Education and CubeSatSim Project Update

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AMSAT Space Symposium 2025

Topics

- CubeSatSim Team
- What is a CubeSatSim?
- CubeSatSim Technical Details and Telemetry
- CubeSatSim in the Classroom, at Events, in the Journal, etc
- New Activity Guides
- FunCube mode and Cross Band Repeater Demo
- Get Involved
- Q & A
- Acknowledgements

Core CubeSatSim Project Team

Fredric Raab, KK6NOW

Mark Samis, KD2XS

David White, WD6DRI

Thank You!

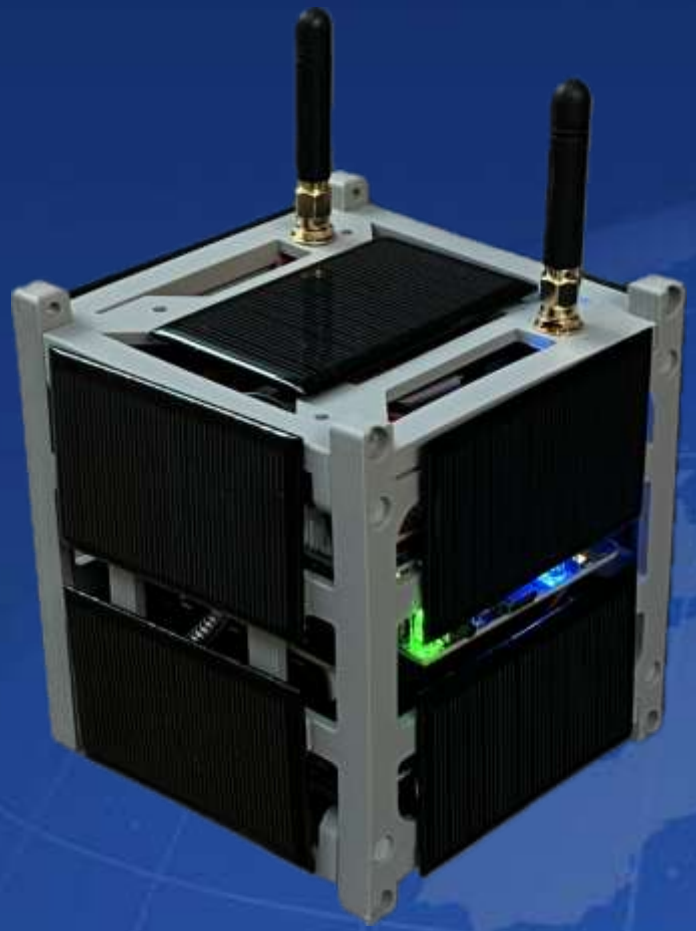
What is a CubeSatSim?

- It is the core of an education program to evangelize the science and technology used in radio satellites.
  - University engineering programs
  - Amateur radio community
  - STEM programs
  - Libraries, Museums, Maker Faires, etc.

Fully open source hardware and software!

What is a CubeSatSim?

- A low-cost satellite emulator that runs on solar panels, batteries, and transmits UHF radio telemetry

