SiLVER SAT

Feasibility Review

SilverSat Limited’s response to NASA’s Announcement of CubeSat Launch Initiative

Agenda

- Overview
- Mission Concept
- Block Diagrams
- Component Selections and Trades
- Analysis and Budgets
- Build and Testing
- Risk Matrix
- Schedule and Funding
- Team Organization
- Conclusion

Courtesy: NASA

Purpose of the Feasibility Review

"Assessment of the technical implementation, including feasibility, resiliency, risk and the probability of success."

- ***NASA CubeSat Launch Initiative Announcement of Opportunity***

Areas of consideration:

- Technical development / technical risk
- Mission risk
- Any areas of critical technology development
- Management / Mentor team, Organization Structure
- Financial Support

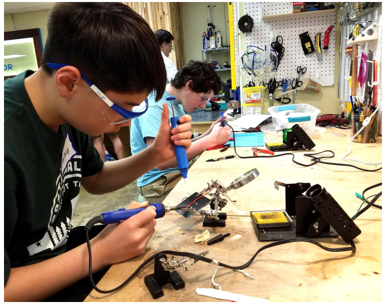
Overview of SilverSat Limited

- Multi-year community-based non-profit serving Silver Spring area tweens and teens.
- Goals include STEM enrichment “to discover and expand knowledge”* and leadership development among tweens and teens, including those from underrepresented and underserved groups in STEM fields.
- Diverse student participation -> different perspectives on the different challenges we face throughout this program.
    - 23 Students in grades 8 - 12
    - Mix of public, private and homeschooled students
    - Greater Silver Spring area: DC, Maryland and Virginia
    - Many different personal interests and aspirations

** NASA 2018 Strategic Plan, NASA Vision - p.6*

Overview of SilverSat Limited (continued)

- Our background will allow us to contribute to NASA's "diverse workforce"* in the future.
- We have students in this program with many different areas of expertise that contribute to our progress and allow us to be more efficient in creating our CubeSat.

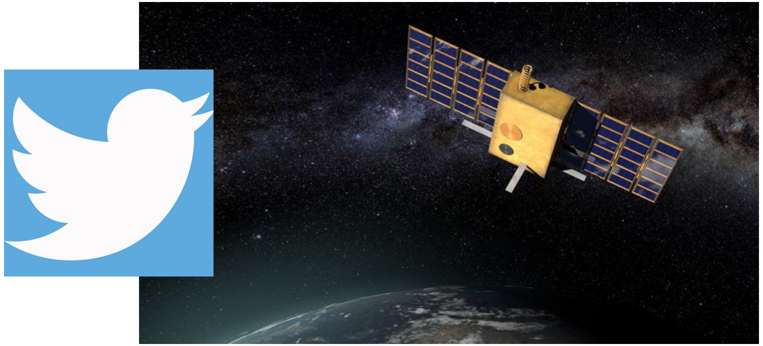


** NASA 2018 Strategic Plan, Strategic Goal 4.4: Manage Human Capital - p.39*

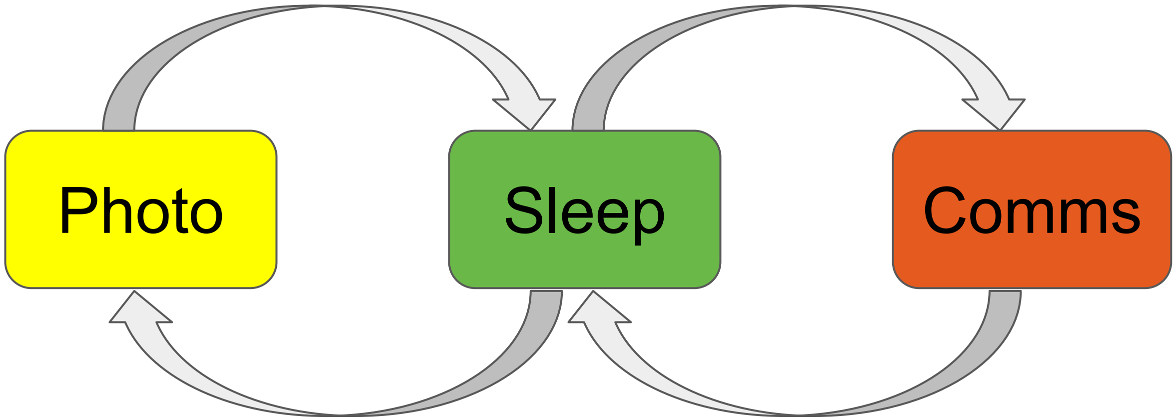
SilverSat Mission Concept

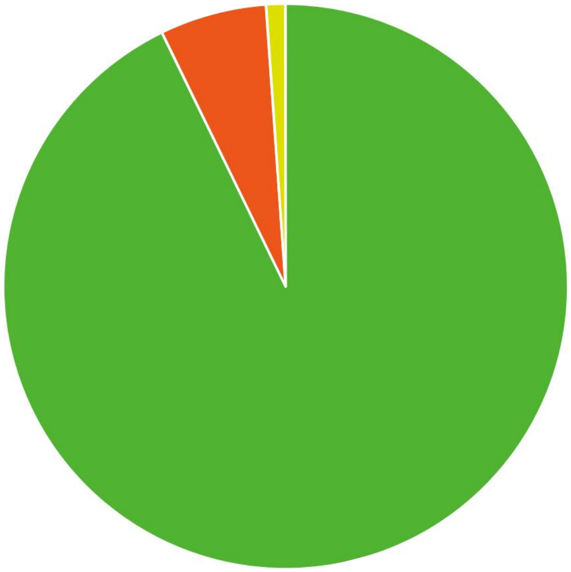
SilverSat is a space photo tweeting CubeSat that:

Takes photos of Earth during its orbit and, when in contact with a ground station, the SilverSat CubeSat logs into Twitter and posts its photos and mission data as Tweets.



Concept of Operations





Total: 90 minutes
(1 Orbit)

Photo: Take pictures of the Earth from space

Comms: Communication with ground station; automated tweet of photo, status

Sleep: Idle, conserve power, wake for photo or communication, beacon

Status of Merit Review Items

Level One Requirement Set* - Done, concurred by Dr. Fox (Systems Team)

Requirements Traceability Matrix* - Done, concurred by Dr. Fox (Systems Team)

Mission Risks* - Done, waiting on concurrence (Elijah)

Enhance Public Involvement** - Done, waiting on concurrence (Alex and Jalin)

Define State Transition Conditions* - Done, concurred by Dr. Fox (Zoe)

Build Plan* - Done, waiting on concurrence (Thomas and Jordan)

Use of Space Network S-band Multiple Access Service** - Done, seeking concurrence (Dave)

**Results are also included in this presentation*
*** Included in backup slides*

SilverSat Science Traceability Matrix

Mission Objectives	Approach	Level 1 Requirements
Educational Objective: SilverSat will educate the greater Silver Spring area on space exploration, in order to inspire the next generation of space explorers.	• Go to elementary Schools • Generate lesson plans to send to elementary schools. • Provide classes for satellites building skills. • Place our lesson plans online for others to learn how to build a CubeSat as well.	**SilverSat shall...** • Provides education resources on satellites and how they work • Maintain a website with information about the mission's progress • Make available educational opportunities for students to advance both in leadership and understanding of the topic they are in charge of • Provide opportunities for the public to interact with the mission
Technical Objective: Demonstrate immediate dissemination of information from the CubeSat to the public	• Take pictures in orbit • Post directly to Twitter • Create a CubeSat that can take pictures • Have camera point towards earth • Be able to take pictures of specific things at specific times.	**SilverSat's CubeSat shall...** • Fly in low earth orbit • Tweet from space without needing human assistance • Take a picture of Earth • Post photos and data to Twitter

Mission Traceability Matrix

Level 1 Requirement	What Ground Needs	What the CubeSat Needs	What the Program Needs
Shall provide opportunities for the public to interact with the mission	• Post pictures regularly • Post things that users can interact with	• Take pictures of what SilverSat followers on social want to see • Take pictures frequently	• Update twitter • Update the website
Shall fly in low earth orbit	• Be able to track the orbit of the CubeSat • Be able to know where the CubeSat is at all times	• Get launched into a low earth orbit • Conduct mission from low earth orbit	• Meet program milestones for launch
Shall tweet from space without needing human assistance	• Provide the CubeSat a connection to the Internet. • Be able to relay posts from CubeSat to Twitter.	• Send photos down to ground • Have the ability to take photos • Have ability to log into and interact with Twitter	• Maintain a Twitter account • Create payload software that allows photos to be posted to twitter

Mission Traceability Matrix

Level 1 Requirement	**What Ground Needs**	**What the CubeSat Needs**	**What the Program Needs**
Shall take a picture of Earth	• Be able to determine what time pictures are taken • Be able to obtain photos that were taken	• Direct itself towards earth • Take a picture at specific times	• Figure out at what times the photos should be taken • Provide a place for the general public to request for pictures
Shall post photos and data to twitter	• Be able to connect to Twitter • Create a direct link between the CubeSat and Twitter	• Move photos to Twitter	• Have a functioning Twitter account

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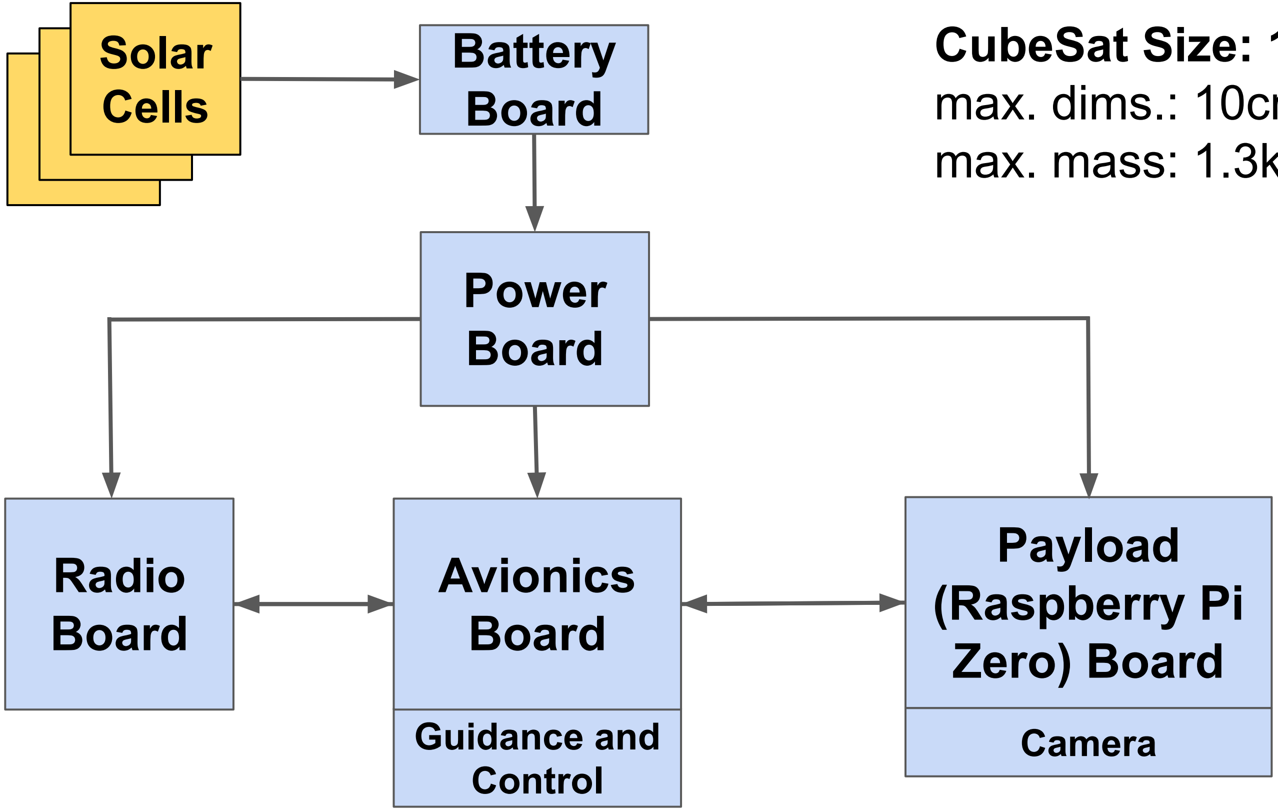
Mission Traceability Matrix

