Fox-1: The New Era of Amateur Radio Satellites

If everything goes as planned, there will soon be a new satellite you can work with nothing more than a handheld FM transceiver and a portable Yagi antenna.

David Jordan, AA4KN, for the Fox Team

Lately, the world of ham satellites has been turned on its head. The price of satellite launches has risen astronomically, so when it comes to building satellites on a shoestring budget, big is out and small is in… and these days, small means *CubeSat*.

A CubeSat looks just like you would imagine — a small, cube-shaped satellite. The CubeSat concept was co-conceived several years ago by Professor Jordi Puig-Suari of California Polytechnic State University along with Professor Bob Twiggs, KE6QMD. Soon universities started building CubeSats as teaching tools, making colleges the new launch customers on the block.

Elizabeth Tracey holding a Fox 1A engineering model CubeSat at the 2014 ARRL National Centennial Convention in Hartford, Connecticut. [Joe Spier, K6WAO, photo]

Introducing the AMSAT-NA Fox CubeSat Program

In 2008, the Radio Amateur Satellite Corporation of North America, better known as AMSAT-NA, was seeking a new direction after cancelling the Eagle satellite project due in part to the rising cost of launches. In October of the same year, newly appointed AMSAT-NA Vice President of Engineering Tony Monteiro, AA2TX (SK), assembled a team with the goal of finding the best options for AMSAT-NA's return to space. They soon agreed that AMSAT-NA could (and should) create a CubeSat, mainly because such a satellite would only cost around $65,000 to launch. The team's findings were presented at the 2009 AMSAT-NA Board of Directors meeting. All agreed to build and (hopefully) launch a number of CubeSats under what is now known as the *Fox Program*.

Noticing the growing interest in CubeSats, and seeing a chance to entice college students to consider seeking careers with NASA, on February 23, 2010 NASA announced the Project ELaNa CubeSat Launch Initiative. This program would give schools a chance at free launches for their CubeSats. By this time, AMSAT-NA was well along in the design of its Fox-1A CubeSat. Noting AMSAT-NA's ability to fly educational experiments along with ham radio modules, Tony petitioned NASA to change ELaNa's qualification rules to include non-profit groups. NASA readily agreed. AMSAT-NA then applied for a "free" ELaNa launch, and in February 2012 NASA selected the Fox-1A.

AMSAT plans to launch a total of four Fox CubeSats in the coming years. All Fox-1 satellites will carry FM voice/low-speed telemetry transponders, plus high-speed (9600 bps) data transponders. Fox-1A will be first, with a launch expected later this year. Along with ham radio, this spacecraft will carry two educational experiments. This flight will be followed by Fox-1C, which AMSAT itself will fund.

Fox-1C carries three student experiments, two of which will initially fly on Fox-1A. The third is a camera provided by Virginia Tech for taking pictures in orbit and downlinking them via an onboard 9600 bps modulator. Fox-1C (and those following it) will have a Maximum Power Point Tracking (MPPT) circuit derived from the design initially developed for the Fox CubeSats by students from the Rochester Institute of Technology, who joined the Fox Team following their graduation. The MPPT is used to optimize the recharging of the satellite's battery pack and enhance its longevity.

RadFxSat (referred to internally at AMSAT-NA as Fox-1B) is being developed by Vanderbilt University in partnership with AMSAT-NA and has already been accepted for an ELaNa launch, probably in mid-2016. Fox-1D will be a backup for Fox-1C if needed. It will also carry an FM transponder and experiments. The Fox-1C and 1D CubeSats will also carry a single-channel

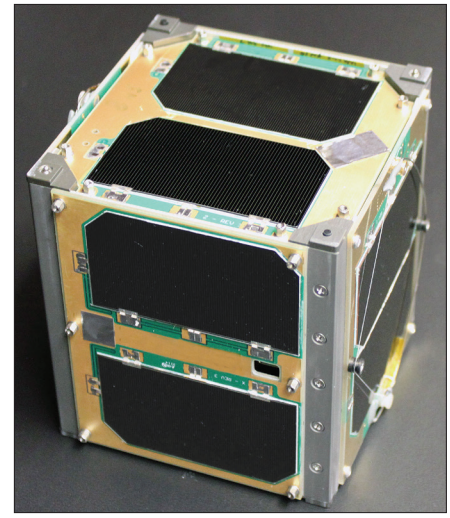


Figure 1 — The Fox-1A satellite is just 4 × 4 × 4 inches and weighs less than 3 lbs. [Jerry Buxton, NØJY, photo]

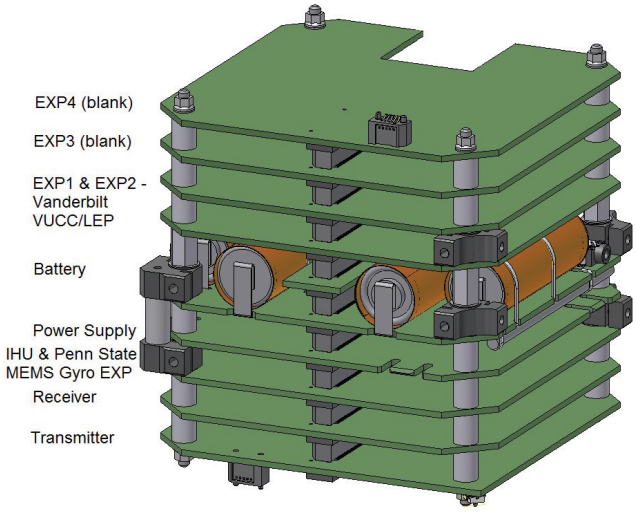


Figure 2 — A Fox satellite has nine vertically stacked printed circuit boards containing a voice repeater, batteries, and various experiments.

