorquers to perform B dot control to detumble the satellite on deployment, and eventually desaturate the reaction wheels during use.

Reaction wheels are necessary to point OreSat over OreSat Live ground passes. A prototype tetrahedral reaction wheel system has already been demonstrated in the Dryden Microgravity Drop Tower at Portland State University. For a current status of this component please see the relevant GitHub Project Site.

The ACS represents the highest risk subsystem in the OreSat Live mission. Plans for 2017 include ME and ECE Capstone teams to build parts of the system, including a two-axis air bearing for testing.

Figure D.4.4-1: Tetrahedral reaction wheel 1U prototype being tested in the PSU Dryden Microgravity Drop Tower. For a video of drop test, please see https://www.youtube.com/watch?v=cC2FpmCP5B4

D.4.5. Camera System

The OreSat Live camera is a simple "web cam" class USB-based 1080p USB 2.1 high speed video camera. The OreSat Live camera faces out of the +Z axis of the spacecraft, down the center of the helical antenna. This allows the OreSat Live to image the location on earth it is pointing to. Surprisingly, looking through the helical antenna does not obscure more than roughly 10% of the view.

D.4.6. DxWiFi S-Band Video Transmission System

The S Band downlink utilizes an Atheros ATH9K transceiver chip and Linux drivers for the radio. There is a 3 watt bidirectional LNA / PA device connected to the transceiver, which is essential to provide the minimal link budget performance as indicated by the link analysis in the below. An RF PIN switch is used between a low low gain S-Band turnstile antenna mounted on the -Z surface , and 16 turn +16 dBi RHCP Helix antenna deployed from the +Z surface. The low gain turnstile provides an alternate S Band antenna option should the Helix fail to deploy properly. The Helix is constructed from 0.5 mm Nitinol wire, and is constrained when deployed by Kevlar fibers. For a current status of this component please see the relevant GitHub Project Site.

D.4.7. Software

Although not often thought of as a "component", software is as critical as any part of the system. There are two main software infrastructures:

- System Controller firmware: this is the mission critical firmware that controls the OreSat bus including the Low Gain Radio communication system. The SC firmware must monitor the satellite for power, health, and implement backup plans when other systems fail. The code is written in C, and is under development by teams of Portland State Students and industry mentors with full code reviews, verification tests, and hardware-in-the-loop testing.
- Flight Computer software: The software running on the flight computer is a combination of C, Rust, and Python running on an embedded version of Linux. Most of the code infrastructure, including data acquisition, control loops, and data processing across multiple buses has already been written and flight tested as part of the PSAS amateur rocketry program.

D.4.8. Failure Modes Effects Analysis (FMEA)

The OreSat system is in the long process of going through a Failure Modes Effects Analysis (FMEA) prior to the Preliminary Design Review (PDR). FMEA will help the OreSat team understand where and how redundancy and backup features should be implemented. Some of the backup plans implemented include:

- **Total ACS Failure:** In the event that the ADS or ACS fails completely and the satellite is tumbling out of control, DxWiFi can be switched from the high gain helical antenna to two phased patch antennas with an omnidirectional pattern. Although the Oregon Educational Ground Stations will not be able to connect to the satellite, any 3m or larger S-band parabolic dish will still be able to receive the 2 Mbps video stream.
- **Total DxWiFi Failure:** In the case of a total failure of the S-band system, data can be rerouted to the 70 cm (436 MHz) LGR. Although live video streaming won't work over this radio, the LGR can still be configured to send Cirrus Flux Camera data, albeit over several days. Further, although it will negatively influence noise margins and power consumption, the LGR software can re-configure the LGR from its normal operating mode of 9600 bps GFSK to up to 600 kbps using FSK.
- **Reaction Wheel Failure:** In the event that the reaction wheels fail, OreSat can still use its magnetorquers to put the satellite in a nadir pointing orientation, allowing for brief uses of OreSat Live as the vehicle is directly overhead.
- **Battery Cell Failure:** In the event that a battery cell fails and brings down solar power bus, the system controller can disable charging on the failing battery. In the unlikely event that a cell failure affects the battery bus through the ORing diodes, then the system controller can turn off the battery outputs as well.

D.5. Technical Details: Cirrus Flux Cam Science Payload

Preliminary theoretical and ground-based prototyping work has been done on the Cirrus Flux Cam (CFC) mission by Dr. Greg Bothun and Eryn Cangi at the University of Oregon Physics department. While these preliminary details are integrated into this proposal, all serious space environment and vehicle integration work of the CFC is contingent on getting accepted to the CSLI program.

D.5.1. Astrophotography Camera

The Cirrus Flux Cam (CFC) plan calls for accurate flux detection of cirrus clouds, requiring a photogrammetric camera with a large field of view and relatively low resolution. The proposed CFC camera is currently a 1.25" diameter by 3" long Orion StarShoot "All-In-One" astrophotography camera. It features a ⅓" 1280 x 960 pixel CMOS sensor with 3.75 micron x 3.75 micron pixels and a USB 2.1 High Speed-based interface. While the current camera selection will easily fit within OreSat, the camera should be modified to optimally fit in OreSat's 2U CubeSat form factor. Further work will be performed on reducing the camera size and other integration issues upon entry into the CSLI program.

Figure D5.1-1: Orion StarShoot "All-In-One" Astrophotography Camera

D.5.2. Filter Wheel Mechanism

In conjunction with the CFC is a series of light filters that will allow for discrimination between cirrus clouds and surrounding structures. A filter wheel assembly will be constructed to fit in front of the CFC and will complete a full revolution while taking a of series pictures in approximately 10 seconds. The short frame rate will allow for post-processing comparison on the ground and will create batches of near identical views. The filter wheel assembly will feature between 6 and 10 optical filters to be determined in the near future. The physical design of the filter wheel assembly will begin upon entry into the CSLI program.

D.5.3. System Requirements

The CFC system has relatively light system requirements. Volume constraints of the filter wheel mechanism are probably the most stringent requirements. Power of the camera is minimal, estimated at 75 mA, and negligible given duty cycle for moving the filter wheels. ACS pointing accuracy also has very loose requirements at ±5°, although because of the shutter length and time between filter changes, there may as yet specified requirements for low angular velocity over the 1 - 10 seconds of data capture.

D.6. Merit and Feasibility Review Questions and Results

D.6.1. Merit Review: OreSat Live

Question	Average Rating
Does the OreSat Live mission contribute to NASA's overarching approach to inspire students to be our future scientists, engineers, explorers and educators?	4.8
Does this mission help contribute to NASA's mission to drive advances in science, education and stewardship of earth?	4.8
Does the primary mission help cultivate a strong future STEM workforce through educational initiatives?	4.60
Does the primary mission help contribute to NASA's objective of contributing to STEM education to bring immediate benefit to schools?	4.60
As an educator, will OreSat contribute to your student's STEM inspiration or learning?	4.40
Would the OreSatLIVE mission add value to the STEM curriculum within your classroom?	4.2
Average Rating	**4.57**

D.6.2. Merit Review: Cirrus Flux Cam

Question	Average Rating
Does the Cirrus Flux Cam contribute to NASA's plan to gain insight into climate change?	4.67
Does the secondary mission contribute to NASA's goal to advance knowledge of Earth as a system?	4.67
Does the secondary mission help contribute to NASA's mission to drive advances in science, education and stewardship of earth?	4.67
Does the secondary mission contribute to NASA's commitment to environmental stewardship through Earth observation and science?	4.67
Will the secondary mission contribute to additional knowledge about Climate Change based on the study of Cirrus Clouds?	4.67
Average	**4.67**

