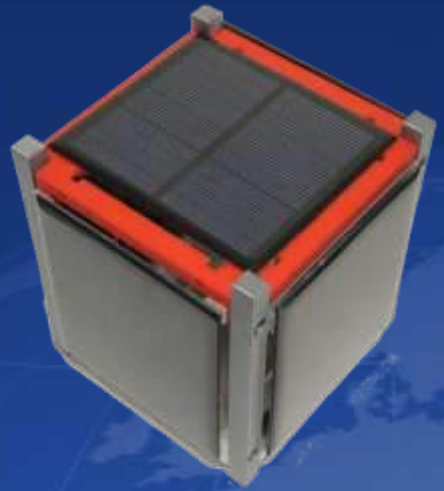
# Classroom Activities with the AMSAT CubeSat Simulator



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**fraab@collegeofthedesert.edu**

***CubeSatSim.org***

# Topics

- Who is AMSAT?
- Use of Amateur Radio by Educational CubeSats
- CubeSat Simulator
- Classroom Activities
- Acknowledgements
- Q & A

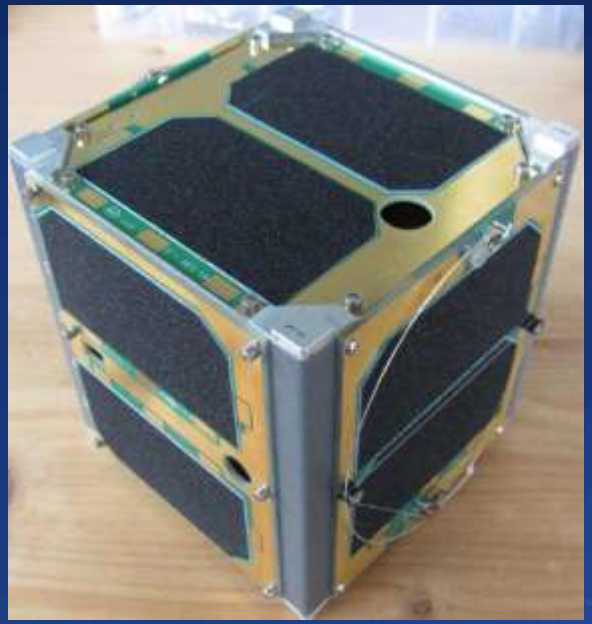
# Who is AMSAT?

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

# OSCAR
# Orbiting Satellite Carrying Amateur Radio

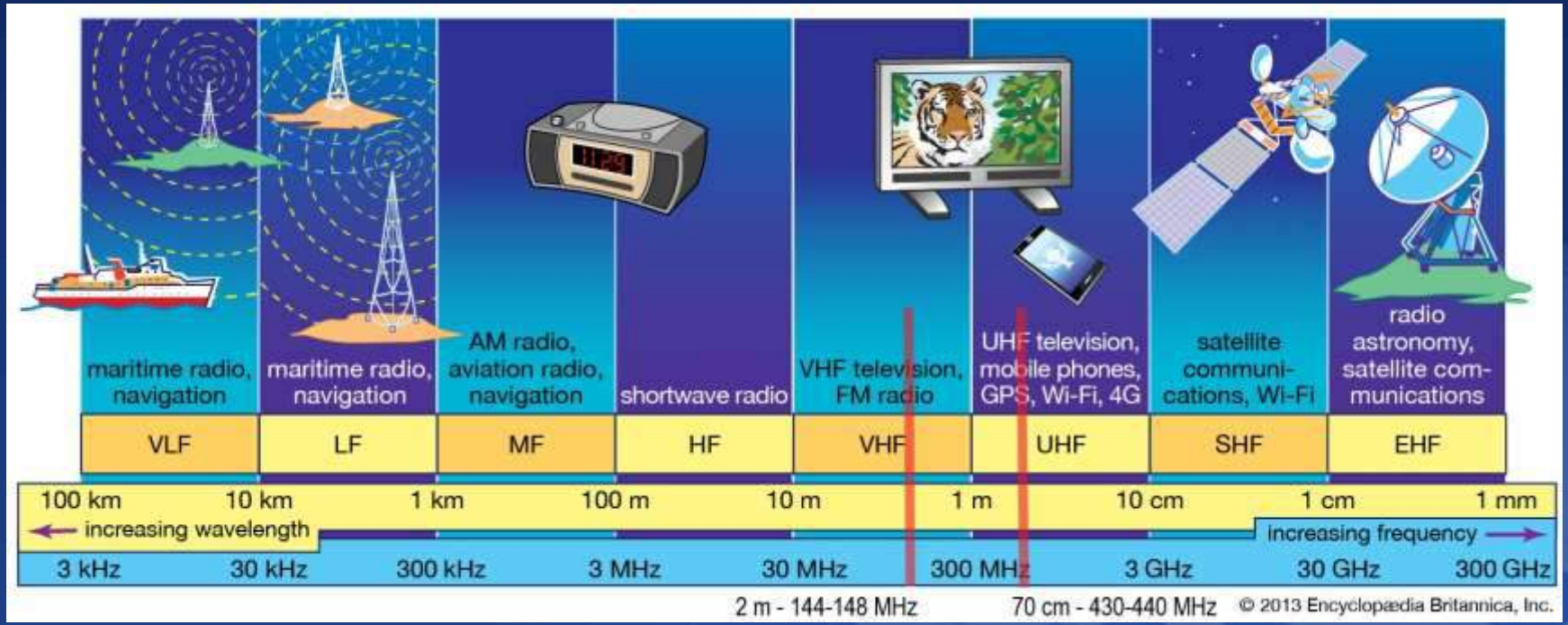
Lance Ginner, K6GSJ with OSCAR 1 launched 1961

