

AMSAT Education and CubeSat Simulator Project Update

ALAN JOHNSTON, PhD, KU2Y
Vice President, Educational Relations, AMSAT
Associate Teaching Professor, Villanova University,
Electrical and Computer Engineering Department
ku2y@arri.net

Abstract- The AMSAT CubeSatSim, the CubeSat Simulator, is a small, low cost, spacecraft simulator that serves as a tool for academic education, public demonstrations and theory and design disciplines. It can be used in a classroom, lab or training setting to introduce the basics of satellite operations, or it can be used to teach STEM (Science, Technology, Engineering, Math) exercises. This article gives an update on the CubeSatSim Project up to October 2025 since the last AMSAT Space Symposium. The update includes classroom activities, events, academic papers, and overall project status.

Overview

The AMSAT CubeSatSim model is shown in Figure 1. The AMSAT CubeSatSim, or CubeSat Simulator, is a Raspberry Pi Zero-based, 3D printed, functional model of a 1U form factor CubeSat. It is designed to act, as reasonably as possible, as one flying in Low Earth Orbit (LEO) to demystify how satellites work. The construction plans and software are fully open sourced, and information about building one is available at <https://CubeSatSim.org>. Like real LEO satellites, this simulator is self-powered through onboard rechargeable batteries and solar panels. It transmits wireless telemetry on the amateur radio UHF band in a variety of formats.

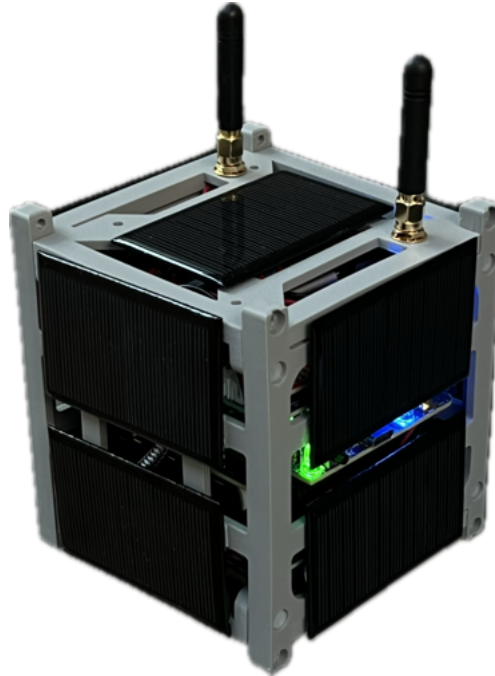


Figure 1. The AMSAT CubeSatSim

The CubeSatSim has three custom PCBs and a Raspberry Pi Zero 2 in the board stack as shown in Figure 2.

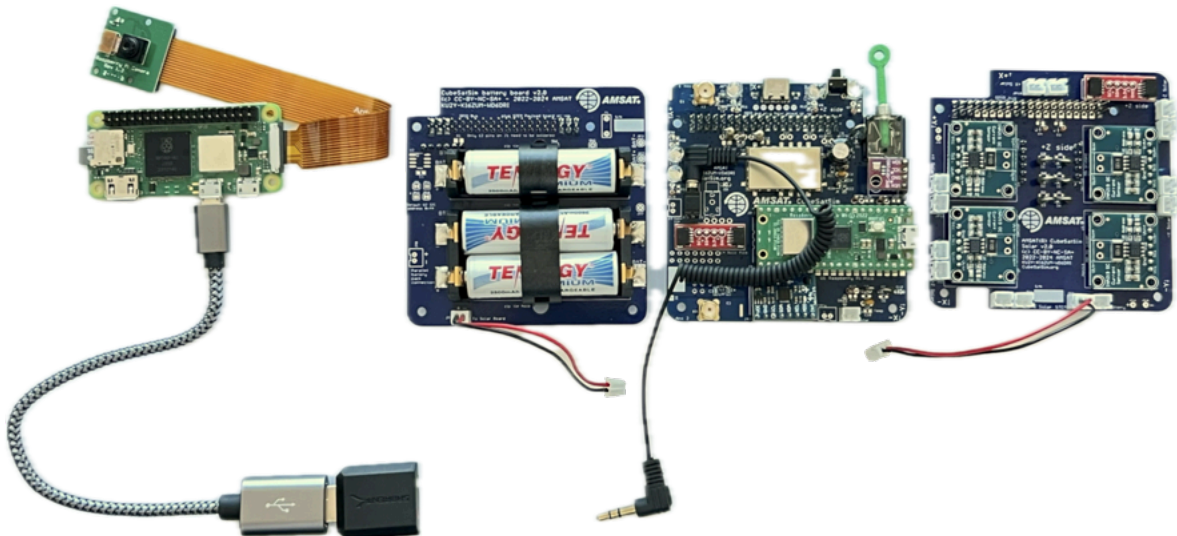


Figure 2. The CubeSatSim Beta v2 boards: From left to right, Pi Zero 2 with Pi Camera and USB sound card, Battery board, Main board, and Solar board.

The Main board is shown in Figure 3 with the major components labeled. The SR105U FM transceiver module is shown in yellow. The Raspberry Pi Pico WH microcontroller is shown in green. The BME280 Pressure/Temperature/Humidity/Altitude sensor is shown in purple. The

MPU6050 Gyro/IMU is shown in blue. The Qwiic connector for adding new sensors is shown in red.

