The AMSAT® Journal

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FT4 Goes to Space!

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000252 10 0.2 1884 + N7ZO WA6DNR +08
000300 Tx 1780 + WA6DNR N7ZO R+10
000307 7 0.1 1885 + N7ZO WA6DNR RR73
000315 Tx 1780 + WA6DNR N7ZO 73
000245 10 0.0 1239 + CQ W5SAT DM26
000326 Tx 1780 + W5SAT N7ZO CN85
000330 10 0.0 1237 + CQ W5SAT DM26
000337 Tx 1780 + W5SAT N7ZO CN85
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000352 Tx 1780 + W5SAT N7ZO CN85
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In this issue —

Periodicals
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AMSAT Announcements

The AMSAT Journal Needs Your Words and Wisdom

The AMSAT Journal is looking for interesting articles, experiences and photos to share with other AMSAT members. Writing for the *Journal* is an excellent way both to give back to the AMSAT community and to help others learn and grow in this most fascinating aspect of the amateur radio avocation.

Find a quiet place, sit yourself down, get out your laptop or pick up a pen, and …

1. *Launch* your inner writer;
2. *Downlink* your knowledge and experiences to others by:
   - Sharing your adventures in the "On the Grids" column or
   - Describing your AMSAT career in "Member Footprints;"
3. *Transmit* lessons learned from operational and technical projects;
4. *Log* some of your more interesting passes across the sky; and
5. *Boost* others to a higher orbit of know-how and experience.

After your article lands in members' mailboxes, and the kudos start arriving for your narrative payload, you can enjoy the satisfaction of knowing you've elevated the collective wisdom of AMSAT to a higher trajectory. Send your manuscripts and photos, or story ideas, to: **journal@amsat.org**.

Our editors are standing by!

AMSAT's Mission

AMSAT is a non-profit volunteer organization which designs, builds and operates experimental satellites and promotes space education. We work in partnership with government, industry, educational institutions and fellow Amateur Radio societies. We encourage technical and scientific innovation, and promote the training and development of skilled satellite and ground system designers and operators.

AMSAT's Vision

Our Vision is to deploy satellite systems with the goal of providing wide-area and continuous coverage. AMSAT will continue active participation in human space missions and support a stream of LEO satellites developed in cooperation with the educational community and other amateur satellite groups.

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Apogee View

Clayton Coleman, W5PFG
President

As the world continues to cope with the COVID-19 pandemic, AMSAT continues to move forward on its mission of Keeping Amateur Radio in Space. Amateur radio contacts made via OSCAR comply with even the strictest social distancing guidelines. Many operators enjoy and appreciate the large fleet of satellites to keep us occupied all hours of the day. The diversity of FM, linear transponder, and digital satellites currently on orbit creates many opportunities for experimentation.

AMSAT as an organization continues to transform during this period. With the successful launch of Wild Apricot, membership management is now handled completely using an automated, self-service system. The system not only significantly simplifies AMSAT's office operations, but it also allows members to have more control over updating their data record and verifying their membership status — all completely paperless and any time of day. We thank Martha, our office manager, for her dedication to handling phone and paper-based membership over the past several decades.

A concept I am introducing in this Apogee View column is "being AMSAT." Not just being a member but being an *active part of AMSAT* and contributing to the organization and greater community.

First, I will begin with an introduction to how things work at AMSAT. A common misconception is that AMSAT as an organization having a physical office, officers, and volunteers, should execute, or at a minimum attempt, any brilliant idea that falls into its hands.

A good example would be when someone in the amateur radio community poses a question like, "Why doesn't AMSAT call Elon Musk and ask for a free SpaceX launch?" Certainly, on its face, this sounds like a wonderful idea. Mr. Musk, being a significant figure in the world of space technology, could certainly open doors to new opportunities for AMSAT. Short of having a personal connection to Mr. Musk, a significant effort would be required of any organization, non-profit or for-profit, to develop and nurture the type of relationship needed to even begin seeking such an opportunity. Given the right resources, however, this task is not impossible.

AMSAT's chief resource currently is the time given unselfishly by its volunteers. Successfully pursuing the kind of idea described above typically would require a dedicated staff focusing its time and attention on it — a resource that currently does not exist. Could it be done? Yes. Who will lead it? That is the bigger question. This is where you, the member, come into the equation. We need you to volunteer and be an active part of AMSAT. Together, we can do many great things.

AMSAT leadership is always open to new ideas such as the example above. No idea is too small or too large. However, one request I would ask of you is to transmit your ideas directly to AMSAT leaders rather than sharing them initially only on social media, Facebook groups, or email lists such as the AMSAT-BB. While these platforms can be good for a basic discussion of a new suggestion, they all rely on the chance that someone from AMSAT leadership learns of your idea and brings it back to the entire organization for evaluation. You easily can submit your ideas directly to info@amsat.org, and I encourage you to copy me as well, **w5pfg@amsat.org**.

As a busy and engaged organization, AMSAT pursues many ongoing projects and activities at any given time. These range from bestowing operating awards to identifying satellite launch opportunities, developing satellite technology, delivering information technology projects, seeking grants, and managing the internal operations of the corporation. All these endeavors, and many more, are performed predominantly by volunteers. AMSAT offers ample opportunities for you to contribute your talents to make a positive impact.

The number of eager and humble volunteers who have performed duties for AMSAT over the decades never ceases to amaze me. Whether it be curating the weekly AMSAT News Service content or NASA Two Line

Elements, or monitoring for potential collisions with our satellites, dedicated individuals perform such activities week after week without hesitation. I applaud the tireless efforts of these volunteers. AMSAT would love to have you as part of its team.