# FOX Series – Five 1U CubeSats



First launched Oct 2015 & Nov 2017
All carried experimental university payloads.

# Use of Amateur Radio by Educational CubeSats

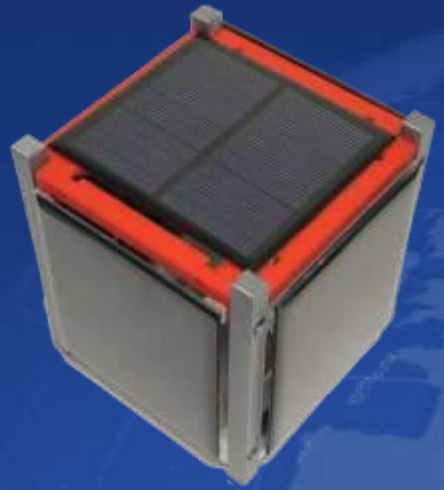


# Use of Amateur Radio by Educational CubeSats


db.satnogs.org/stats
20 June 2022

# What is a CubeSatSim?

- A low-cost ($350) satellite emulator that runs on solar panels in sunlight, batteries in eclipse, and transmits UHF radio telemetry using the most commonly used transmission modes and protocols.



# What is a CubeSatSim?

- Uses a 3-board stack that contains a Raspberry Pi single board computer, an Arduino compatible microcontroller, rechargeable batteries, voltage/current sensors, and environment sensors.

# CubeSatSim Features

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

# Technical Details

- Main Board
  - Plugs into Rasberry Pi Zero
  - 8 Voltage/Current Sensors
  - 1 Charge Controller for Batteries
  - 1 Boost Converter/Regulator

# Technical Details

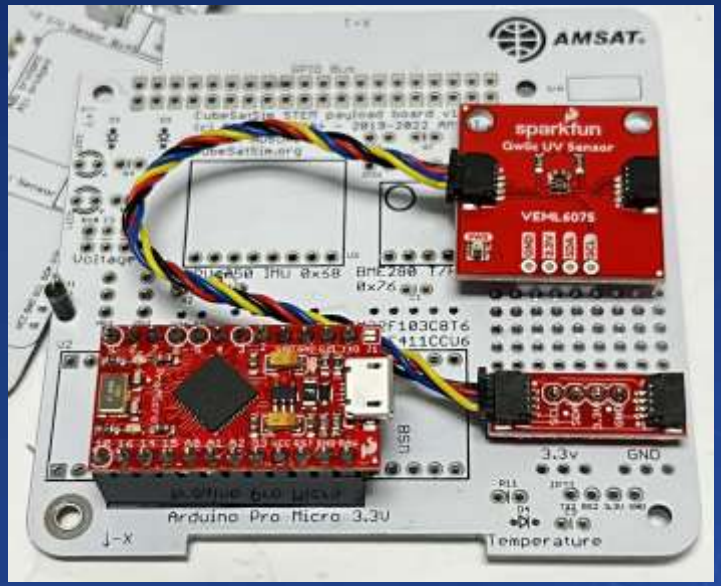
- Battery Board
  - 3 AA/AAA Nickel Metal Hydride (NiMH) Batteries for safety
  - Can operate in demo mode for 3 hours
  - Charged with USB-C cable

# Technical Details

- STEM Payload Board
  - 1 Arduino compatible microcontroller
  - 1 Temperature/Pressure/Humidity Sensor (BME-280)
  - 1 3-Axis Accelerometer/Gyroscope (MPU-6050)

