

Classroom Activities with the AMSAT CubeSat Simulator



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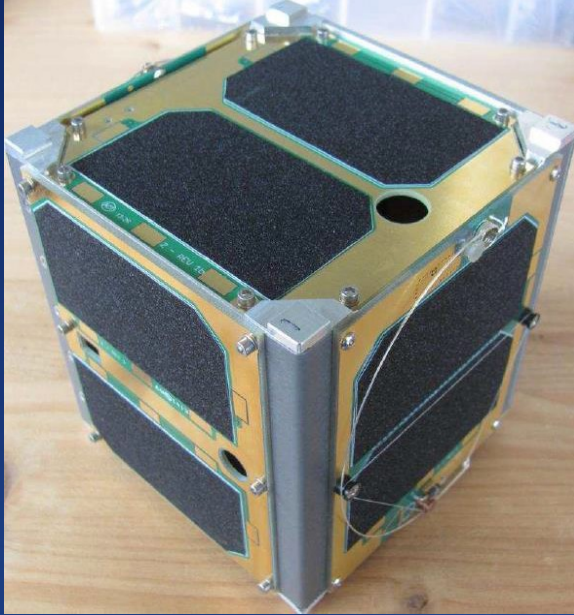
CubeSatSim.org

Who is AMSAT?

- The Radio Amateur Satellite Corporation, or AMSAT, is a worldwide, volunteer, not for profit educational and scientific organization that has been designing, building and launching small satellites since 1961.
- These satellites have typically been used by amateur radio operators for voice communications.
- Some included digital packet communications and slow scan television



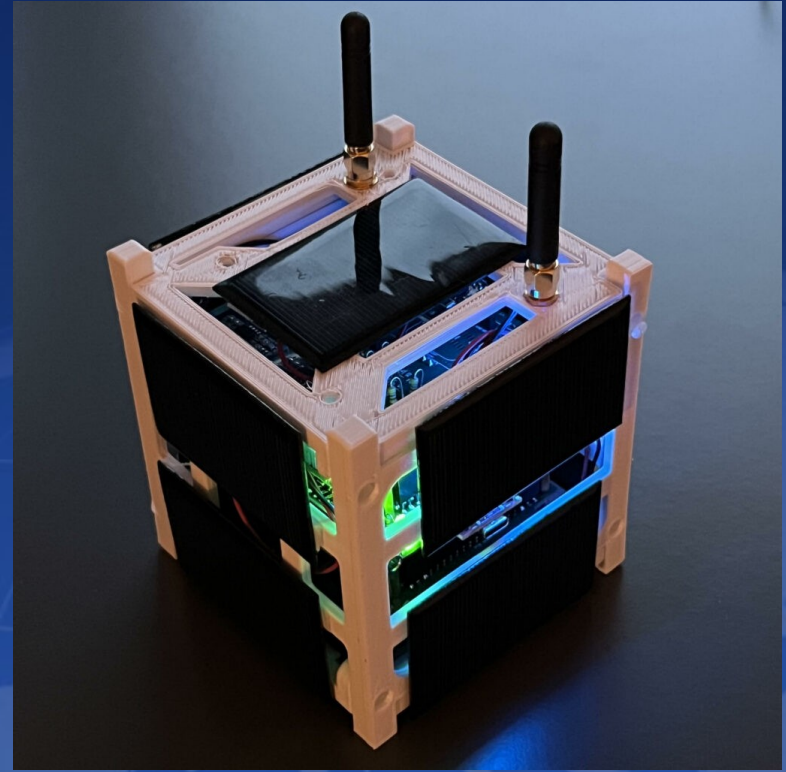
FOX Series – Five 1U CubeSats



First launched 2015 and carried experimental university payloads. AMSAT designed radio modules are used in many university CubeSats.

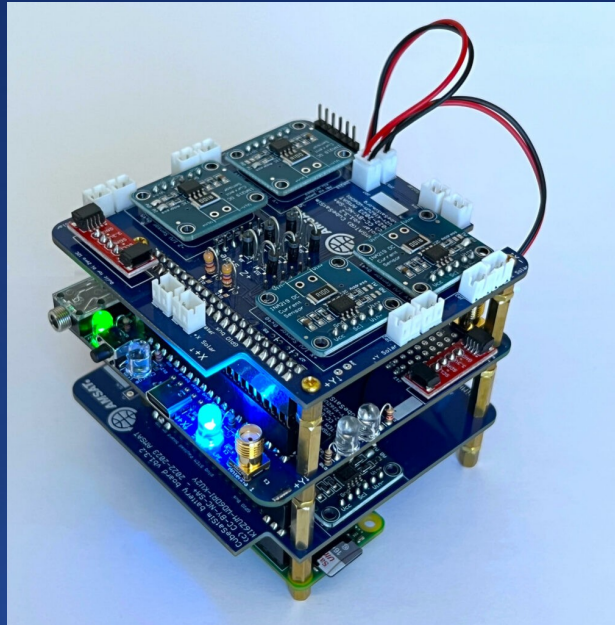
What is a CubeSatSim?