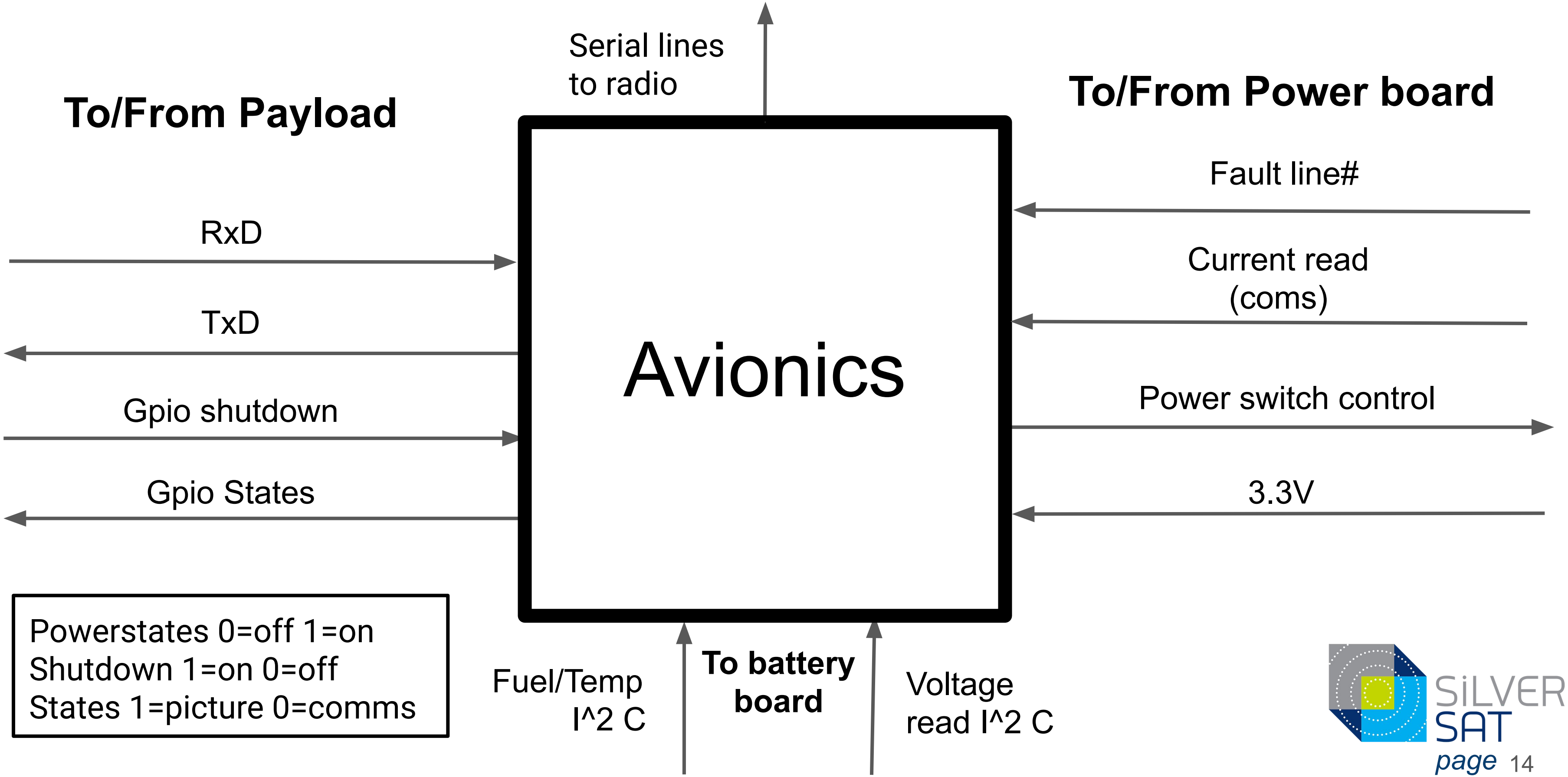
Level 1 Requirement	What program needs to do
Shall educate schools on CubeSats and how they work	● Create lesson plans ● Set visits with Elementary schools ● Post and advertise lesson and classes
Shall update SilverSat website with launch info and status	● Have a functioning website ● Have a designated team that will update the website after every meeting
Shall make available other educational opportunities inside SilverSat	● Continuing to create different leadership roles for different kids ● Create opportunities where kids can step up and lead

CubeSat Block Diagram

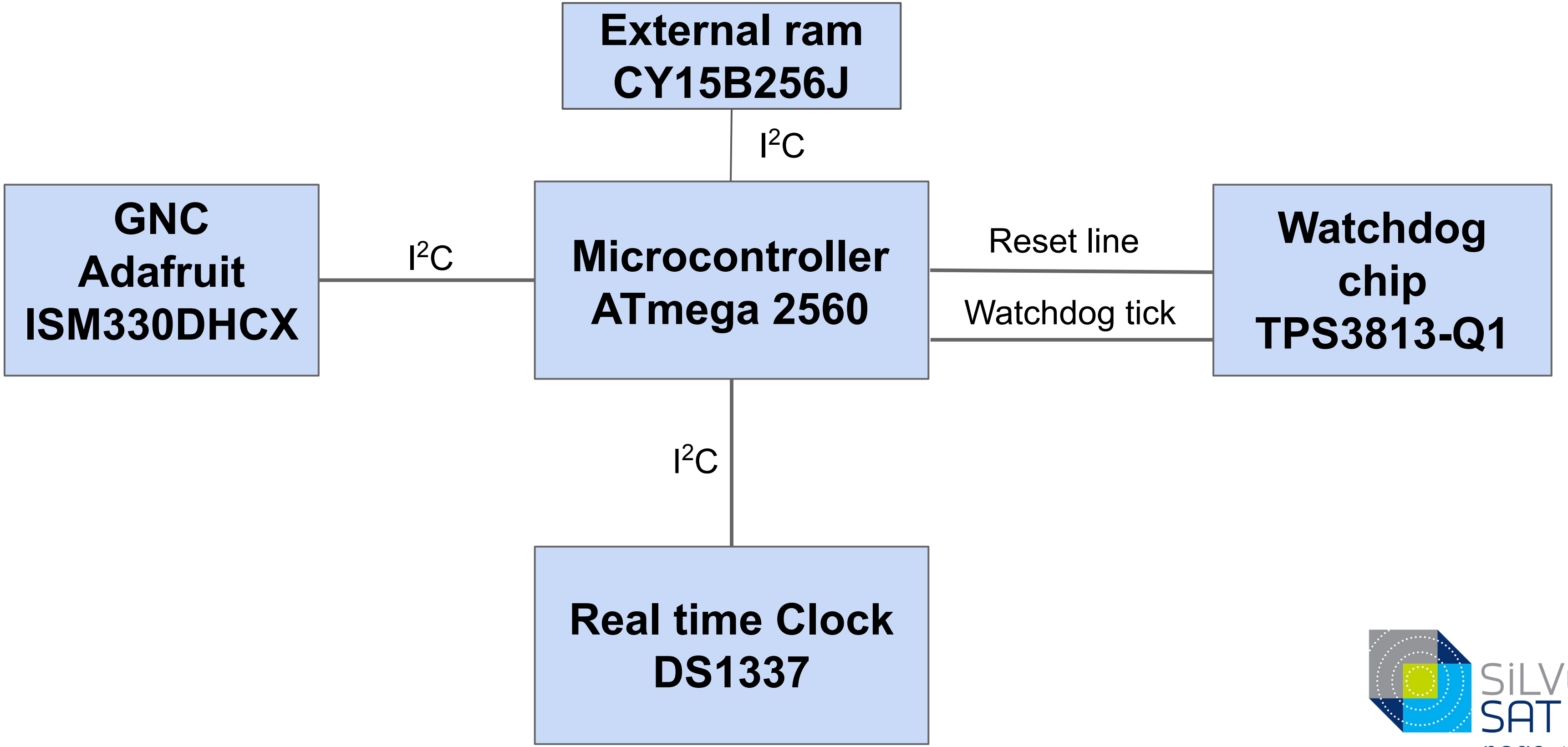


CubeSat Size: 1U
max. dims.: 10cm x 10cm x 11cm
max. mass: 1.3kg

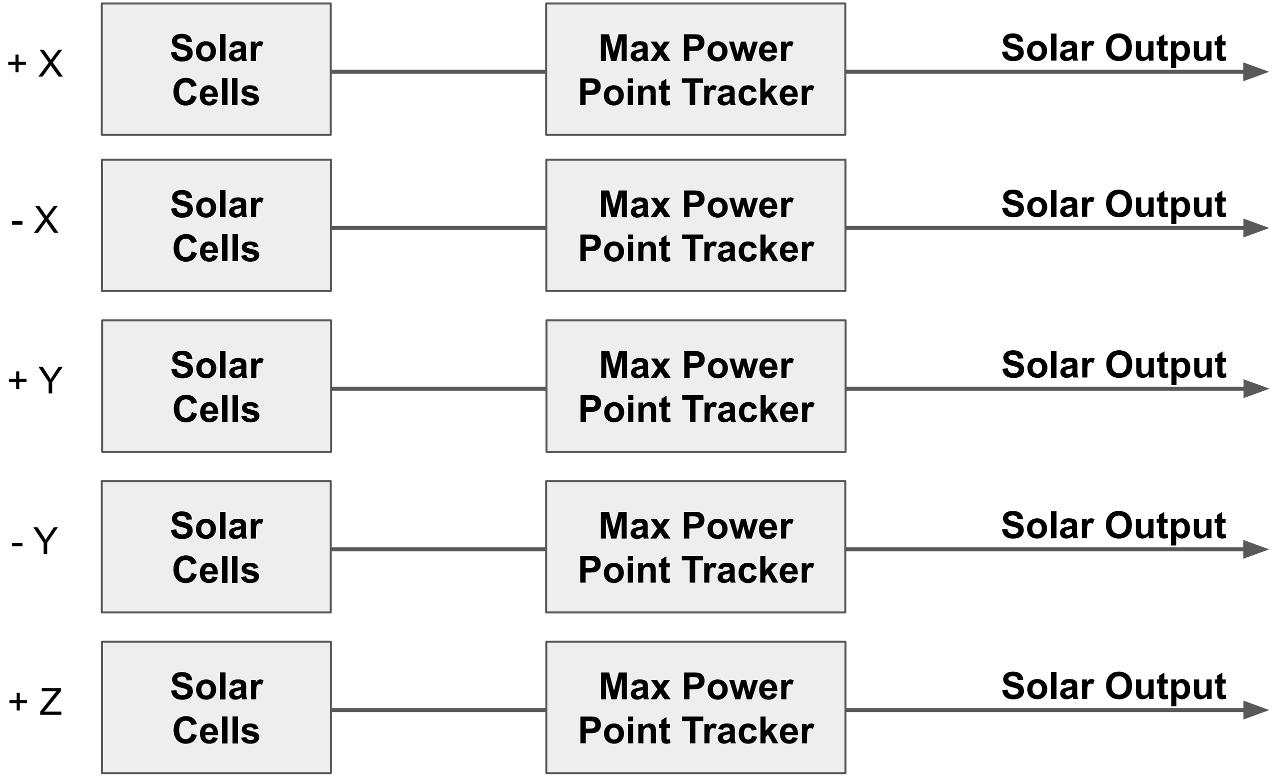
Avionics Diagram - Connections to other boards



Avionics Diagram - Connections inside the board

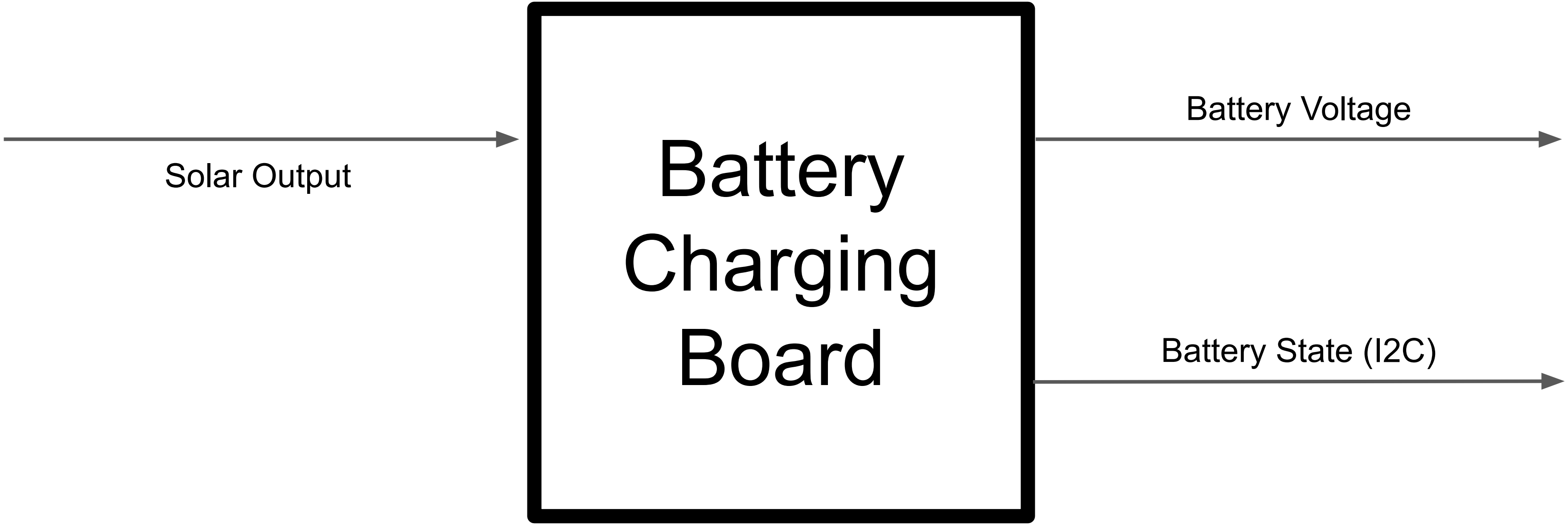


Solar Array Block Diagram



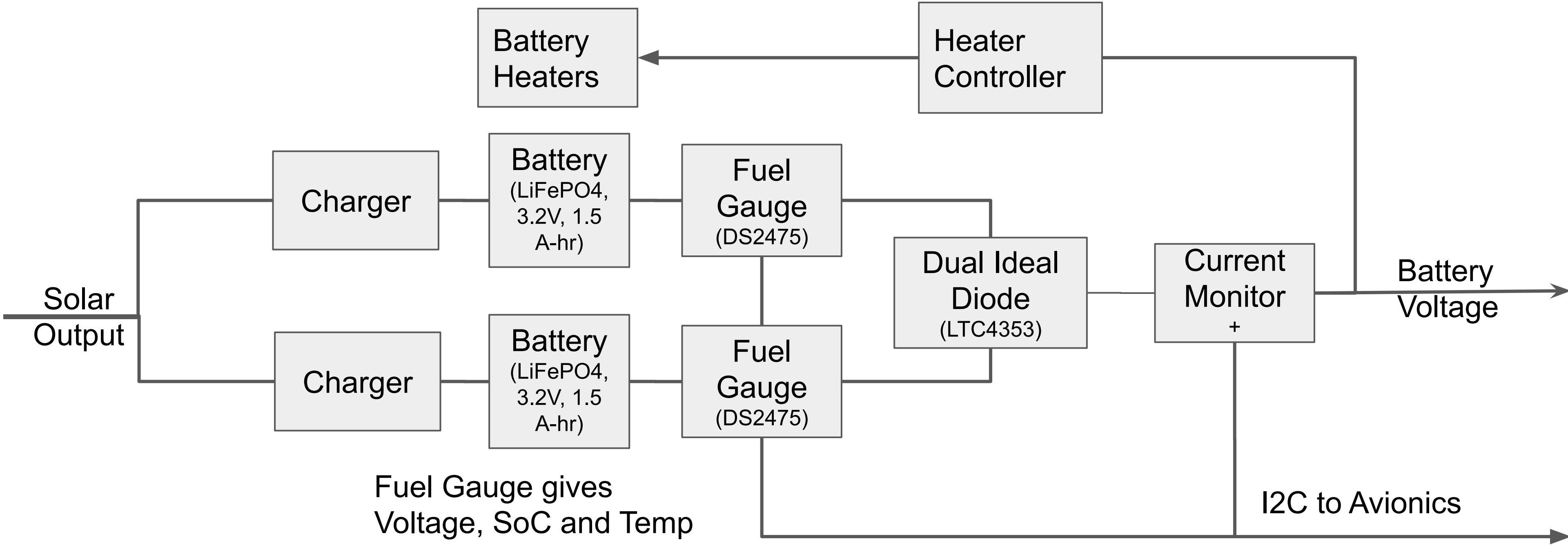
May add additional cells on -Z, if needed.