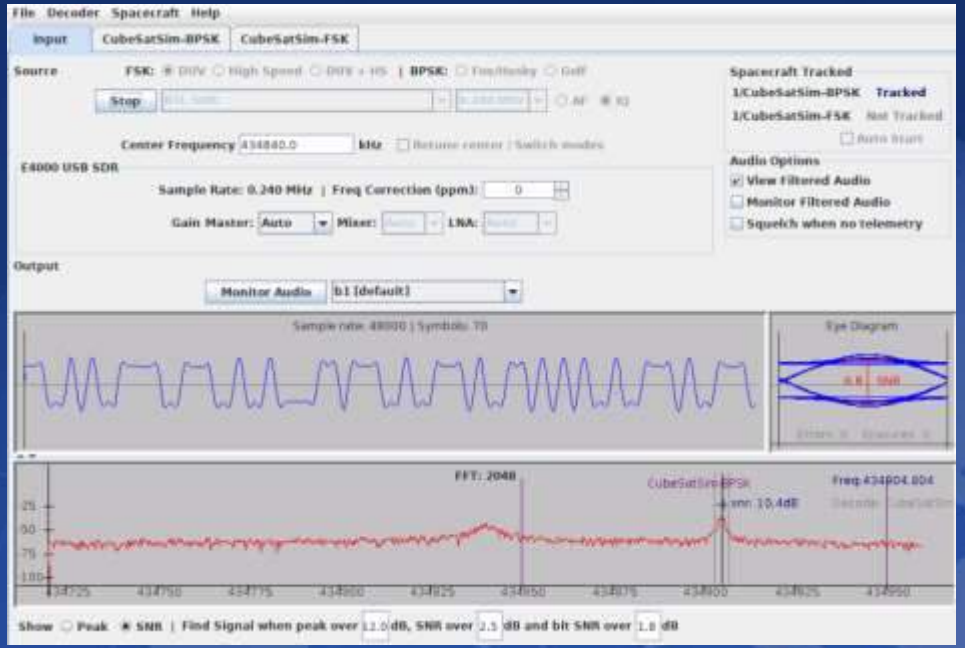
# Technical Details

- STEM Payload Board
  - Extendable via QWIIC boards from Sparkfun & Adafruit




# Ground Station Software

- FoxTelem for Windows, Mac & Linux receives, decodes, visualizes and records telemetry data from Fox CubeSats via a $35 RTL-SDR

# Ground Station Software

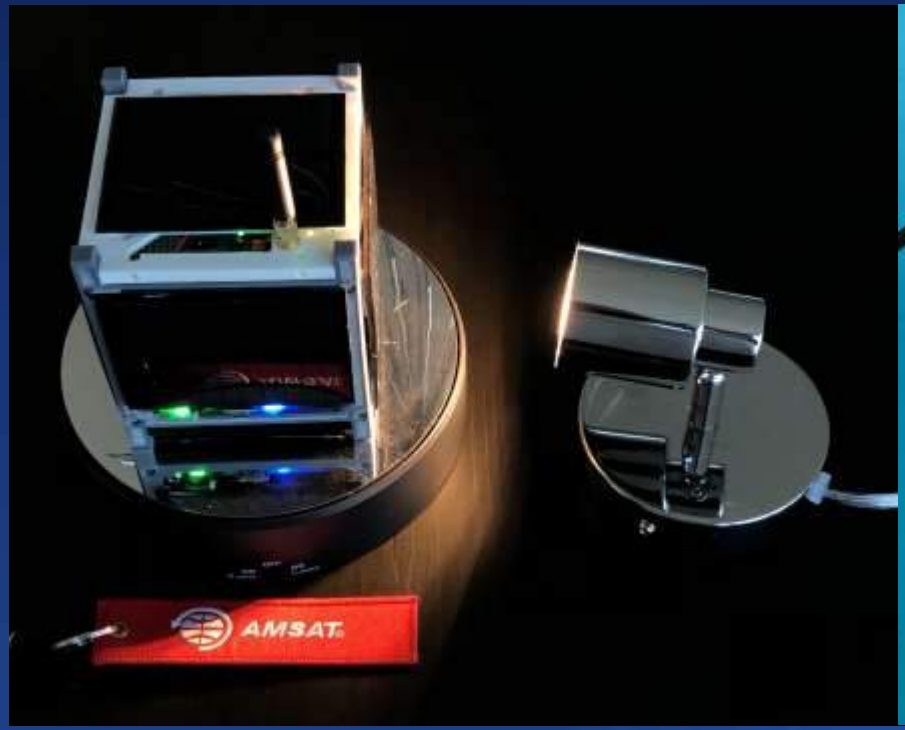
- Ground Station
  - Pre-built Software Stack (Fox-in-a-Box)
  - Or, install on your own PC