- A low-cost (\$400) fully functional satellite used to teach basic assembly skills, principles of satellite operation, UHF radio communications using the most common transmission modes and the interpretation of telemetry data.



What is a CubeSatSim?

- Uses a 3-board stack (from top): solar board w power sensors, radio board with payload computer, battery board with Raspberry Pi Zero 2 flight computer attached underneath.



CubeSatSim Unique Features

- Two processors: flight & payload
- Six solar panels, each with voltage & current monitoring
- Expandable payload via I2C sensors with QWIIC cables
- Raspberry Pi camera
- Two UHF radios using 5 telemetry modes
- Open Source hardware and software on GitHub
- Open Source Raspberry Pi / RTL-SDR ground station
- Loaners available for educators and demonstrators



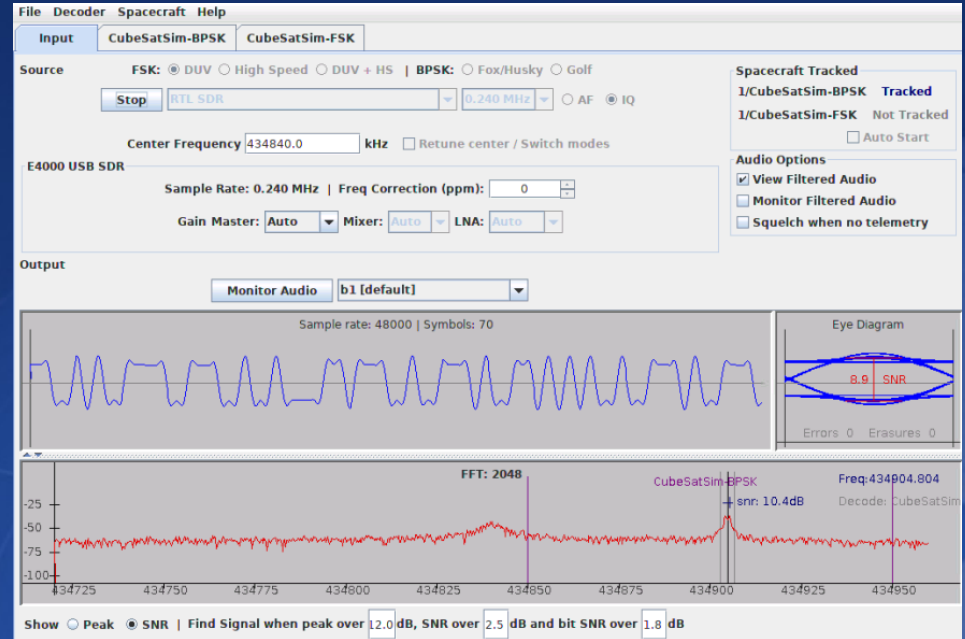
Available as a No-solder Kit

- Easy to assemble
 - Assemble stack using stand-offs
 - Assemble 3D printed frame
 - Install stack and camera in frame
 - Plug in solar panel connections
 - Secure solar panels to frame
 - Attach antennas
- Can be disassembled for use by another class
- Full instructions and videos on Wiki



Ground Station Software

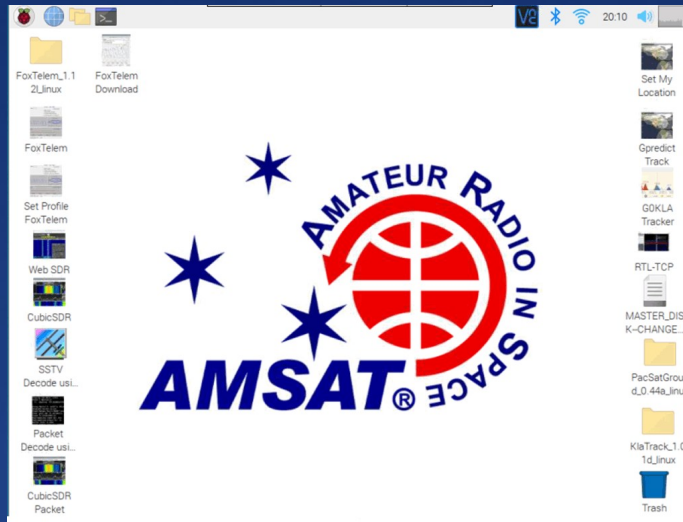
- FoxTelem for Windows, Mac & Linux receives, decodes, visualizes and records telemetry data from Fox CubeSats via a \$25 RTL-SDR



Ground Station Software

- Ground Station for Raspberry Pi
 - Pre-built Software Stack (Fox-in-a-Box)
 - Flash to SD card or install on your own

- Software:
- FoxTelem
- Direwolf
- QSSTV
- OpenWebRX
- CubicSDR
- RTL-TCP
- Gpredict
- KLaTracker