Battery Diagram

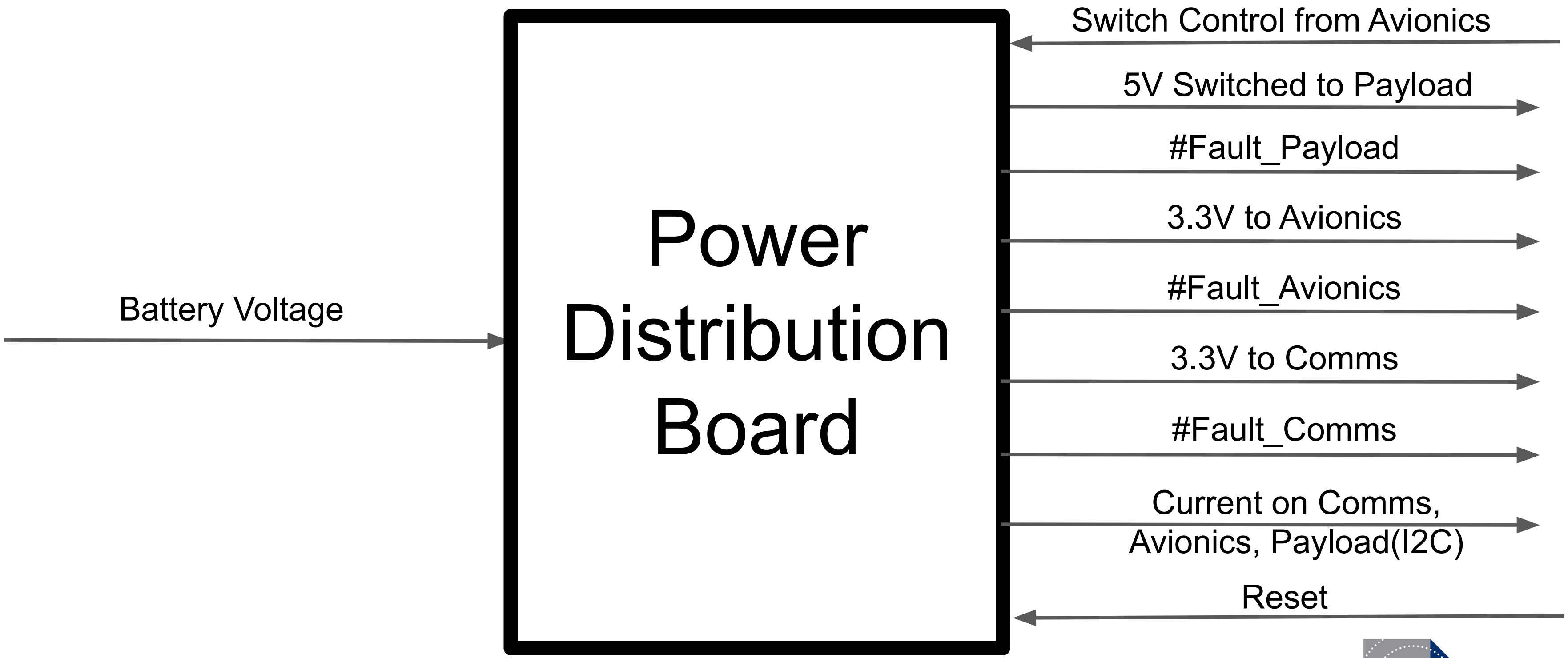


Battery State includes each cell's voltage, temperature and State of Charge (SoC or % of charge)

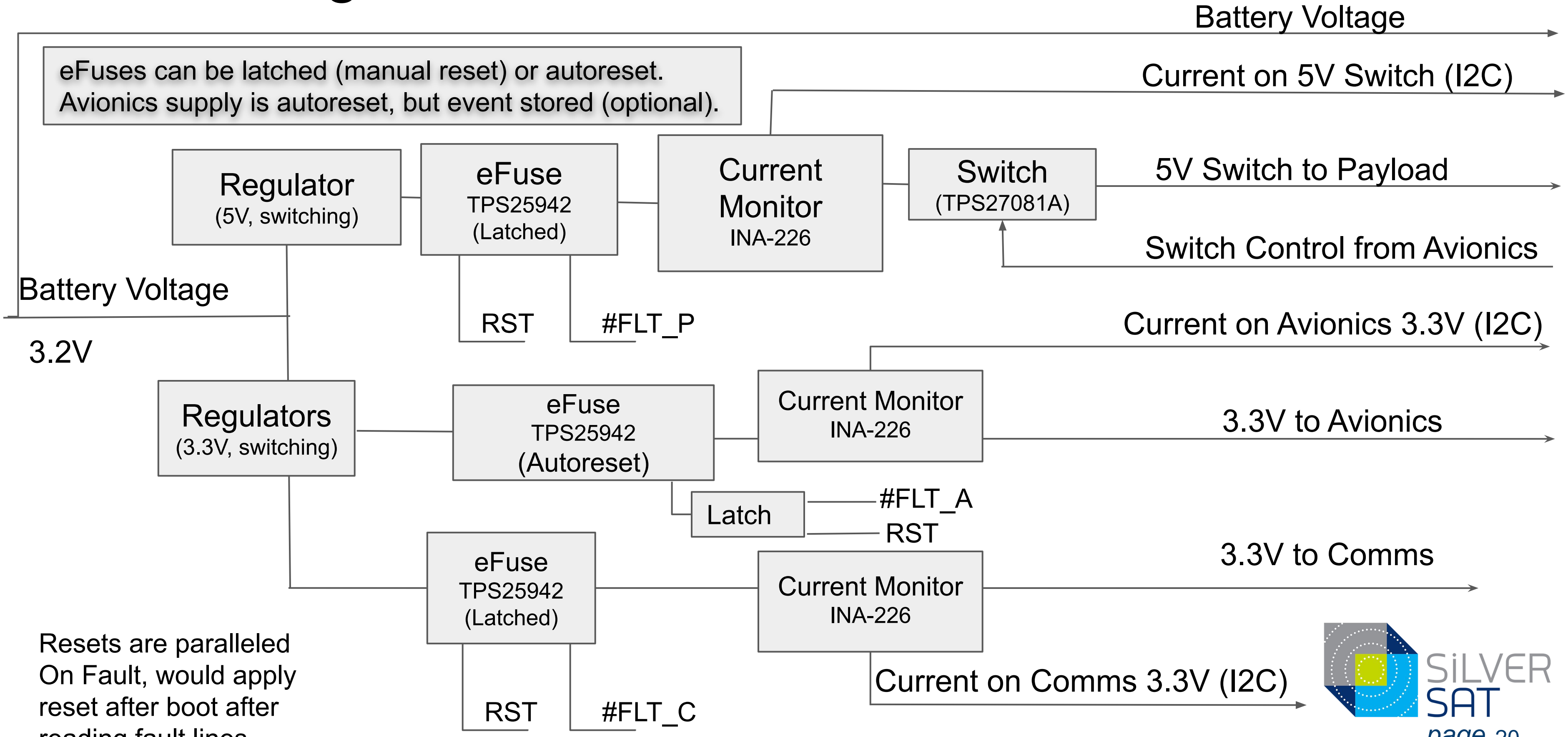
Battery Board Block Diagram



Power Distribution Diagram - Connections to other boards

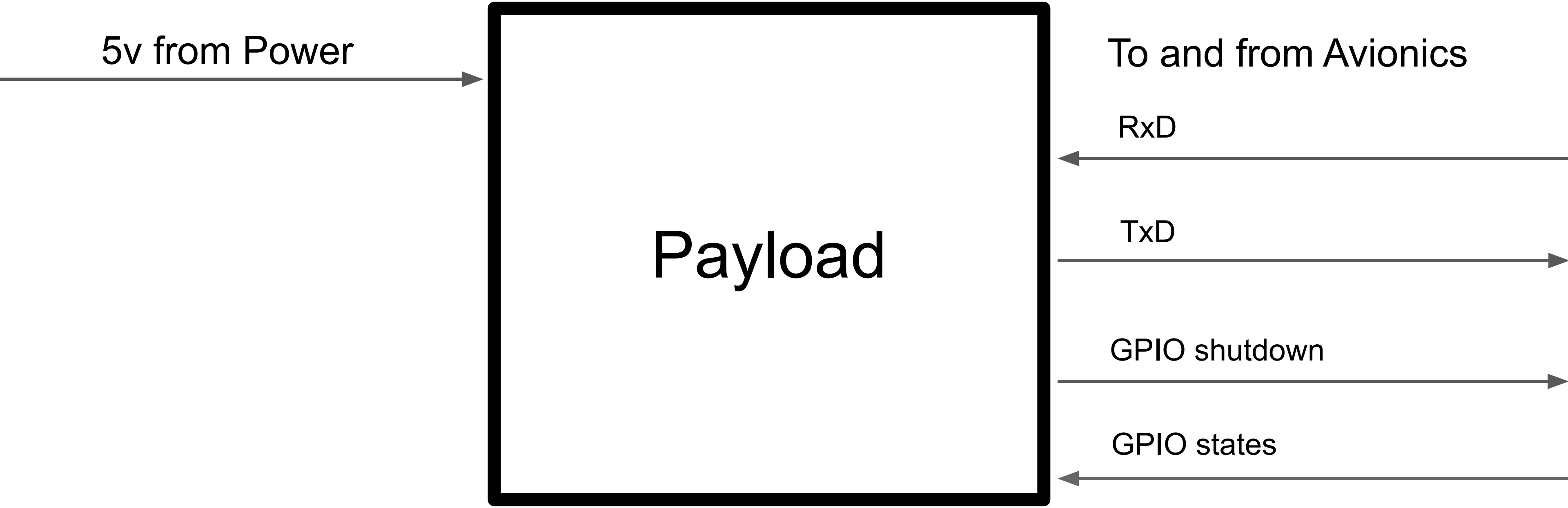


Block Diagram - Power Distribution Board

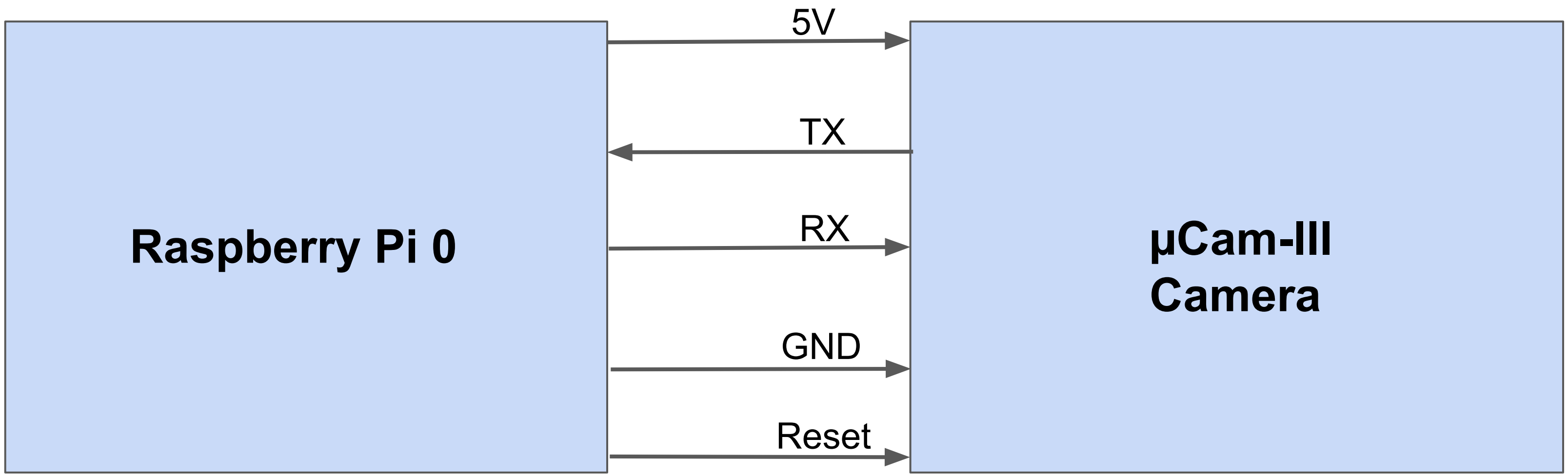


Resets are paralleled
On Fault, would apply
reset after boot after
reading fault lines