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

# Loaner Kits Available

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

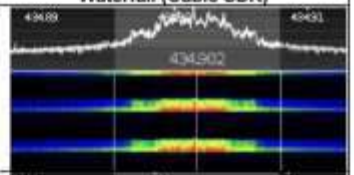
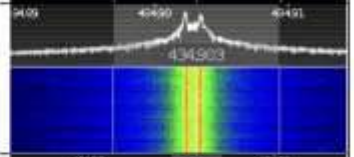
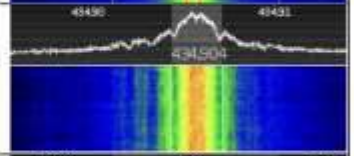
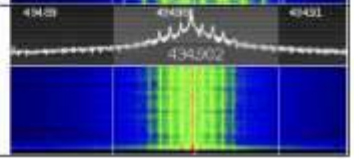
# Classroom Activities




# 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<br>Raspberry Pi/Linux: OpenWebRX or Direwolf<br>with spreadsheet<br>http://cubesatsim.org/telem | `config -a` | 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 | `config -f` | 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 | `config -b` | 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<br>Raspberry Pi/Linux: QSSTV | `config -s` | 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 | `config -m` | CubeSatSim.org/m |  |

# 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 accelormeter
- Determine orientation using solar cells
- Determine spin rate using gryoscope
- Determine spin rate using solar cells
- Determine camera direction
- Simulate mission scenarios

# STEM Payload Sensors

- Additional sensor support via QWIIC
  - IR / UV sensors
  - Environmental
- On-board sensor processing
- GPS support