D.6.3. Feasibility Review

OreSat System	Average Rating
OreSat Structure	4.75
OreSat Bus-Physical card / backplane system	4.75
OreSat Bus-Solar modules	3.75
OreSat Bus-System Controller	4.75
OreSat Bus-Low Gain Radio	4.25
OreSat Live-Flight computer	3.75
OreSat Live-SDR GPS	4.75
OreSat Live-DxWiFi	4.25
OreSat Live-Camera system	4.50
OreSat Live-ADS (Sunsensors)	4.00
OreSat Live-ACS (magnetorquers + reaction wheels)	3.75
Cirrus Flux Cam-Camera	4.50
Cirrus Flux Cam-Filter wheel	3.25
OreSat Live Educational Ground Station	4.00
OreSat Ground station	4.25
Average	**4.22**

D.7. Scientific Details: Cirrus Flux Cam Science Payload

Author: Dr. Bothun, University of Oregon

Climate feedback models in combination with the basic physics of radiative transfer show that high ice clouds (cirrus clouds) generate the most positive radiative forcing which therefore contributes to the warming of the Earth's atmosphere. This is because high-level clouds restrict emission from leaving the atmosphere directly to space. As the surface of the Earth continues to warm there will likely be a water vapor feedback loop in which warmer sea surface temperatures drive more evaporation thus increasing atmospheric water vapor. One potential prediction is that the atmosphere will become increasingly cloudy at some point. At the moment, there is considerable uncertainty in the altitude of this increased cloud cover but more high altitude clouds are a likely possibility given the mechanism described below (see also Liu etal 2105; Wang etal 2011).

As deep tropical convection (DTC) increases in direct response to warming of equatorial waters, there is a reasonable expectation that this water vapor will be carried up to high altitudes. If so, then the amount of high ice clouds (see Cooper 1996) that form may increase thus amplifying the entire warming circuit. The longest time series of measurements of stratospheric water vapor are the balloon borne measurements carried out by NOAA Earth System Research Laboratory at Boulder Colorado. The image below shows these measurements with a fitted smoothed trend line suggesting an increase over this time period:

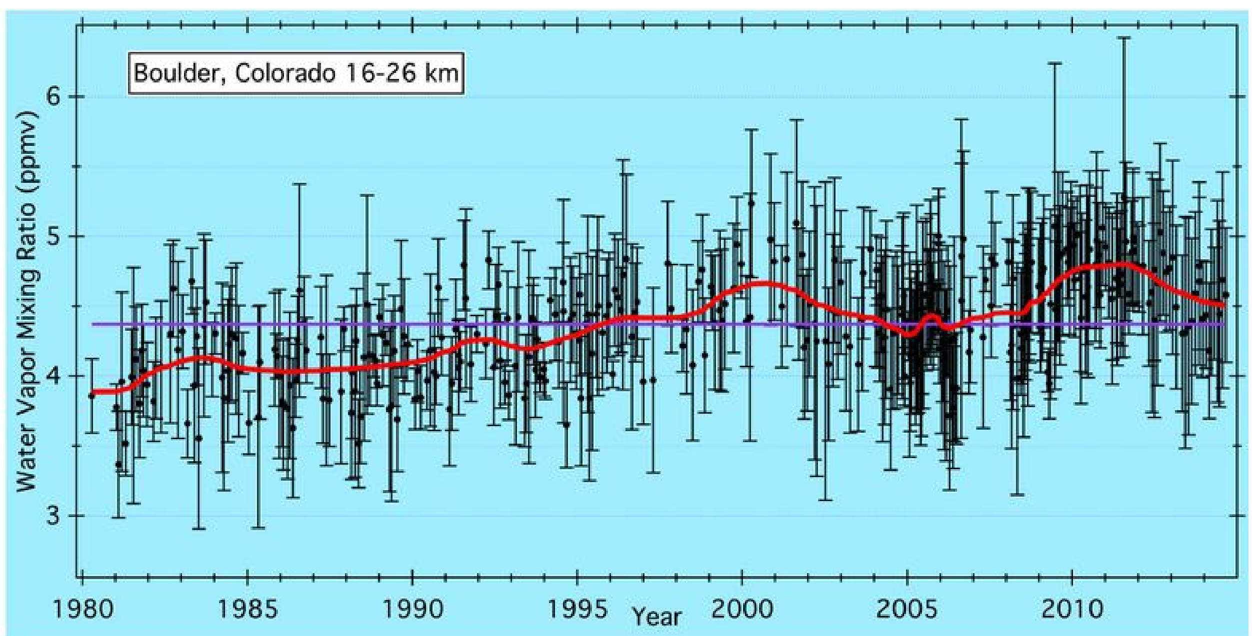

Figure D7-1: Long Term Measurements of Atmospheric Water Vapor

The peak at 2012 is approximately 10% higher than the long term mixing ratio shown by the purple line. However, it is clear from the individual data points (black points + error bars) that random fluctuations are high (both due to instrumental and physical factors) and therefore detection of any systematic trend requires a large smooth window. In addition, available data through 2010 are showing a slight decrease (positive anomalies) in total cirrostratus global cloud cover (but see Mace et al 2011).

However, most current methodology of cirrus cloud detection remains ambiguous. As emphasized by Brocard etal (2011), traditional means of cloud detection from satellites rely on infrared radiometry from satellites. While this method easily detects optically thick clouds due to high IR signal enhancement, optically thin cirrus clouds produce only a small enhancement and can be barely distinguishable from clear sky. They propose a new technique which relies on fluctuations of the IR brightness temperatures (IRBT) rather than absolute values of the IRBT. However, this technique is ultimately limited by detector noise. Similar, spectroscopic detection of cirrus data remains problematic primarily due to the complication spectrum of water vapor at various altitudes in the atmosphere. Satellite observation sample the entire column of air below them which has many components to the observed integrated spectrum (see Marchand and Ackerman 2010). A recent improvement to the spectral imaging detection of cirrus clouds is deployed, as of 2013, in a new 1.38 micron channel on LandSat 8. At 1.38 microns our atmosphere is so optically thick, due to the presence of water vapor, that no photon coming from the surface of the Earth would reach the top of the atmosphere. Since this water vapor is primarily confined to the tropopause reflected 1.38 micron photons from the tops of cirrus clouds, would be unaffected (however, cirrus clouds are not particularly reflective at those wavelengths). In addition, this technique also produces false positives through the detection of jet contrails (many of them) as well as snow and ice on the top of high mountains.

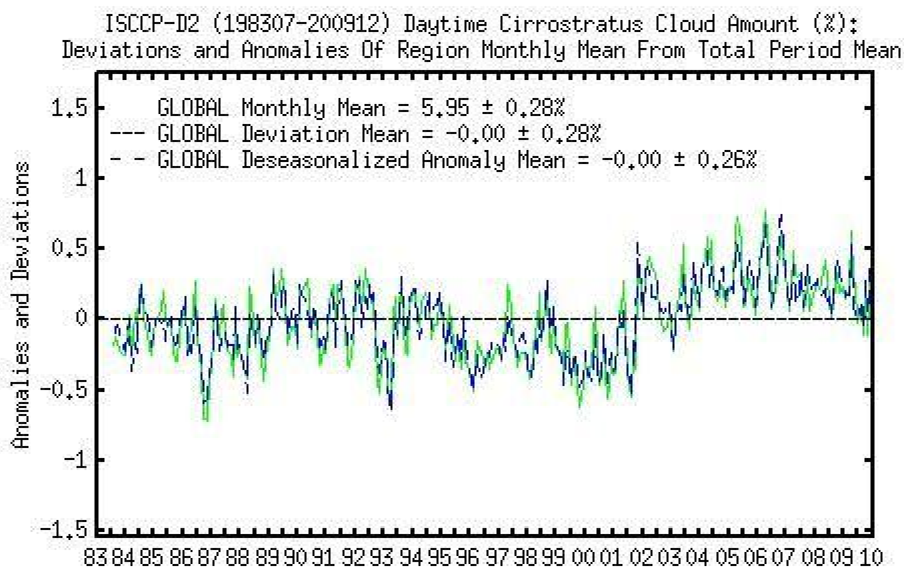

Figure D7-2: International Satellite Cloud Climatology Project Measurements of high level clouds

It has been fairly well documented (see Wielicki and Parker 1992; Rossow and Schiffer 1999) that upper level cloudiness has been underestimated due to a detection bias against very thin cirrus clouds. Rossow and Schiffer (1999) estimated that in the International Satellite Cloud Climatology Project (ISCCP — see Figure 2), up to 20% of the cirrus clouds have not been detected due to different detection rates between the ISCCP and the Polar Orbiting satellites that tend to detect more cirrus clouds using their multispectral technique (see Wylie and Menzel 1998). Recently Kox et al (2014) have produced yet another new technique for measuring the topical optical thickness of cirrus cloud cover, which is based on the very complicated backscatter properties of these structures.