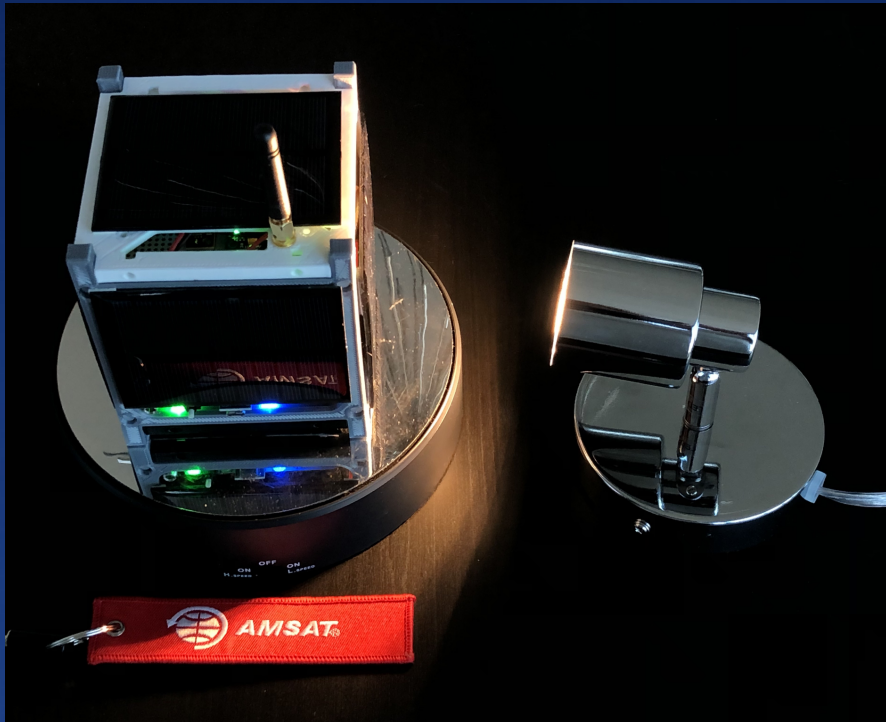


Loaner Kits Available

- Includes CubeSat Simulator, ground station, turntable, LED lamp



Classroom Activities

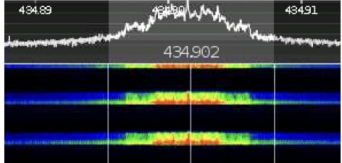
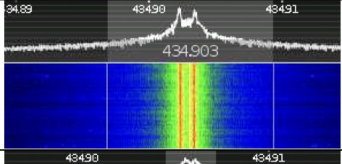
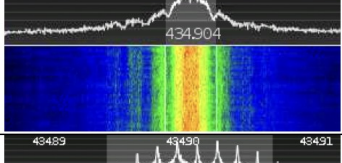
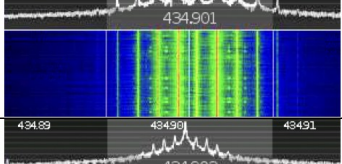


Classroom Activities

- CubeSat Radio Communications
- Solar Cells & Power Management
- CubeSat Orientation & Spin Rates
- STEM Payload Sensors
- Software Enhancements



CubeSat Radio Communications

Blinks	Mode	Description	Decoding	Command	Audio	Waterfall (Cubic SDR)
1	APRS	Automatic Packet Reporting System. This digital mode sends a packet of data with AFSK or Audio Frequency Shift Keying modulation.	Windows: SoundModem or Direwolf Raspberry Pi/Linux: OpenWebRX or Direwolf with spreadsheet http://cubesatsim.org/telem	<code>config -a</code>	CubeSatSim.org/a	
2	FSK	Frequency Shift Keying. This mode transmits a continuous signal that makes a rumbling sound that emulates the AMSAT Fox CubeSats such as Fox-1C or AO-95. Also known as DUV or Data Under Voice.	Windows/Raspberry Pi/Linux: FoxTelem	<code>config -f</code>	CubeSatSim.org/f	
3	BPSK	Binary Phase Shift Keying. This mode transmits a continuous signal that sounds like noise that emulates the AMSAT Fox-1E or HuskSat-1 CubeSats. You need to demodulate using USB.	Windows/Raspberry Pi/Linux: FoxTelem	<code>config -b</code>	CubeSatSim.org/b	
4	SSTV	Slow Scan TeleVision. This mode transmits stored images in Scottie 2 format which sounds like a series of tones.	Windows: MMSSTV Raspberry Pi/Linux: QSSTV	<code>config -s</code>	CubeSatSim.org/s	
5	CW	Continuous Wave or Morse Code. This mode transmits a FM modulated tone at 20 words per minute Morse Code telemetry.	Windows/Raspberry Pi/Linux: fldigi with spreadsheet http://cubesatsim.org/telem	<code>config -m</code>	CubeSatSim.org/m	

CubeSat Radio Communications

■ Command & Control

- Radio listens and responds to DTMF tones
- Currently used to switch between transmission modes
- Can be used for other satellite functions in the future