# 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

# Acknowledgements


- 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

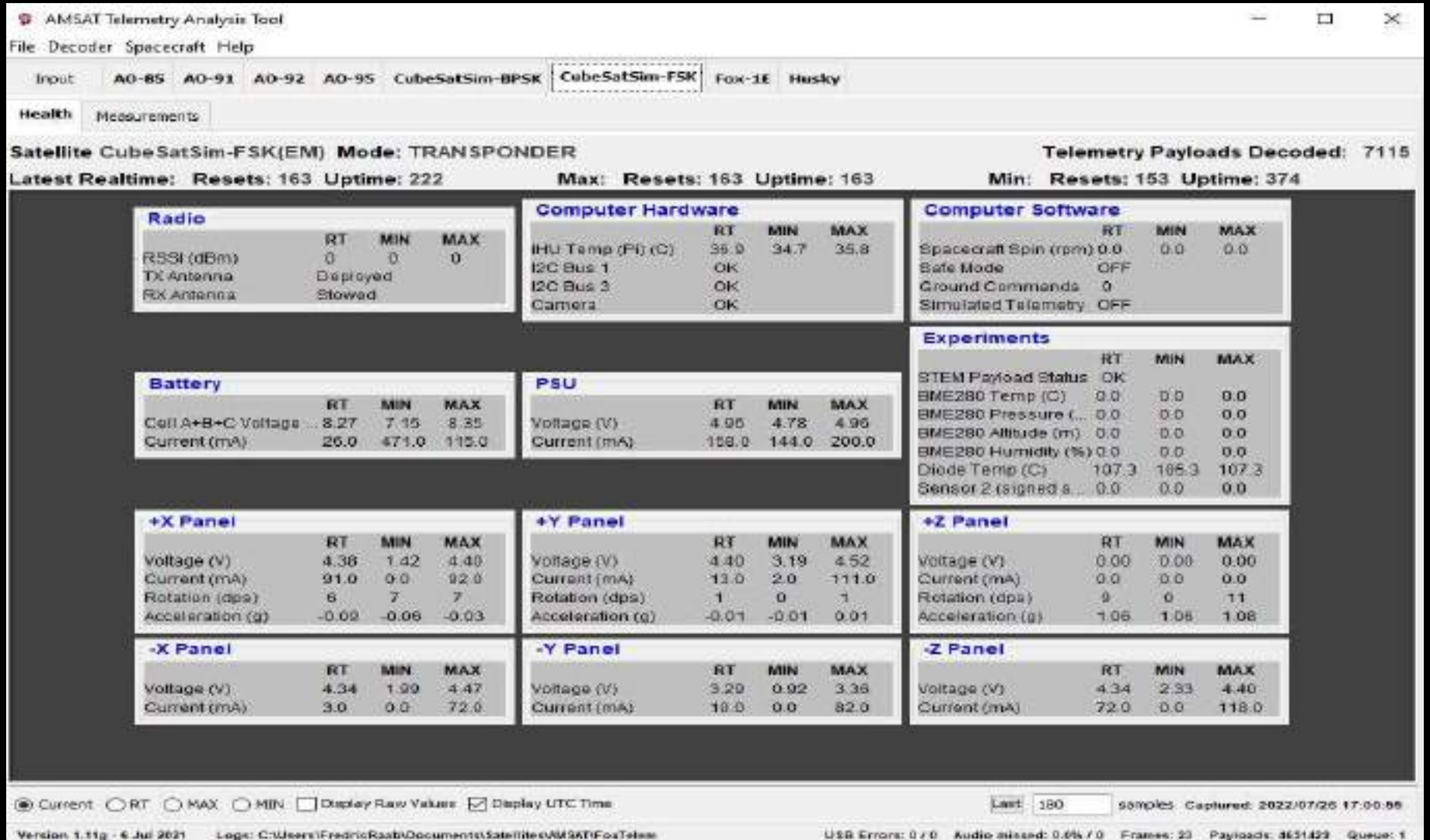