Payload Diagram - Connections to other boards



Payload Diagram - Connections inside the board



Criteria for Components Selection

Educational value - Students can work with a part and learn from the experience

- Learning tools and beginner-friendly IDEs available
- Strong educational community supporting the components
- Students can easily build prototypes
- Can be soldered by hand

Flight Suitability - Component poses a low risk to mission reliability

- Flight heritage in a similar mission
- High-reliability or automotive version available
- Assembly manufactured for flight
- *Open trade* - selective use of radiation-hard or -tolerant components

Criteria for Components Selection

Educational Value

- Raspberry Pi Zero
- Real-Time Clock
- Arduino-compatible microcontrollers
- Radio Build Option
- Antenna Build Option

- Industrial Camera
- Watchdog Timer
- FRAM
- Stacking connectors

Flight Suitability

- Solar Arrays
- Frame
- 18650 batteries
- Power board ICs
- Radio buy option
- Antenna buy option

Satellite Radio: Build vs. Buy

Build		**Buy**	
Pros	Cons	Pros	Cons
• We can control many parts of the design including how it works	• Can be very difficult	• Easier option	• Likely expensive
• Schematics may already be published	• Testing may also be difficult	• Documentation and drivers are already available	• Requirements may not be compatible
• Cheaper option	• Documentation and specifications needed	• Radios are be shake and vacuum tested	• May also use proprietary protocols
• Design can be improved upon for the final satellite	• Licensing and certification may be required		

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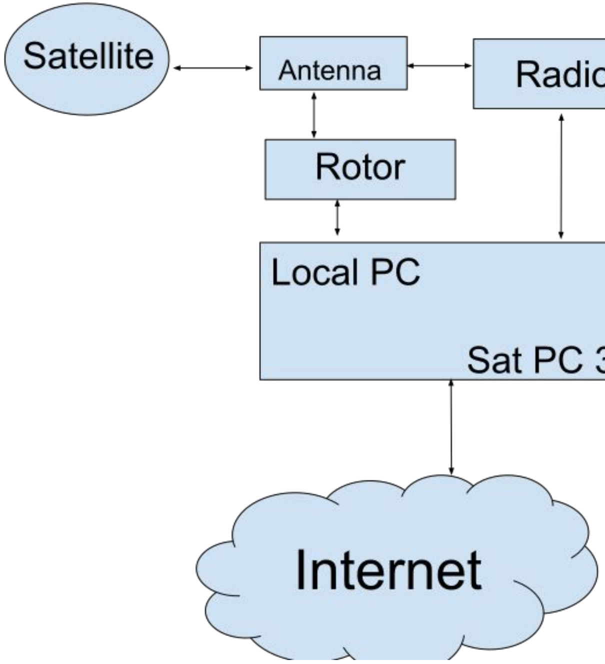
Block diagram for the Ground Station



Ground Station Options

Antenna	Radio	Rotor	Computer
M² 436CP16 432-438 MHz, 13.3 dBi	Icom IC-9100 HF (Amateur), 144-148, 430-450	Yaesu G5500 Computer control adapter may be required	Generic Windows/Mac PC
M² 436CP30 432-440 MHz, 15.5 dBi	Icom IC-9700 HF (Amateur), 144-148, 430-450	M² Az/El Series Controller sold separately	Raspberry Pi® Does not support SatPC32, but does support GPredict
M² 436CP42UG 420-440 MHz, 18.9 dBi	Kenwood TS-2000 Ditto *(Discontinued)*		
M² EB-432/RK70cm 400-470 MHz, 5.5 dBi	LimeSDR or HackRF Series HackRF may be noisy		

All antennas are yagis except for the M² EB-432 which is their special "Eggbeater" type.

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Comparing Microcontrollers

Properties	Type of Microcontroller			
	Atmega328P	Atmega4809	Atmega1284	Atmega2560
Program Memory Size (Flash Size)	32KB	48KB	128KB	256KB
SRAM Memory Size	2,048	6,144	16,384	8,192
# of GPIO pins available	32	48	44	100
# of UART ports available	1	4	2	4
# of I2C ports available	1	1	1	1
Operating Temperature Range	-40°C to 85°C	-40°C to 125°C	-40°C to 85°C	-40°C to 85°C
Is it used on Arduino?	Yes	Yes	Yes	Yes
TQFP Package? # of pins?	Yes, 32 pins	Yes, 48 pins	Yes, 44 pins	Yes, 100 pins
DIP or PDIP Package? #of pins?	Yes, 28 pins	Yes, 40 pins	Yes, 40 pins	Yes, 38 pins

CubeSat Shop 1U Solar Panels

Power: Not Specified

Open Circuit Voltage: 5.4 V

Mass: 50g

Magnetorquer Coils: No

Temp Monitor: Yes

Sun Sensor: Yes (DHV Tech)

Price: About $2,250

https://www.cubesatshop.com/product/cubesat-solar-panels/

Endurosat 1U Solar Panels

Power: 2.4W

Open Circuit Voltage: (Max Voltage 4.66V)

Mass: 81-89 mg/cm2

Magnetorquer Coils: Has a Connector for external magnetorquer

Temp Monitor: Has a Temperature Sensor with SPI Interface

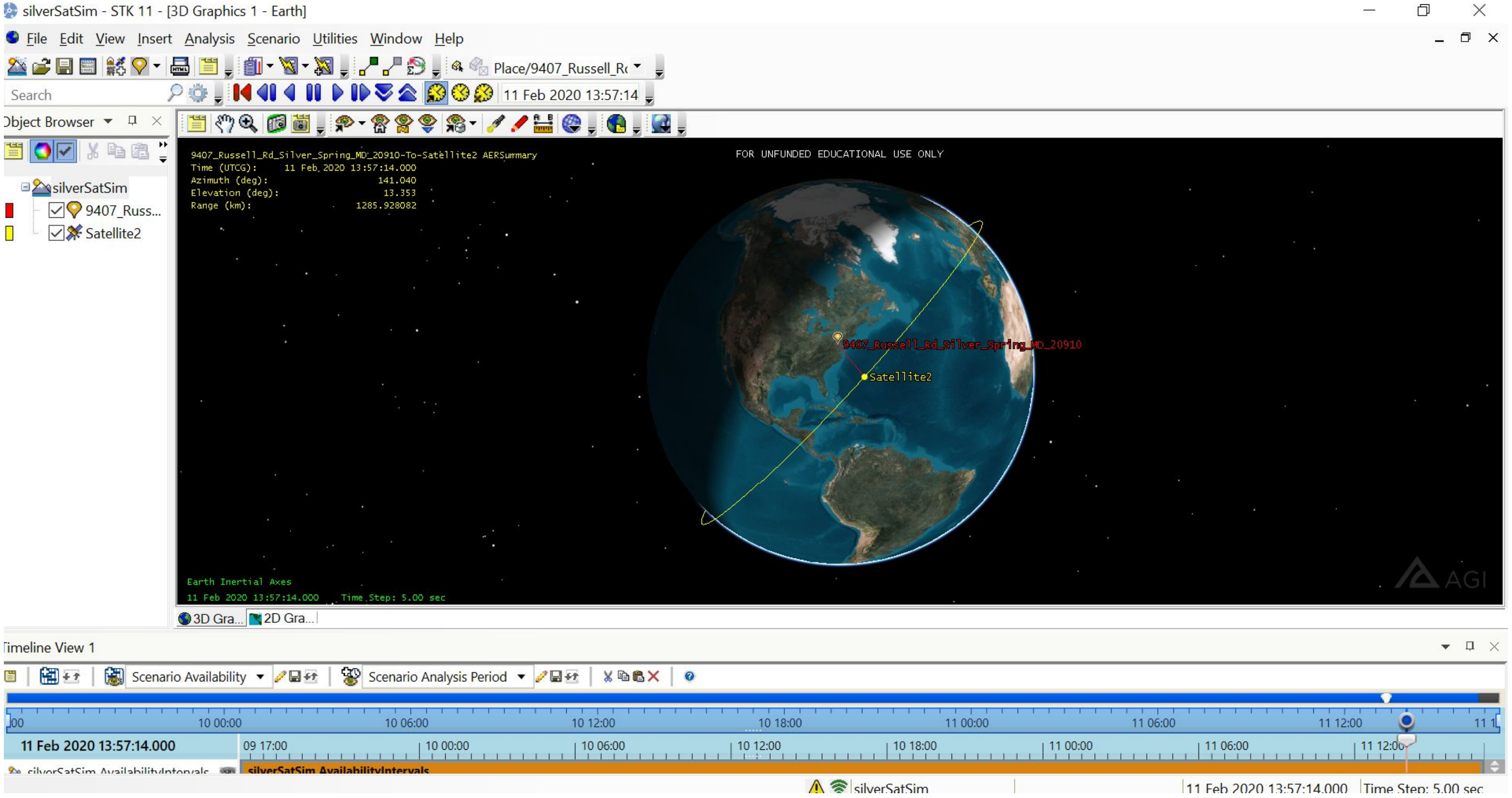
Sun Sensor: Yes

Price: About $1700

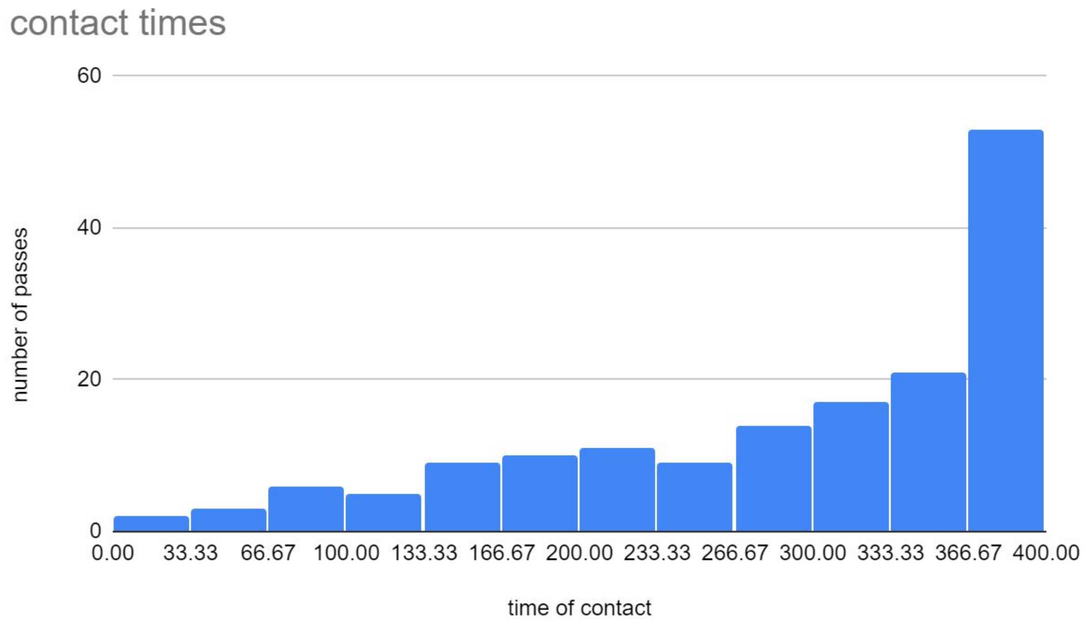
https://www.endurosat.com/products/cubesat-solar-panels-x-y/

STK Simulation: Access Times

The data from this simulation assumes we have the same orbit as the ISS and uses my house as the ground station. The duration of the simulation is 30 days with a total of 160 access times.