■ APRS relay

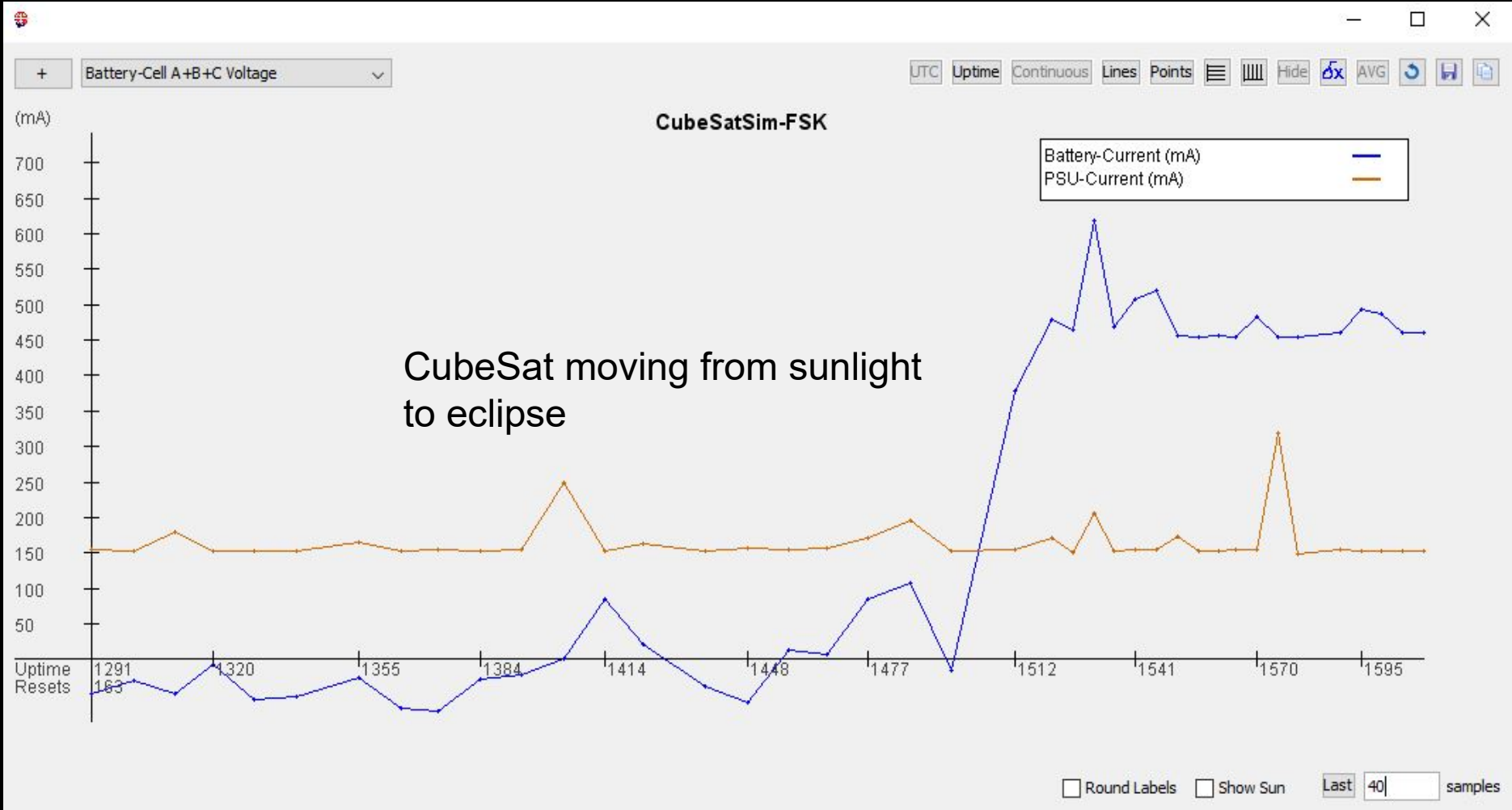
- Retransmits received APRS packets
- Demonstrates communications between CubeSats

■ Audio & voice capability for future applications



Solar Cells & Power Management

- Measure and record differences in solar panel output
- Measure battery voltages and currents
- Measure power consumption and generation under different levels of sunlight
- Determine when processor will shutdown
- Determine how long CubeSat will operate in eclipse
- Observe voltage and current changes as CubeSat enters and leaves eclipse
- Determining solar panel failures or performance issues



CubeSat Orientation & Spin Rates

- Determine orientation using accelerometer
- Determine orientation using solar cells
- Determine spin rate using gyroscope
- Determine spin rate using solar cells
- Determine camera direction
- Simulate mission scenarios