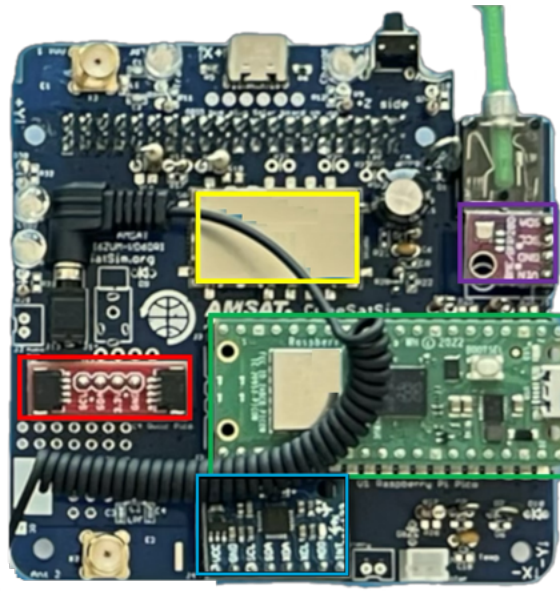


Figure 3. Main Board showing the components.

Table 1 shows the seven telemetry modes of the CubeSatSim and the decoding software used for that mode.

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: fidiqi with spreadsheet http://cubesatsim.org/telegram	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	

Table 1. CubeSatSim Telemetry Modes.

The current version of the CubeSatSim PCBs is v2.0 which are available at the AMSAT Store and were also available at Hamvention. Raspberry Pi CubeSatSim SD cards and Fox-in-a-Box SD cards are also available on the store. These are 16 GB micro SD cards with the software pre-installed and configured.

There is also an active Discussion Forum on Github for the CubeSatSim which you can access with this URL: <https://github.com/alanjohnston/CubeSatSim/discussions>

The full project acknowledgements are at the end of this paper, but the key core CubeSatSim team members are:

Fredric Raab, KK6NOW
Mark Samis, KD2XS
David White, WD6DRI

Their contributions on a weekly basis to this project cannot be overstated. Without their help in fulfilling orders, testing and putting together kits, and testing and verifying every hardware and software update, this project would not be as successful as it is.

This article gives an update on the CubeSatSim Project up to October 2025 since the last AMSAT Space Symposium.

Recent Improvements

The pace of development in 2025 was similar to 2024 with several new features rolled out. The v2.1 software release added two new telemetry modes: FunCube Mode and Cross Band Repeater Mode. In addition, the Fox-in-a-Box v4 Beta Raspberry Pi Ground Station disk image was also released.

Cross Band FM Repeater Mode

The CubeSatSim Cross Band FM Repeater mode uses the FM transceiver module in receive mode, with the squelch pin read by the Raspberry Pi Zero to detect a transmission. This mode utilizes the USB sound card connected to the Pi Zero 2 with the OTG cable, and the audio jumper from the Main board to the sound card provides the received audio to the Pi Zero. The Pi Zero 2 then connects the microphone input to the rpitx transmitter. One of the CubeSatSim antennas is receiving the UHF signal, the other is transmitting the VHF signal at the same time, just like a real CubeSat with an FM repeater.

The v2.0 software release had a Repeater mode, but you couldn't turn it on and off with the pushbutton, and it was unstable in that the repeater function would stop working and require a

reboot. It also had uplink and downlink frequencies in the UHF band which made reception difficult.

The v2.1 software release has fixed these issues, and moves the downlink to the VHF band. This provides a “U/V” operation with an FM UHF uplink, VHF downlink similar to many AMSAT CubeSats such as AO-91 (RadFxSat / Fox-1B) and AMSAT-UK AO-73 (FunCube).

To try out the Cross Band Repeater Mode, you will need two VHF/UHF FM radios (HTs), or one UHF FM radio and an SDR (such as a Baofeng and an RTL-SDR plugged into a Pi or Computer) or a VHF/UHF transceiver with full duplex (such as an Icom IC-9700). These options are shown in Figure 4.



Figure 4. Radio Options for the Cross Band Repeater Mode: Two HTs, One HT and one SDR, or One Full Duplex Transceiver

In the Cross Band Repeater mode, the CubeSatSim is listening on the default frequency of 435 MHz. When the squelch is broken on that frequency, the CubeSatSim will retransmit the FM signal received at the default frequency of 144.9 MHz. Figure 5 shows the Raspberry Pi Ground Station receiving the VHF downlink signal.