https://CubeSatSim.org

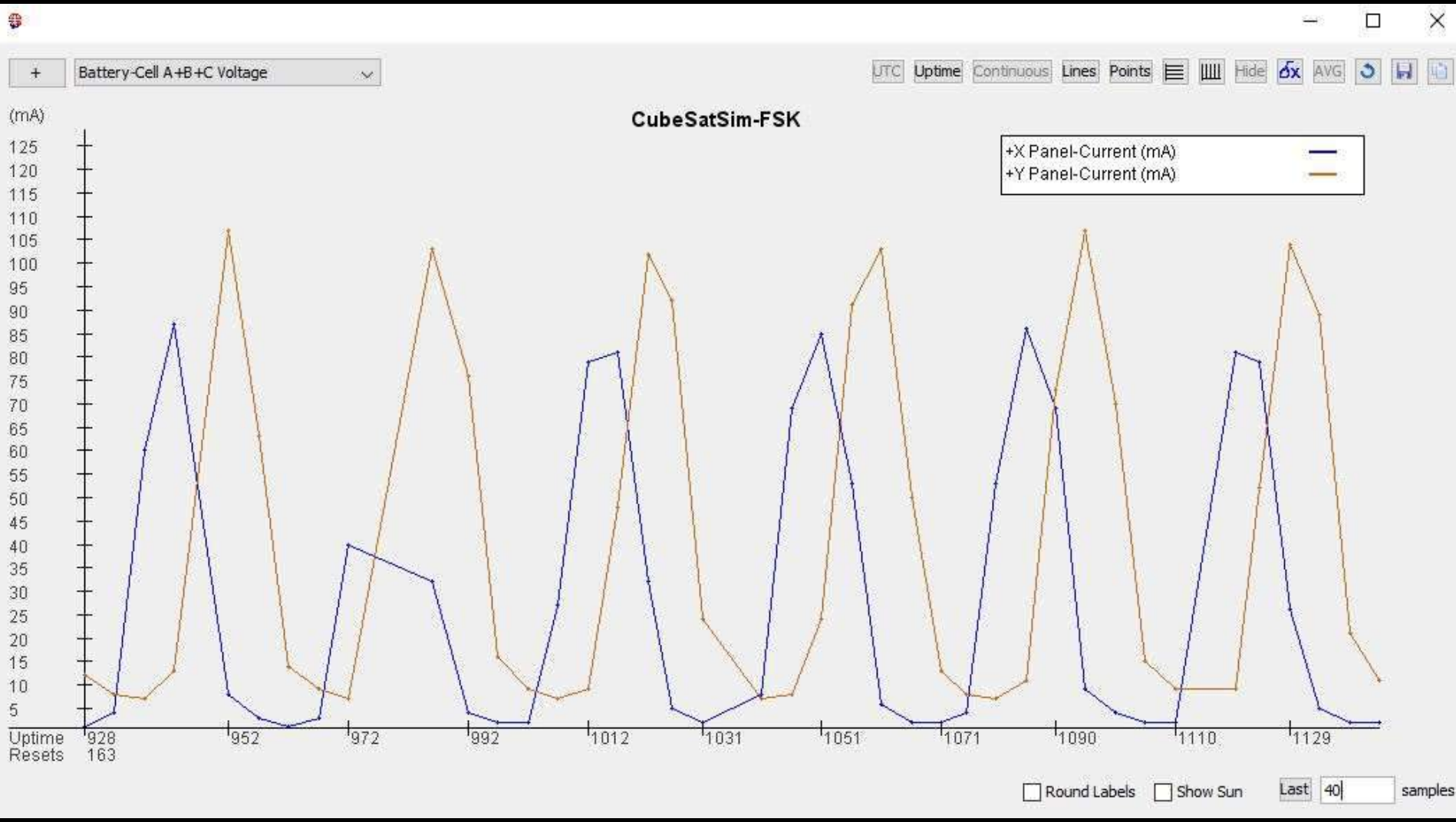
https://www.amsat.org

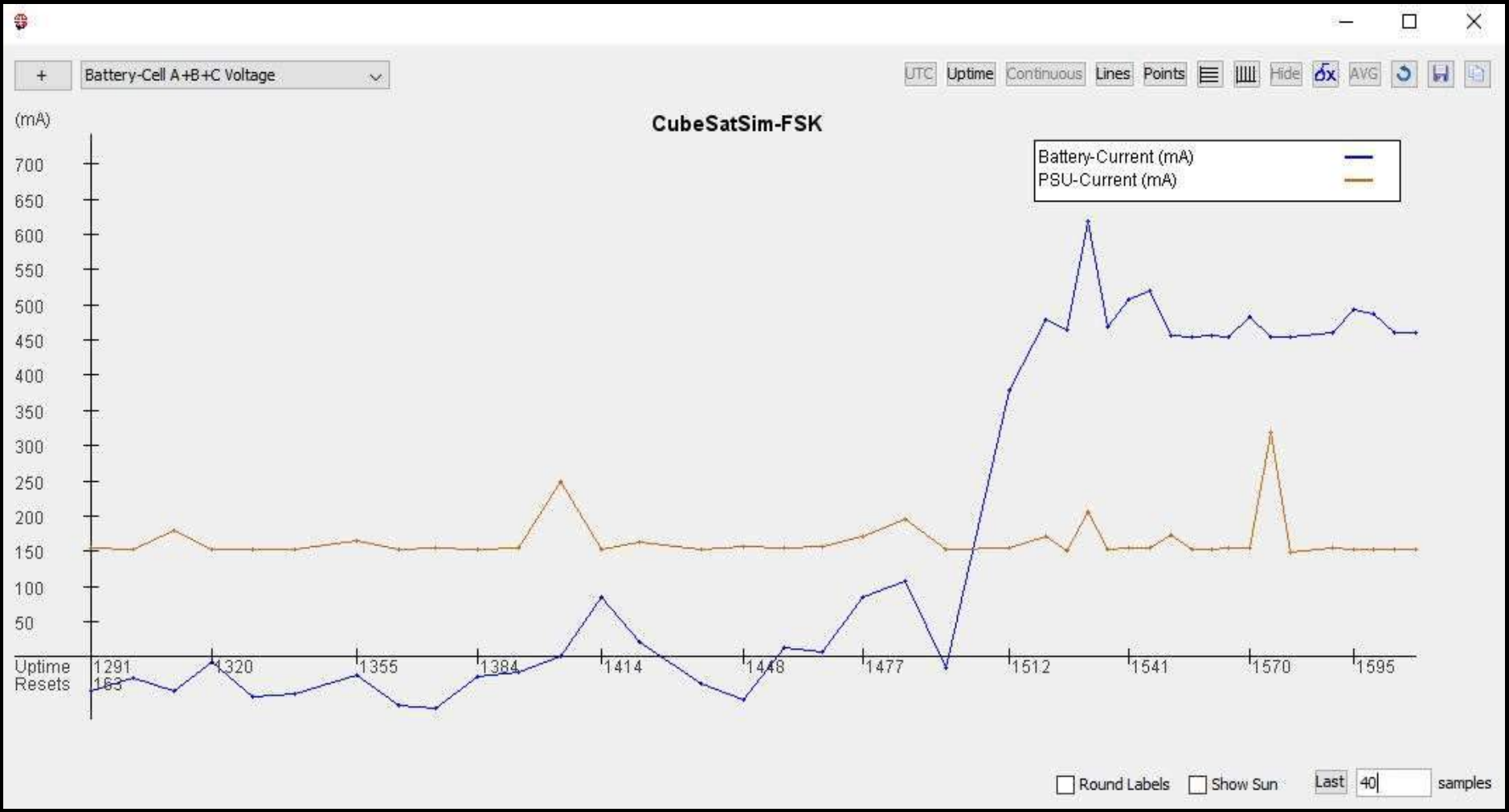
https://github.com/alanbjohnston/CubeSatSim/wiki

