Meet the CubeSatSim

AMSAT, ARRL, and ARISS joined forces to help students learn about amateur radio satellite operation.

Mark Samis, KD2XS

The fully assembled AMSAT CubeSatSim. [Photo courtesy of Mark Samis, KD2XS]

In early 2019, I came across the CubeSat Simulator (CubeSatSim) Project Page (**https://cubesatsim.org**), an educational project sponsored by the Radio Amateur Satellite Corporation (AMSAT). It offered detailed instructions on how to build a low-cost, fully functional cube satellite emulator.

Over the years, I had been intrigued by small educational CubeSats and considered building one for myself, but the real, space-ready models were expensive and difficult to assemble. The CubeSatSim, however, being just a simulated satellite, does not need space-certified parts and can therefore be built on a reasonable budget — it uses readily available components, and the four-part frame is available for 3D printing. What's more, it's open source all the way through, with the bill of materials (BOM) and other hardware information, including Gerber files, linked on their project wiki (see **https://github.com/alanbjohnston/CubeSatSim/wiki**). Notably, the device can be considered a true CubeSat, because its hardware and software are compatible with most space-worthy cube satellites.

Building the CubeSatSim

The CubeSatSim uses a Raspberry Pi Zero 2 W for a brain, and it contains sensors for temperature, humidity, pressure, altitude, battery voltage, and current, as well as voltage and current for the six solar panels and three rechargeable batteries that power the device.

The completed simulator uses a handful of printed circuit boards (PCBs), and because the board Gerber files are all available, all I had to do was send the files to a PCB manufacturer — in this case, PCBWay (**www.pcbway.com**) — and within a couple of weeks, I had the assembled boards. I had to buy a minimum of five copies of each PCB, so I planned to assemble several CubeSatSims to give to friends. I ordered the other parts individually, mostly from DigiKey, Adafruit, and Amazon.

An important part of the CubeSatSim Project is the accompanying Ground Station, which receives and decodes all the telemetry and images from the CubeSatSim. The assembled Ground Station uses *FoxTelem*, an open-source AMSAT telemetry decoding software application designed by Chris Thompson, GØKLA/AC2CZ (**www.amsat.org/foxtelem-software-for-windows-mac-linux**), and it includes a Raspberry Pi 4B connected to a software-defined radio (SDR) and a 433 MHz antenna. Detailed assembly instructions are available at **https://github.com/alanbjohnston/CubeSatSim/wiki/3.-Ground-Station**.

I spent quite a bit of time putting the simulator together, and the designer of the project, Alan B. Johnston, PhD, KU2Y, an associate professor of electrical engineering at Villanova University and Vice President for Educational Relations at AMSAT, was extremely helpful and answered all of my questions. His CubeSatSim was based on the original ARRL Education and Technology Program's CubeSat Simulator, designed by Mark Spencer, WA8SME, and published in two parts in *The AMSAT Journal*'s September/October 2009 (**www.arrl.org/files/file/ETP/CubeSat/CubeSat-Pt1-SepOct09.pdf**) and November/December 2009 (**www.arrl.org/files/file/ETP/CubeSat/CubeSat-Pt2-NovDec09.pdf**) issues.

The PCB stack for the no-solder CubeSatSim kit, consisting of a main board, solar board, battery board, and a Raspberry Pi Zero 2 W, assembled during a 2025 ARRL Teachers Institute on Wireless Technology (TI) Space Comms and Radio Astronomy session. [Matt Severin, N8MS, photo]

Surprisingly, building the CubeSatSim from scratch took only a few hours once I received the PCBs. There were no surface-mount devices, because those devices were already mounted on boards. It was all through-hole soldering, with no toroids to wind — if you have ever built a kit with through-hole soldering, you should not have a problem. The construction took about 6 hours in total, spread over 2 days.

The simulator includes three boards: the main board, the solar board, and the battery board. Alan's instructions are very detailed, with great pictures and videos for each board. The main board is exactly what it sounds like — it holds the transceiver chip, one button for mode change, a USB-C connector for power input, myriad LED lights, and a "Remove Before Flight" switch for power on/off. Of course, there are also a few resistors, diodes, capacitors, and the general-purpose input/output pins, which are on all boards as the "backplane" of the entire project.

A Raspberry Pi Zero 2 W running the CubeSatSim software, connected at the bottom of the board stack, is the primary control for all the boards. The main board is by far the most difficult to assemble, simply because it has the most components — it holds sensors that detect temperature, pressure, motion, battery voltage, solar voltage, and current. The battery board is very simple by comparison. The solar board is also simple and very repetitive because it monitors each of the solar panels.