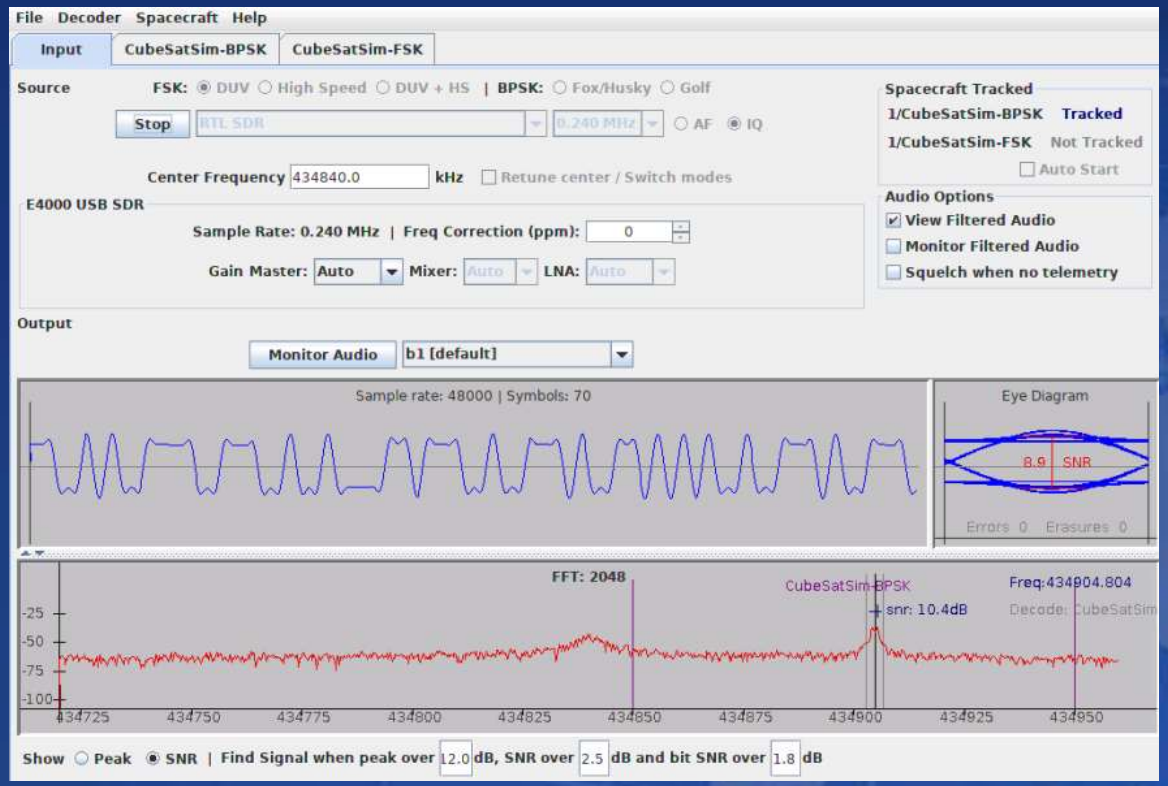


What is a CubeSatSim?

- Uses a custom 3-board stack plus Raspberry Pi Zero 2 and a Raspberry Pi Pico microcontroller, rechargeable batteries, voltage/current sensors, and environment sensors.

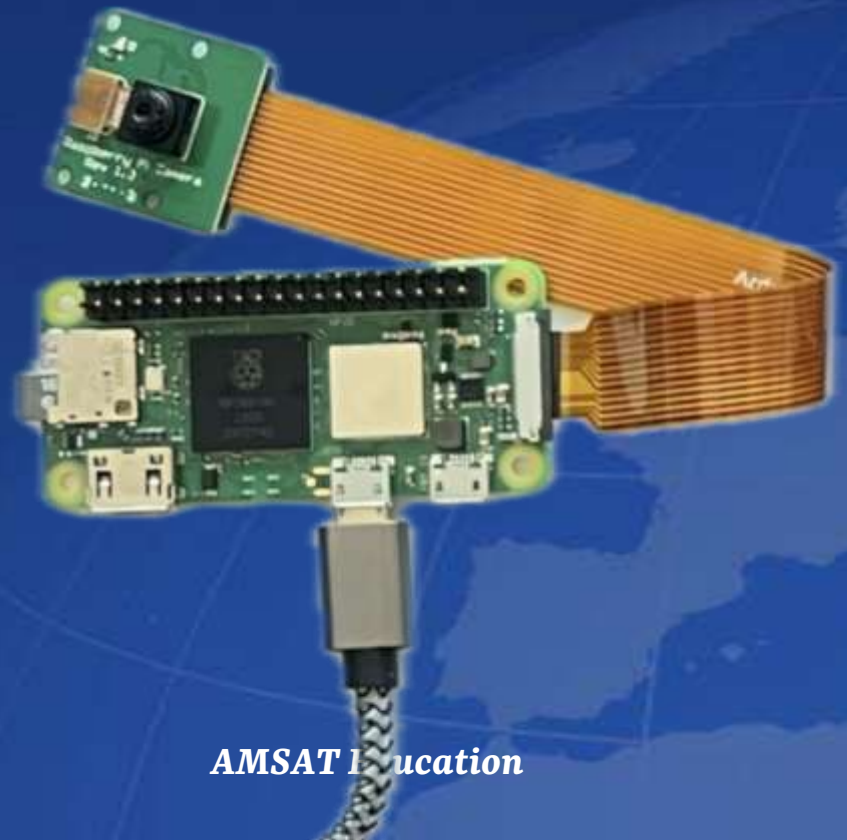
What is a CubeSatSim?

- Transmits 70cm amateur band UHF radio housekeeping telemetry to a ground station in multiple formats - describing the operational location/health of the satellite.