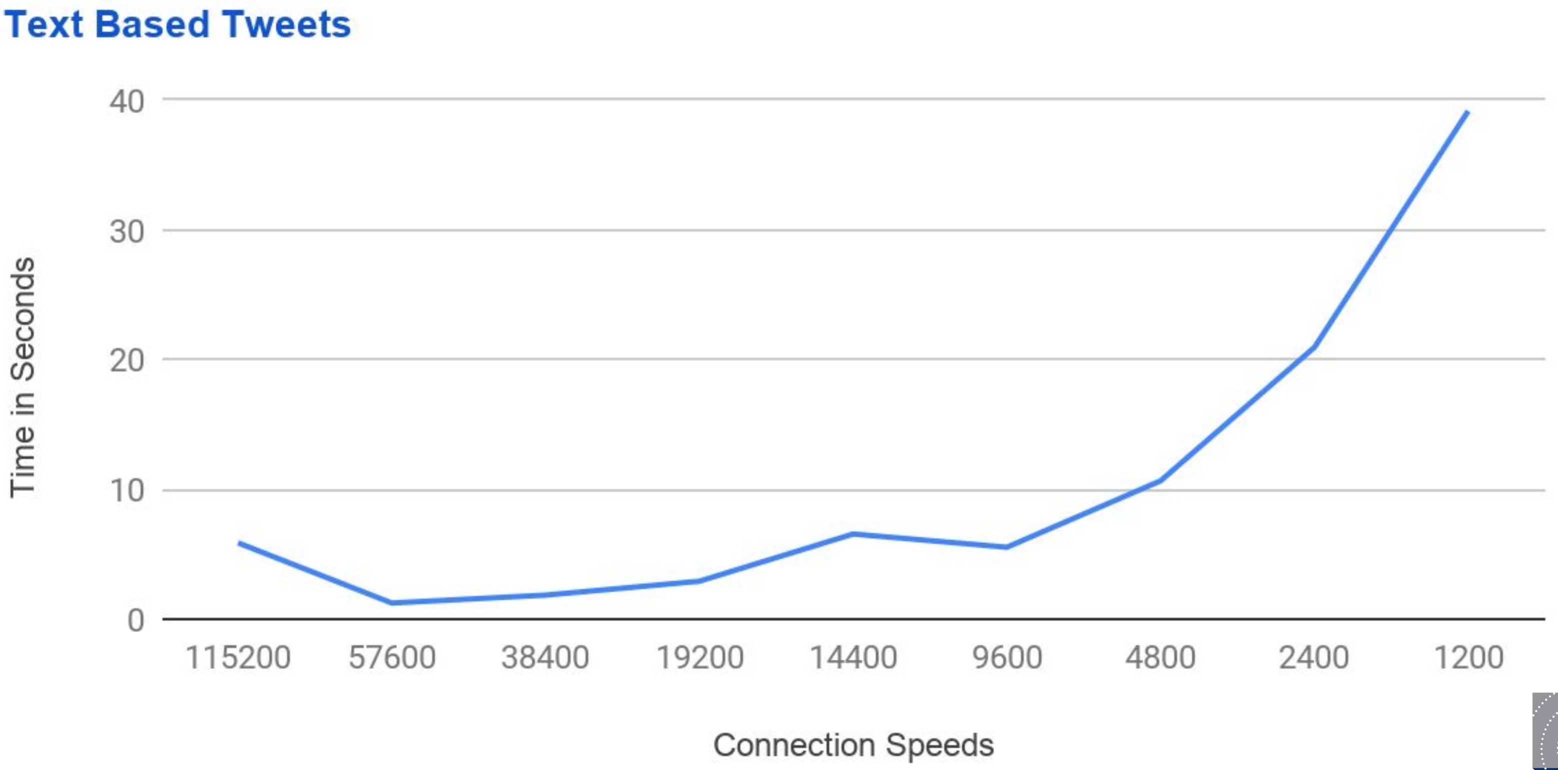


Contact time with ground station in relation to number of passes

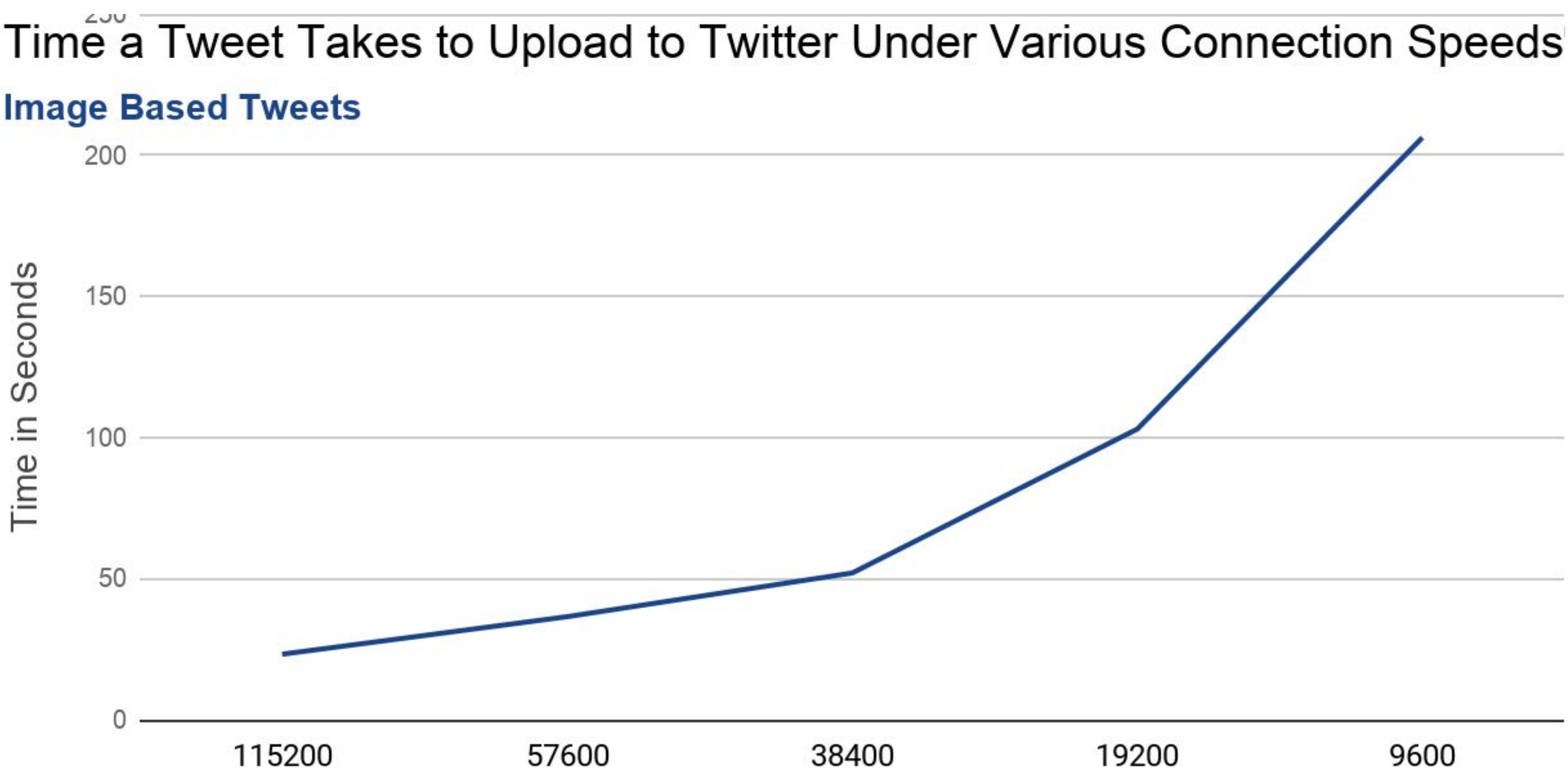


⅓ of contact times are roughly 400 seconds

Time a Tweet Takes to Upload to Twitter Under Various Connection Speeds



*We had one connection termination while testing 1200 bits per second

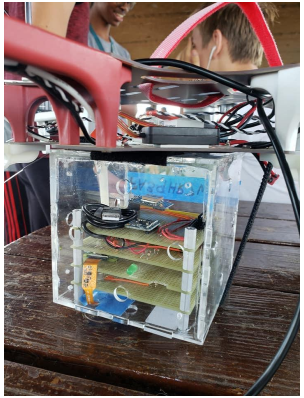


Connection Speeds

According to Twitter the image we posted with this test was 176 kB

Prototype 1

Here’s our drone with the prototype below



Here’s our prototype with boards and Camera

Our photo taken and posted with the satellite

Attitude Control Options

- Permanent Magnet
- Magnetorquer, Reaction Wheel, Spintorquer
- NSS CubeSat ACS solution

Attitude Determination

- Gyroscope
- Accelerometer

Link Requirements

- Our satellite link must be efficient to allow us to complete the connection.
- It must be fast enough to carry a full TCP/IP connection, but still be able to conserve power and bandwidth.
- We must also be able to send a morse code beacon.
- To ensure this, we need a good link budget.

Considerations

Here is what we considered

- Antenna Gain
- Signal Loss (cable, path, etc)
- Transmitter Power
- Data Rate
- Amplifier Noise Figure
- Signal-to-noise ratio
- Noise (assuming galactic noise dominates)

Possible Link Situations

We considered four different situations to help consider our options

	Situation 1		Situation 2		Situation 3		Situation 4	
	Sat.	Gnd.	Sat.	Gnd.	Sat.	Gnd	Sat.	Gnd.
Data Rate (baud)	9600		9600		19200		38400	
Antenna Gain (dBi)	0	13.3	0	15.5	0	15.5	0	18.8
Total EIRP (dBm)	29.95	52.3	29.95	54.5	29.95	54.5	29.95	57.8

13.3 dB Antenna: M² 436CP16, 432-438 MHz (https://www.m2inc.com/FG436CP16)
15.5 dB Antenna: M² 436CP30, 432-440 MHz (https://www.m2inc.com/FG436CP30)
Link Situations assume a 3 dB polarization loss

Results

	Situation 1		Situation 2		Situation 3		Situation 4	
	Up	Down	Up	Down	Up	Down	Up	Down
Received Eb/N0 (dBm)	33.491	24.444	5.681	26.133	42.833	23.633	32.971	23.923
Required Eb/N0	15 decibels (estimated)							
Imple-menta-tion Loss	3 decibels (estimated)							
Margin (dB)	15.491	6.444	17.681	8.133	14.681	5.633	14.971	5.923

Overall Power Budget Results

The energy used on a power cycle is shown here.

Name	Current Best(J)	Calculated Worst(J)
Power Intake	6960	5796
Power Use	4006	5218
Margin	2954	578

Total Margin: (MPV-CBE)/CBE*100%=(5796-4006)/4006*100% or 44%
Allocated Margin:(MEV-CBE)/CBE*100%=(5218-4006)/4006*100% or 30%

Battery Specifications

- Two LiFePO 18650 battery
- 1500 mA-hr per battery
- Voltage 3.2V
- 17280 Joules per battery
- 7000 Discharge cycles

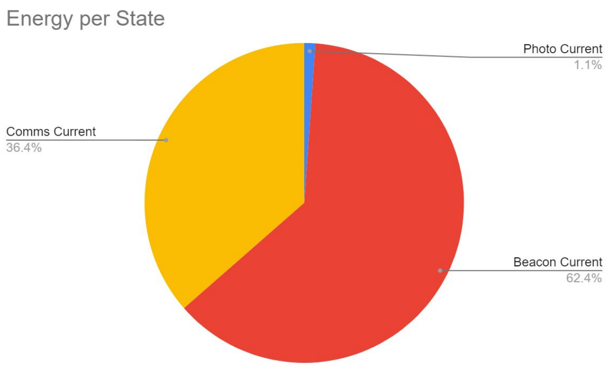
Solar Cells Assumptions

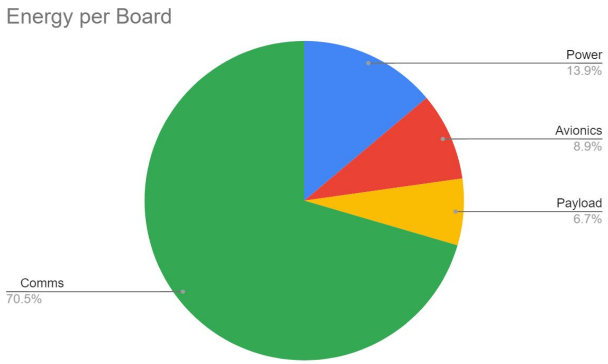
Endurosat 1u solar panels.

- 60.3cm^2 total area per panel
- 30.15cm^2 per cell
- The cells have 29.50% efficiency
- 1.9-2.4 watts of power can be produced
- 4.66 max voltage
- .517 max amps
- Normal intake in solar cells is 1353 W/m^2

Power Budget Assumptions

- 90 minutes per orbit
  - 58 light minutes
  - 32 dark minutes
- 1 minute in photo state
- 8 minutes in comms state
- 81 minutes in sleep state/beacon
- Transmit duty cycle 80% in comms
- A beacon lasts 10 seconds every 1.5 minutes
- Assuming 90% efficiency for power converter
- 100 mA draw from the payload board
- Comms board draw based on Endurosat Radio
- Avionic board draws 20 mA





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Mass Budget

	Frame	Battery Board	Avionics	Payload Board	Power Board	Comms Board	Solar Arrays	Antenna	Magnets
Total Mass, CBE	151.17g	130.6g	40.16g	58.67g	56.36g	94g	273g	85g	10g
MEV	158.73g	143.15g	46.19g	66.59g	67.63g	112.8g	286.65g	102g	12g

*All values rounded to the nearest 100th

Mass Budget Total and Margins

CBE	898.96g
MEV	995.75g
Allocated Margin	10.7%
Unallocated Margin	30%
Total Margin	44.6%

*All values rounded to the nearest 100th

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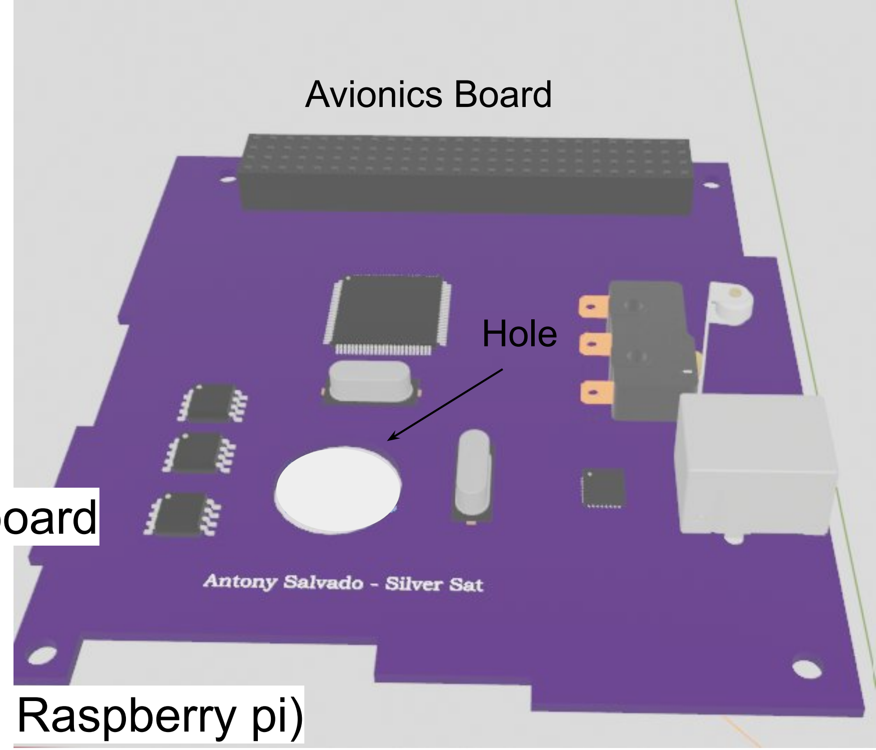
CubeSat model