I recommend arranging the components for each board on your work area *around* the board they're intended for, as shown in the directions, and following those directions in the correct order. The final steps are to stack the boards, construct the 3D-printed frame around the stacked boards, attach and mount the solar panels, and do the final tests. The instructions also outline some tests you should do throughout the soldering of each board. Please don't skip those tests; otherwise, it may be difficult to solve any issues found at the end of the construction.

Bringing the Simulator to the Classroom

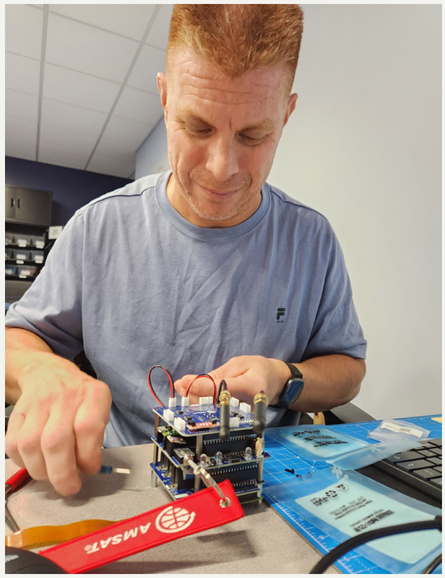
After I built the CubeSatSim and learned as much about the device as I could, I gave it to one of the many science teachers I know to try it out, along with an old VHF/UHF handheld transceiver so he and his students could listen to the signals from the simulator. I explained how he could monitor the current and voltage being produced by each of the solar panels, use the attached slow-scan television (SSTV) camera to capture images, and monitor the transmitter's signal strength both on the Ground Station and on the handheld. He was blown away by the realistic feel of the simulator and the amount of data that it could transmit for reception by the Ground Station, which he assembled in the classroom with his students.

The ARRL Teachers Institute on Wireless Technology (TI) has also included the CubeSatSim in its curriculum. Teachers attending the TI Space Comms and Radio Astronomy class sessions had the chance to assemble the newer, no-solder version of the simulator and perform experiments. The teachers could then bring the CubeSatSim back to their own classrooms and demonstrate the device to their students in turn (for more information about the ARRL TI program, visit **www.arrl.org/teachers-institute-on-wireless-technology**). STEM classrooms in countries around the world have also been working with the CubeSatSim, and AMSAT has been collecting data and reactions from students and teachers to help implement lesson plans for all education levels.

After building my own, I kept up with the CubeSatSim's development progress over the years as new upgrades and features were regularly added. Then, after I retired in 2021, Alan, KU2Y, asked me to join the CubeSatSim Educational Materials Team, alongside David White, WD6DRI, and Fredric Raab, KK6NOW. Since I started on this journey, it has been incredibly exciting to see how many teachers, students, administrators, hobbyists, hams, and scientists have become CubeSatSim evangelists, both across the US and around the world.

CubeSatSim at the ARRL Teachers Institute

Jeremy Montgomery, KD9RUO, attended a 2025 ARRL TI session on the CubeSatSim. After assembling his own, he went on to introduce the simulator to students, parents, and school faculty during aerospace education presentations to Civil Air Patrol (CAP) cadets and the DuPage and Kane County branches of the University of Illinois Extension 4-H STEM Ambassador Club. Here, Jeremy recounts his experience presenting the CubeSatSim:



Jeremy Montgomery, KD9RUO, assembling a no-solder CubeSatSim kit during a 2025 ARRL TI Space Comms and Radio Astronomy session. [Matt Severin, N8MS, photo]

In the CAP presentation, which included approximately 25 cadets and five adults, the CubeSatSim served as an opportunity to discuss space-bound payloads — the design, purpose, and operation. I demonstrated all of the simulator's modes in real time and explained what each one was, including the real-world applications. This was all presented on a large screen using an ARRL-provided Raspberry Pi. I had the simulator situated on a motorized turntable to demonstrate its rotation. This allowed me to explain the power telemetry readings on the CubeSatSim software.

In the two presentations for the University of Illinois Extension 4-H STEM Ambassador Club, the Raspberry Pi 5 and the CubeSatSim software were running on a separate large screen alongside my presentation. The CubeSatSim itself was spinning slowly on the turntable and sending telemetry data for all to see. I had it set to CW mode and had a handheld radio set to the same frequency — when I got to the part of my presentation where I discussed the implementation of the CubeSatSim, the attendees were able to hear CW over the radio. I spent some time discussing what it takes for us to get to this point and how the simulator is put together. First, they learned about the Raspberry Pi as an independent course where they learned the software distribution and how to navigate. Next, they learned about SDRs and their many ways of operation. Then, they put these two lessons together to "hack the sat."