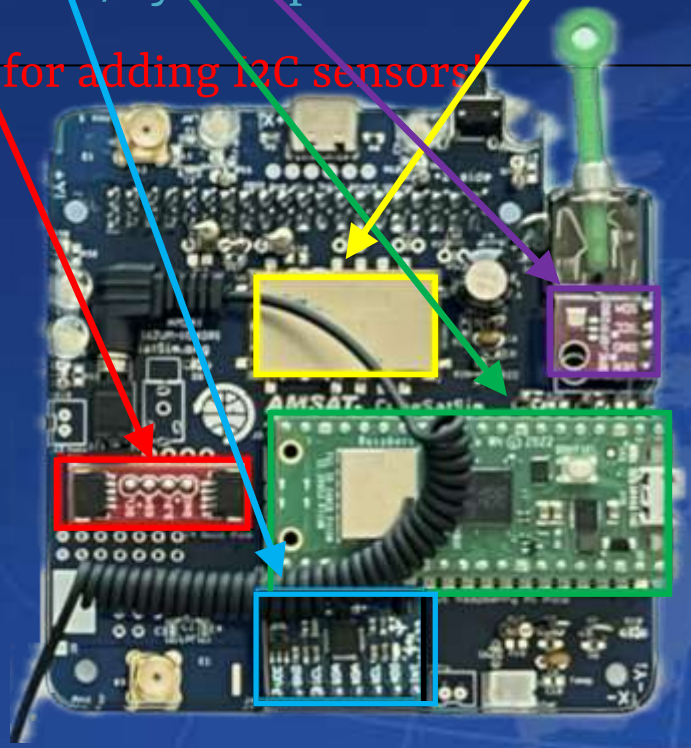
Technical Details

- Raspberry Pi Zero 2
  - Runs housekeeping software: C, Python
  - Has Pi Camera and USB Sound Card



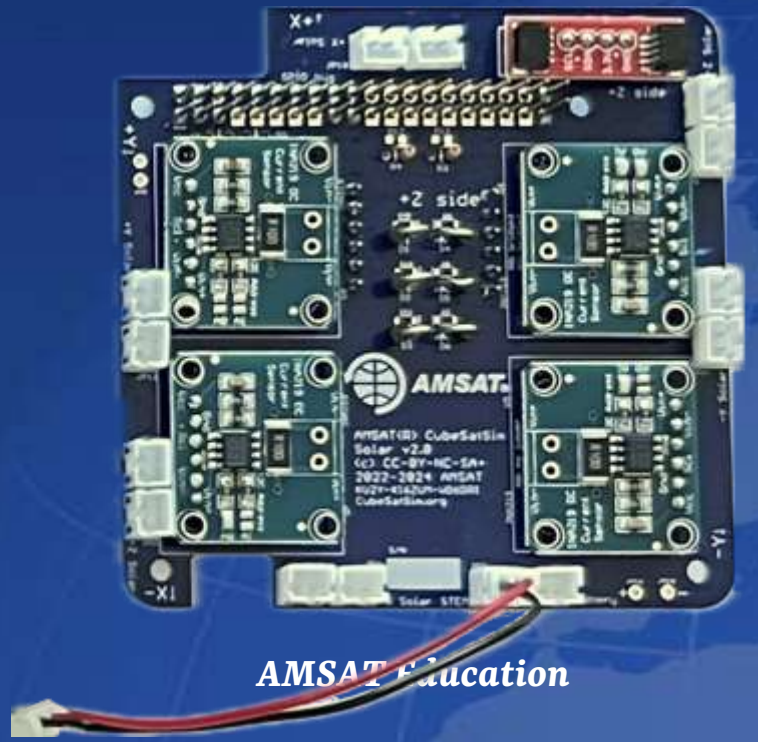
Technical Details

- Main Board
  - Raspberry Pi Pico W microcontroller and FM transceiver
  - **Temperature/Pressure/Humidity Sensor BME280**
  - 3-Axis Accelerometer/Gyroscope MPU6050
  - Qwiic connector for adding I2C sensors!



Technical Details

- Solar Board
  - 6 INA219 Voltage/Current Sensors – one for each side Solar Panels
  - Solar panels plug into JST 2.0 connectors
  - Uses low cost solar panels ($1.50/panel)



Technical Details

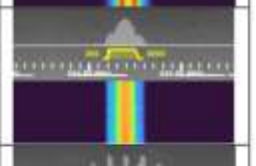
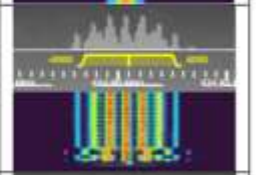
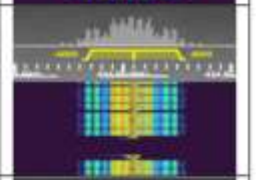
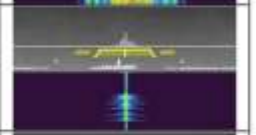
- Battery Board
  - 3 AA Nickel Metal Hydride (NiMH) Batteries for safety
    - New improved 2800 mAh PRO batteries
  - Includes INA219 current and voltage sensor
  - Charged with solar panels or USB-C cable

Technical Details

- Ground Station
  - Pre-built Software Stack (Fox-in-a-Box v4 Beta)
    - Now works on Pi 5 Bookworm
  - Or, install on your own PC

- Software:
  - FoxTelem
  - Direwolf
  - QSSTV
  - OpenWebRX
  - **SDR++ (new!)**
  - CubicSDR
  - RTL-TCP
  - Gpredict
  - KLATracker

Technical Details

Blinks	Mode	Description	Decoding	Command	Audio	Waterfall(WebSDR)
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	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	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 CubeSat. You demodulate using USB.	Windows/Raspberry Pi/Linux: FoxTelem	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 Raspberry Pi/Linux: QSSTV	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	m	CubeSatSim.org/m	
6	Cross Band Repeater	Simulates a U/V (UHF uplink, VHF downlink) FM satellite repeater. Default uplink is 435 MHz and downlink is 144.9 MHz.	OpenWebRX	e	CubeSatSim.org/e	
7	Fun Cube	FUNcube simulates the BPSK telemetry of the FUNcube series of CubeSats such as AO-73.	Raspberry Pi: FUNcube Telem	j	CubeSatSim.org/j	