FM L-Band uplink that will allow L/V operation as well as U/V operation.If Fox-1C goes well, AMSAT-NA will likely submit an ELaNa launch proposal just for Fox-1D.

When discussing CubeSats, 1U, 2U, 3U, etc. are common terms. 1U stands for 1 unit or one CubeSat, 2U refers to a single CubeSat having the length of two CubeSats and 3U, a CubeSat the length of three, etc. For deployment, a CubeSat is placed in a single ejection housing called a *deployer*. At one end of the deployer is a spring that is depressed as the CubeSat is loaded. A hinged door is closed at the other end to hold the satellite in place. Once the rocket reaches the altitude for orbit, the door is opened and the spring pushes the CubeSat out of the deployer and into orbit. Deployers can be designed to house and launch multiple CubeSats. For the Fox CubeSats, the deployer is called the *P-POD*.

The Fox-1A Satellite

The Fox-1A satellite is a 1U craft with the standard CubeSat dimensions of 4 × 4 × 4 inches and weighing less than 3 lbs (see Figure 1). It has nine vertically stacked printed circuit boards (see Figure 2) containing a voice repeater, batteries, and various experiments, all surrounded by an aluminum housing. Fox-1A will travel in an elliptical orbit at a maximum height of 780 km (485 miles). At this altitude, a pass over the middle US will put coast-to-coast contacts within reach. This should also put Europe in range for hams on the East Coast.

Fox-1A's Antennas

Fox-1A is primarily an FM voice repeater operating in Mode U/V, meaning you transmit to it on the 70 centimeter band at 435.180 MHz and listen on 2 meters at 145.980 MHz. Fox-1A deploys separate "spring wire" antennas for each band. Before launch, the antennas are hand wound into coils and then bound with release cables and mounted flat to the sides of the spacecraft. After the CubeSat reaches orbit, a command is sent to release the antenna bindings, allowing the wires to quickly spring outward to form straight wire whips. With the whips deployed, both antennas become dipoles. The 70 centimeter dipole is created with the shorter wire whip as one half of the antenna while the satellite body forms the other half. The 2 meter dipole consists of another extended whip acting as one-half of the antenna, with the other half being the 70 centimeter whip and the satellite body.

The Power System

The spacecraft is powered by solar panels mounted on its six sides. There are two solar cells per panel, generating an average of 2.7 V each. The panels act as power sources to charge the six-battery, 3.6 V array that is mounted on a printed circuit board seated within the stack. Also included is an active heat control system for damping swings in the battery temperature during orbit. Heat from both the Sun and onboard electronics fluctuates as the satellite orbits the Earth. This active battery heater system acts much like a thermostat, warming the batteries as needed (primarily when the satellite travels through the Earth's shadow). This feature should also help sustain battery life during the mission.

Housekeeping in Space

Satellite operation is managed by the onboard Internal Housekeeping Unit, or IHU. Think of it as the brains of the CubeSat, because its duties include collecting telemetry information, controlling onboard experiments, managing telemetry downlinking to Earth, and handling other jobs to guarantee nominal satellite operation.

The Ham Gear on Board

As mentioned earlier, Fox-1A will have an FM voice transponder. Like a terrestrial FM repeater, the transponder will listen for signals on 435.180 MHz that include 67 Hz CTCSS tones. It will repeat these signals on 145.980 MHz. The 67 Hz CTCSS tone ensures that the satellite's transmitter will only turn on when there are hams around to use it. This saves the battery charge for when the CubeSat is in darkness.

Fox-1A's telemetry reports the health of the spacecraft. This information will be sent continuously over the FM transponder as a sub-audible, 140 bps data stream residing below the voice frequencies at around 200 Hz. There is also a 9600 bps data modulator on board for downlinking telemetry when the low speed data stream is not in operation. The 2 meter transmitter can deliver between 400 and 800 mW to the antenna. To improve receiver performance, the satellite's receiver also has a low-noise preamp.