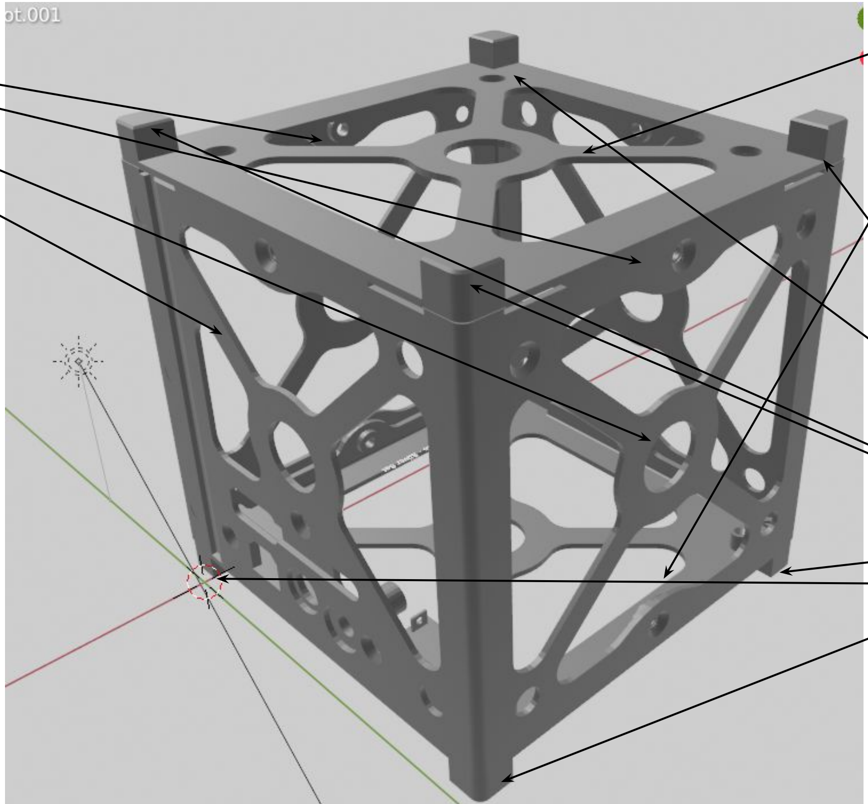
- The CubeSat is 1U
  - 10 cm x 10 cm x 11 cm and 1.3 kg
- CubeSat Frame
- Board layers
  - Top board is the power distribution board
  - Communications board (Has radio)
  - Battery board (Has batteries)
  - Payload board (Has the camera and Raspberry pi)
  - Bottom board is the avionics board (Note: board has a hole for the camera)
- Solar Cells



CubeSat Frame

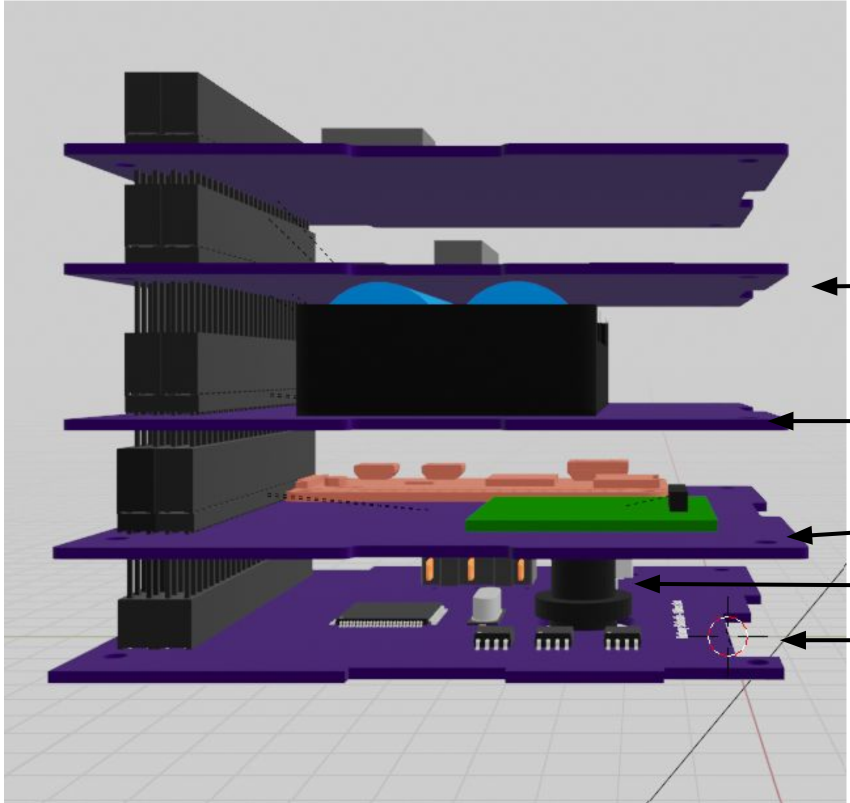
Side panels

Top and
bottom panels



Rails

Board stack



Power Distribution

Communication

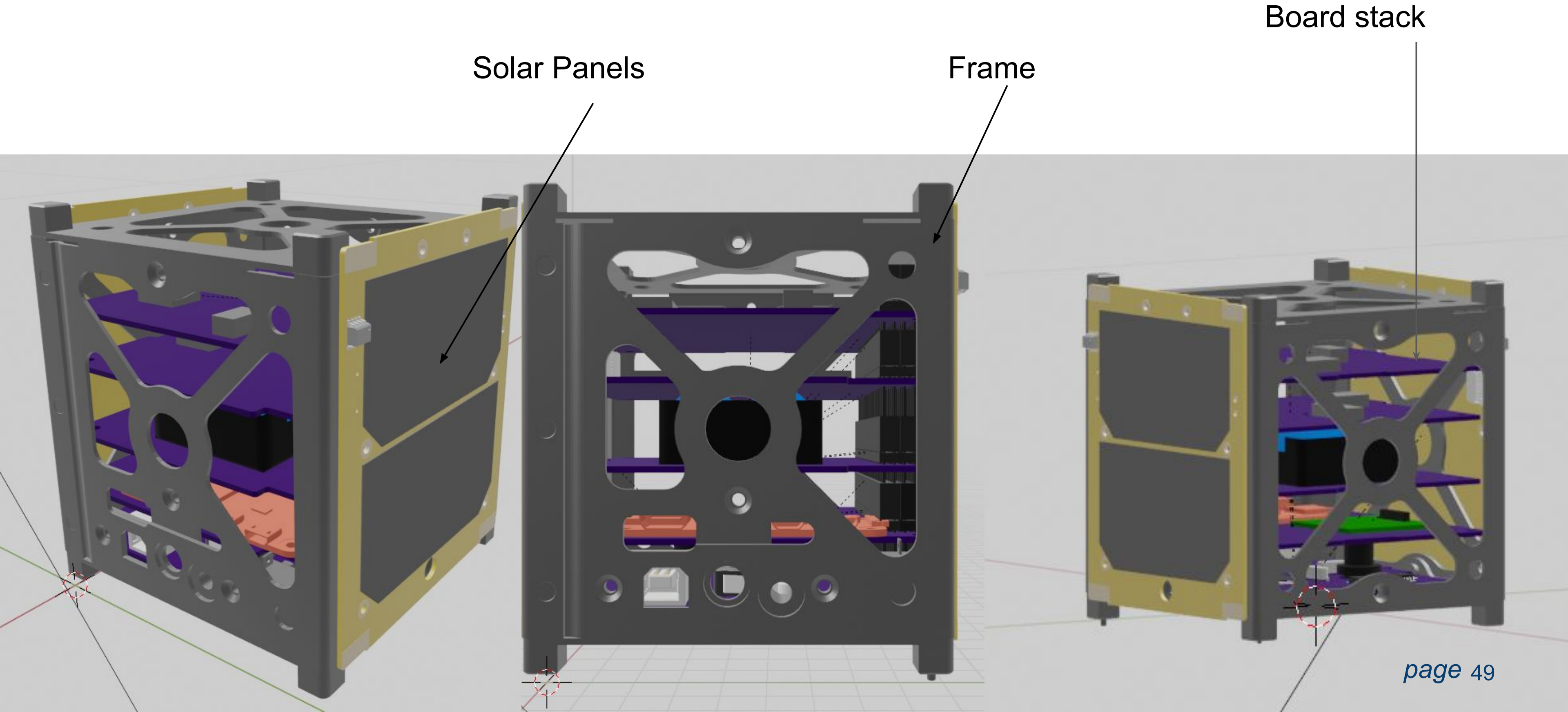
Battery

Payload

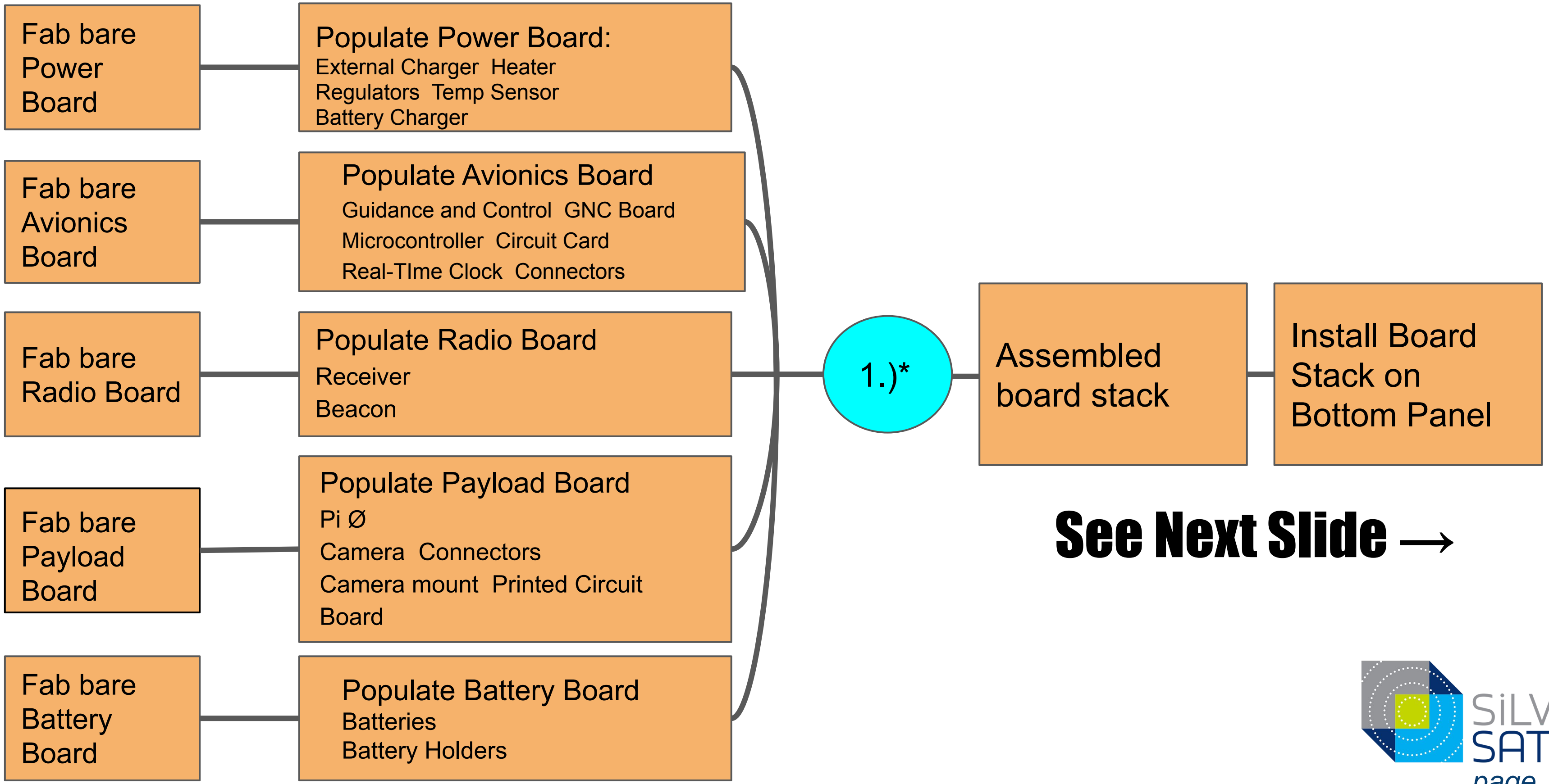
Camera

Avionics

Final model (put together)