# Demo


AMSAT Telemetry Analysis Tool
File Decoder Spacecraft Help
Input
AO-85
AO-91
AO-92
AO-95
CubeSatSim-BPSK
CubeSatSim-FSK
Fox-1E
Husky
Source
FSK:
BPSK:
Stop
Center Frequency 434600.0 kHz
R820T USB SDR
Sample Rate: 0.240 MHz | Freq Correction (ppm):
Bias T
Gain Master: Automatic
Mixer:
LNA:
VGA:
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
SNR
CubeSatSim-FSK
FFT: 4096
SNR 13.0dB
Freq:434902.402
434800
434825
434850
434875
434900
434925
434950
434975
435000
Show Peak SNR | Find Signal when peak over 12.0 dB, SNR over 2.5 dB and bit SNR over 1.9 dB
Version 1.11g - 6 Jul 2021
USB Errors: 0 / 0
Frames: 23
Payloads: 4651429
Queue: 1


AMSAT Telemetry Analysis Tool
File Decoder Spacecraft Help
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
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 a... 0.0 0.0 0.0
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
+X Panel
RT MIN MAX
Voltage (V) 4.36 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
Version 1.11g - 6 Jul 2021 Logs: C:\Users\FredricRaab\Documents\Satellites\AMSAT\FoxTelem
USB Errors: 0 / 0 Audio missed: 0.4% / 0 Frames: 20 Payloads: 4631423 Queue: 1


+
Battery-Cell A+B+C Voltage
UTC
Uptime
Continuous
Lines
Points
Hide
AVG
CubeSatSim-FSK
(mA)
+X Panel-Current (mA)
+Y Panel-Current (mA)
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
Uptime 928
Resets 163
952
972
992
1012
1031
1051
1071
1090
1110
1129
Round Labels
Show Sun
Last
40
samples


+
Battery-Cell A+B+C Voltage
UTC
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Lines
Points
Hide
dx
AVG
(mA)
CubeSatSim-FSK
Battery-Current (mA)
PSU-Current (mA)
700
650
600
550
500
450
400
350
300
250
200
150
100
50
Uptime
Resets
1291
163
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 PRofiles Program RadioCommand Help
Sync RX History TX Template
RX Mode
Auto
Robot 36
Robot 72
AVT 90
Scottie 1
Scottie 2
ScottieDX
Martin 1
Martin 2
SC2 180
1200 1500 1900 2300
Log
Call His 595 My
Name Qth
Note
QSL RxID TxID
QSO Data Find Clear List 14.230
Lock ReSync Auto history
DSP
AFC LMS
S.pix S.templates 1 2 3 4
Show with template Draft 2/17