- Telemetry Modes
  - APRS (Automatic Packet Reporting System)
  - FSK (Frequency Shift Keying DUV (Data Under Voice)
  - BPSK (Binary Phase Shift Keying)
  - SSTV (Slow Scan TV)
  - CW (Continuous Wave aka Morse Code)
  - **FunCube mode (New!)**
  - **Cross Band Repeater (New!)**
    - U/V FM

Recent CubeSatSim Improvements

- CubeSatSim v2 hardware and software released in 2024 as v2.0
- Software v2.1 released in 2025 adding:
  - New FunCube telemetry mode
  - New Cross Band Repeater mode
  - Improved Command and Control (C2C)
- Beta v2.2 testing underway
  - Improved simulated telemetry
  - Support for BME and MPU sensors attached to Pi Zero
  - Simulated failures

Kits, Kits, and More Kits!

- We now have no-solder CubeSatSim kits available periodically at Hamvention and on the AMSAT Store
    - 1-2 hours of assembly, no soldering!
- Price increase due to tariffs
- 100 produced so far!
    - 40 in 2024
    - 40 so far in 2025 plus 20 for ARRL Teachers Institute
    - https://CubeSatSim.org/kit
- **Look for AMSAT News Service announcement on the AMSAT BB mailing list for next batch**

Loaner Kits

- Thanks to grant from Quarter Century Wireless Association (QCWA)
- Has a Pi Ground Station, turntable, LED lamp, and Kit parts
- Receive as no-solder kit, return assembled
- Trialed by students of the San Diego area Mount Carmel High School Amateur Radio Club (MCHSARC) club sponsor, teacher John Earnest, KG6EQU
- **Available to anyone who wants to take into a classroom or build as a group**

Project Partnerships

- ARISS
  - SPARKI (ARISS Radio Pi)
  - STAR (Lite - see later slide)
- ARRL
  - Teachers Institute (see later slide)
- Science Centers
  - CubeSatSim on display at Cox Science Center and Aquarium in West Palm Beach, FL by Jim Nagle, KF4OD
- **Look for more in 2026!**

New Lite v2 Coming Soon

- Single board, size of a Pi Zero
- Plug into a Pi Zero 2 and it generates simulated telemetry in all 7 modes
- Can add BME and MPU sensors via Qwiic connector
- Can add GPS with serial port
- Can do C2C with USB sound card and OTG cable
- Can plug a 3-cell battery with JST connector including full Battery Board
- Can remove attenuator for 0.5 W FM transmission for balloon payload
- **In the AMSAT Store soon!**

ARRL Teachers Institute on Wireless Technology

- ARRL Teachers Institute on Wireless Technology
  - Space Comms and Radio Astronomy course
  - Used 20 kits
    - They soldered the BME and MPU sensors
  - Each teacher built a CubeSatSim and took it home!
  - Very positive feedback from instructors and teachers
- GitHub Discussion board active!
  - Helping troubleshoot
  - Enhancements – new Yaw Pitch Roll – see demo
  - https://github.com/alanbjohnston/CubeSatSim/discussions

ARRL Teachers Institute on Wireless Technology

Photo courtesy of ARRL

ARRL Teachers Institute on Wireless Technology

Photo courtesy of ARRL

New CubeSatSim Quick Start Guides

https://CubeSatSim.org/qsg

Problem Statement

I just built (or borrowed) a CubeSatSim!

What can I do with it?

What are Activity Guides?

- Step by step instructions for how to do a STEM educational activity using a CubeSatSim
- Most work with just a CubeSatSim or Lite
- Some are very easy
  - Listening to the sounds of the different modes on a HT and/or looking at modes on an SDR waterfall
- Some are more challenging
  - Telemetry analysis using FoxTelem