If you are having difficulty getting "plugged in" to AMSAT to volunteer, we are lucky to have Sean Kutzko, KX9X, onboard to help you navigate the various opportunities. Sean can be reached at **kx9x@yahoo.com**.

Something I occasionally hear from AMSAT members is that they are seeking more and regular communications about the organization. AMSAT publishes information to members in the form of short articles delivered in the AMSAT News Service. If you are not subscribed to receive this free weekly email news service, please do so on our website.

In addition to the AMSAT News Service, meeting minutes from our board of director meetings are posted on our website along with other official documents. Lastly, if you are curious as to the status of a particular program or initiative at AMSAT, contact our office via email at **info@amsat.org**. Your email will be forwarded to the appropriate contact person within the organization for response. Feel free to copy me directly, **w5pfg@amsat.org**. I love hearing from our members.

By now you may have received news that our *in-person* Annual Space Symposium has been canceled for 2020. We anticipate having an online version of the event during the originally announced weekend, though we have not officially confirmed this. As online events are new to AMSAT, if you have experience orchestrating them, we would love to hear from you.

On behalf of the many volunteers who enjoy service to AMSAT, especially our leadership team, we thank you for being a member in support of our mission.

73
Clayton
W5PFG

User Services Update

Robert Bankston, KE4AL
Vice President User Services

I've been moving at a dead sprint since my last update. Not only have we launched AMSAT's new Member Portal, but we also had to deal with an office shutdown and converting all our processes to remote access.

The launch of our new Member Portal (**launch.amsat.org**) has been a huge success. We staffed computers day and night to assist our members in getting signed up and added member benefits that have never been offered before. Through our hard work, we have seen a resurgence in both new and renewing AMSAT memberships. You know you are doing something right when members, who left in the 1990s, suddenly rejoin.

If you have not yet logged in, you are really missing out. The Member Portal allows our members to take charge of their member account, automates the membership renewal process, and provides exclusive, member-only content, like access to past issues of *The AMSAT Journal*. You can even download the latest *AMSAT Satellite Frequency Guide*.

Of course, none of this would have been possible without the hard work and dedication of our Member Portal Team. I want to personally thank Paul Stoetzer, N8HM, Bruce Paige, KK5DO, Joe Fitzgerald, KM1P, and Matthew Alberti, KM4EXS, for their invaluable assistance. Paul has done a phenomenal job collecting and uploading members-only content (*The AMSAT Journal Archives* and *AMSAT Satellite Frequency Guide*), as well as assisting me with site administration. Bruce has been planning the launch of a new store. And, Joe and Matthew provided much needed technical support.

As if this were not enough to keep us busy, we were also faced with the AMSAT office closure. The State of Maryland issued a stay-at-home order related to the COVID-19 pandemic in March. This forced us to close our office and send Martha, our Manager and sole AMSAT employee, home, with only what she could carry — the checkbook and current month's files.

March and April were certainly an uncertain time, not only for us but also for the world. Markets tumbled and unemployment skyrocketed, as businesses scrambled to find ways to work remotely. We saw our own reserves, which are invested in stocks and bonds, suddenly worth half as much. In addition, many of our critical processes were run through the office, and, unfortunately, Martha was unable to bring home the two office computers, containing our accounting software and membership database.

Our first priority was to gain online access to our bank accounts, not an easy feat when a message on the bank's website said it may take up to eight weeks for a response. Next was restoring a backup of our accounting records, which Martha had the foresight to send just before she locked the door. Finally, we had to retrieve the membership database. This was critical for the launch of our new Member Portal. Luckily, Joe, KM1P, had a recent backup that, when combined with subsequent online store membership payments, gave us a complete record.

We spent the rest of March and all of April reestablishing workflows. As painful as this was, we saw it as an opportunity to modernize how we do business and how we serve you, our members. We are in a better position now because of it and will continue to implement improvements in the coming months.

AMSAT is committed to "keeping amateur radio in space" by not only maintaining our current fleet of satellites, working on Project GOLF, and supporting space science education, but also by continuing to explore new opportunities to reach even higher orbits. Of course, none of this would be possible without the hard work of our volunteers and the support of our members. We thank you!

The sky is not the limit – only our imagination!

Smile for AMSAT at Amazon.com

When making purchases from Amazon, you can select a charity and Amazon will donate .5% of a qualified purchase towards that charity. Select smile.amazon.com when making your Amazon purchases and make Radio Amateur Satellite Corporation (AMSAT) your chosen charity.

Having selected a charity, when you go to amazon.com, you will be prompted to go to smile.amazon.com. However, you can put everything you want in your cart at the original amazon.com site, then leave the site and go to smile.amazon.com and all your items will still be in your cart.

AMSAT's New Member and Event Portal

Robert Bankston, KE4AL
Vice President, User Services

We are delighted to confirm that AMSAT's new online member management system, the AMSAT Member and Event Portal, is now up and running. As a follow-up to our initial announcement in the last issue of the *AMSAT Journal*, we have discontinued use of the old database. Also, we have removed all member application/renewals from the AMSAT website store and no longer accept paper-based applications/renewals through the mail or delivered in person.

The AMSAT Member and Event Portal, powered by Wild Apricot, is a gamechanger in how AMSAT will interact with you, our members. Gone are the days of maintaining and manually updating multiple systems. Instead, Wild Apricot provides us with an all-in-one, fully automated, member service solution. The best part, though, is now YOU ARE IN CHARGE of your AMSAT membership account.