+ Battery-Cell A+B+C Voltage

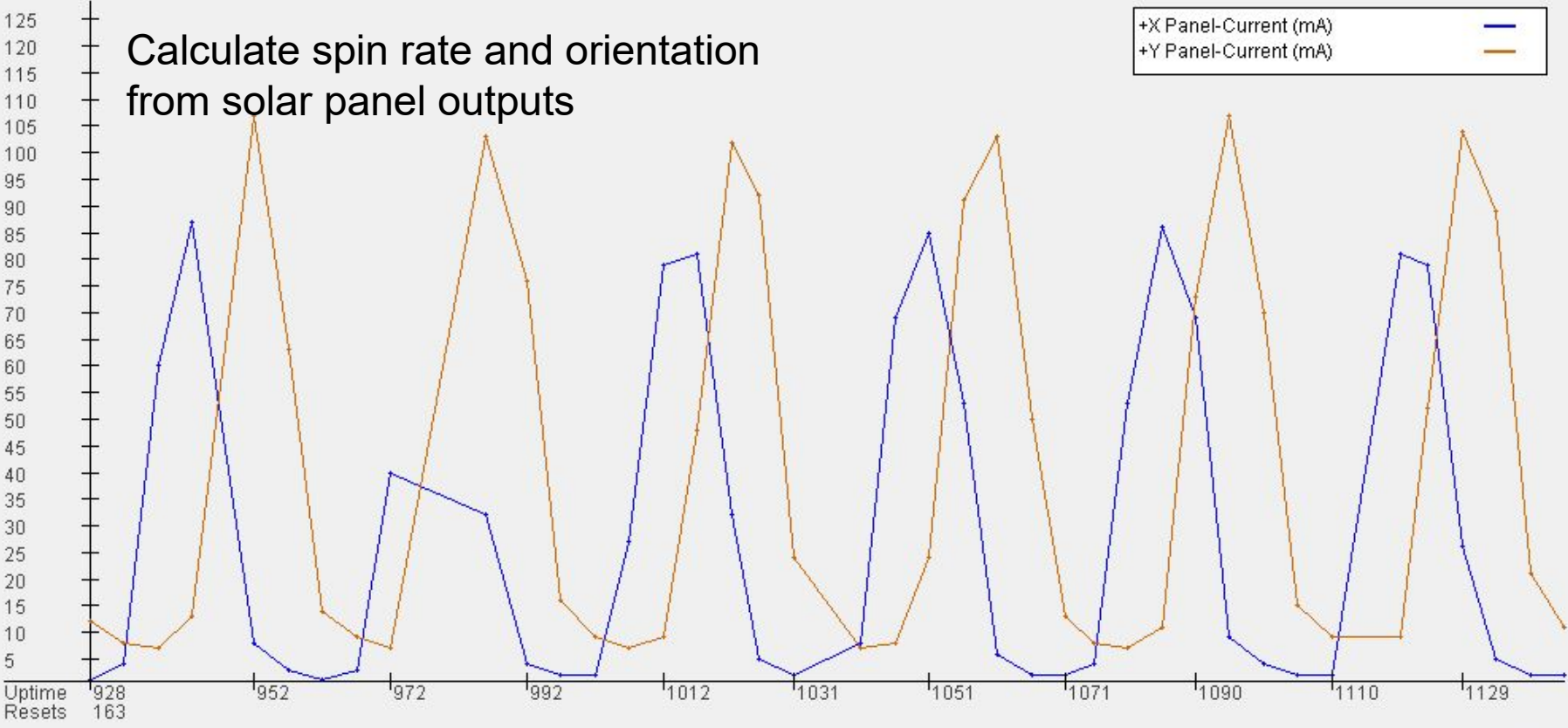
UTC Uptime Continuous Lines Points Hide δx AVG

(mA)

CubeSatSim-FSK

Calculate spin rate and orientation
from solar panel outputs

+X Panel-Current (mA) —
+Y Panel-Current (mA) —



☐ Round Labels ☐ Show Sun Last 40 samples

STEM Payload Sensors

- Easy to add sensors via QWIIIC plug-n-play cabling system
 - IR / UV / spectral sensors
 - Environmental sensors
 - Displays and servo controllers
- Programming is done on the simpler Pi Pico microcomputer
- GPS support is available

Software Enhancements

■ Flight Software

- Power sensor calibration
- Active power management (transmitter control)
- Automatic communications mode switching
- Improved camera scheduling
- On-board storage of sensor data
- Scheduled transmission of sensor data

CubeSatSim Project Team

■ Leadership

- Alan B Johnson, PhD, KU2Y
VP, Educational Relations,
AMSAT

■ Hardware

- Jim McLaughlin, KI6ZUM
- David White, WD6DRI

■ Educational Materials

- Paul Graveline, K1YUB
- Fredric Raab, KK6NOW
- Mark Samis, KD2XS
- David White, WD6DRI

■ Beta Builders

- Kerry Bonin, KJ7HTG
- Jim Nagle, KF4OD
- Virginia Smith, NV5F
- Chris Thompson, G0KLA/AC2CZ
- Randy Standke, KQ6RS,
- Christine Mehner, MD, PhD,
KO4EWG
- Sopwith, N1SPW
- Kai Ji, AC3EN