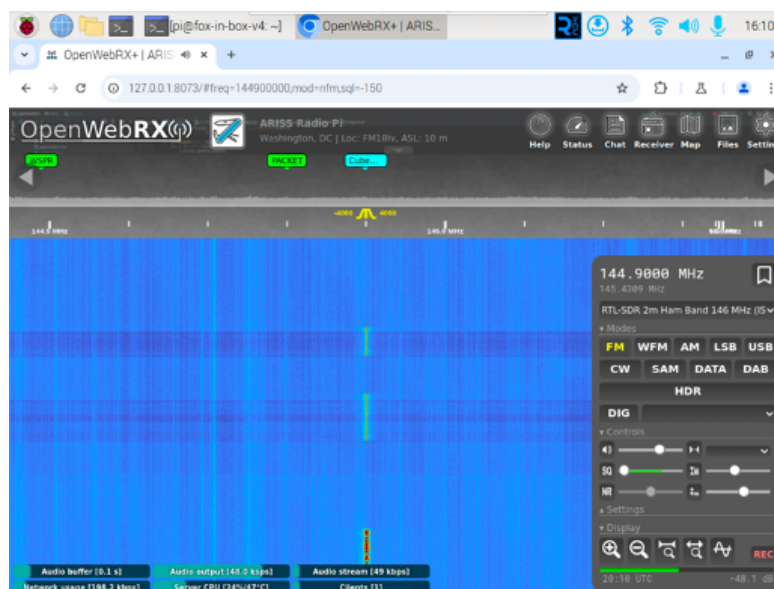


Figure 5. Raspberry Pi Ground Station based on the Fox-in-a-Box image for monitoring the VHF downlink using the OpenWebRX WebSDR.

New FunCube Mode

The CubeSatSim now has a new FunCube Mode 7. This BPSK (Binary Phase Shift Keying) 1200 bps (bits-per-second) transmission mode emulates the AMSAT-UK FunCube CubeSat (AO-73) and several other CubeSats that also use this transmission including Nayif 1 (EO-88), UKube-1, and JY1 Sat (JO-97). The transmission is very similar to the Fox-1E BPSK 1200 bps transmission already supported by the CubeSatSim in BPSK Mode 3. However, it has a different data structure and error correction. Special thanks to Duncan Hills, the lead FunCube Dashboard developer from AMSAT-UK who provided technical details and support to get this code working!

If you listen to this mode, it sounds similar to BPSK, except for every four seconds it sounds like there is a “beep” or tone.

To decode FunCube telemetry, you need a FunCube Dongle (FCDPro or FCDPro+) and decoding software (an RTL-SDR dongle will not work). For the FunCube satellites in orbit, there is a Windows Dashboard for each satellite that decodes the telemetry and uploads the data to the AMSAT-UK Data Warehouse. We don't yet have a Windows Dashboard, but we do have a Raspberry Pi application which will decode it, shown in Figure 6. It is part of the new Fox-in-a-Box-v4 beta image.

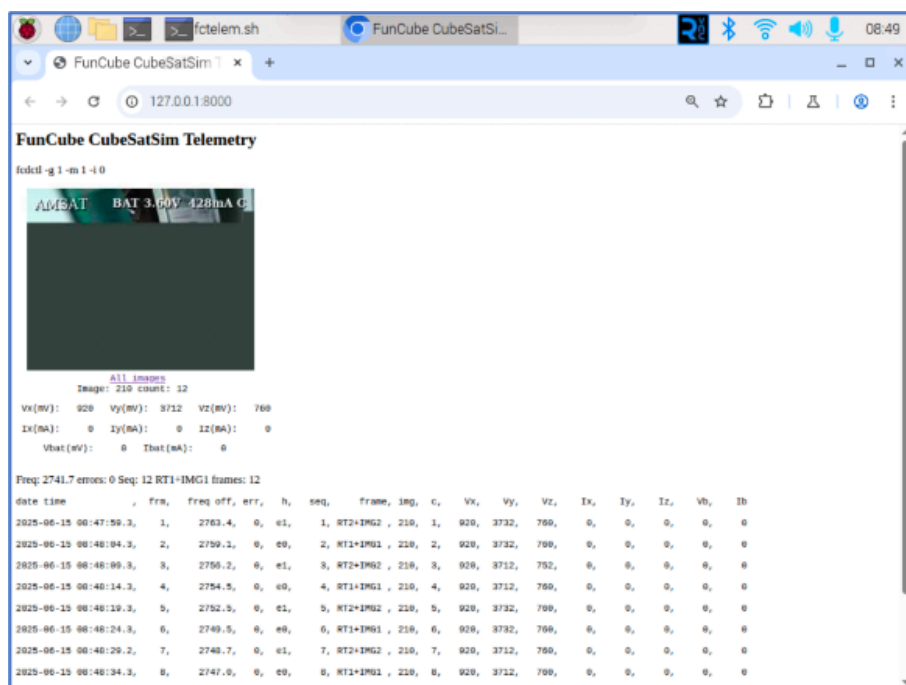


Figure 6. FunCube Telemetry Decoding using a FunCube Dongle on a Raspberry Pi with FIABv4

The telemetry data is a similar format to JY1 Sat (JO-97) with a camera image and telemetry data in each frame.

Unlike the CubeSatSim SSTV mode 4 which uses tones to transmit image pixels in Scottie 2 format, FunCube uses SSDV to encode JPEG images suitable for packetization. It uses the Reed-Solomon codec written by Phil Karn, KA9Q. You can see the image come in block by block, and if a frame is lost, there is a rectangular dropout in the image. Otherwise, the image quality is perfect. This makes an interesting comparison with the analog SSTV Mode 4 in which the image quality degrades as the signal strength decreases.