To get started, follow these 10 easy steps::

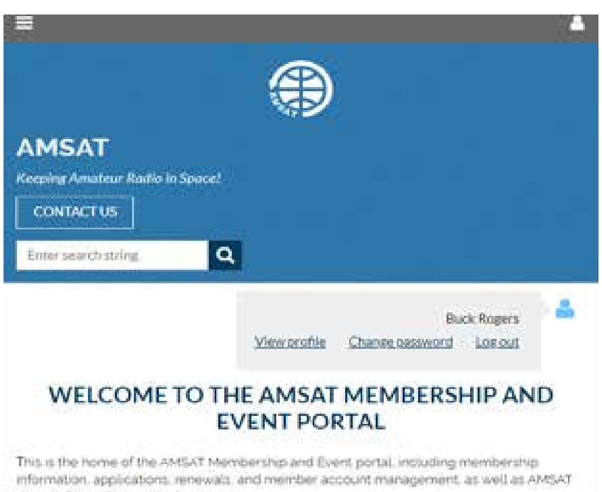
1. Visit launch.amsat.org.
2. Click on LOG IN button in upper right corner.
3. On the page that appears, click Forgot password link.
4. Enter *Your email address and the displayed *Code, then click SUBMIT.
5. Open the email, and click on link to reset password.
6. Enter and confirm your new password, then click SET NEW PASSWORD.
7. Log in with your email address and new password.
8. Accept the Wild Apricot's Terms of Use.
9. On the AMSAT Membership and Event Portal home page, click on the blue member symbol.
10. On the My Profile edit page, review and update your personal information.

NOTE: If you receive a message "ERROR WARNING – Email not found" message after clicking SUBMIT in Step 3, send an email to **members@amsat.org**, with HELP in the subject line. In the body of the message, all we need is your full name, your call sign, and your AMSAT member number (if you know it).

For the time being, your member account on the AMSAT Member and Event Portal is separate and apart from AMSAT's main website and AMSAT store login. Changing information on the AMSAT Member and Event Portal will not affect your account on amsat.org website.

That's it. You're done! Congratulations and thank you for helping us take the next step in AMSAT's modernization.

We will add more capability in the future. In this initial rollout, we've only scratched the service of what Wild Apricot can do. Once we get everyone online, we'll unlock other features, to include improved interaction, member-only content, and so much more. Afraid you'll miss out? Don't worry. We will send you email notifications with each new, added feature.



Treasurer's Report

Robert Bankston, KE4AL
Treasurer

I want to thank all of you for your kind words and support regarding my Treasurer's Report – A 10-Year Financial Analysis, which appeared in the last issue of The AMSAT Journal; however, there still seems to be some confusion among certain members and even one of our Directors regarding AMSAT finances, so let's get this cleared up.

At the heart of this confusion is the difference between financial information presented at AMSAT forums and that in my recent Treasurer's Report. As an example, past President Joe Spier, K6WAO, stated we faced a $237,000 projected deficit in his presentation at the 2019 Hamvention AMSAT Forum, while I reported that AMSAT had a profit of over $138,000 for the same year. That is a HUGE difference - $375,000 to be exact, so I can understand how that could lead to confusion and cause doubt, especially if one does not understand the context of what is being presented.

The explanation for this difference is easy. The first talks about what we think will happen – the projection, while the latter reports how we actually did – the financial report.

Each year, AMSAT prepares a budget, based on what we hope to accomplish in the coming year and how much money we think we can raise. Figuring out what we must spend is the easiest part. We have certain recurring expenses and others are linked to the number of members we have. The rest requires us to estimate planned engineering, operations, and education project costs. Estimating revenues is the difficult part, because economic conditions and member satisfaction plays such an important part. From what I can tell, AMSAT has always taken a conservative approach when projecting revenues and probably why each year, as far back as I can see, projected expenditures far exceed projected revenues.

Faced with a budget deficit does not mean we automatically start canceling projects or cutting services. Instead, our Officers roll up their sleeves and go find the needed money. This includes asking for donations, developing new products for sale, and recruiting new members.

You should never judge an organization on what they think might happen. Budgets and projections are NOT performance metrics. Instead, look at their financial statements to see what they were able to accomplish and where they stand.

Designing, building, launching, and maintaining satellites, as well as educating the public and serving our members, is expensive. We can only accomplish this through the support of our membership, the generosity of our donors, and the hard work of our volunteers, who seek out new revenue sources. As you can see by our financial statements, we have done exactly that.

We, at AMSAT, are committed to keeping amateur radio in space and doing so in a fiscally responsible and transparent manner.

eBay Sellers Donate to AMSAT

Are you an eBay seller? One item, ten items, or a full-time business you can donate a percentage of your winning bid to AMSAT.

To do so, do not list your item with the basic listing tool, select advanced tools. eBay will give you a warning message that it is for large volume sellers, however this is where the eBay for Charity tool is found.

You can “select another nonprofit you love” and search for either AMSAT or Radio Amateur Satellite Corporation. Choose the percentage amount of the sale you would like to donate to AMSAT, and boom!.

When your item sells and the winning bidder pays, eBay will deduct the percentage from your take and forward it to AMSAT. Please consider giving a piece of the pie to a new satellite and choose AMSAT for your eBay Charity.

Educational Relations Update

Alan Johnston, Ph.D., KU2Y
Vice President, Educational Relations

With the crazy online teaching spring semester winding down, I was finally able to concentrate on some other things. One of those is an effort underway in ARISS to put together a radio kit for educational purposes.

ARISS was asked by ISS National Labs (CASIS) to develop a radio kit as part of a partnership that they have with the JFK Library and Raytheon. The kits will be shared with schools and educational groups to promote learning about radio.