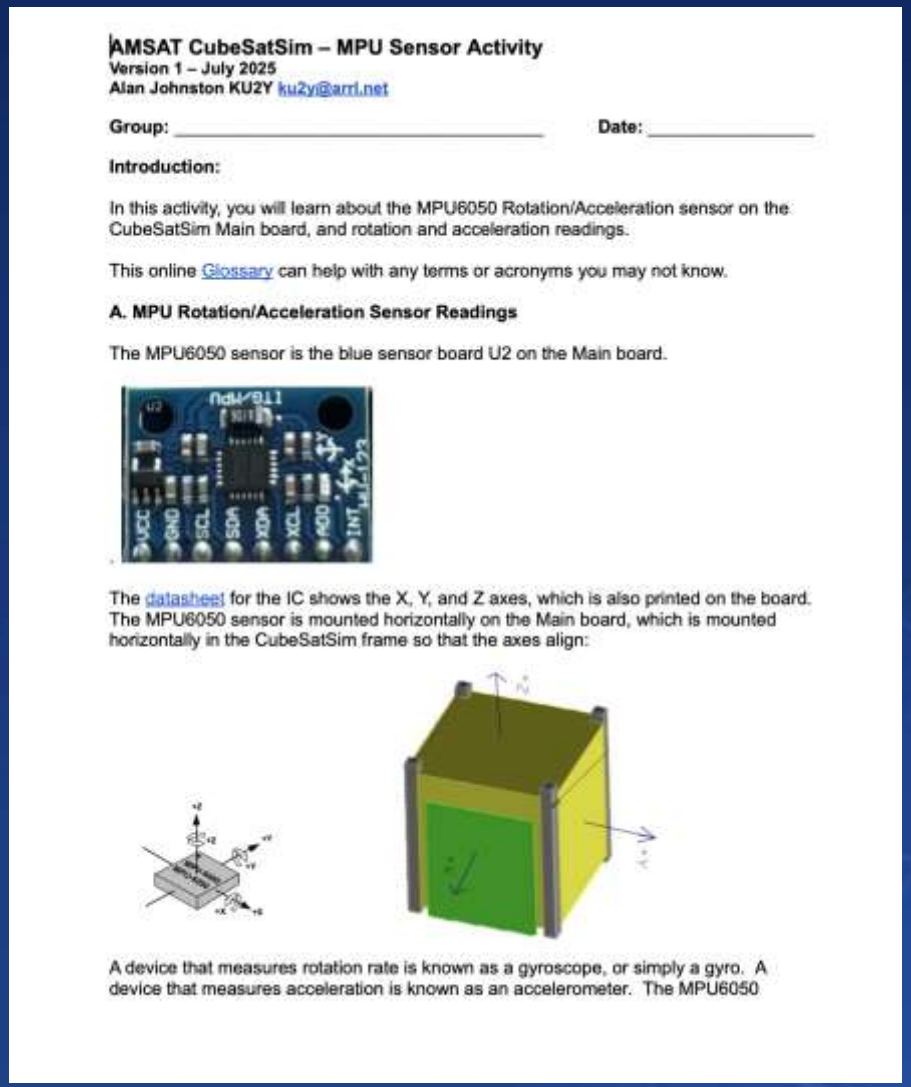
What are Activity Guides?

- Activity Guides include questions
- Instructors Guide has example data and answers to questions
- Released under Creative Commons with Attribution license
    - Teachers can edit and include in their lesson plans

Status of Activity Guides

- They have been under review over the summer
- Published on GitHub now
  - https://github.com/alanbjohnston/CubeSatSim/wiki/CubeSatSim-Activity-Guides
- 10 available now – more in future
- Videos available soon!

List of CubeSatSim Activity Guides



AMSAT CubeSatSim – MPU Sensor Activity
Version 1 – July 2025
Alan Johnston KU2Y ku2y@arrl.net

Group: _____ **Date:** _____

Introduction:

In this activity, you will learn about the MPU6050 Rotation/Acceleration sensor on the CubeSatSim Main board, and rotation and acceleration readings.

This online Glossary can help with any terms or acronyms you may not know.

A. MPU Rotation/Acceleration Sensor Readings

The MPU6050 sensor is the blue sensor board U2 on the Main board.

The datasheet for the IC shows the X, Y, and Z axes, which is also printed on the board. The MPU6050 sensor is mounted horizontally on the Main board, which is mounted horizontally in the CubeSatSim frame so that the axes align:

A device that measures rotation rate is known as a gyroscope, or simply a gyro. A device that measures acceleration is known as an accelerometer. The MPU6050

- Listening Activity Guide
- Telemetry Activity Guide
- Advanced Telemetry Activity Guide
- BME Sensor Activity Guide
- MPU Sensor Activity Guide
- Solar Panel Activity Guide
- Battery Activity Guide
- Troubleshooting Activity Guide
- Group Building Activity Guide
- MQTT Adafruit IO Activity Guide

Example: CubeSatSim MQTT Adafruit IO Activity Guide

- New code on Raspberry Pi Pico W microcontroller so it connects to your WiFi network!
- BME and MPU sensor data is published to the Adafruit IO cloud
  - Uses an Internet-of-Things protocol called **MQTT**
  - Free account at https://adafruit.io
  - Instructions to create a call web-based dashboard that is updated in real time
- Shows an alternative way to get telemetry from a CubeSat

CubeSatSim…

in the Classroom

- *Villanova University*, PA Electrical and Computer Engineering Freshman Projects by Alan Johnston, KU2Y and Xun Jao, 6 CubeSatSims built
- *Johns Hopkins University, MD*, Drew Knuth is using CubeSatSims and Lites in a Small Satellite Development and Experimentation capstone graduate class
- *University of Texas at Dallas, TX,* Ron Dang, K5SUS, Kangkook Jee, Jaehyun Park, Agustya Bose organized a satellite workshop at University of Texas at Dallas
    - See Agustya presentation today!
- *Iowa State University, IA* building CubeSatSims in Make to Innovate (M2I) and Cy Sat program, organized by Matthew Nelson