■ Documentation

- Alan B Johnson, PhD, KU2Y
- Sopwith, N1SPW

■ Students

- Villanova University, Villanova, PA
CubeSat Club and Spring 2019
and 2022 ECE 1205 Freshman
Projects classes
- Bishop O'Connell High School,
Arlington, TX DJO ARC students
and teacher Melissa Pore,
KM4CZN

■ CAD

- Lindsay White, KI6LZN
- Low Pass Filter Design
and Testing
- Randy Standke, KQ6RS



Acknowledgments

- Thanks to Mark Spencer, WA8SME, for his trailblazing work on CubeSat simulators and to Bob Bruninga, WB4APR, for ideas and inspiration from his undergrad “LabSat” developments.
- Pat Kilroy, N8PK, was instrumental in getting the CubeSat Simulator project going again.
- We would also like to acknowledge all the open source hardware and software that is a part of the AMSAT CubeSatSim.
- Photos from CubeSatSim.org and AMSAT.org websites
- Finally, we would like to acknowledge the support of the AMSAT Board of Directors and the members of AMSAT for their support and encouragement of this project.



Q & A

Contact Fredric at fraab@collegeofthedesert.edu
or FredricRaab@yahoo.com

<https://CubeSatSim.org>

<https://www.amsat.org>

<https://github.com/alanbjohnston/CubeSatSim/wiki>



Extra Slides Follow



Input

AO-85

AO-91

AO-92

AO-95

CubeSatSim-BPSK

CubeSatSim-FSK

Fox-1E

Husky

Source

FSK: ☒ DUV ☐ High Speed ☐ DUV + HS | BPSK: ☐ Fox/Husky ☐ Golf

Stop

RTL SDR

0.240 MHz

☐ AF☒ IQ

Center Frequency 434900.0

kHz

☐ Retune center / Switch modes

R820T USB SDR

Sample Rate: 0.240 MHz | Freq Correction (ppm): 0

☐ Bias T

Gain Master:

Automatic

Mixer:

Automatic

LNA:

Automatic

VGA:

312

Spacecraft Tracked

1/AO-85 Not Tracked

1/AO-91 Not Tracked

1/AO-92 Not Tracked

1/AO-95 Not Tracked

1/CubeSatSim-BPSK Not Tracked

1/CubeSatSim-FSK Tracked / No TLE

1/Fox-1E Tracked / No TLE

1/Husky Tracked / No TLE

☐ Auto Start

Audio Options

☒ View Filtered Audio☒ Monitor Filtered Audio☐ Squelch when no telemetry

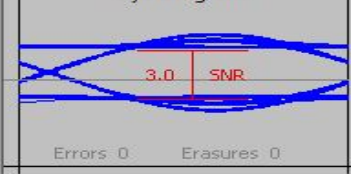
Output

Silence Speaker

Sample rate: 48000 | Symbols: 70



Eye Diagram

Show ☐ Peak ☒ SNR | Find Signal when peak over 12.0 dB, SNR over 2.5 dB and bit SNR over 1.8 dB

Input AO-85 AO-91 AO-92 AO-95 CubeSatSim-BPSK **CubeSatSim-FSK** Fox-1E Husky

Health Measurements

Satellite CubeSatSim-FSK(EM) Mode: TRANSPONDER

Telemetry Payloads Decoded: 7115

Latest Realtime: Resets: 163 Uptime: 222

Max: Resets: 163 Uptime: 163

Min: Resets: 153 Uptime: 374

Radio

	RT	MIN	MAX
RSSI (dBm)	0	0	0
TX Antenna	Deployed		
RX Antenna	Stowed		

Computer Hardware

	RT	MIN	MAX
IHU Temp (Pi) (C)	36.9	34.7	35.8
I2C Bus 1	OK		
I2C Bus 3	OK		
Camera	OK		

Computer Software

	RT	MIN	MAX
Spacecraft Spin (rpm)	0.0	0.0	0.0
Safe Mode	OFF		
Ground Commands	0		
Simulated Telemetry	OFF		

Battery

	RT	MIN	MAX
Cell A+B+C Voltage ...	8.27	7.15	8.35
Current (mA)	26.0	471.0	115.0

PSU

	RT	MIN	MAX
Voltage (V)	4.96	4.78	4.96
Current (mA)	158.0	144.0	200.0

Experiments

	RT	MIN	MAX
STEM Payload Status	OK		
BME280 Temp (C)	0.0	0.0	0.0
BME280 Pressure (...)	0.0	0.0	0.0
BME280 Altitude (m)	0.0	0.0	0.0
BME280 Humidity (%)	0.0	0.0	0.0
Diode Temp (C)	107.3	105.3	107.3
Sensor 2 (signed s...	0.0	0.0	0.0

+X Panel

	RT	MIN	MAX
Voltage (V)	4.38	1.42	4.40
Current (mA)	91.0	0.0	92.0
Rotation (dps)	6	7	7
Acceleration (g)	-0.09	-0.06	-0.03

+Y Panel

	RT	MIN	MAX
Voltage (V)	4.40	3.19	4.52
Current (mA)	13.0	2.0	111.0
Rotation (dps)	1	0	1
Acceleration (g)	-0.01	-0.01	0.01