Frank Bauer, KA3HDO, AMSAT Vice-President Human Spaceflight, formed a Radio Kit Project Team in January led by John Kludt, K4SQC, with the following members:

Frank Bauer, KA3HDO
Andrew Deskur, KA1M
Dave Johnson, W9DWJ
Alan Johnston, KU2Y
Dave Jordan, AA4KN
John Kludt, K4SQC
Ron Parker, KR5P
Melissa Pore, KM4CZN
Ronny Risinger, KC5EES
Darrell Warren, KA6OSC

We have been meeting online every few weeks, and the team has come up with some really interesting ideas. Some of the lessons planned include:

- Codes: Morse, Q, and the phonetic alphabet
- Sending and Receiving Morse Code with a keyer
- Wave Propagation visualization with a Slinky
- Series and parallel circuits with Snap Circuits kit
- Radio listening with an SDR

I've been substantially involved in the SDR part given my experience using SDRs as ground stations for the CubeSatSim and also in the classroom to expose students to radio concepts.We have been using RTL-SDR USB dongles directly connected to PCs, connected to a router, and connected to a Raspberry Pi. The advantage of connecting the RTL-SDR to a router is that no drivers need to be installed on the PC to use it. The advantages of connecting the RTL-SDR to a Raspberry Pi is that all the software can be preinstalled and configured, and no software needs to be installed on other computers to access the radio.

We have been using Web SDR software OpenWebRX, which allows students with just a browser to connect to the RTL-SDR and have the experience of tuning an SDR. We have bands set up for ham 2 m and 70 cm bands voice and APRS, airband for air traffic control voice, weather radio, and FM radio.

We are also testing FoxTelem, Gpredict, and RTL-TCP software on the Raspberry Pi. We have also been experimenting with a YouLoop antenna, a low-cost passive magnetic loop antenna for HF and VHF by Airspy. Look for more information about this project as we beta test with schools later in the year.

In CubeSatSim news, we now have a dedicated Twitter account **@CubeSatSim**. Follow us for the latest information on this project! In this issue of the Journal, see the article on FoxTelem telemetry activities that can be accomplished with a CubeSatSim.

Also, loaner CubeSatSims are available. If you plan to perhaps demo it to a group or school later in the year, I can ship you one now to learn and test. Contact me via email **ku2y@amsat.org** or on Twitter **@alanbjohnston**.

AMSAT CubeSatSim Activities with Fox Telem

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Introduction

In the previous issue of the *AMSAT Journal* (March/April 2020), we introduced new design updates to the AMSAT CubeSatSim as an improved tool for education and demonstrations. In this article, we will describe several educational activities that can be enjoyed with the CubeSatSim using FoxTelem, the free telemetry analysis software used by AMSAT members for on-orbit CubeSats. Some of these activities were also applied to the original design of the CubeSat Simulator in the January/February 2019 issue of the *AMSAT Journal* (**cubesatsim.org/content/CubeSatSimPaper2.pdf**) based on the educational activities proposed for the original ARRL ETP CubeSat Simulator by Mark Spencer, WA8SME, in the AMSAT Journal, November/December 2009 issue (**www.arrl.org/files/file/ETP/CubeSat/CubeSat-Pt2-NovDec09.pdf**).

First, we will describe how to download and configure the FoxTelem software for the CubeSatSim. For those without an AMSAT CubeSatSim model at hand, we posted several WAV files that can be downloaded to get experience with real-time analysis of telemetry from the CubeSatSim. Next, we will discuss various activities that can be done and describe how to proceed step by step using FoxTelem.

Background

The AMSAT CubeSatSim, our CubeSat Simulator, shown in Figures 1, 2, and 3, is a Raspberry Pi Zero-based, 3D-printed, functional model of a 1U form factor CubeSat. The simulator is designed to act, as

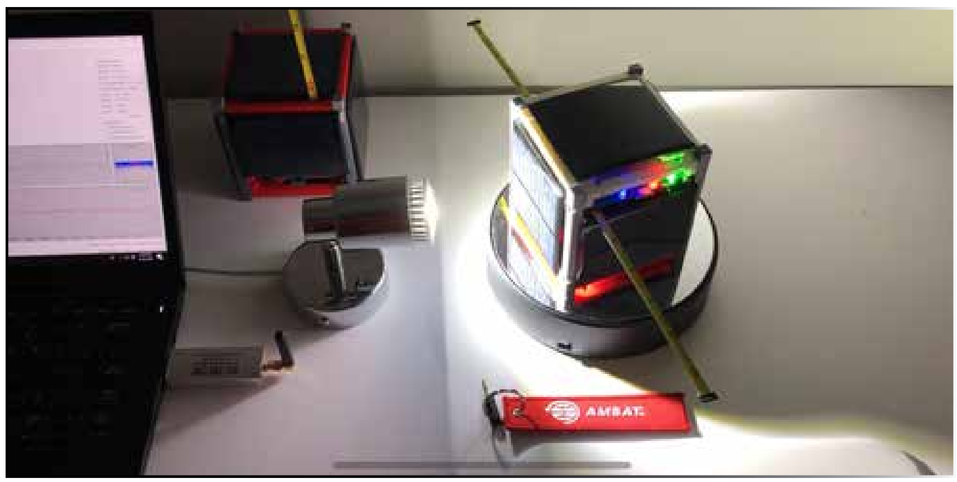


Figure 1 — The AMSAT CubeSatSim is shown on a rotating turntable in front of a sun simulator LED lamp, with FoxTelem running on a laptop and an RTL-SDR USB dongle serving as the ground station receiver. The tape measure monopole antenna is shown on the upper left; the optional dipole version appears to its right.