Build Plan



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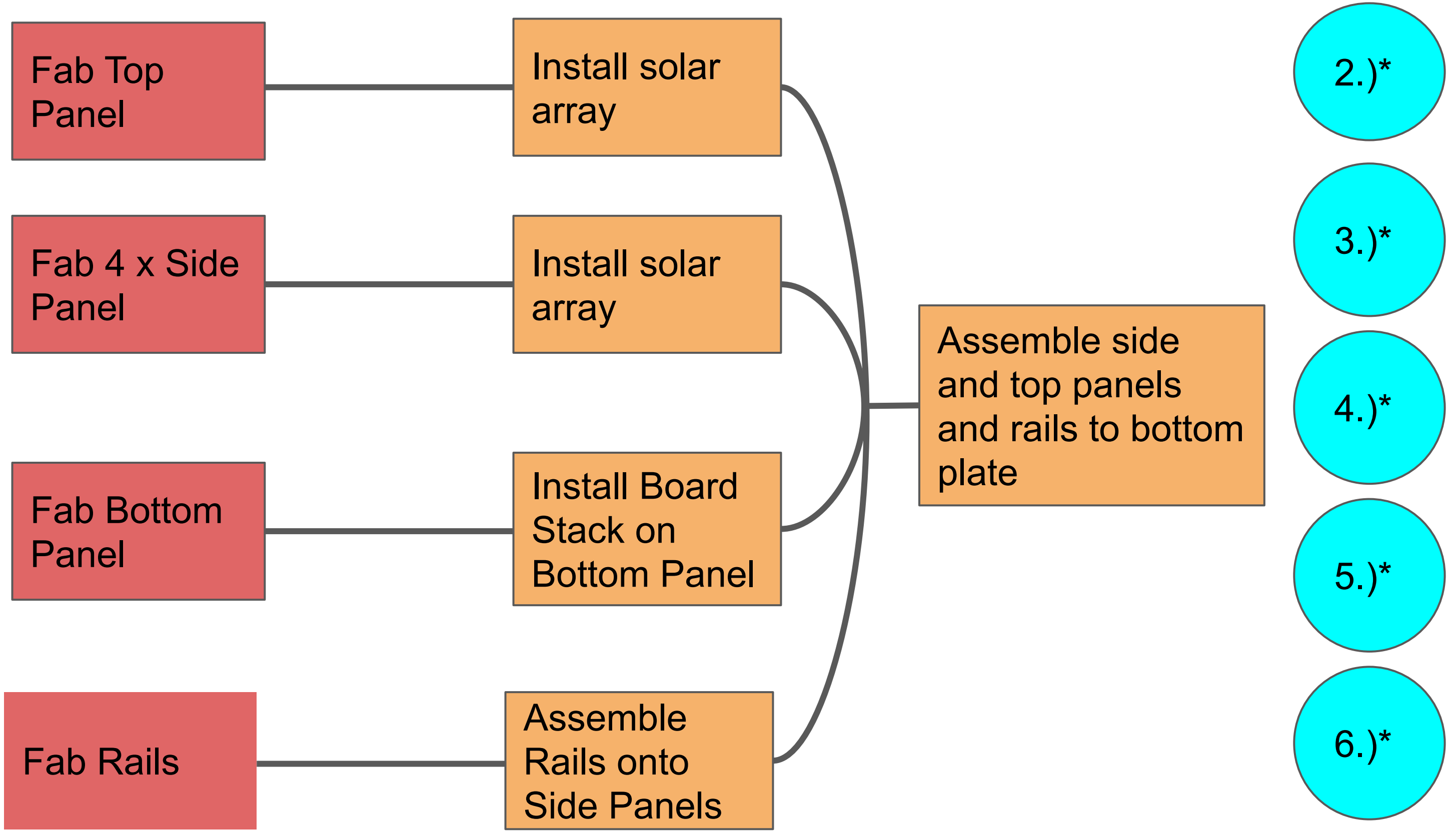
Build Plan

* Numbers Coordinate to Next Slide



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Test Plan

1.)* Flat Satellite Test

2.)* Comprehensive Performance Test

3.)* Vibration/Shock Test

4.)* Thermal Vacuum Bakeout (TVAC)Test

5.)* Comprehensive Performance Test

6.)* Day In The Life (DITL) Test

*Numbers Coordinate to Previous Slide

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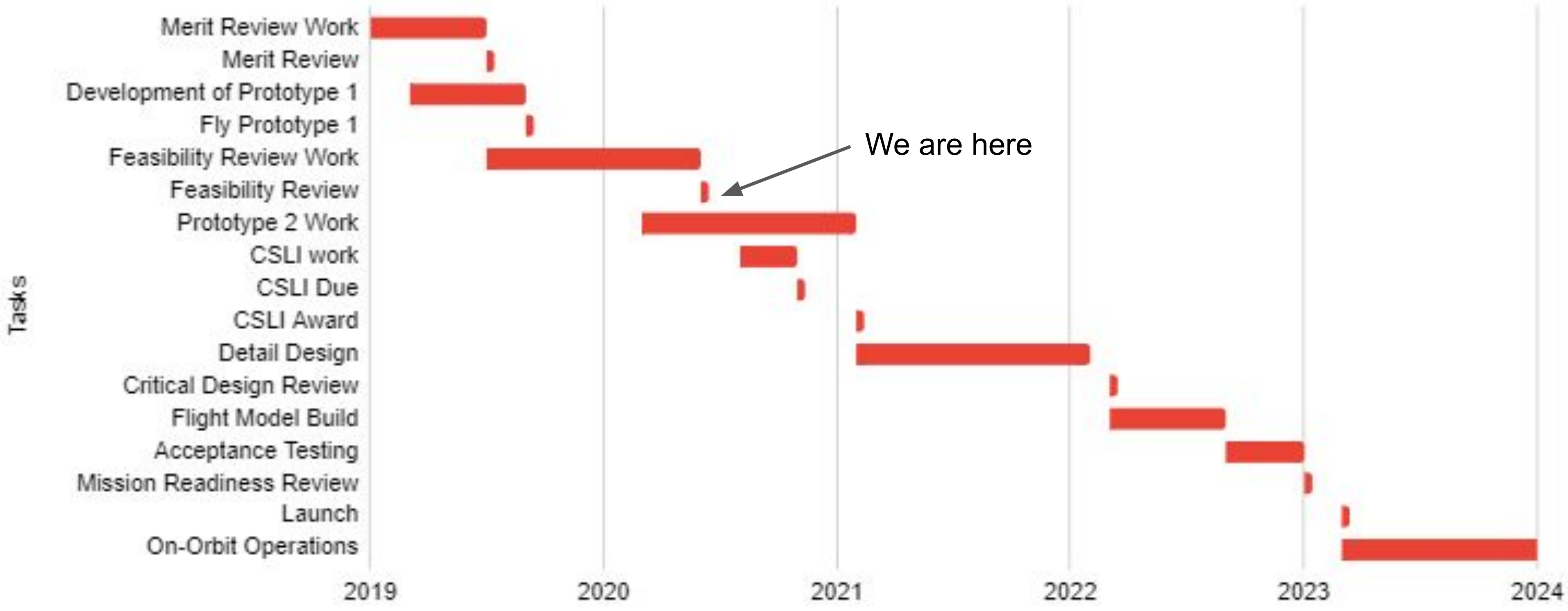
Risk Matrix

consequence						
	5	10				
	4	11, 12	5,6	3,4		
	3		7,8,9		2	1
	2		13			
	1			14		
		1	2	3	4	5
		likelihood				

Risk Number	Risk	Likelihood	Consequence
1	If critical personnel leave the team due to graduation then our schedule may be delayed.	5	3
3	If we cannot acquire facilities for building and securing flight hardware project may be severely delayed	3	4
5	If we run out of funding, then the project cannot advance.	2	4
6	If an expensive piece breaks before launch, then we would need to replace the part.	2	4
7	If certified amateur radio members are not available then links may not be established.	2	3
8	If grant funding for this year cannot be acquired, then the project will be set back.	2	3
9	If the camera fails, then the satellite can no longer send pictures.	2	3
10	If critical parts break during launch vibrations then the mission might fail.	1	5
11	If temperature exceeds parts limits then critical functions may fail.	1	4
12	If raspberry pi fails then we can no longer serve major parts of the mission	1	4
13	If parts do not arrive on time then launch will be severely delayed.	2	2
14	If data takes too long to send, then we will not complete a tweet in a pass.	3	1

Schedule



We are here
Tasks
Merit Review Work
Merit Review
Development of Prototype 1
Fly Prototype 1
Feasibility Review Work
Feasibility Review
Prototype 2 Work
CSLI work
CSLI Due
CSLI Award
Detail Design
Critical Design Review
Flight Model Build
Acceptance Testing
Mission Readiness Review
Launch
On-Orbit Operations
2019
2020
2021
2022
2023
2024

Funding - What We Need

To complete NASA's 2020 Announcement of Opportunity, which will secure us a ride to space, we need to demonstrate financial viability.

- **We have already raised $57,283**
  - From Foundations
  - From Individuals
- We estimated needing to raise additional funds to fully finance the program.
  - Crowdfunding will play a role
  - We are seeking corporate support
- Costs include:
  - Supplies
  - Construction
  - Testing
- **We are also exploring in-kind options that will reduce costs to what we have already raised.**

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Program Cost Estimates - Two Approaches

Outsource option (total $111k):

- **BUY** the CubeSat radio, solar arrays, antenna, and frame
- Pay for environmental testing (TVAC and Vibe)

DIY option (total $63k):

- **BUILD** the CubeSat radio and antenna
- Buy the frame base, but BUILD the rest of the frame
- Buy the solar arrays
  - *Additional savings possible if we build our own, but not currently factored in.*
- NASA provides environmental testing as part of the CSLI service
- **If we pursue this option, we are $6000 from reaching our budget goal.**

Both options assume:

- 10% margin on all expenses has been included.
- We will build our own ground station from new parts.
  - *Additional savings possible if we team with a group such as the Goddard Amateur Radio Club for the ground station, buy used, or get in-kind donations.*

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Conclusion

- SilverSat mission is technically feasible, with high probability of success
- SilverSat is designing an intentionally simple CubeSat platform to meet its educational and technological objectives
- Our major risks involve personnel and funding, with mitigation efforts underway
- Many of the educational goals of SilverSat are met during the design and build phases of the project
- Our remaining open trades lie in either
  - Hardware choices where many of suitable alternatives exist
  - Technical issues within the expertise of SilverSat mentors

Thank You

- SilverSat Limited would like to thank you, the reviewers, for your time and your feedback.
- We wish to also thank those individuals and organizations that have supported our efforts to date:
  - Montgomery County
  - AGI, Inc
  - The Maryland Space Business Roundtable
  - Rockville MakerSpace
  - Steve Morris, Catylator, LLC.

SilverSat Limited logo designed by Brent Almond, Designer Daddy

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Questions?

Backup Slides

How can we make SilverSat's mission more interactive?

- Survey to decide what a majority wants a picture of.
    - People who want a picture can choose on location out of four that they want a picture of.
    - #Silversat #Location tweets for requests
- Requests through social media or the silver sat website where people can make a request for a picture to be taken and tweet out the picture.
    - Have a map on the website, with the areas we can't take pictures of either blurred out or removed, where a person who wants a picture can pinpoint a location by clicking on it on the map.
    - Location of satellite on map
- Donating option after picture request
    - A donate option will appear after they make a request.
- Timeline of photos
    - A timeline that state the time that photos were taken and when they can be taken.
- Have you heard our beacon?
    - In case we can't hear it people can message us through the website or social media if they can.
    - #Silversat Location

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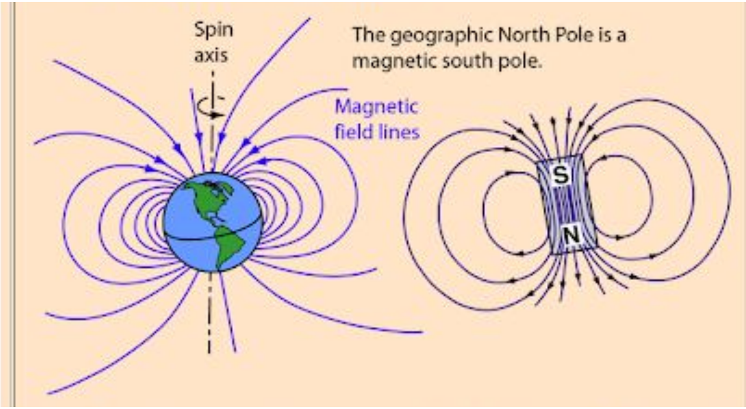
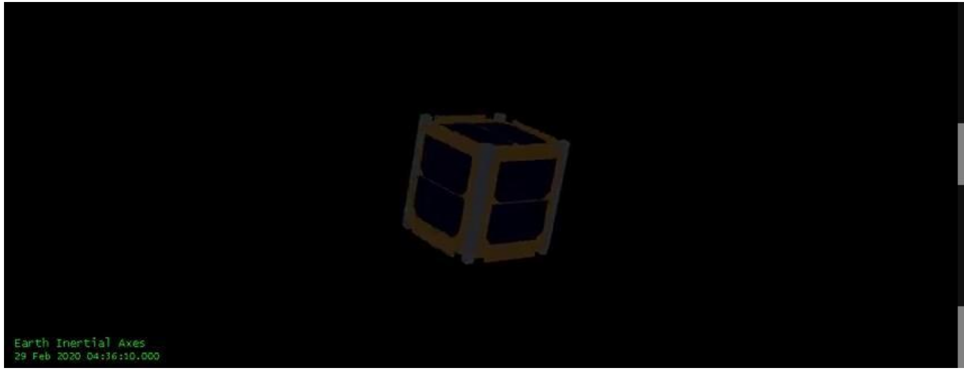
Passive Attitude Control

- We plan to use passive magnetic attitude control to conserve power
- Permanent magnets orient the craft relative to earth magnetic fields (relative to Z or roll axis)
- Hysteresis rods to dampen motion in pitch and yaw
- Silversat follows the gradient of the earth's field to orient the Z axis toward nadir over the northern hemisphere
- This means we will point toward space over the southern hemisphere, so we might try to flip the magnets
- Alternatively if there's power available, a magnetorquer would easily allow the dipole to be flipped.