Fox-in-a-Box v4 Beta Ground Station Software

The Fox-in-a-Box (FIAB) Raspberry Pi disk image has been available from AMSAT for a long time. It has always provided a Raspberry Pi disk image with FoxTelem pre-installed for receiving telemetry from AMSAT's CubeSats, starting with Fox-1A (AO-85) through MESAT1 (AO-122). FIAB runs on a Raspberry Pi with a FunCube or RTL-SDR v3 dongle and an antenna, and can be used to receive, decode, and upload telemetry.

Starting with the FIABv3, the ARISS Radio Pi project was merged with FIAB which not only provided FoxTelem but other satellite and SDR software including:

- Direwolf for APRS decoding
- QSSTV for SSTV decoding
- CubicSDR for general SDR operation
- OpenWebRX as a WebSDR, a minimal configuration web-based SDR interface
- Gpredict for tracking satellites
- RTL-TCP for connecting to an RTL-SDR dongle over the internet
- KLaTracker for monitoring satellite passes
- PacSat a ground station for Packet Satellites

The new FIABv4 Beta image, shown in Figure 7, has all the capabilities of FIABv3 in addition to:

- Improved simulated telemetry providing more realistic data.
- Support for the Raspberry Pi 5
- Support for the RTL-SDR v4 dongle (except in FoxTelem which does not support it yet)
- OpenWebRX+ which adds built in decoders for SSTV and CW modes
- FunCube Telem, a new experimental telemetry decoder for FunCube mode
- SDR++ an open source SDR which has the same user interface in Windows and Mac as on the Pi

As before, the FIABv4 image is available for download so that you can write it to a 16GB or larger micro SD card. <https://cubesatsim.org/download/fiabv4-beta.iso.zip> It is also available for purchase on the AMSAT Store.

The FIABv4 Raspberry Pi Ground Station software is recommended for the CubeSatSim as it has the FunCube Mode 7 telemetry decoder.

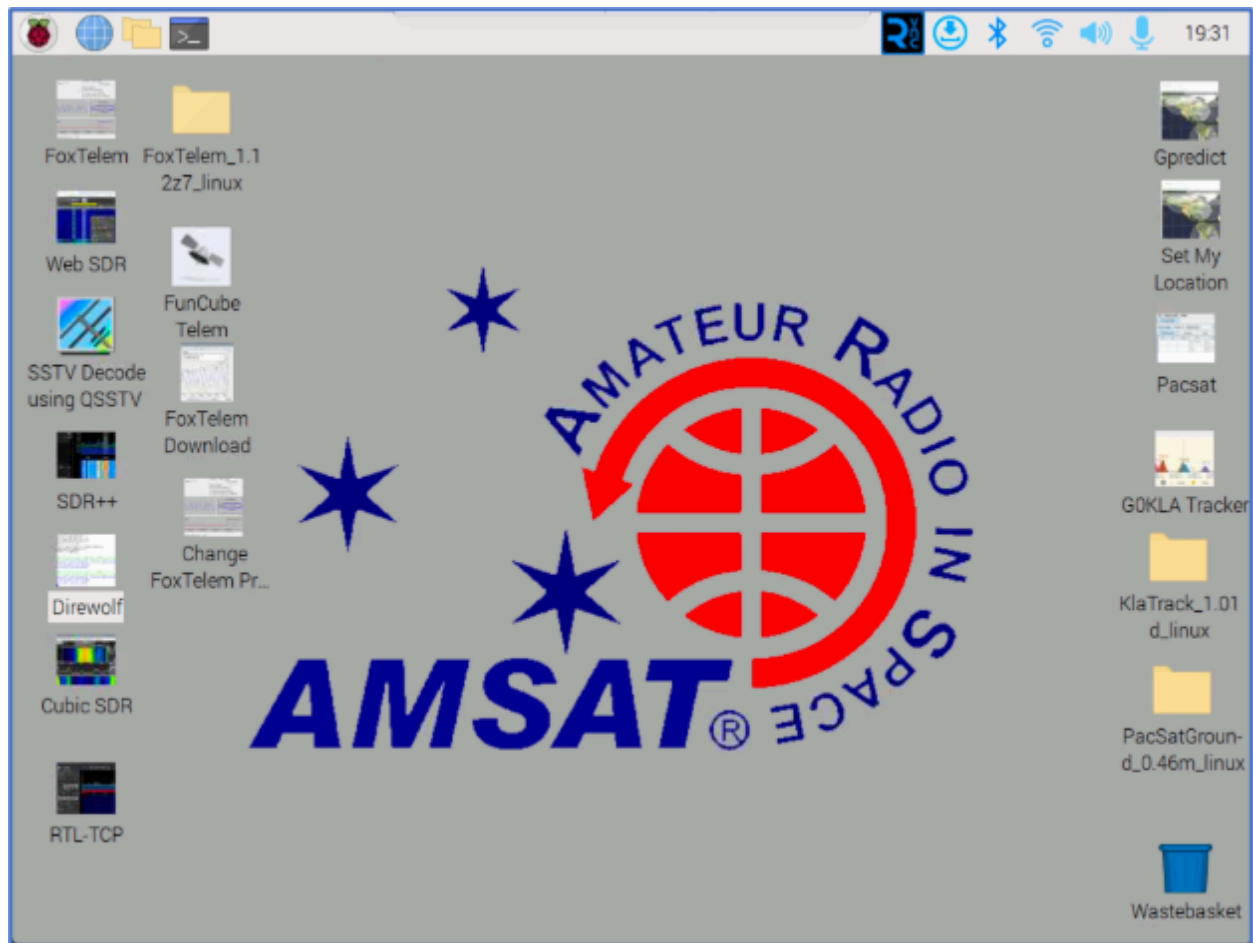


Figure 7. Fox-in-a-Box v4 Beta Raspberry Pi Image

Future Updates

We are also working on a software update for v2.2 which will add these capabilities:

- Improved simulated telemetry providing more realistic data.
- Support for BME and MPU sensors attached to Pi Zero 2.
- Simulated failures.