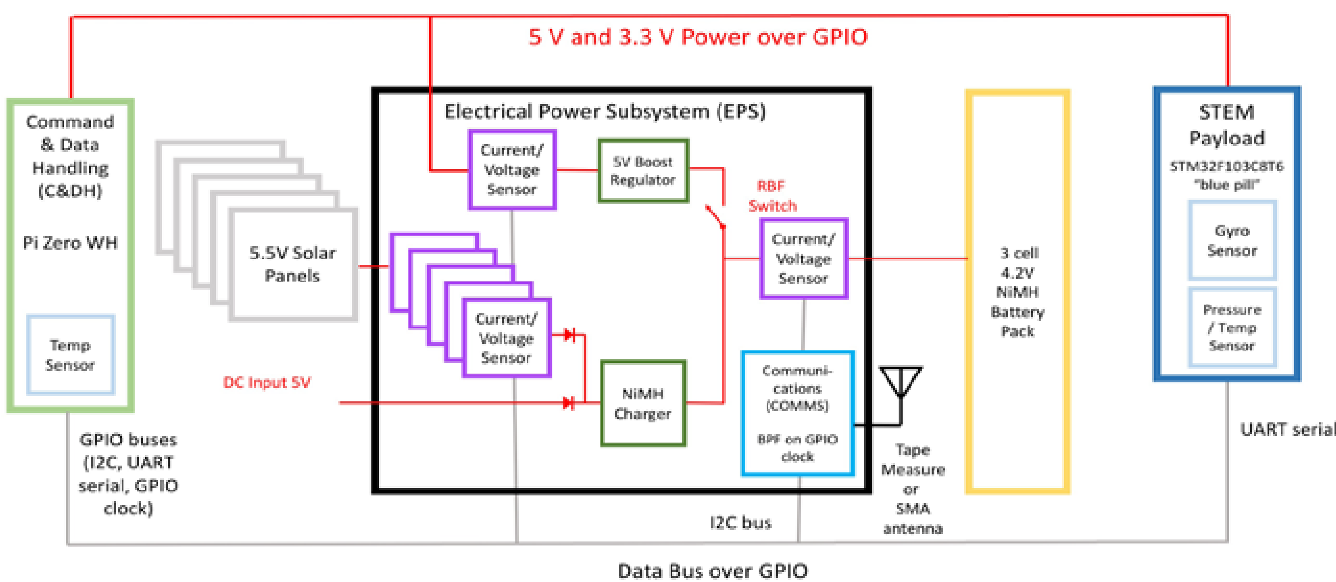


Figure 2 — The CubeSatSim Block Diagram showing the main functional blocks: Command & Data Handling (CD&H), Electrical Power Subsystem (EPS), Communications (COMMS) subsystem, Battery pack, and expandable STEM Payload.

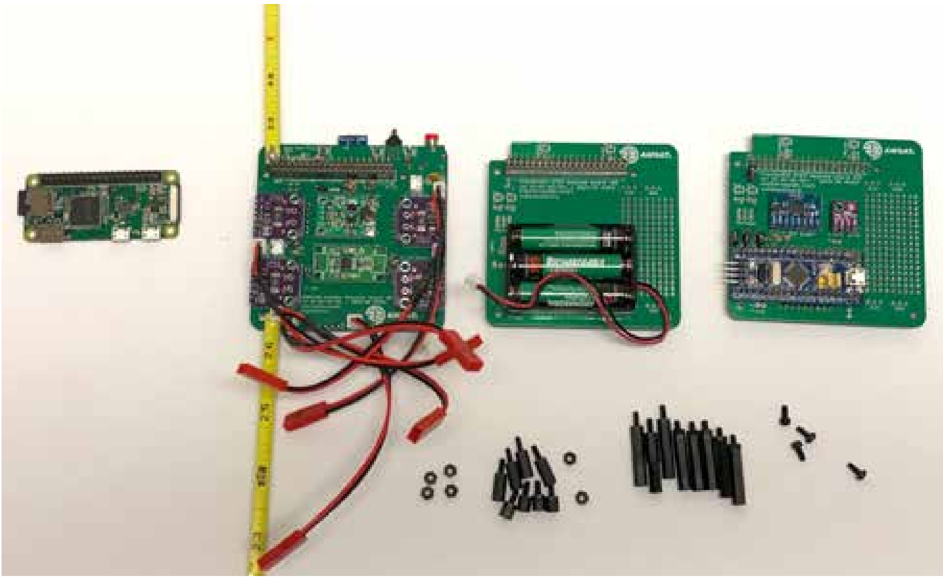


Figure 3 — The CubeSatSim board stack showing (from left to right) Raspberry Pi Zero WH (C&DH), Main Board (EPS and COMMS), Battery Board and the STEM Payload Board.

reasonably as possible, like a real 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 cubesatsim.org. Like real LEO satellites, this simulator is self-powered through onboard rechargeable batteries and solar panels. It transmits telemetry on UHF. For details on the design and construction of the simulator, see our article in the March/April 2020 issue of the *AMSAT Journal* (**www.amsat.org/**wordpress/wp-content/uploads/2020/04/The-AMSAT-Journal-March-April-2020.pdf).

Getting Telemetry Using FoxTelem

FoxTelem is the open-source AMSAT Telemetry Analysis Tool by Chris Thompson, G0KLA/AC2CZ, that AMSAT uses for its on-orbit CubeSats such as Fox-1B, Fox-1Cliff, Fox-1D, HuskySat-1, and in the future Fox-1E. Many *Journal* readers already use FoxTelem. Even if you don't yet have an AMSAT CubeSatSim, we would encourage you to install FoxTelem and upload the telemetry you copied and decoded from a local overhead pass to AMSAT's servers. Your data is then displayed at amsat.org/tlm/ to support and share with all.