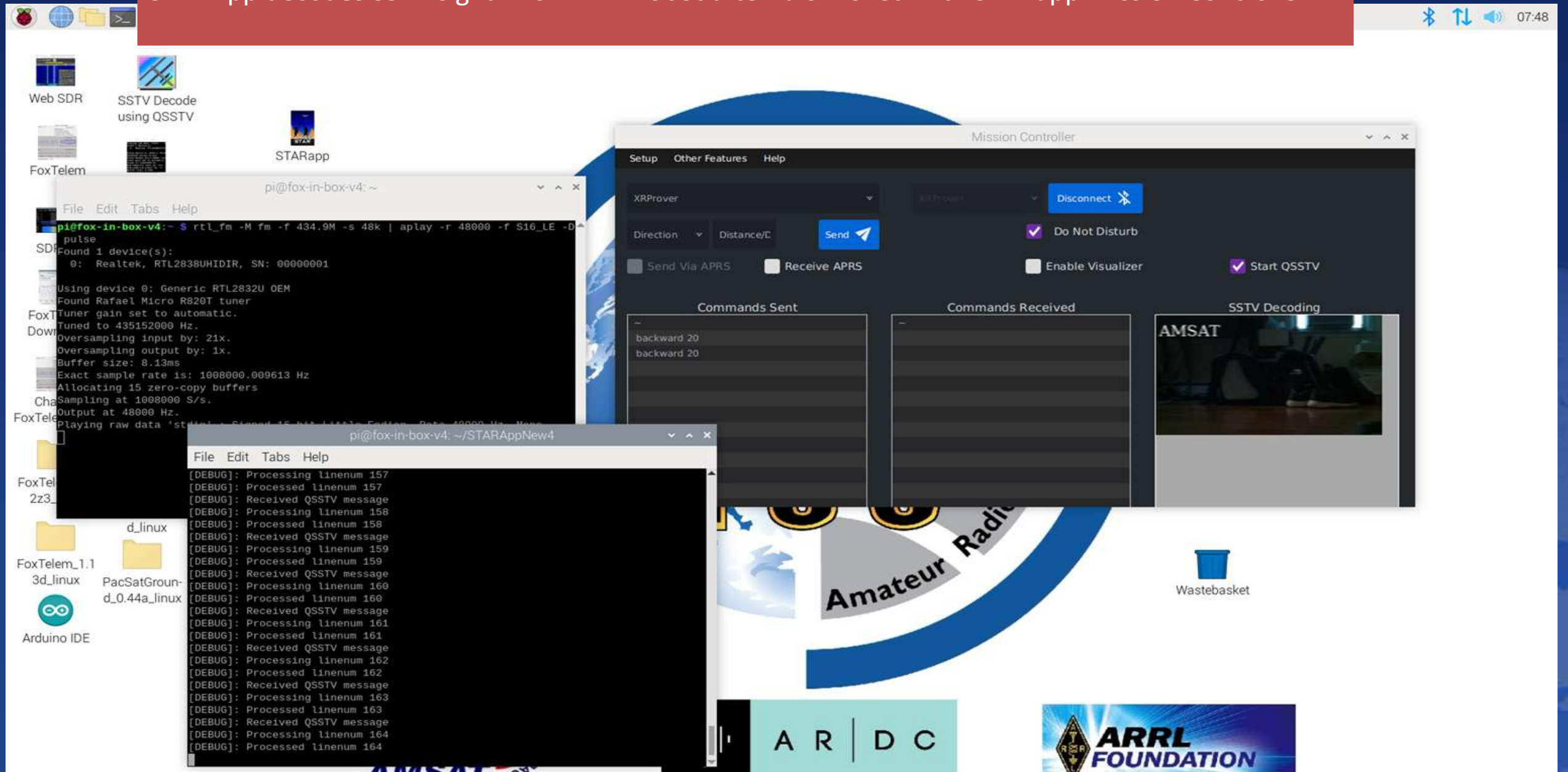
at Events

- *Hamcation 2025, FL* by Dennis Veselka, KI4KNC
- H*amvention 2025, OH*
    - Thanks to Jack Spitznagel, KD4IZ, Carsten Glasbrenner, KQ4SJM, and Dennis Veselka, KI4KNC for running education table
- *Frontiers of Flight Moon Day, TX* by Tom Schuessler, N5HYP and Virginia Smith, NV5F with 2U loaner
- Don Rhodes, KB2YSI, borrowed one in May and organized an AMSAT table at the Cheanago Valley Amateur Radio Association Hamfest NY
- Rusty Moore K1FVK Field Day NC
- Garth Likens and Nick Pugh, K5QXJ, multiple events for CAPE Satellite Program, University of Louisiana at Lafayette