The ability to simulate 10 different failures which can be detected in the telemetry is a nice new feature.

We are also working on some v2.1 hardware updates. These updates will improve battery charging and will add a PTC resettable fuse to the Main board.

Lite Board

The CubeSatSim Lite board was last available as a beta board in 2022. The new Lite v2 board under development is shown in Figure 8.



Figure 8. CubeSatSim Lite v2 Board.

The Lite board is a minimal board based on the CubeSatSim Main board that plugs into a Pi Zero or Pi Zero 2 and generates all seven telemetry modes with simulated telemetry. It can also be run on a battery, but does not have a built-in charging circuit. It does not have a Raspberry Pi Pico microcontroller, but using the Qwiic connector, a BME and/or MPU sensor can be added, along with a GPS module. With the addition of a USB sound card connected to the Pi Zero with an OTG cable and an audio jumper wire, it can support Command and Control (C2C). Finally, if the RF attenuator is disconnected, the 500 mW FM transmitter can be used as a high altitude balloon payload.

Look for the Lite board to be in the AMSAT store in early 2026.

Quick Start Guides

Besides the basic CubeSatSim Quick Start Guide, there are now three other single page guides. They are shown in Figure 9 and include Ground Station, Cross Band Repeater, and Command and Control. The Quick Start Guides are available at <https://CubeSatSim.org/qsg>



Figure 9. CubeSat Sim Quick Start Guides including Ground Station, Cross Band Repeater, and Command and Control.

Activity Guides

In 2025, we released the first set of CubeSatSim Activity Guides.

The problem statement for the Activity Guides is as follows:

I just built (or borrowed) a CubeSatSim. What can I do with it?

Activity Guides are step-by-step instructions for how to do a STEM educational activity using a CubeSatSim. Most work with just a CubeSatSim (or even just a Lite). Some are very easy to do, such as listening to the sounds of the different modes on a HT and/or looking at modes on an SDR waterfall. Others are more challenging such as doing telemetry analysis using FoxTelem.

Activity Guides include questions for students to answer as they do the activity. Each also has an Instructors Guide which has example data and answers to the questions.

The CubeSatSim Activity Guides are released under a Creative Commons with Attribution license so anyone can edit and modify them as long as they indicate they were originally developed by AMSAT. This allows teachers to customize them and include them in their lesson plans.

They have been under review over the summer - thank you to our reviewers who have provided feedback! The initial set of ten are published on GitHub now

<https://github.com/alanbjohnston/CubeSatSim/wiki/CubeSatSim-Activity-Guides> More will be available in the future, and we plan to record videos as well.

Here is the list of the current set of Activity Guides:

- 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

Figure 10 shows the first page of the MPU Sensor Activity Guide.

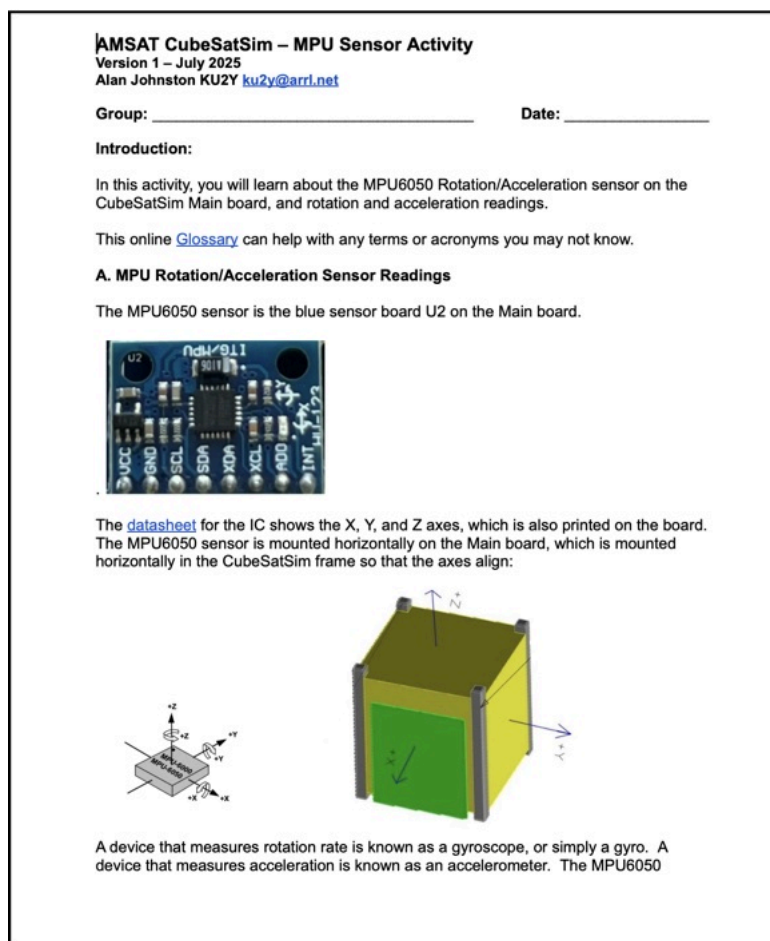


Figure 10. MPU Sensor Activity Guide.