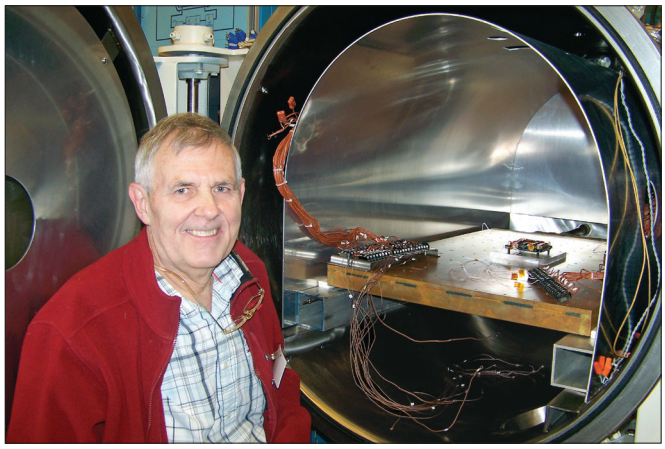
Student Experiments Have a Ticket to Ride

Penn State University — Attitude Determination Experiment

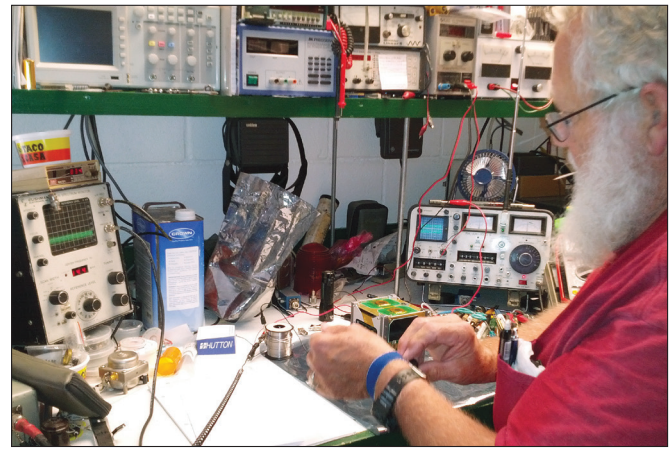
As Fox-1A orbits the Earth, it spins about its Z axis. An internal bar magnet, mounted in one corner of the satellite and pointing in the Z directions, serves to ensure that the spacecraft and its antennas are approximately aligned with the Earth's changing magnetic field. As the satellite spins, there will be some wobble, which the hysteresis bars help to dampen. The whole idea is to steady the antennas to reduce signal fading, and also help regulate radiant heating effects from the Sun.

So with this all in place, we now need a way to continually and accurately monitor any remaining wobble in the system. To do this, the Attitude Determination Experiment (ADE) was developed for the Fox Program by senior engineering students at Penn State University in partnership with AMSAT-NA. The ADE circuit was integrated into the IHU board to save space and weight.

On AMSAT flights in the past, changes in the spinning behavior of the satellites could only be measured by carefully analyzing



Burns Fisher, W2BFJ, with a Fox-1A battery board in a thermal vacuum test chamber. [Burns Fisher, W2BFJ, photo]



The Fox engineering unit being tested by Fox Team member Paul Finch, WB5IDM. [Jerry Buxton, NØJY, photo]

telemetry data and comparing it to corresponding solar panel output levels. The ADE should offer much better data since it uses three-axis, microelectromechanical (MEMS) gyros as sensors to determine the spin rate of the satellite. MEMS will also measure the torquing forces of the craft's stabilizing magnets as they interact with the Earth's magnetosphere to maintain stabilization in the Z axis.

Vanderbilt University — Low Energy Proton Radiation Detection Experiment

To help overcome problems posed by radiation in space, Fox-1A is flying an experiment called the Low Energy Proton Experiment, which was created by students at Vanderbilt University. Ground tests have found that exposure to low-energy protons can degrade static random access memory (SRAM) ICs. Vanderbilt's experiment includes eight 4 MB SRAM ICs storing a known data pattern. Once in orbit, the SRAM memory patterns will be checked after 5-minute exposure intervals for any degradation. The data will then be downloaded to Earth using Fox-1A's high- or low-speed digital modulators. After evaluation by the students, the results will be used to improve current modeling programs.

Using Fox-1A

With a minimum power output of 400 mW, Fox-1A should be easy to work with an ordinary VHF/UHF FM handheld transceiver and a dual-band handheld Yagi antenna. Most VHF/UHF handhelds can only communicate in "half duplex." This means they cannot receive simultaneously while transmitting. A half-duplex rig will be adequate for the Fox satellites, but a "full duplex" transceiver is even better. A full duplex transceiver receives and transmits at the same time. This allows you to monitor the quality of your signal through the satellite so that you can make antenna and frequency adjustments as needed.

As mentioned earlier, Fox-1A will stream digital telemetry. A broadband receiver such as the popular FUNcube Dongle or similar device is all you need to acquire the signals. Anyone will be able to demodulate this telemetry by downloading and installing free software that will be made available at the AMSAT-NA website at **www.amsat.org** prior to the Fox-1A launch.

Needless to say, Fox-1A will be a fabulous addition to science, technology, engineering, and math (STEM) classroom curriculums. A simple ground station is all students will need to study satellite tracking and interpret telemetry to monitor the health of the satellite and observe how radiation affects its operation.

Stay tuned to ARRL News and **www.amsat.org** for updates (including launch information) for the entire Fox series of AMSAT-NA satellites.

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