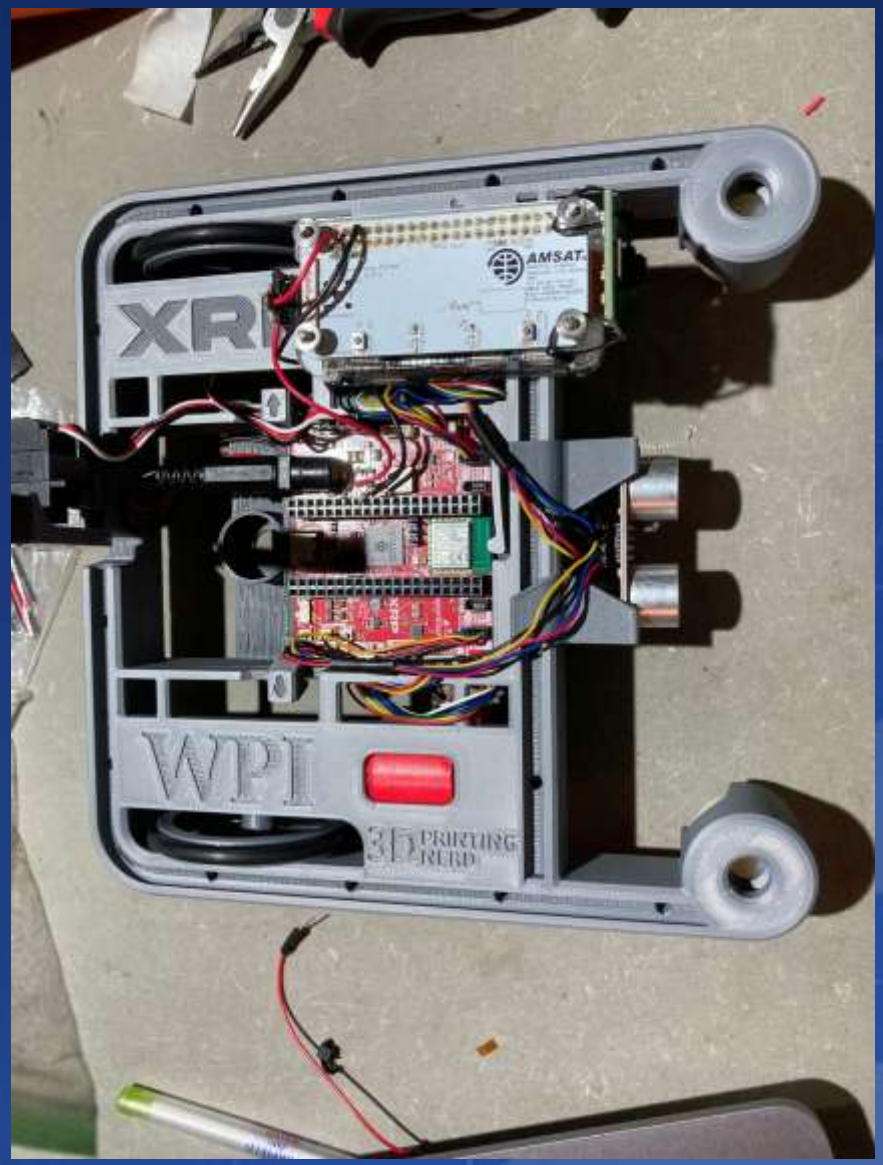
CubeSatSim and the ARISS STAR Program Update

- We continue to work with ARISS on the STAR Project (Space Telerobotics with Amateur Radio).
- We provide SSTV and telemetry from a CubeSatSim Lite attached to the top of an **XRP rover.**
- The XRP is controlled from an ARISS Pi ground station with a new STAR app which now hosts the SSTV images broadcast from the rover.
- The XRP rover can receive commands sent via APRS or from other locations on the Web via MQTT that are passed to the STARApp's Mission Controller
- The CubeSatSim Lite can receive commands via APRS, DTMF or directly from the ARISS Pi.
- The CubeSatSim Lite can also operate as a cross-band repeater as it sits on top of the XRP