If you have a CubeSatSim, why not give one a try and let us know how it goes.

Educational Outreach

Recent AMSAT educational outreach activities include demonstrations at Hamvention, hamfests, and other events. Loaners and Kits continue to be key to its use in STEM outreach. The CubeSatSim has also been used in college level classes as part of engineering courses. For the first time, it has been used at the ARRL Teachers Institute. Finally, there have been several academic papers and conference presentations about the CubeSatSim.

CubeSatSim Loaners

The CubeSatSim Loaners have continued to be popular throughout the year. A Loaner is a fully assembled CubeSatSim in a hard shipping case with a Raspberry Pi touch screen ground station, LED lamp, and turntable. AMSAT members can borrow a loaner to show at an event or in a classroom. Any teacher can also borrow a loaner – just contact me via ku2y@arrl.net.

CubeSatSim Kits

We also have kits available periodically. So far, 100 kits have been produced. The kit is shown in Figure 11. The kits have all three PCBs fully assembled. No soldering or 3D printing is required. After a few hours of assembly, you will have a working CubeSatSim! This year, some were sold at Hamvention and some on the AMSAT Store. Another batch will be available on the AMSAT Store in the December/January time frame.



Figure 11. CubeSatSim Kit Parts.

We now have two Loaner Kits available thanks to a grant from Quarter Century Wireless Association (QCWA). Each is similar to a Loaner in that it has a Pi Ground Station, turntable, and LED lamp in a hard shipping case. However, the CubeSatSim is in parts as a no-solder kit. It requires an hour or two of assembly to put together the CubeSatSim. The Loaner Kit is returned assembled, then we disassemble it ready for the next loan!

A Loaner Kit was recently trialed by students of the San Diego area Mount Carmel High School Amateur Radio Club (MCHSARC). The club sponsor is teacher John Earnest, KG6EQU. Assembly and demonstration of the CubeSatSim was very successful. Figure 12 shows the students assembling it:

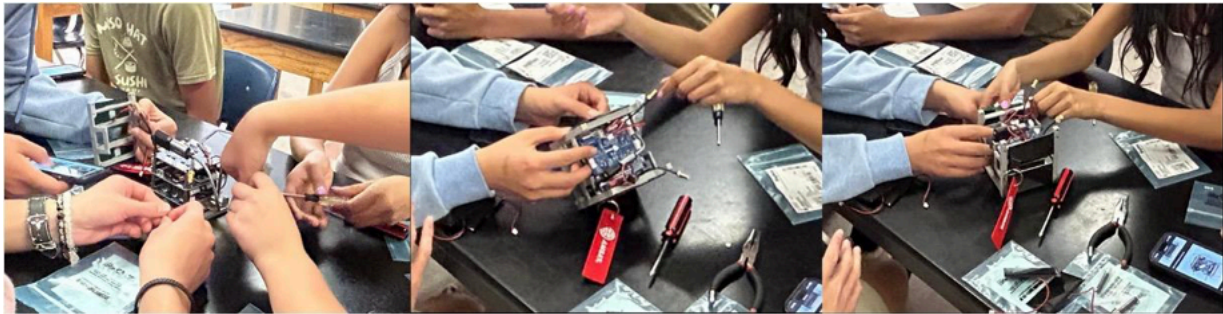


Figure 12. Students of the Mount Carmel High School Amateur Radio Club (MCHSARC) W6SUN radio club building the CubeSatSim Kit Loaner. Photo courtesy of David White, WD6DRI.

The AMSAT CubeSatSim Loaner Kits are available to anyone who wants to take into a classroom or build as a group.

ARRL Teachers Institute

For the first time in 2025, the ARRL Teacher's Institute used CubeSatSim kits in their Space Comms and Radio Astronomy summer class:

<https://www.arrl.org/teachers-institute-on-wireless-technology>

The CubeSatSim team worked closely with Wayne Greene, KB4DSF, and Steve Goodgame, K5ATA, in the spring to put 20 kits together for them to use in two summer sessions of the class. Figures 13 and 14 show some photos from the event.

They spent almost a full day of the weeklong class building and testing their own CubeSatSim. Their kits were very similar to the kits sold on the AMSAT Store except the BME and MPU sensors needed to have pin header soldered on. This provided a review of soldering that they had done in an earlier Teachers Institute class. At the end of the week, they then took the assembled CubeSatSim home, and hopefully will utilize it in their classroom soon!



Figure 13. Photo from ARRL Teachers Institute Space Comms and Radio Astronomy class using CubeSatSim Kits. Photo courtesy of ARRL.



Figure 14. Photo from ARRL Teachers Institute Space Comms and Radio Astronomy class using CubeSatSim Kits. Photo courtesy of ARRL.