The CubeSatSim can operate in Fox-1 emulation mode, transmitting telemetry at 434.900 MHz in a format compatible with the FoxTelem software, allowing users to decode and graph telemetry in real-time. The ground station receiver at the input to FoxTelem can be as simple as the low-cost RTL-SDR USB dongle, the audio output from an SDR application, or simply a saved WAV or a downloaded CubeSatSim example test WAV file (link below). The following steps will help you install and configure FoxTelem. FoxTelem is written in Java, which means that it can run on your choice of Windows or MacOS, or Linux (as on the Raspberry Pi). For the latest installation instructions, see the CubeSatSim Wiki Ground Station page at **github.com/alanbjohnston/CubeSatSim/wiki/Ground-Station**.

Support for the CubeSatSim is included in FoxTelem version 1.09 and later. The latest version for your operating system is available for download at amsat.us/foxtelem/. If version 1.09 or later is available, download it. If not, then you need to download a test version of 1.09 available at **www.g0kla.com/foxtelem/downloads/test/**.

If you already have FoxTelem 1.09 or later installed, but you do not see CubeSatSim spacecraft tabs, then you need to add them. Under the menu Spacecraft, select Add and then select the file CubeSat_Simulator_DUV_fm.MASTER, and select Add. After a minute, the CubeSatSim-FSK tab will appear. Select Spacecraft Add again selecting CubeSat_Simulator_PSK_fm.MASTER to add the CubeSatSim-BPSK tab.

Once downloaded, you will need to extract all the files and follow the install steps guided by your operating system. When you run

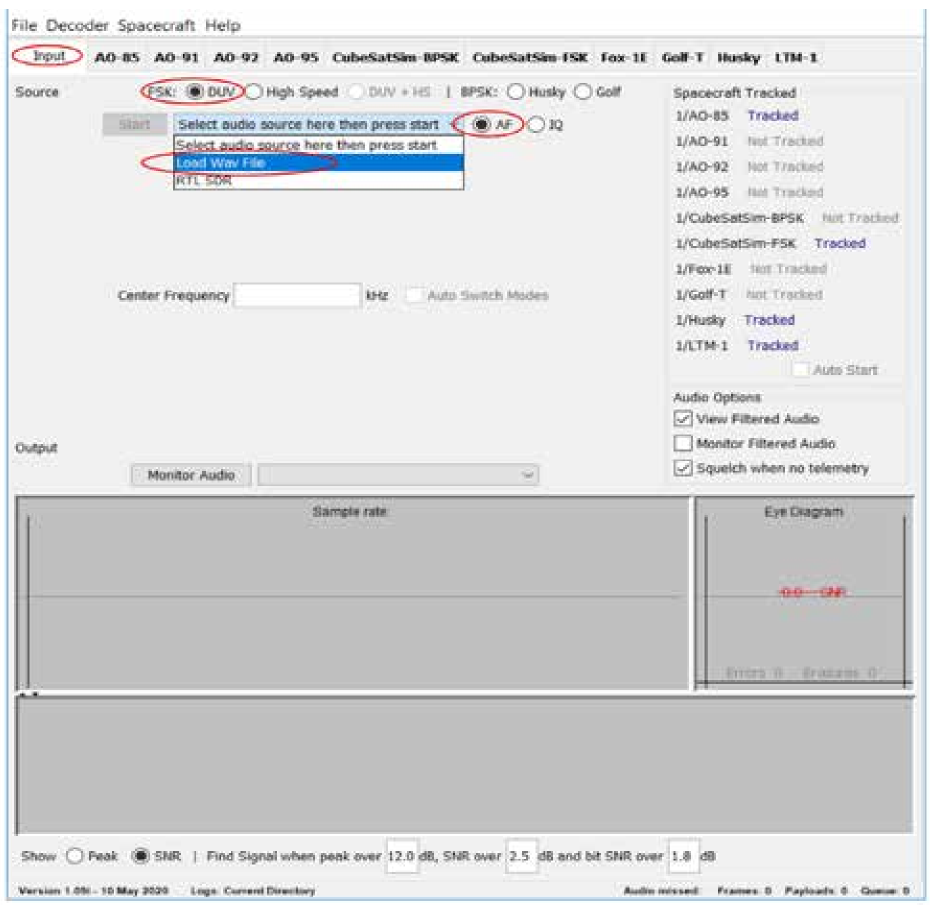


Figure 4 — AMSAT FoxTelem Telemetry Analysis Tool loading a test WAV file.