In principal, NASA Cubesat technology provides another global monitoring platform. Here we propose to use a simple but novel and inexpensive technique for the detection of high ice clouds. This technique relies, like one mentioned, earlier, on a reflection signal, but in this case we will work in the optical, and use the UBV filter system of optical astronomy as the detection system. The technique is simple — direct reflection from ice clouds in the top of the atmosphere will have the same photometric signature as the incoming solar spectrum but reflection from clouds that contain water vapor will have different flux ratios. While the UBV system seems to be preferred on a priori grounds, virtually any combination of filters from blue to red should produce adequate discrimination.

Indeed, we have done sufficient preliminary work to identify the right camera plus filter system that could be part of the CubeSat payload. In the spring of 2016 we used a commonly available all-sky astrophotography camera with a variety of combinations of 7 different bandpass filters to the sky under a variety of cloud conditions. Many of these images do, in fact, contain only thin cirrus clouds. Again, the concept is that these thin clouds, made almost exclusively of ice crystals, should directly reflect sunlight and therefore have the same filter flux ratios as the sun. Clouds with higher moisture content will have different filter flux ratios. Standard astronomical photometric techniques are then applied to these all sky images. Preliminary results show that good detection of cirrus clouds on bright, clear days occurs with use of the 82a blue, 11 yellow, or LRGB luminance filter alone or in combination.

Since CubeSat observations made from approximately 450 km above the atmosphere will image a variety of cloud structures at once, the total column observations will have to be deconvolved into individual components following the general procedure and techniques of Hack and Pedretti (2000) and Khairoutdinov and Randall (2001).

That is the reason that we are doing all the calibration work from the ground to get as many different filter flux ratios as possible for different kind of clouds in order to produce an overall component model, which then can uniquely identify the signature of high altitude ice clouds. Obviously, as CubeSat orbits the earth, we will obtain many images of total cloud cover over a variety of land and ocean masses, through different seasons, such that statistical cloud cover of the Earth can be obtained in a much more straightforward manner than is currently in case with the variety of extant satellites. This will help compliment other surveys that are attempting to measure any systematic trends in the wake of highly variable phenomena.

The digital camera used for these observations has form factor of a thin cylinder approximately 1.25” in diameter and 3” in length. Our work from the ground suggests that the use of 6 filters will allow for good detection of different cloud types. While the camera can be operated remotely, the major piece of engineering will involve the designing of a filter wheel for the camera. The dimensions needed for this filter wheel (each filter is 1 inch in diameter) are less than the 10x10x11.35 cm size requirements for the CubeSat payload. The ground based observations show that good results can be obtained with exposure times of 5 secs or less. The pixel detector in the camera is relatively small (about 400x400 pixels) so that each image has a very small data size. High resolution is not needed at all for these observations, as we are attempting to measure the various different kinds of clouds in the total global cloud cover. Indeed, for such an experiment, the lower resolution the better.

Finally, we would coordinate these CubeSat observations with surface observations from citizen scientists using cell phones pointed at the sky. This would occur under local clear sky conditions so that no low clouds would get in the way. This would provide some kind of independent calibration of the detection of high ice clouds from looking down, compared to looking up and just using visual detection by observers trained using the Lynch et. al. 2002 protocols for visual detection of cirrus clouds.

D.7.1. References

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D.8. Detailed Financial Budget

The OreSat budget assumes building 3 complete satellites and having 1 component spare. Numbers are approximate, and depend heavily on purchasing COTS vs space rated components.

System	Subsystem	Qty	Price	Ext.
OreSat Bus	Structure	4	$1,750.00	$7,000.00
	Solar Modules	25	$200.00	$5,000.00
	Battery modules	25	$100.00	$2,500.00
	System controller	4	$300.00	$1,200.00
	Low Gain Radio	4	$300.00	$1,200.00
	LGR 70 cm antenna	4	$250.00	$1,000.00
	OreSat backplane	4	$500.00	$2,000.00
Oresat Live	720p video camera	4	$100.00	$400.00
	Flight Computer	4	$1,000.00	$4,000.00
	SDR GPS	4	$200.00	$800.00
	GPS antennas	9	$100.00	$900.00
	Inertial Measurement Unit + Mag.	4	$1,000.00	$4,000.00
	Attitude Det. (Sun sensors)	4	$2,000.00	$8,000.00
	Attitude Control (RWs + MTs)	4	$2,500.00	$10,000.00
	DxWiFi communication system	4	$250.00	$1,000.00
	DxWiFi S band high gain antenna	4	$500.00	$2,000.00
	DxWiFi S band low gain antenna	4	$1,000.00	$4,000.00
	S band low gain antenna	9	$ 50.00	$450.00
	L band antenna	4	$100.00	$400.00
Cirrus Flux Cam	Astrophotography camera	4	$450.00	$1,800.00
	Filter wheel system	4	$500.00	$2,000.00
Ground Station	Primary and secondary ground stations	2	$2,500.00	$5,000.00
Testing	Amateur rocket launch	1	$2,000.00	$2,000.00
	Balloon launch	2	$750.00	$1,500.00
	Environmental	1	$6,000.00	$6,000.00
	Antenna propagation + EMI	1	$2,000.00	$2,000.00
Misc	Contingency	1	$10,000.00	$10,000.00
	TOTAL			**$86,150.00**

D.9. Link Budget Analysis: Low Gain Radio (LGR)

The link budget analysis involves the use of the AMSAT / IARU Annotated Link Model System spreadsheet version 2.5.3. Complete details of the link were described in the spreadsheet.

D.9.1. Command Uplink

Link Details

Frequency	437.50 MHz
Specified B.E.R.	1.00E-05
Demodulator Type	BPSK
Eb/No Threshold	10.6 dB
BW bpf	12000 Hz
Bit rate	9600 bps
F.E.C. Decoder Type	None
Elevation	10 deg

<u>Link summary: Eb/No Method</u>
Eb/No: 35.6 dB
Link Margin: 25.0 dB (Link Closes)

<u>Link summary: S/N Method</u>
S/N: 34.7 dB
Link Margin: 21.7 dB (Link Closes)

Received At Spacecraft

G/T	-24.5 dB/K
T sys	327 K
T 2nd Amp	500 K
Gain LNA	20.0 dB
T LNA	35 K
Loss total line	1.39 dB
Loss Line A	0.03 dB
Loss other	0.5 dB (Directional Coupler)
Loss Line B	0.03 dB
Loss Hybrid	0.5 dB (Hybrid)
Loss Line C	0.03 dB
Gain Rx Ant	2.0 dBi (Canted Turnstile)
Polarization	RHCP

Path Loss

Lp (Loss Due To Free Space)	148.6 dB
Total Link Losses	150.9 dB

Transmitted At Ground Station

EIRP ground station	22.3 dBW
Gain Tx Ant	16.0 dBi (Helix)
Polarization	RHCP
Loss total line	3.62 dB
Loss Line C	1.250 dB
Loss other	0.5 dB (Directional Coupler)
Loss Line B	0.015 dB
Loss bpf	1.0 dB
Loss Line A	0.050 dB
Power Tx (RF)	10.0 watts