+Z Panel

	RT	MIN	MAX
Voltage (V)	0.00	0.00	0.00
Current (mA)	0.0	0.0	0.0
Rotation (dps)	9	0	11
Acceleration (g)	1.06	1.06	1.08

-X Panel

	RT	MIN	MAX
Voltage (V)	4.34	1.99	4.47
Current (mA)	3.0	0.0	72.0

-Y Panel

	RT	MIN	MAX
Voltage (V)	3.29	0.92	3.36
Current (mA)	10.0	0.0	82.0

-Z Panel

	RT	MIN	MAX
Voltage (V)	4.34	2.33	4.40
Current (mA)	72.0	0.0	118.0

☒ Current ☐ RT ☐ MAX ☐ MIN ☐ Display Raw Values ☒ Display UTC Time

Last 180 samples Captured: 2022/07/26 17:00:55



+ Battery-Cell A+B+C Voltage ▾

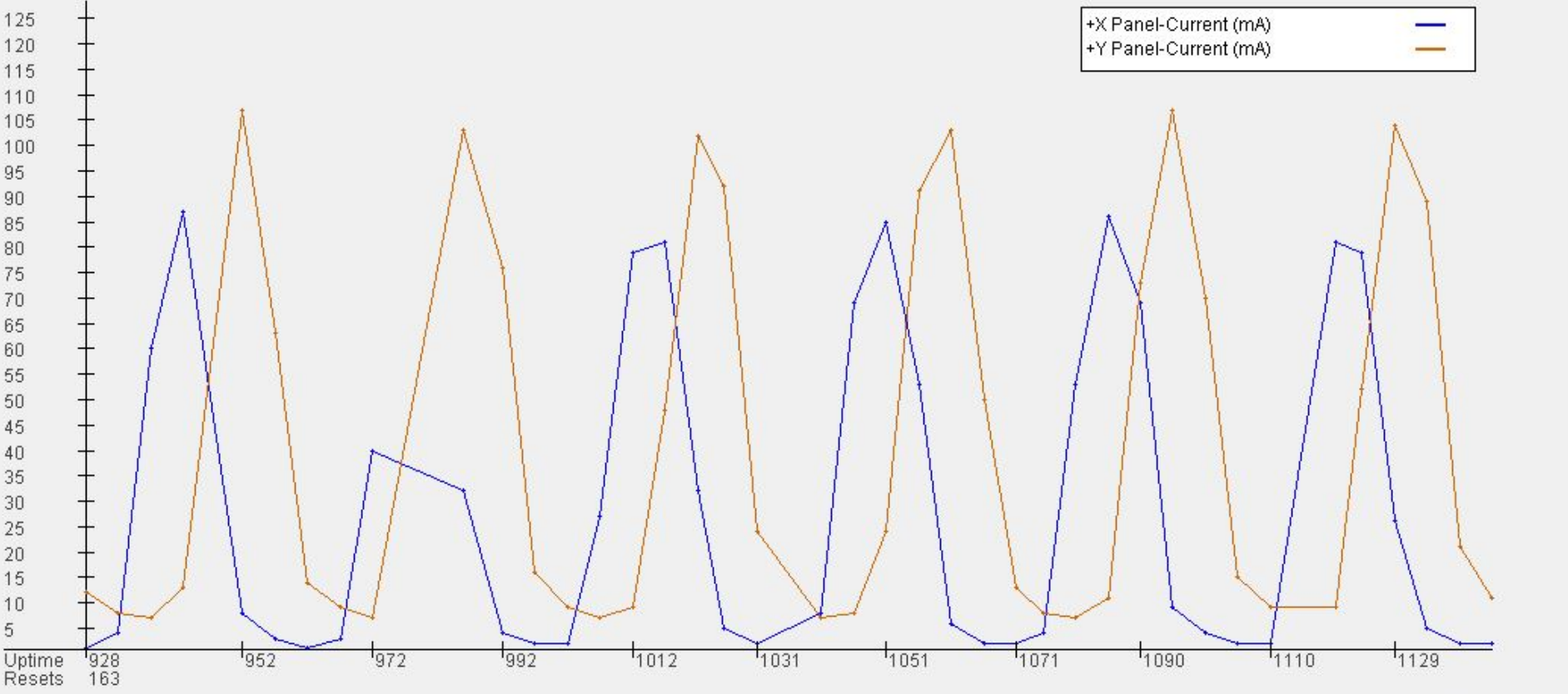
UTC Uptime Continuous Lines Points Hide AVG

(mA)

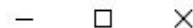
CubeSatSim-FSK

+X Panel-Current (mA)

+Y Panel-Current (mA)