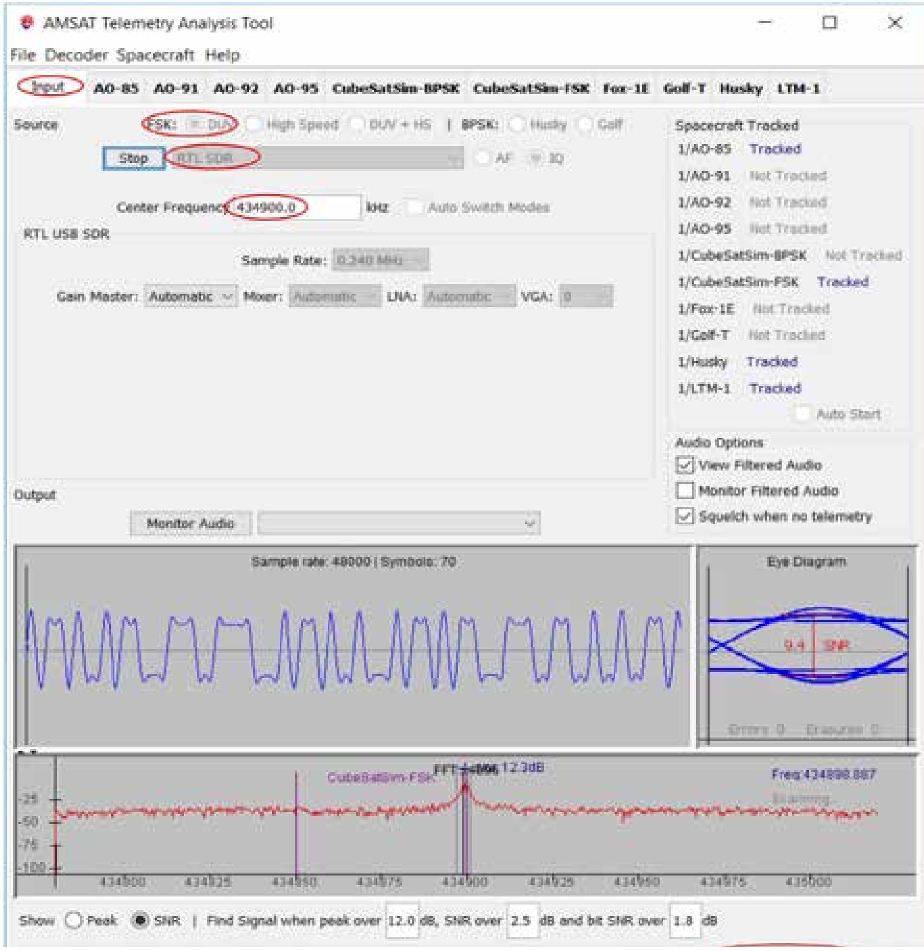


Figure 5 — FoxTelem with RTL-SDR input receiving CubeSatSim FSK telemetry.

FoxTelem, you may be prompted to update Java on your computer. If you have never installed FoxTelem before, you will get a "Welcome to the Amsat Fox Telemetry Analysis Tool" pop-up. Select Continue to choose the default location for your directory. You will then need to select "Yes" a number of times to install the spacecraft files. In a minute, the FoxTelem application will load.

You should see a CubeSatSim-FSK tab and a CubeSatSim-BPSK tab because we use different Fox IDs for the two different telemetry modes: Fox ID of 7 for the 200 bps FSK (Frequency Shift Keying) mode that emulates Fox-1B, Fox-1Cliff, and Fox-1D telemetry, and Fox ID of 99 for the 1200 bps BPSK (Binary Phase Shift Keying) mode that emulates HuskySat-1 and Fox-1E telemetry.

You can test your FoxTelem installation by downloading the test WAV files from cubesatsim.org/wav. Here's how to use them: in the Input tab, under FSK select the DUV option. On the audio source, select the AF option. Next, click on the "Select audio source here then press start" drop-down menu, and select "Load Wav File" as shown in Figure 4.

A file menu will open, and you should select the WAV file you downloaded in the previous paragraph, then click on Open and then the Start button. You will see the data being processed. The Frames and Payloads counts at the bottom of the window should increase. This means you are ready to go!

If you have an RTL-SDR USB dongle plugged in, you can receive live telemetry from your CubeSatSim if it is transmitting FSK telemetry. In the Input tab, make sure you still have selected, under FSK, the DUV option. In the Source drop-down menu, select RTL SDR. Set the frequency by clicking on the Center Frequency box and typing 434900 and then click Start. Drag the bottom of the FoxTelem window down, and the FFT spectrum plot window will appear. If your CubeSatSim is transmitting nearby, you should be receiving the signal, as shown in Figure 5.

If no signal appears from your CubeSatSim, you instead may see something similar to what appears in Figure 6 in FoxTelem. Note there is no peak in the FFT spectrum at the bottom. You can ignore the warning at the bottom. Having both Find Signal and Doppler Tracking disabled is not a problem