ARISS STAR Project

The CubeSatSim is a part of the ARISS (Amateur Radio on the ISS) STAR (Space Telerobotics with Amateur Radio) Project. In SSTV mode with a Pi Camera, a CubeSatSim Lite mounted on the XRP Experiential SparkFun robot rover provides images, as shown in Figure 15. The XRP rover 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.

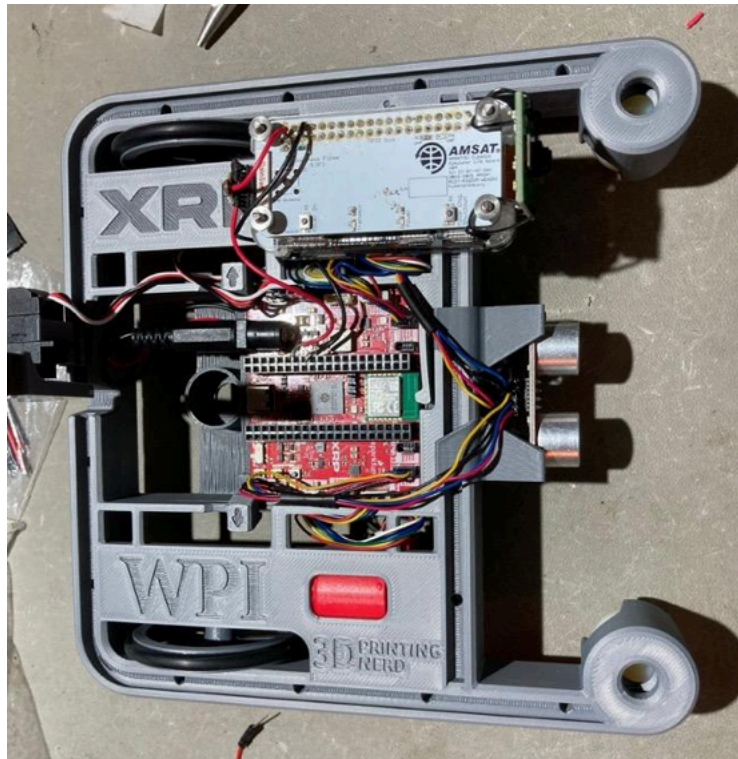


Figure 15. ARISS STAR Project XRP Robot Rover with CubeSatSim Lite with Pi Camera.

CubeSatSim in the Classroom

The CubeSatSim continues to be used in classes at a number of universities and colleges.

At Villanova University, Villanova, PA, students in the Electrical and Computer Engineering Freshman Projects class taught by Alan Johnston, KU2Y and Xun Jao, built and tested 5 CubeSatSims. Four of them are shown in Figure 16.

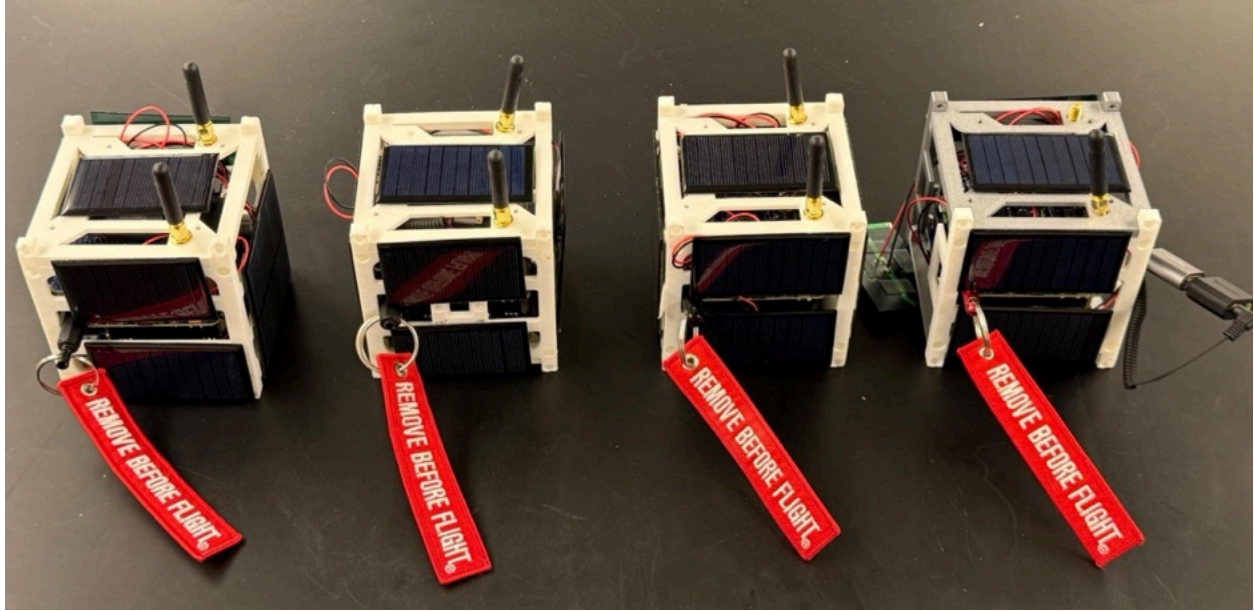


Figure 16. Four CubeSatSims built by Villanova University students in a Freshman Electrical and Computer Engineering Class.