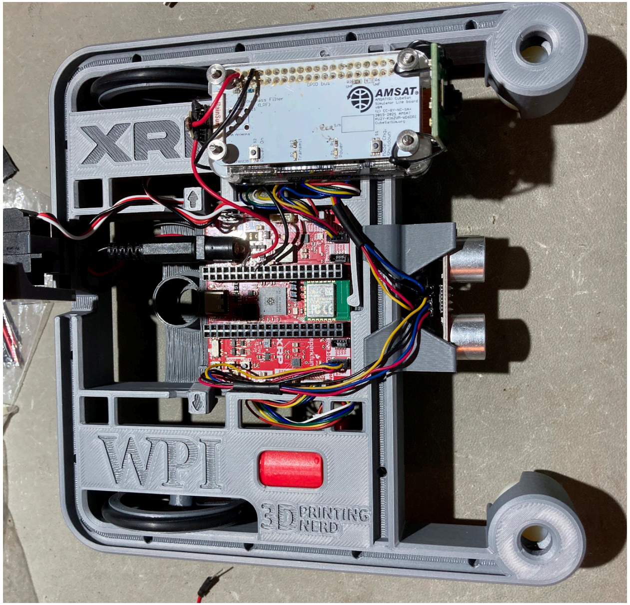
Reactions from students were very positive — they asked a lot of good questions, and they seemed very interested. Many asked how to get their ham radio license, and some students wanted to incorporate the CubeSatSim into their own county and state fair science projects.

Keeping Up with the CubeSatSim

Even though the costs of parts have increased, it is still very inexpensive to build — and, if you don't want to build your own, educators can borrow one from AMSAT to use for classroom demonstrations. The latest CubeSatSim kits offered in the AMSAT Store are solderless and basically just snap together, making for more build options and an easier path to getting your own simulator (**www.amsat.org/product/cubesatsim-kit**). If you intend to build your own from scratch, the BOM is readily available.

The CubeSatSim has been used both in and outside of the classroom with students ranging from middle school to university level — it's even been used as a payload in high-altitude balloons! Our education team is always working on new instructional materials and lesson plans for various grade levels — for ideas on how to use the CubeSatSim in the classroom, see **https://cubesatsim.org/ActivityGuides**. Recent additions to the simulator include a Command-and-Control function that allows hams to send APRS messages from a handheld radio to the CubeSatSim to change transmission from CW to SSTV, for example. The CubeSatSim can now also act as a cross-band repeater and can transmit yaw, pitch, and roll angles.

The CubeSatSim Educational Materials Team has also been working with the Amateur Radio on the International Space Station (ARISS) program's Space Telerobotics using Amateur Radio (STAR) project, an educational initiative where students can remotely control robots via amateur radio to simulate NASA rover operations. The ARISS Pi is a CubeSatSim Ground Station with various radio and satellite software pre-installed, which was designed for ARISS use and accommodates both robotic control of a simulated Mars rover and reception of SSTV images from the rover (see **https://github.com/alanbjohnston/CubeSatSim/wiki/Radio-Pi**). The CubeSatSim Lite,



The ARISS STAR XRP Rover, with a CubeSatSim Lite installed. This device allows students to simulate NASA Mars rover operations; the attached CubeSatSim serves as an SSTV camera, and it can also be used as a cross-band repeater. [Mark Samis, KD2XS, photo]

meanwhile, is a minimalist build of the original CubeSatSim (see **www.amsat.org/product/cubesatsim-lite-complete**) — with its attached camera, it's a perfect addition to the STAR Mars Robot. The CubeSatSim Lite sends images to the ARISS Pi via SSTV, and those images are received within the STAR Mission Control application. The STAR Mars Robot can be controlled directly in the Mission Control application as well as remotely from other ARISS Pi Ground Stations. A licensed amateur radio operator could also control the Robot using APRS commands from a handheld radio.

It is great to see ARRL, ARISS, and AMSAT all working together on these educational projects! With all of these capabilities, the CubeSatSim offers a wide variety of avenues for students, educators, and hobbyists to investigate aerospace science and unpack the same sorts of fascinating data recorded on real spacefaring satellites. Our educational team continues to work on lesson plans and experiments to produce interesting results and memorable experiences, allowing students to explore the marvels of space from the comfort of the classroom.

Mark Samis, KD2XS, is Project Manager for the ARISS STAR Project and a member of the AMSAT CubeSatSim Educational Materials Team. He was first licensed in 1967 as WA2GCS and is a former science and computer teacher and an educational technology administrator. He was also a candidate in the original NASA Teacher in Space Program (1984 – 1986).

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