D.9.2. Telemetry Downlink

Link Details

Frequency	437.50 MHz
Specified B.E.R.	1.00E-05
Demodulator Type	BPSK
Eb/No Threshold	10.6 dB
BW bpf	12000 Hz
Bit rate	9600 bps
F.E.C. Decoder Type	None
Elevation	10 deg

Link summary: Eb/No Method
Eb/No: 22.3 dB
Link Margin: 11.7 dB (Link Closes)

Link summary: S/N Method
S/N: 21.3 dB
Link Margin: 8.3 dB (Link Closes)

Transmitted At Spacecraft

Efficiency Tx	40.0%
Total Tx DC Power Supplied	1.3 watts
Tx Dissipation	0.8 watts
Power Tx (RF)	0.5 watts
Loss Line A	0.0 dB
Loss Hybrid	0.5 dB (Hybrid)
Loss Line B	0.0 dB
Loss other	0.5 dB (Directional Coupler)
Loss Line C	0.1 dB
Loss total line	1.6 dB
Gain Tx Ant	2.0 dBi (Canted Turnstile)
Polarization	RHCP
EIRP spacecraft	-2.6 dBW

Path Loss

Lp (Loss Due To Free Space)	148.6 dB
Total Link Losses	150.9 dB

Received At Ground Station

Gain Rx Ant	16.0 dBi (Helix)
Polarization	RHCP
Loss Line C	0.03 dB
Loss other	0.0 dB
Loss Line B	0.03 dB
Loss Rx bpf	1.5 dB
Loss Line A	0.2 dB
Loss total	2.0 dB
T LNA	49 K
Gain LNA	20.0 dB
T 2nd amp	1000 K

D.10. Link Budget Analysis: DxWiFi S-Band Communications System

The link budget analysis involves the use of the AMSAT / IARU Annotated Link Model System spreadsheet version 2.5.3. Complete details of the link were described in the spreadsheet.

D.10.1. Data Downlink

Link Details

Frequency	2412.00 MHz
Specified B.E.R.	1.00E-05
Demodulator Type	BPSK
Eb/No Threshold	10.6 dB
BW bpf	5.0E06 Hz
Bit rate	2.0E06 bps
F.E.C. Decoder Type	None
Elevation	45 deg

Link summary: Eb/No Method
Eb/No: 18.4 dB
Link Margin: 7.8 dB (Link Closes)

Link summary: S/N Method
S/N: 14.4 dB
Link Margin: -2.2 dB (Link Does Not Close)

Transmitted At Spacecraft

Efficiency Tx	40.0%
Total Tx DC Power Supplied	7.5 watts
Tx Dissipation	4.5 watts
Power Tx (RF)	3.0 watts
Loss Line A	0.0 dB
Loss Hybrid	0.0 dB (Hybrid)
Loss Line B	0.0 dB
Loss other	0.0 dB (Directional Coupler)
Loss Line C	0.0 dB
Loss total line	0.6 dB
Gain Tx Ant	16.0 dBi (Helix)
Polarization	RHCP
EIRP spacecraft	20.2 dBW

Path Loss

Lp (Loss Due To Free Space)	155.2 dB
Total Link Losses	155.8 dB

Received At Ground Station

Gain Rx Ant	16.0 dBi (Helix)
Polarization	RHCP
Loss Line C	0.01 dB
Loss other	0.0 dB
Loss Line B	0.01 dB
Loss Rx bpf	0.0 dB
Loss Line A	0.0 dB
Loss total	0.2 dB
T LNA	35 K
Gain LNA	18.0 dB
T 2nd amp	1000 K

D.10.2. Data Uplink

Link Details

Frequency	2412.00 MHz
Specified B.E.R.	1.00E-05
Demodulator Type	BPSK
Eb/No Threshold	10.6 dB
BW bpf	5.0E06 Hz
Bit rate	2.0E06 bps
F.E.C. Decoder Type	None
Elevation	45 deg

Link summary: Eb/No Method

Eb/No: 27.0 dB
Link Margin: 16.4 dB (Link Closes)

Link summary: S/N Method
S/N: 23.0 dB
Link Margin: 8.6 dB (Link Closes)

Received At Spacecraft

G/T	-6.9 dB/K
T sys	178 K
T 2nd Amp	500 K
Gain LNA	18.0 dB
T LNA	35 K
Loss total line	0.42 dB
Loss Line A	0.04 dB
Loss Line B	0.04 dB
Loss Line C	0.04 dB
Gain Rx Ant	16.0 dBi (Canted Turnstile)
Polarization	RHCP

Path Loss

Lp (Loss Due To Free Space)	155.2 dB
Total Link Losses	155.8 dB

Transmitted At Ground Station

EIRP ground station	24.1 dBW
Gain Tx Ant	16.0 dBi (Helix)
Polarization	RHCP
Loss total line	1.87 dB
Loss Line C	0.025 dB
Loss other	0.5 dB (Directional Coupler)
Loss Line B	0.015 dB
Loss bpf	0.5 dB
Loss Line A	0.025 dB
Power Tx (RF)	10.0 watts

D.11. Technical Details: 70 cm Canted Turnstile Antenna for CubeSat Telemetry

A Canted Turnstile is a common omnidirectional antenna used for communications on spacecraft in Low Earth Orbit. NASA Goddard documented the design for spacecraft antenna systems in Sept. 1967 in publication X-712-67-441 [1]. The Canted Turnstile is constructed using four monopoles, each fed in quadrature phase, and tilted above or below the plane by some angle between 15 and 65 degrees. With respect to the plane, the radiated propagation is mostly horizontal-linear near the plane, and becomes right hand circular (RHCP) above, and left hand circular (LHCP) below the plane. For a practical implementation, this is very close to the hypothetical isotropic radiator which radiates uniformly in all directions within a sphere. For a spacecraft with unknown and varying attitude, this behavior is beneficial.

Roughly following guidance from the NASA document for spacecraft Explorer 35, a Canted Turnstile using a Shimizu [2] type 90 degree stripline hybrid coupler to feed the four monopoles was chosen. The MiniCircuits QBA-07+ 90 degree hybrid coupler [3] was found to meet the requirements for frequency, power handling, temperature range and size appropriate for a CubeSat antenna. The QBA-07+ has the four basic ports, input, 0 degree, 90 degree and isolated as described by the Shimizu design. Three couplers and one 90 degree coax phasing section was chosen to form the four quadrature signal phases. Figure D11-1 describes the layout of the quadrature phasing arrangement.