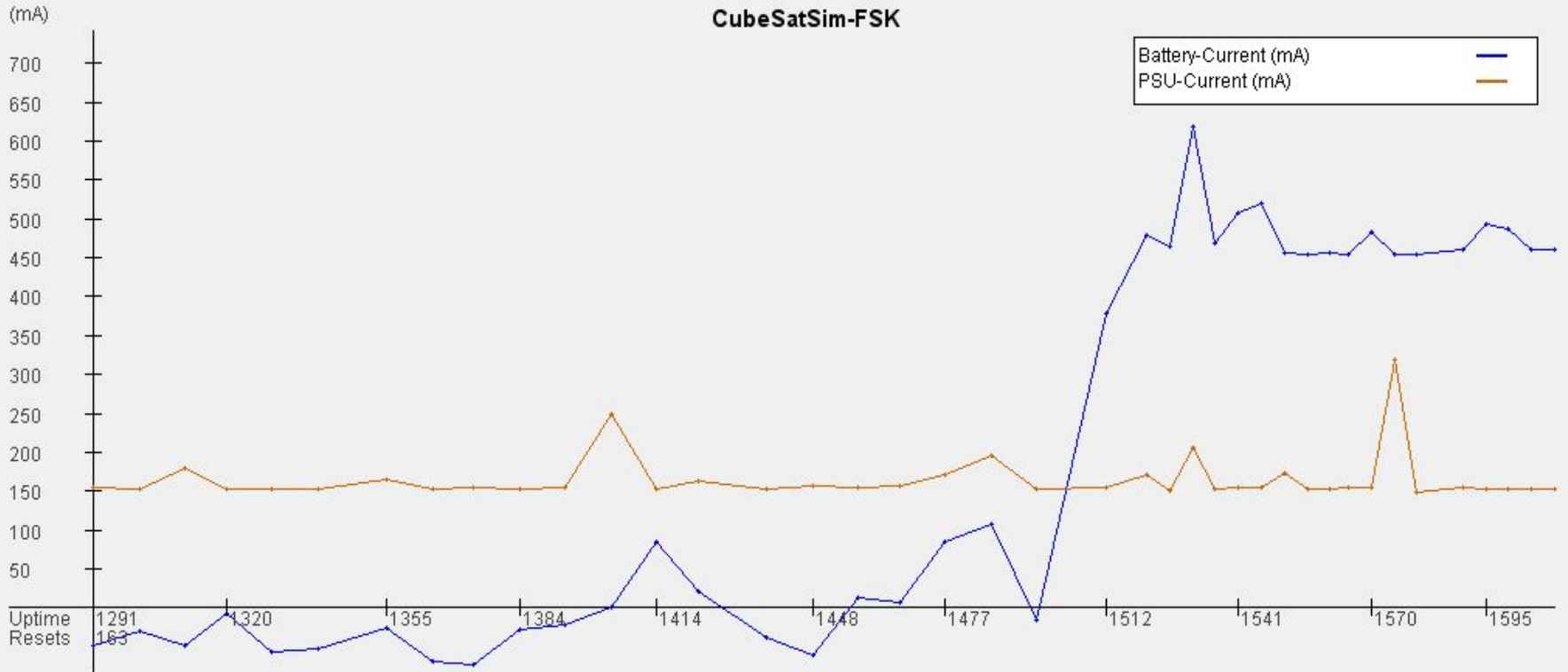
☐ Round Labels ☐ Show Sun Last 40 samples



+ Battery-Cell A+B+C Voltage ▾

UTC Uptime Continuous Lines Points Hide AVG

CubeSatSim-FSK



Uptime Resets 1291 1320 1355 1384 1414 1448 1477 1512 1541 1570 1595

☐ Round Labels ☐ Show Sun Last 40 samples



KK6NOW (KK6NOW.MDT) - MMSSTV Ver 1.13A



File Edit View Option PProfiles Program RadioCommand Help

Sync RX History TX Template



Lock

ReSync

☒ Auto history

S.pix

S.templates 1

2

3

4

RX Mode

Auto

Robot 36

Robot 72

AVT 90

Scottie 1

Scottie 2

ScottieDX

Martin 1

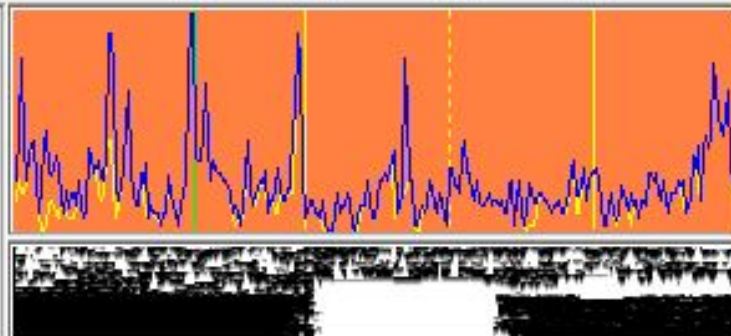
Martin 2

SC2 180

DSP

AFC LMS

1200 1500 1900 2300



Log

Call His 595 My

Name Qth

Note

QSL RxID TxID ABC

QSO Data Find Clear List 14.230

☒ Show with template☒ Draft

2/17



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AIRSPY