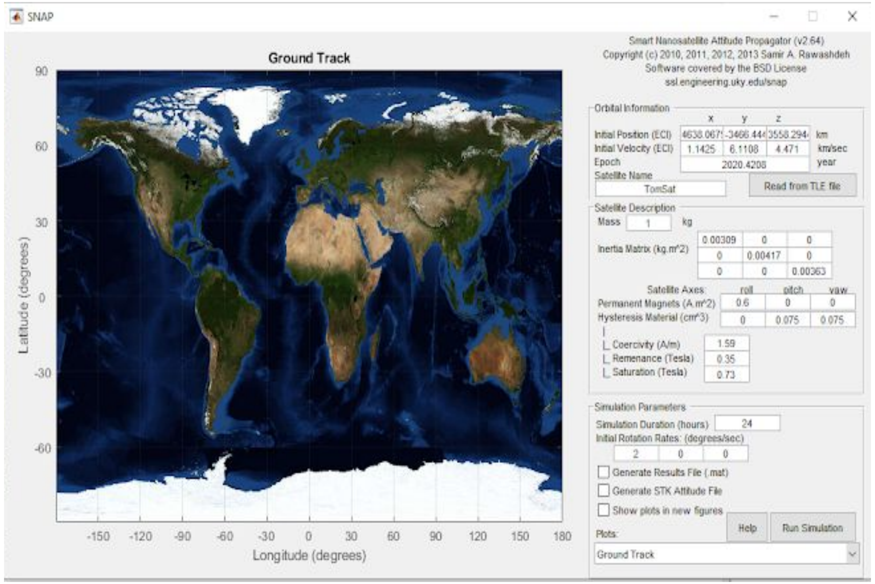
http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/MagEarth.html



The cubesat takes a few days to settle into a stable orientation, depending on initial conditions

Estimating the magnet size

- We are using the SNAP tool developed for KySAT-1[1] to model the dynamic motion of the spacecraft
- SNAP runs on MATLAB
- Generates attitude data which can be plotted in MATLAB or used for STK orbital simulation
- The default magnetic parameters (from KySAT) used to estimate the size and mass of the magnets
- So, given:
  - Rare earth magnet (Alnico performs similarly)
  - Magnet remanent flux = 1.2 Tesla
  - Magnet dimensions adjusted to achieve equivalent magnetic dipole to KySat
  - Density = 7.5 gm/cm^3
- **Estimated magnet mass = 4.88 grams**



[1] Samir A. Rawashdeh, Space Systems Laboratory, University of Kentucky

For comparison, KySAT used 24 smaller (1.5mm dia. x 12.7mm long) magnets (6 in each corner) equal to about 4 gms.
Note: this simulation will need to be re-run once we know the inertia matrix for the satellite.

Hysteresis Rods

- Current mass estimate is based on published data.
- CSSWE was a 3U satellite that used materials similar to KySAT.
- 2 rods/axis
- HyMu-80 density is 8.74 gms/cm^3
- Estimated total mass of four rods (using dimensions from table) = 2.6 gms

Table 3. Hysteresis Rod Comparison

Property	UNISAT-4[5]	CSSWE
Rod Length [cm]	15	9.5
Rod Diameter [mm]	1	1
Material	HyMu-80	HyMu-80
Material H_c [A/m][8]	0.96	0.96
Material B_r [Tesla][4]	0.35	0.35
Material B_s [Tesla][8]	0.74	0.74
Apparent H'_c [A/m]	12	12*
Apparent B'_r [Tesla]	0.004	0.004*
Apparent B'_s [Tesla]	0.025	0.027**

*Estimated value **Calculated value

From “Passive Magnetic Attitude Control for CubeSat Spacecraft, Gerhardt and Palo, 24th Annual AIAA/USU conference on small satellites

SilverSat Merit Review

Response to Action Item 7:
Use of Space Network S-band Multiple Access Service

Action Item Statement

Use of Space Network S-band Multiple Access Service

Action: Assess the feasibility of using the SN S-band Multiple Access service for this mission. Conduct a link calculation to determine impact to satellite power and complexity.

Notes from Review Panel: SilverSat's use of existing real-time social media networking on Twitter could in fact (with proper ubiquitous communications coverage such as from TDRSS) be leveraged for real-time world-wide notifications of random astronomical events to send out a notification to the rest of NASA's spacecraft fleet, for example to a) point in the direction of the event in the case of a gamma ray burst or b) "batten down the hatches" in the case of an upcoming solar storm or other space weather event.

Introduction to the NASA Space Network

NASA's Space Network (SN)

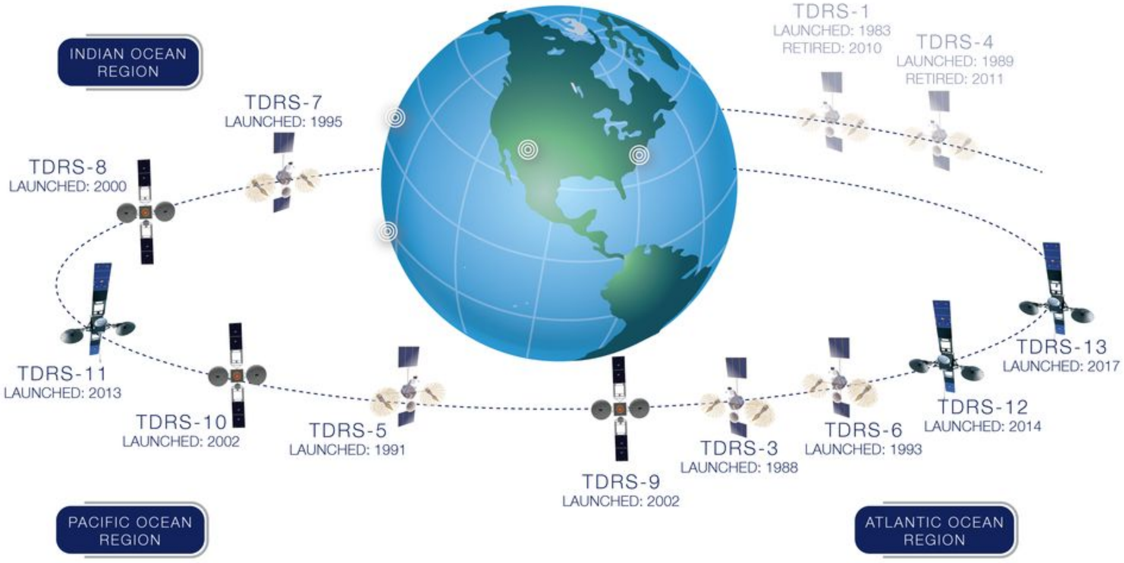
Data and tracking relay from geosynchronous orbit (GEO)

Constellation of Tracking and Data Relay Satellites (TDRS satellites)

User satellite in LEO communicate upwards to a TDRS, not down to a ground station

Each TDRS relays user data between the user satellite and a NASA ground station

-main ground station in White Sands, NM



Courtesy NASA

Impact of using the SN for a CubeSat mission:

Benefits (from [1])

- Continuous coverage
- On-demand access through the Demand Access Service (DAS)
- Contact without mission operator involvement
- Emergency support
- Automatic data logging from mission: users can just pull files from White Sands
- Navigation radiometrics

Issues for consideration:

- Higher path loss to GEO: ~ 26 dB more loss on initial contact
- More constant path loss: best-case/worst-case path loss during a pass ~ 2 dB
- More complex radio than typical for CubeSats.

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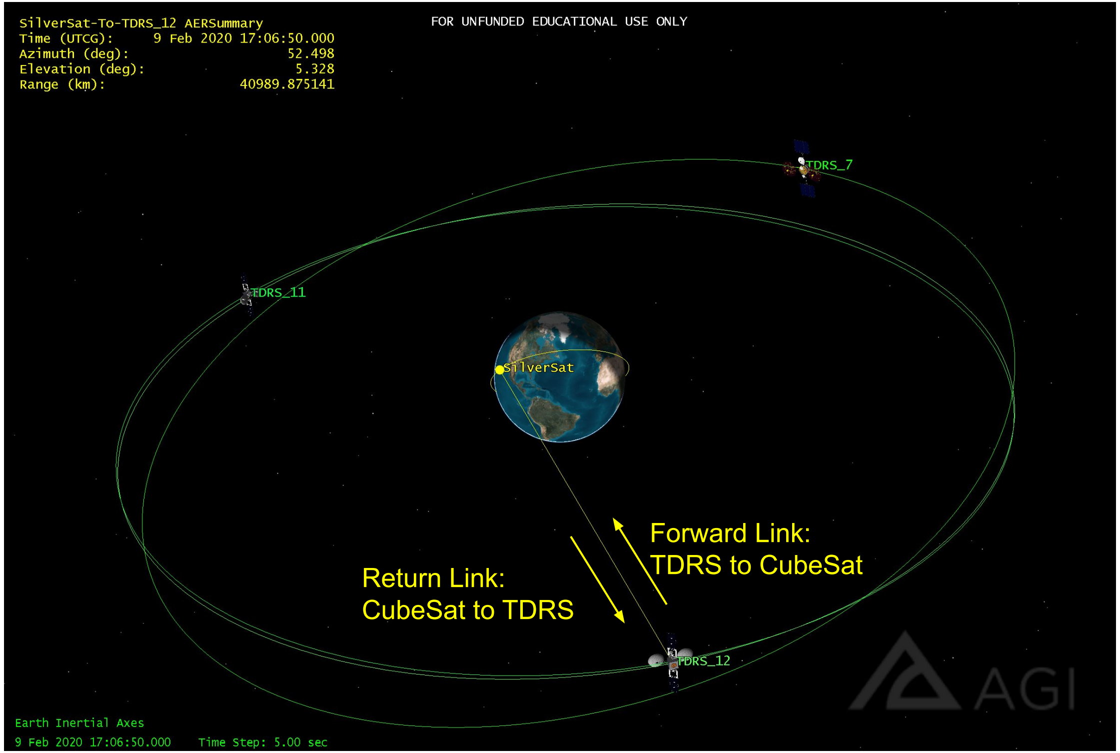
Scenario



- User: LEO in ISS Orbit
- TDRS 7, 11, 12 provide coverage
- Use the S-band Multiple Access Service (S-MA)
- Max Range 41000 km

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Assumptions

- Limit operation to 2nd and 3rd generation TDRS, LEO Field of View
- Data Group 1 (DG1) Mode 2 operation
  - Uplink and downlink are both direct-sequence spread-spectrum
  - Uplink frequency = 2106.4 MHz
  - Downlink frequency = 2287.5 MHz
  - Non-coherent downlink
- Spacecraft antenna is LHCP - match the SN service polarization
- Data rates (forward and return link) are symmetric: 1200 bps and 9600 bps
  - By comparison, SilverSat plans to operate at 9600 bps
- Return link is rate ½ convolutional coded. Forward link is uncoded
- BER = 10^{-5}

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Link Calculations - Return Link

- 1200 bps possible with 2W transmitted power and omni antenna
- 9600 bps possible with 5W transmitted power and patch antenna (5 dBi gain)

Parameter	Rtn Link at 1200 bps	Rtn Link at 9600 bps	Units
Service K	-223.7	-223.7	dBW/bps
Path Loss @ 41000 km	191.9	191.9	
10*log(Data Rate)	30.79	39.82	dBbps
Polarization Loss	0.5	0.5	dB
Pointing Loss	0.5	0.5	dB
Link Margin	3	3	dB
Required EIRP	**2.99**	**12.02**	**dBW**

EIRP is within the capabilities of a CubeSat format
Transmit power required for 9600 bps would be difficult for a 1U CubeSat, but possible in larger CubeSats

Link Calculations - Forward Link

G/T Calculation:
1200 bps - omni (0 dBi) antenna
9600 bps - patch (5 dBi) antenna

Noise Figure = 2 dB
Passive Losses = 2 dB
Ant. Noise Temp = 50K

Parameter	**Fwd Link at 1200 bps**	**Fwd Link at 9600 bps**	**Units**
TDRS EIRP	40	40	dBW
Path Loss @ 41000 km	191.2	191.2	
10*log(Data Rate)	30.79	39.82	dBbps
Polarization Loss	0.5	0.5	dB
Pointing Loss	0.5	0.5	dB
Spacecraft G/T	**-26.90**	**-21.90**	**dB/K**
10*log(kB)	-228.60	-228.60	dBW
Eb/N0	18.71	14.68	dB
Implementation Loss	1.5	1.5	dB
Required Eb/N0	9.9	9.9	dB
Margin	**7.31**	**3.28**	**dB**

Antenna requirements for forward link match those for return link
Noise figure and passive losses are feasible for a CubeSat

Complexity Considerations

- Radio functionality is modestly more complex than is typical for CubeSat missions
  - Operation is at S-band: now becoming more common in CubeSats
  - Forward and Return link paths are Direct Sequence Spread Spectrum
    - PN code applied to return link, modulation bandwidth now set by the chip rate
    - PN correlator required for forward link
    - Both of these functions are feasible in modest additions to a CubeSat radio (i.e. FPGA)
  - Return link frequency accuracy +/- 700 Hz: requires +/- 0.3 ppm Internal clock accuracy
    - May require oven-controlled oscillator, increasing power conumption
- Operation at higher rate requires directional antenna
  - Patch antenna is sufficient: available for CubeSats
  - **CubeSat will need attitude determination and control**
    - Harder in a 1U CubeSat (but possible)
    - Common in 3U and higher CubeSats

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Power Considerations

- 1200 bps case: Tx Power of 2W will require ~5W DC Power
  - Higher than typical for a 1U CubeSat, but in line with capabilities of 3U and larger CubeSats
  - Typical orbit-averaged power (OAP) available to a 1U satellite is 1.2W-1.5W: a transmit duty cycle on the order of 10% would be possible with 20% margin assuming comms consumes half the OAP
- 9600 bps case: Tx Power of 5W will require ~12.5W DC Power
  - 10% duty cycle would require 1.25 W: Assuming comms consumes half the OAP and 20% margin, the required OAP is 3W: within the capability of a 3U CubeSat
- Increased radio processing for spreading will further increase power requirement

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Conclusions

- Operation of SilverSat's mission concept through the SN MA service is feasible
- SilverSat as planned is a 1U satellite: power concerns and the lack of attitude control would make use of SN MA difficult, and limit data rate
- The SN MA service would be an attractive means of communication for a 3U, attitude-stabilized satellite.

References:

[1] - Safavi, H., Shaw, H., "NASA Space Network (SN) Support and Services for SmallSats", presentation to the 32nd Annual AIAA/USU Conference on Small Satellites, Report No. GSFC-E-DAA-TN59232, NASA Goddard Space Flight Center, 2018.

[2] - *Space Network Users' Guide (SNUG)*, Revision 10 DCN 001, NASA, July 18, 2017.