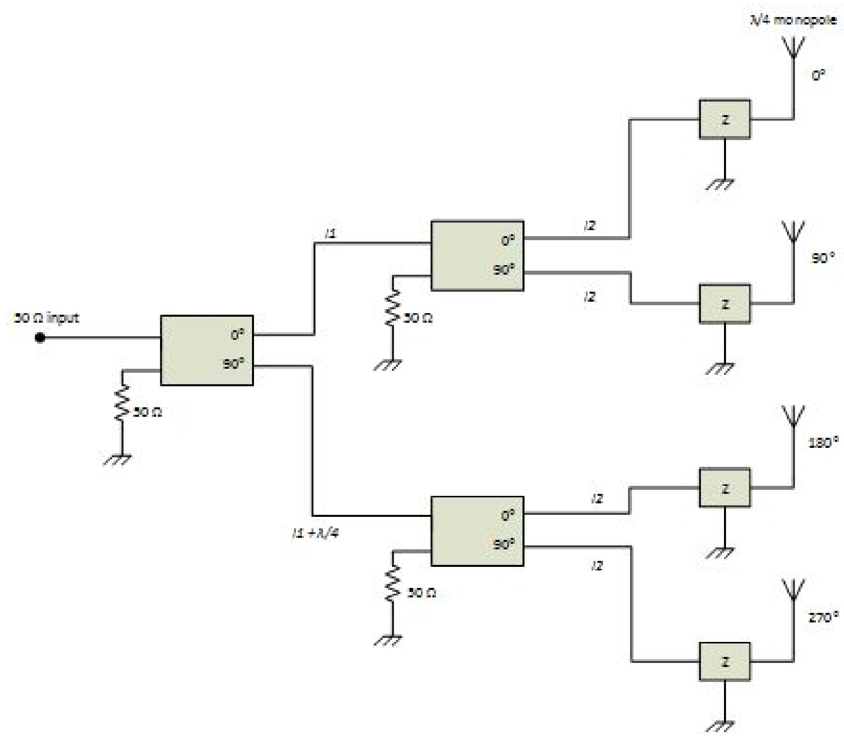


Figure D11-1: Quadrature Phasing Section

The impedance match shown as Z between the $\lambda/4$ monopole and the hybrid coupler is formed using an L-Section, and is intended to match the 50 Ω impedance of the coupler, to the typical 32 Ω impedance of a $\lambda/4$ monopole. Upon testing it was found that the impedance of the monopoles in their configuration on a CubeSat electrical mock-up was actually close to 50 Ω, so leaving the L-Section out entirely performed best. It was also found that pruning the monopole lengths slightly provided an optimum match at the 50 Ω input. The pruning resulted in the 0 and 180 degree elements to be 140 mm, or 25 mm shorter, and the 90 and 270 degree elements to be 190 mm, or 25 mm longer.

Elements slightly shorter become more capacitive, and ones longer are more inductive. Figure D11-2 shows the impedance measured using an HP 8753E Vector Network Analyzer (VNA) at the 50 Ω input port, at the design frequency of 436.5 MHz.

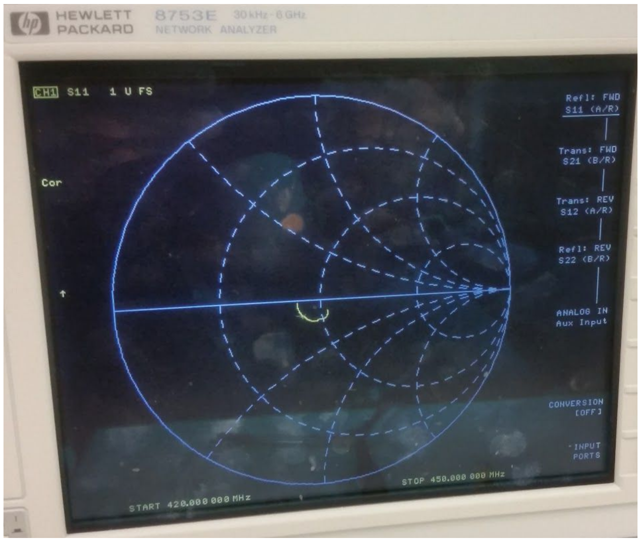


Figure D11-2: Impedance at 50 Ω input

The antenna was placed into an RF anechoic chamber [4] and tested for far field radiation, which resulted in propagation patterns for both the horizontal and vertical polarizations around the +Z axis, and +Y axis. The orientation of the antenna in the +Z axis is shown in Figure D11-3, and relative propagation measurements for the horizontal and vertical polarizations are shown in Figure D11-4, and Figure D11-5 respectively. The orientation of the antenna in the +Y axis is shown in Figure D11-6, and relative propagation measurements for the horizontal and vertical polarizations are shown in Figure D11-7, and Figure D11-8 respectively. The propagation patterns measured do not indicate any extreme signal dropout, however are not indicative of a perfect isotropic radiator. This is entirely expected and wholly acceptable when considering the actual propagation will be the conjunction of both horizontal and vertical propagations combined. Where both are strong in both horizontal and vertical components, the resultant polarization will become mostly circular. Where one of the propagation levels drops down, the resultant polarization will become elliptical in that sense, and in the extreme case, approach linear polarization.