At Johns Hopkins University, Baltimore, MD, Drew Knuth continues to use CubeSatSims and Lites in a Small Satellite Development and Experimentation capstone graduate class. A conference paper on the topic was presented this year - see the CubeSatSim in Academia section below.

At the University of Texas at Dallas, TX, Ron Dang, K5SUS, Kangkook Jee, Jaehyun Park, and Agustya Bose organized another satellite workshop at University of Texas at Dallas where they built and tested CubeSatSims. Here is the workshop website: <https://satworkshop.syssec.org/> See Agustya Bose's symposium paper for more details about this excellent event.

At Iowa State University, Ames, IA Matthew Nelson is planning to build CubeSatSims in their Make to Innovate (M2I) and Cy Sat program.

CubeSatSim at Events

CubeSatSims were utilized at many events in 2025.

In February, the CubeSatSim was shown at Hamcation in Orlando, FL by Dennis Veselka, KI4KNC. Figure 17 shows his excellent display including live FoxTelem on a monitor and multiple CubeSatSims and PCBs.



Figure 17. Hamcation CubeSatSim display showing v1.2 CubeSatSim, v2 CubeSatSim, and blank and soldered PCBs under plexiglass. Photo courtesy of Dennis Veselka, KI4KNC.

In March, a CubeSatSim was displayed at an AMSAT table at the Cheanago Valley Amateur Radio Association Hamfest organized by Don Rhodes, KB2YSI, in New York state.

In April, AMSAT Ambassador Philip Jenkins, N4HF, borrowed a CubeSatSim loaner and showed it at RARSfest, the Hamfest by the Raleigh Amateur Radio Society in Raleigh, NC.

In May, Jack Spitznagel, KD4IZ, Carsten Glasbrenner, KQ4SJM, and Dennis Veselka, KI4KNC, ran the education table at the AMSAT booth and displayed the CubeSatSim and Pi Ground Station.

In June, Tom Schuessler, N5HYP, and his team again ran an AMSAT table at the Moon Day event at the Frontiers of Flight Museum in Dallas, TX. He used a CubeSatSim loaner for an SSTV selfie display.

For ARRL Field Day in June, Rusty Moore, K1FVK, borrowed a CubeSatSim loaner and used it during the day in North Carolina.

In August, John Bews, VK4JBE, showed off his v1.2 CubeSatSim at the “Switch on to Science 2025” event at the Redlands Coast Museum in Brisbane, Queensland, Australia. The table was organized by Bayside and Districts Amateur Radio Society (BDARS).

In October, the AMSAT-UK Colloquium in October will also feature a CubeSatSim demo by Patrick Wood, 2E0IFB.

Garth Likens and Nick Pugh, K5QXJ, showed off a CubeSatSim loaner at multiple events for their CAPE Satellite Program at the University of Louisiana at Lafayette.

CubeSatSims in Academia

Greg Magone received his PhD from Colorado State University, Ft Collins, CO this year with his dissertation “Scalable system architecture for CubeSat test & evaluation for enhanced mission success”. He borrowed a CubeSatSim Loaner during his research and used it as a model to do tests. His dissertation can be downloaded here:

<https://mountainscholar.org/items/52206ea7-01d7-4eea-9bfd-859fe61edc15>

At the Universidad de Navarra, Pamplona, Spain, Juan Lacosta Arpide received his Degree in Telecommunications Systems Engineering with his final thesis project titled "Analysis of a satellite platform based on AMSAT V.1.3.2 for the study of sustainable mobility." He carefully analyzed all aspects of the design of the CubeSatSim Beta v1.3.2, even performing measurements of the range of its transmitters. The thesis can be downloaded here:

<https://dadun.unav.edu/entities/publication/27b99943-dddf-429e-81f8-3b1b6c952182>

Luke Korth, James Gardiner, and Miranda Threewitt published a paper “Building a CubeSat Capstone for Master's Students” at the 2025 IEEE Aerospace Conference in Big Sky, MT. Their paper describes how they redesigned the Johns Hopkins Space Systems Engineering master's program capstone course by its graduating students around the CubeSatSim. The paper is available from the IEEE or from the authors

<https://ieeexplore.ieee.org/abstract/document/11068771>.

Participating in the CubeSatSim Project

You can participate in the AMSAT CubeSatSim Project! Here are some of the ways:

- Document your CubeSatSimulator build and testing on social media
- Offer to demonstrate your CubeSat Simulator to local schools, your ham club, Makerspace or Hackerspace gatherings, or other STEM event

Conclusion

This paper provides an update of the previous twelve months for AMSAT Educational activities and the CubeSatSim Project. Your suggestions and comments on ways to improve the AMSAT CubeSat Simulator project are always most welcome!

Acknowledgements

We would like to thank all the CubeSatSim Project team volunteers:

Jim McLaughlin, KI6ZUM
David White, WD6DRI
Paul Graveline, K1YUB (SK)
Fredric Raab, KK6NOW
Mark Samis, KD2XS
Sopwith, N1SPW
Kerry Bonin, KJ7HTG
Jim Nagle, KF4OD
Virginia Smith, NV5F
Chris Thompson, G0KLA/VE2TCP
Christine Mehner, MD, PhD, KO4EWG
Kai Ji, AC3EN
Melissa Pore, KM4CZN
Lindsay White, KI6LZN
Randy Standke, KQ6RS

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.

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.