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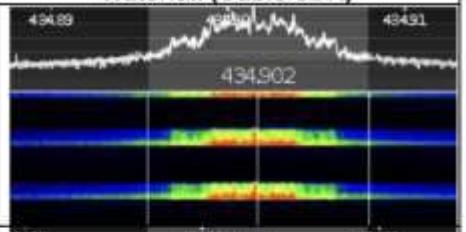
| 1 | APRS | Automatic Packet Reporting System. This digital mode sends a packet of data with AFSK or Audio Frequency Shift Keying modulation. | Windows: SoundModem or Direwolf<br>Raspberry Pi/Linux: OpenWebRX or Direwolf<br>with spreadsheet<br>http://cubesatsim.org/telem | `config -a` | CubeSatSim.org/a |  |
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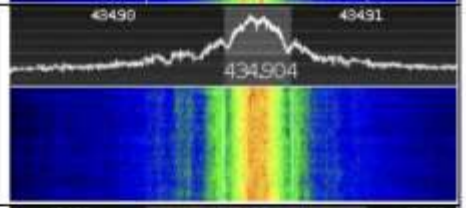
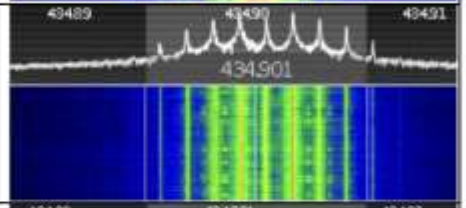
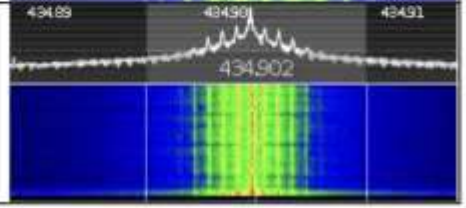
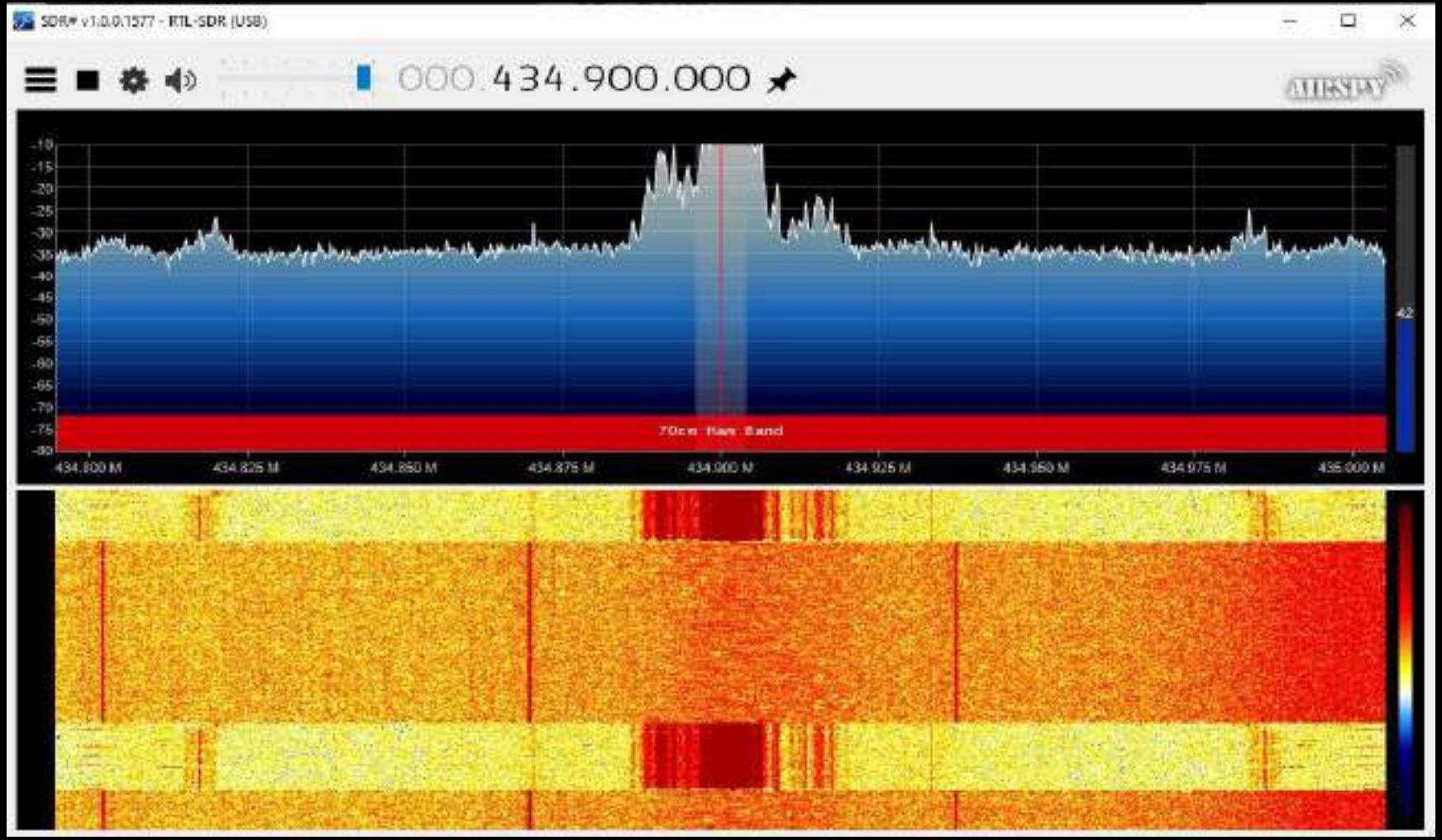
| 3 | BPSK | Binary Phase Shift Keying. This mode transmits a continuous signal that sounds like noise that emulates the AMSAT Fox-1E or HuskSat-1 CubeSats. You need to demodulate using USB. | Windows/Raspberry Pi/Linux: FoxTelem | `config -b` | CubeSatSim.org/b |  |
| 4 | SSTV | Slow Scan TeleVision. This mode transmits stored images in Scottie 2 format which sounds like a series of tones. | Windows: MMSSTV<br>Raspberry Pi/Linux: QSSTV | `config -s` | 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 | `config -m` | CubeSatSim.org/m |  |


SDR# v1.0.0.1577 - RTL-SDR (USB)
000 434.900.000
70cm Ham Band
434.800 M
434.825 M
434.850 M
434.875 M
434.900 M
434.925 M
434.950 M
434.975 M
435.000 M