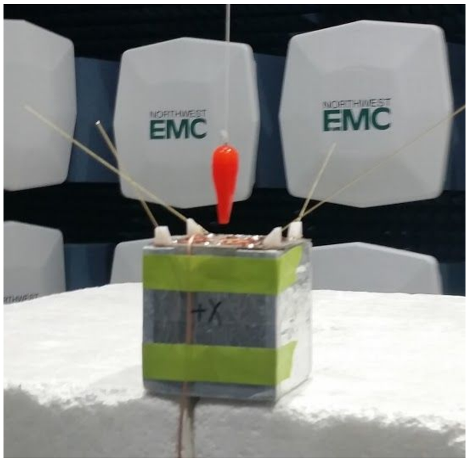


Figure D11-3: Orientation in the +Y axis

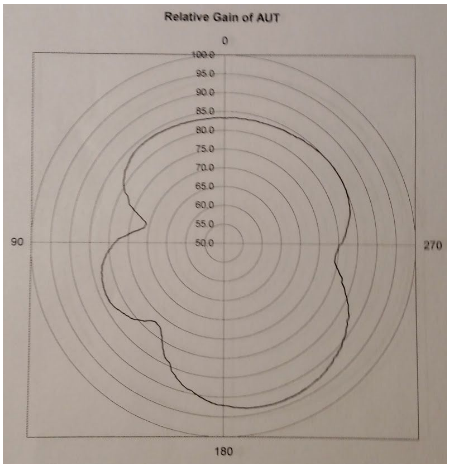


Figure D11-4: Horizontal Polarization

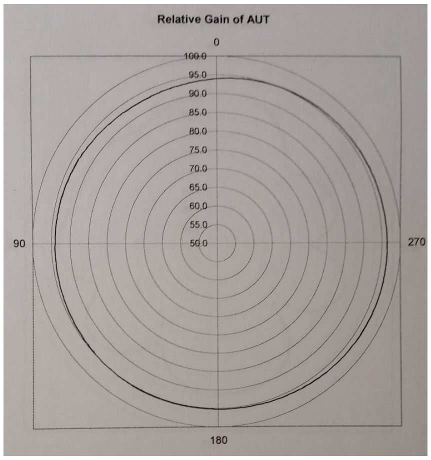


Figure D11-5: Vertical Polarization

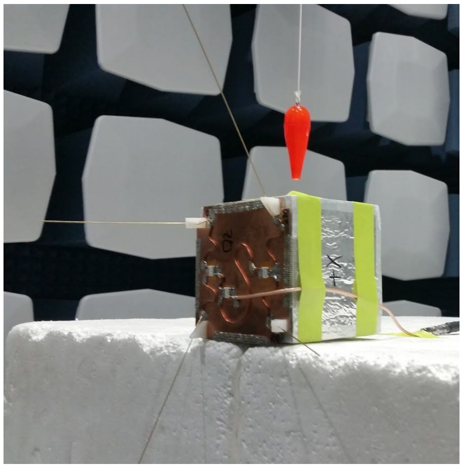


Figure D11-6. Orientation in the +Y axis

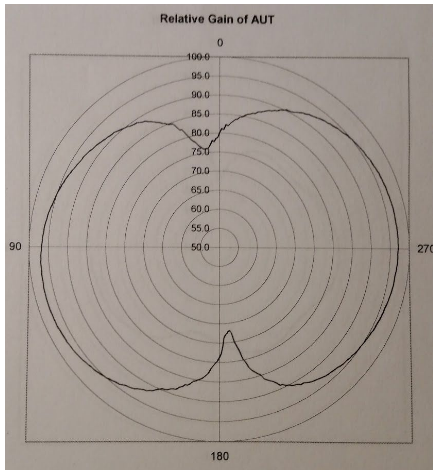


Figure D11-7. Horizontal Polarization

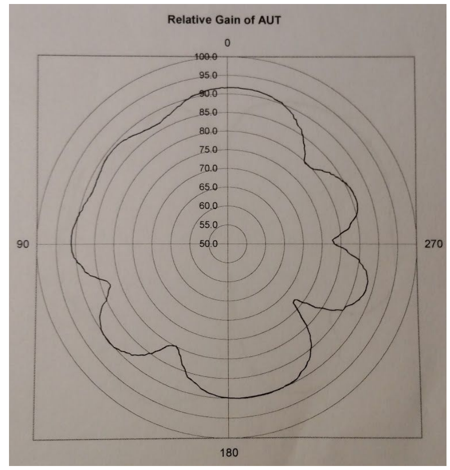


Figure D11-8. Vertical Polarization

D.11.1. References

[1] Jackson, R. B., The Canted Turnstile As An Omnidirectional Spacecraft Antenna System, NASA Goddard Document X-712-67-441, Sept. 1967
[2] Shimizu, J. K., Stripline 3 dB Couplers, Stanford Research Institute.
[3] MiniCircuits QBA-07+, 2-Way 90 degree Splitter/Combiner, http://www.minicircuits.com
[4] Jeff Alcoke, NWEM0324, Northwest EMC, http://www.nwemc.com/

D.12. Technical Details: OreSat Ground Station Infrastructure

OreSat will utilize two ground stations for this project, a primary station, and a fully-capable secondary station. The primary station is being constructed by the students involved in the project and will be located on the Portland State University Engineering Building. The secondary station is an existing amateur satellite ground station located at a different location for spatial diversity. It can be used to help verify and check out the primary station as construction progresses, and serve as a backup to the primary station. The two stations are identical.

The ground station infrastructure provides two communications functions between the ground and the spacecraft, (1) up and down communications on UHF for the Telemetry and Command (T&C) subsystem onboard the spacecraft, and (2) downlink communications on S-band for mission payload and camera data.

The UHF component is centered in the 435 to 438 MHz amateur spacecraft band and utilizes both a RHCP and LHCP directional helix antennas mounted on an azimuth/elevation antenna positioner. Coax switches connect one of the antennas to either a Low Noise Amplifier (LNA) for receiving, or a Power Amplifier (PA) for transmitting. The LNA and PA are then connected to a Software Defined Radio (SDR) that provides both UHF RF input and output signals.

The S-Band component is centered on the 2.4 to 2.43 GHz WiFi channel in the ISM / amateur service spectrum. A 0.5 meter parabolic reflector with a RHCP/LHCP feed is mounted on the same antenna positioner as the UHF antenna. A coax switch is used to select RHCP or LHCP signal from the feed, is then switched to either an LNA or PA. The LNA and PA are connected to a Software Defined Radio (SDR) that provides both S-Band RF input and output signals.

The SDR used is the LimeSDR from LimeMicro, which utilizes GnuRadio for modulation and demodulation. The emission type is BPSK at 9600 bps, and was chosen because of the capability of the T&C transceiver radio on the spacecraft, an acceptable performance indicated in the link budget, and is somewhat common in the amateur satellite community.

An antenna positioner controller is used to aim the antenna array and is interfaced serially using the EasyComm control protocol accessible through the HamLib control library. The positioner controller is based on the Open Source hardware/software project of SatNOGS, and provides the ability for tracking control locally using GPredict, or by the SatNOGS Network software across the Internet.
Data is passed into/out of the ground station radio through GnuRadio ModCod blocks and can provide raw IQ sample files from the payload data. Doppler shift can be compensated for in real time using the tracking software and an interface into GnuRadio.

The T&C subsystem provides telemetry data to the ground in two forms, a BPSK modulated data frame in response to a command request, and a very short Morse code modulated telemetry sequence and satellite ID if no activity is present for a given period of time. This Morse code ID allows the satellite to be heard by the general amateur radio community and will help with identifying the satellite once on orbit. There are several satellite housekeeping commands that can be sent up from the ground to control power, attitude and payload functions, and most importantly a command to reliably shut off all RF transmissions if required. All commands up to the satellite are encrypted for security.

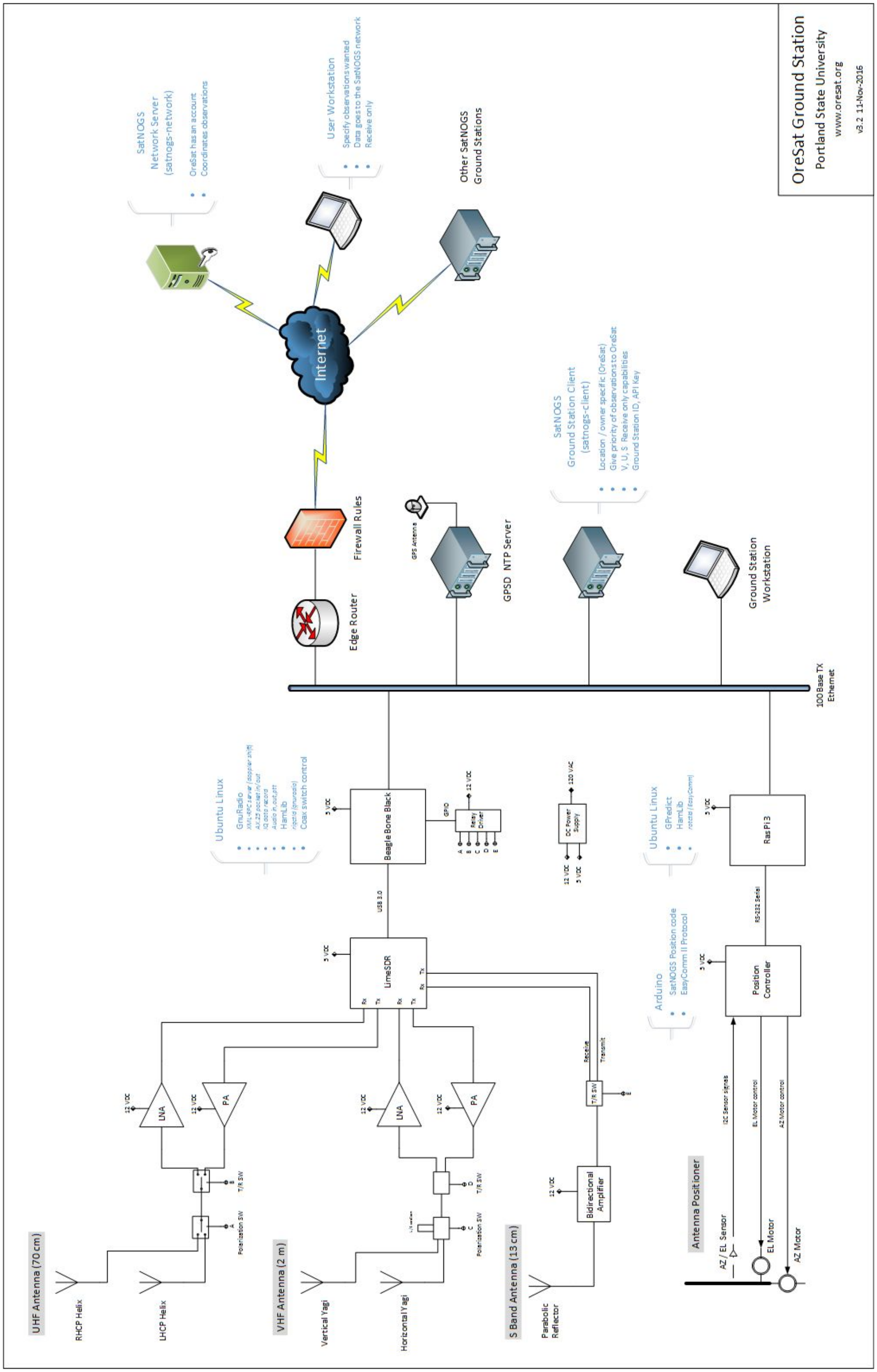


Figure D12-1: OreSat Ground Station block diagram

D.13. Detailed list of Funding Sources

Members of the OreSat project are enthusiastically raising money and services to ensure the project's success. Current funding sources include:

- **Alta Devices** is donating the cells for 25 solar modules, at a cost of $100 each, for a total in-kind donation of $2,500.
- **OSH Park**, a PCB fabrication house, has donated $5,000 worth of 2 and 4 layer PCBs.
- **Machine Sciences**, an aerospace grade machine shop, has agreed to donate machining for the structure as needed. We estimate this to be at $7,500 worth of services.
- **Cascade TEK** has agreed to either donate or discount environmental testing services, including thermal and vibration testing. We estimate this to be around $6,000 worth of services.
- **NW EMC** has donated 8 hours of testing time in their 5m EMC chamber for antenna and EMI testing. This is worth $2,000.
- **Crowdfunding** - Portland State Aerospace Society holds a yearly crowdfunding campaign that in the last two years has raised a total of $25,000. These monies have supported the early OreSat prototyping efforts. Based on the enthusiastic responses to the previous campaign, OreSat can conservatively count on at least $10,000 from this funding source.
- **Portland State University** is funding the facilities for OreSat, including a OreSat room and access to all engineering labs, including the ECE Microwave lab, ECE Lab for Interconnected Devices rapid prototyping facility, the MME Machine Shop, and access to the roof of the engineering building along with to-code wiring for the OreSat Ground Station.
- The **Oregon Space Grant Consortium** has agreed to support the OreSat project for $10,000 per year for two years as part of the Undergraduate Hands-On Learning program.
- **Crowd Supply** - Crowd Supply is a online "Kickstarter"-like company that funds and launches small and technology-based "thoughtfully crafted products". Crowd Supply not only runs the marketing campaign of a product, with backers, press releases, etc., but also stocks, sells, and ships their projects; this takes a tremendous burden off the project organizations. For more information please see see https://www.crowdsupply.com/. Josh Lifton, the CEO of Crowd Supply, has agreed to host the two OreSat ground stations as projects on Crowd Supply. This enables the OreSat project to raise funds by selling ground systems. Crowd Supply will provide:

    - OreSat Live Educational Ground System: Fully assembled units, Component kits and Individual components
    - OreSat Ground Stations (SatNOGS-class ground station): Component kits and Individual components

  Crowd Supply, based on their experience and analysis of the OreSat project, estimate that OreSat will conservatively net roughly $50,000 from the proceeds of these sales, with most of the income coming from private space enthusiasts wanting an OreSat Ground Station. Since this method of funding is still risky, the net estimate has been reduced by 70% to $35,000.

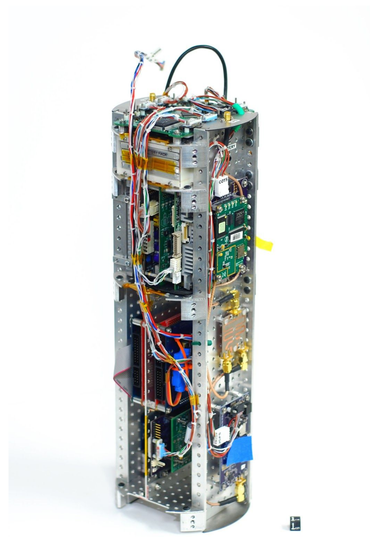
The total funding, monetary and in-kind, is approximately $88,000.

D.14. OreSat's Technology Heritage: The Portland State Aerospace Society

The Portland State Aerospace Society (PSAS) has been launching rockets and furthering STEM education for students since 1997. Comprised of over 100 students, faculty, and local industry mentors, PSAS has provided the local community with hands-on aerospace experience and real world skills development in an interdisciplinary, application-based environment. Over the course of 20 years, students have gone above and beyond their coursework by taking ownership of designing, building, testing, and flying amateur rockets and sophisticated avionics systems in Oregon. More information, including onboard videos of rocket flights, can be found at http://psas.pdx.edu/.

PSAS technology is based on open-source principles and has a rich heritage of iterative design and broader community engagement. A few examples of this technology heritage are featured below.

The **PSAS avionics** stack is a world-class open-source amateur rocket communications and control system. It has gone through four iterations and is among the most advanced amateur systems in the world. The last generation features a 1 Ghz Intel Atom-based flight computer that talks 100 Mbps Ethernet to sensor and actuator nodes, including a SDR GPS receiver and a 6 DOF IMU.



The first PSAS amateur rocket control system was the 1 DOF roll control system (RCS). Using canards and a PID loop to stabilize rocket rotation while in flight, it was PSAS' first experience with control and remains one of the very few successful example of amateur rocketry control systems.

Considered one of the PSAS original claims to fame, the microwave cylindrical patch antenna (CPA) was designed and constructed in-house before cylindrical patch antennas were cool. The PSAS design has been used by multiple organizations including other U.S. amateur rocketry groups and a European amateur group. hHown here are 1.5 GHz, 2.4 GHz, and 5.8 GHz antennas.

Possibly the technology with the largest impact on OreSat, the DxWifi system uses 802.11b over extreme distances to transmit information in an unconventional way. An updated version of this technology will fly on OreSat and make its missions possible.

The most recent PSAS control actuator is a full 3 axis reaction control system (RCS) that uses 4,000 PSI cold gas with 3D printed nozzles to stabilize the rocket in flight. This system will make its debut on the next rocket launch in Spring 2017.

PSAS's next rocket evolution is one of its largest yet. For several years PSAS has been designing liquid fuel rocket engines to take the place the currently used solid motors. The image at right is of the liquid engine test stand which will make its debut firing in the coming months.

PSAS has 3D printed regeneratively cooled aluminum rocket nozzles. This technology will ultimately grow in size to allow for larger, scalable rockets.