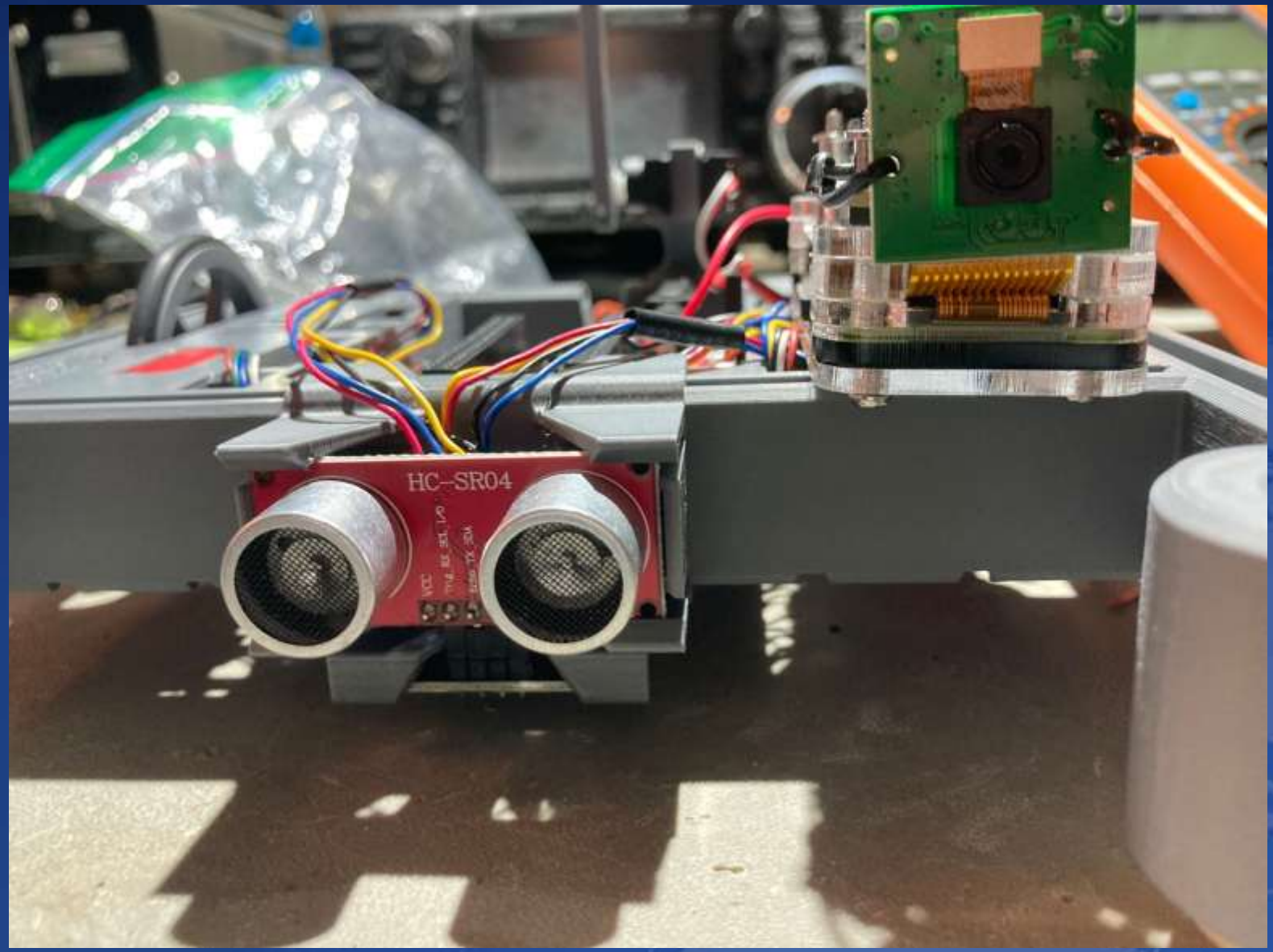
STARApp decodes SSTV signal from XRP Robot after it is moved with STARapp Mission Controller



CubeSatSim Lite and Camera attached to the top of XRP Robot. A separate battery supply is positioned in the back of the XRP to power the CubeSatSim.



View from the front of the XRP showing the CubeSatSim Lite with camera facing forward on the right side of the robot. The XRP's ultrasonic sensors are in the center.



AMSAT Educator's Guide to Using Satellites in the Classroom

https://CubeSatSim.org/EducatorsGuide

- Preface
- Introduction by David A. Vine, WA1EAW
- AMSAT® CubeSatSim Project Wiki
- CubeSatSim Quick Start Guide
- Ground Station Quick Start Guide
- Cross Band Repeater Quick Start Guide
- Command and Control Quick Start Guide
- CubeSatSim Activity Guides
- AMSAT Youth Initiative Update
- AMSAT Education and CubeSat Simulator Update
- Bridging Orbit and Classroom: SatNOGS and CubeSatSIm
- New CubeSatSim Features and Capabilities
- Building AMSAT CubeSatSims in the Classroom
- CubeSatSim YouTube Playlist Links
- AMSAT CubeSatSim Glossary
- Radio Amateur Satellite Corp. Strategic Plan - 2021-2031
- Join AMSAT

CubeSatSim v2.1 New Modes

Ready for the Demo?

Get Involved with the CubeSatSim Project

- Borrow a CubeSatSim Loaner
  - AMSAT members can borrow a loaner to show at an event or in a classroom
  - Teachers can also borrow a loaner – contact me!
- Borrow a Loaner Kit
  - Available now for classrooms or other group activities
- Build a CubeSatSim
  - Fully open source – about $400 to build

Questions?

Contact Alan at ku2y@arrl.net

https://CubeSatSim.org

https://www.amsat.org

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

Acknowledgements

- Thanks to Mark Spencer, WA8SME, for his trailblazing work on CubeSat simulators for the ARRL and to Bob Bruninga, WB4APR (SK), 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.
- 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.

CubeSatSim Block Diagram v2.0