D.15. OreSat System Power Budget

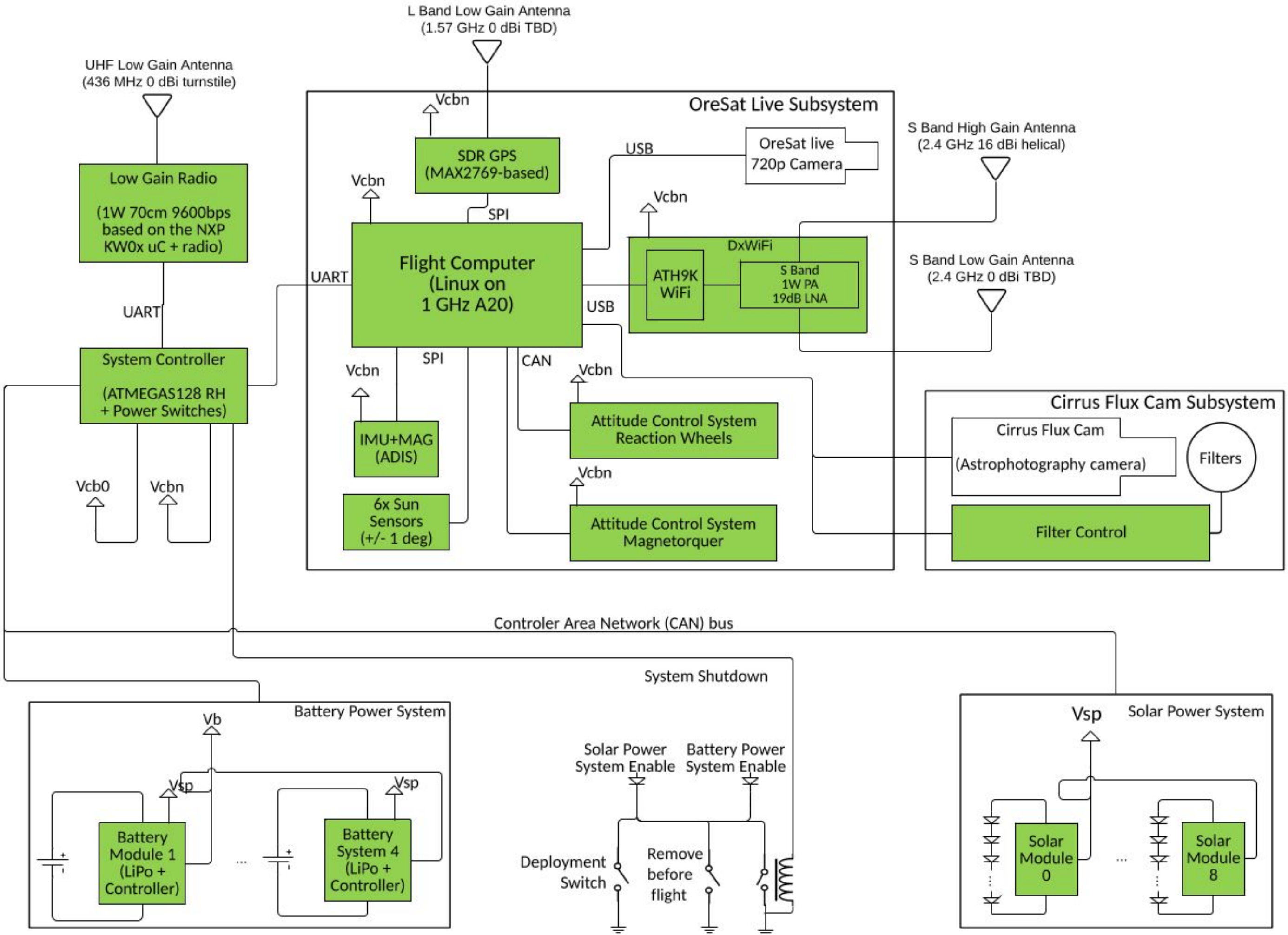
OreSat's power system will go through a full simulation, including parameterizing orbital variables, cell efficiencies, cell temperatures, battery efficiencies at temperature, etc., in order to better predict the power system's behavior in orbit. In the meantime, a simple power budget based on existing OreSat prototypes and component datasheets was used to verify that the power system matches the power needs of the satellite to a first approximation.

Qty	Supply: Solar Modules	mW	Duty Cycle	Tumbl. derating	Effective mW	Period mWh	Notes
2	1.33 W Alta Devices	2,600.00	59%	71%	**1089**	**1634**	Assumes ISS orbit: period ~ 90 min, worst case beta angle of 0 deg.
Qty	**Power Storage**	**Vnom**	**mAh**	**Storage (mWh)**		**60% DOD (mWh)**	**Notes**
4	LiPo Battery cells	3.6	3300	47520		28512	Do not discharge past 60% DOD
Qty	**Load: OreSat Bus in Standby mode**	**mA**	**Duty Cycle**	**Effective mA**	**Eff. mW @ 3.6V**	**Period mWh**	**Notes**
1	Low Gain Radio RX (Kw0x RX + LNA)	50	99%	50	178	267	LGR mostly in RX mode
1	Low Gain Radio beacon mode (Kw0x TX + PA)	3000	1%	30	108	162	LGR occasionally transmitting 70 cm CW beacon
1	System Controller	25	100%	25	90	135	System controller monitoring Rx and Tx
4	Battery module: quiescent power draw	2	100%	8	29	43	Constant monitoring and incoming data from batteries
8	Solar module: monitoring power draw	20	1%	2	6	9	Incoming data from solar arrays
	Total			**114**	**411**	**616**	"Standby mode" (awaiting commands)
Qty	**Load: OreSat Live pass**	**mA**	**Duty Cycle**	**Effective mA**	**Eff. mW @ 3.6V**	**Session mWh**	**Notes**
1	A20 Flight computer (180 mA - 250 mA)	300	100%	300	1080	180	Doing ADS, ACS, capturing and streaming video
1	SDR GPS	200	100%	200	720	120	Streaming raw GPS IQ data
1	IMU + MAG	35	100%	35	126	21	Streaming data to FC
4	ACS Reaction Wheels	500	100%	2000	7200	1200	Fully active
3	ACS Magnetorquers	0	0%	0	0	0	Off
8	ADS Sunsensors	50	100%	400	1440	240	Streaming data to FC
1	DxWiFi transmitter + PA	1000	85%	850	3060	510	Streaming video over DxWiFi
1	OreSat Live camera	75	100%	75	270	45	Streaming video to FC
	Total					**2316**	2.3 Wh used per 10 min maximum OreSat Live "session"
Qty	**Load: Cirrus Flux Cam pass**	**mA**	**Duty Cycle**	**Effective mA**	**Eff. mW @ 3.6V**	**Session mWh**	**Notes**
1	A20 Flight computer (180 mA - 250 mA)	300	100%	300	1080	180	Doing ADS, ACS, capturing and streaming video
1	SDR GPS	200	100%	200	720	120	Streaming raw GPS IQ data
1	IMU + MAG	35	100%	35	126	21	Streaming data to FC
4	ACS Reaction Wheels	500	100%	2000	7200	1200	Fully active
3	ACS Magnetorquers	0	0%	0	0	0	Off
8	ADS Sunsensors	50	100%	400	1440	240	Streaming data to FC
1	Cirrus Flux Camera	100	85%	85	306	51	Sending images to FC
1	CFC filter wheel	100	10%	10	36	6	Switching filters
	Total					**1818**	1.8 Wh used per 10 min maximum Cirrus Flux Cam "session".
Qty	**Load : Detumbling mode**	**mA**	**Duty Cycle**	**Effective mA**	**Eff. mW @ 3.6V**	**Session mWh**	**Notes**
1	A20 Flight computer (180 mA - 250 mA)	200	20%	40	144	24	Doing ADS, ACS, capturing and streaming video
1	SDR GPS	200	20%	40	144	24	Streaming raw GPS IQ data
1	IMU + MAG	35	20%	7	25	4.2	Streaming data to FC
4	ACS Reaction Wheels	0	0%	0	0	0	Off
3	ACS Magnetorquers	450	100%	1350	4860	810	Fully active, using power up to the orbital period energy budget

8	ADS Sunsensors	50	20%	80	288	48	Streaming data to FC
	Total					**910**	0.9 Wh used during detumbling / desaturation mode
Analysis							
	Energy budget per orbital period in standby mode:					1018	mWh. Conclusion: Gain 1 Ah per orbit in standby mode
	Orbits to fully recharged battery pack from 60% DOD					18.7	orbital periods.
	Days to fully recharge battery pack from 60% DOD					1.2	days.
	Number of OreSat Live passes per battery charge (to 60% DOD)					12.3	passes to 60% DOD.
	Number of Cirrus Flux Cam passes per battery charge (to 60% DOD)					15.7	passes to 60% DOD.

As shown in the Analysis section above, OreSat current has about a 1 Wh gain of energy per orbital period when in regular "Standby" mode. This is OreSat's normal mode of operation when not making OreSat Live passes, Cirrus Flux Cam data captures, or detumbling the satellite with magnetorquers. From a full battery depletion (60% depth of discharge) to a full charge is just 1.2 days with a worst case beta angle of 0°. Moreover, the large capacity of the battery pack means that in the worst case, up to 12 sessions of OreSat Live and 15 Cirrus Flux Cam passes can be done before operations must pause for battery recharge. In standard operation only a few passes each day will occur, allowing the battery to be kept fully charged.

D.16. OreSat Block Diagram



OreSat System Block Diagram r3

Note: Green indicates separate "Card" PCB