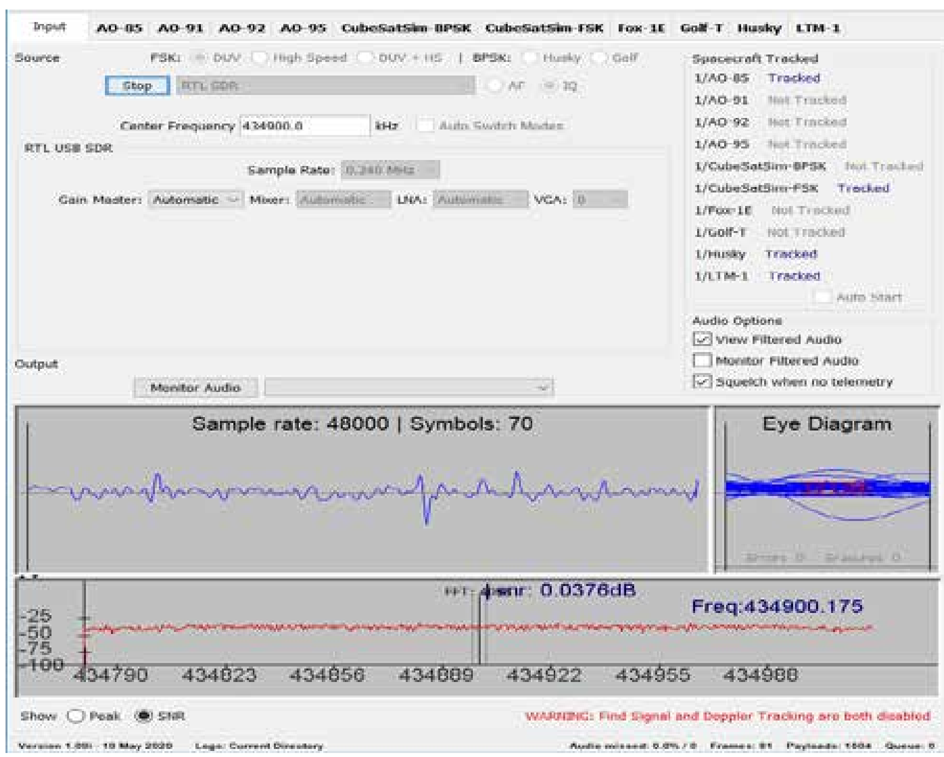
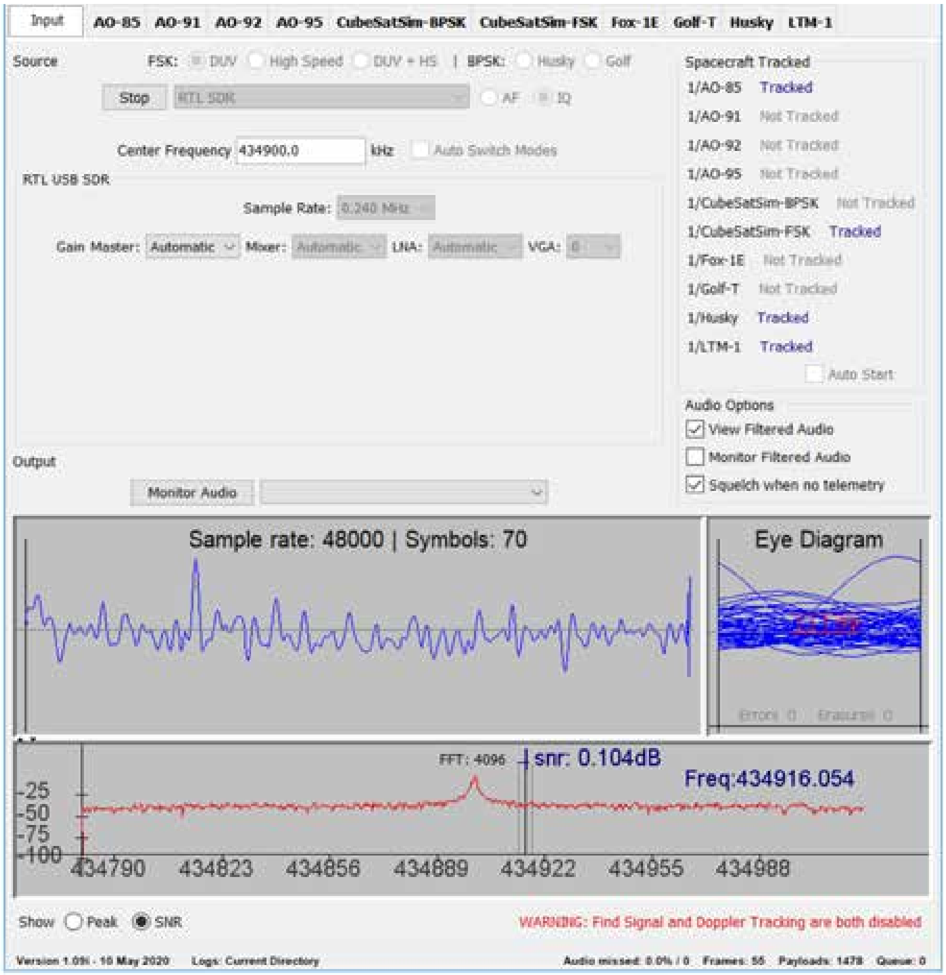


Figure 6 — FoxTelem with no signal from CubeSatSim.



If all values show as zeros, that means that you have not successfully decoded any telemetry frames. Note that the modulation transmitted by the CubeSatSim (FSK) must be the same as the Source setting in the Input tab (DUV FSK), and the satellite tab (CubeSatSim-FSK). If any of these are incorrect, you will not see data.

Note, too, that if the CubeSatSim is run in BPSK telemetry mode, FoxTelem can be set in BPSK mode as well, and similar telemetry will decode in the CubeSatSim-BPSK spacecraft tab. The fields are essentially the same, although some have slightly different names.

Assuming you have made it this far, congratulations! You are now ready to gather the telemetry data in this article. To see a real-time graph of any parameter, double click on the value or parameter name in Figure 8, and a new window will open with a real-time graph displayed.

The remainder of this article will describe a set of activities in the form of questions that can be done in a classroom or in demos using the CubeSatSim and FoxTelem to explain various aspects of radio, communications, orbital space, and satellites. Some of these educational activities were proposed in the original ARRL ETP CubeSat Simulator

Figure 7 — FoxTelem with signal from CubeSatSim but not tuned to signal.

for the CubeSatSim as they can be enabled under File/Settings.

You may also see a signal from the CubeSatSim but without the Frames or Payloads count increasing. This might be because FoxTelem is not tuned to the signal, as shown in Figure 7.

To get FoxTelem to tune the signal, click on the peak in the FFT window at the bottom, and you should start to see telemetry decodes. The Frames and Payload counts, as seen at the bottom of Figure 5, should increase every four seconds or so.

When you click on the CubeSatSim-FSK tab, you will see the spacecraft Health telemetry data, sometimes also known as "housekeeping telemetry," as shown in Figure 8. There should be data under the RT ("Real-Time" values) column. The MIN and MAX columns will show zeros as the minimum and maximum value functionality has not yet been implemented in the CubeSatSim. Uncheck the Display Raw Values checkbox at the bottom if it is checked.

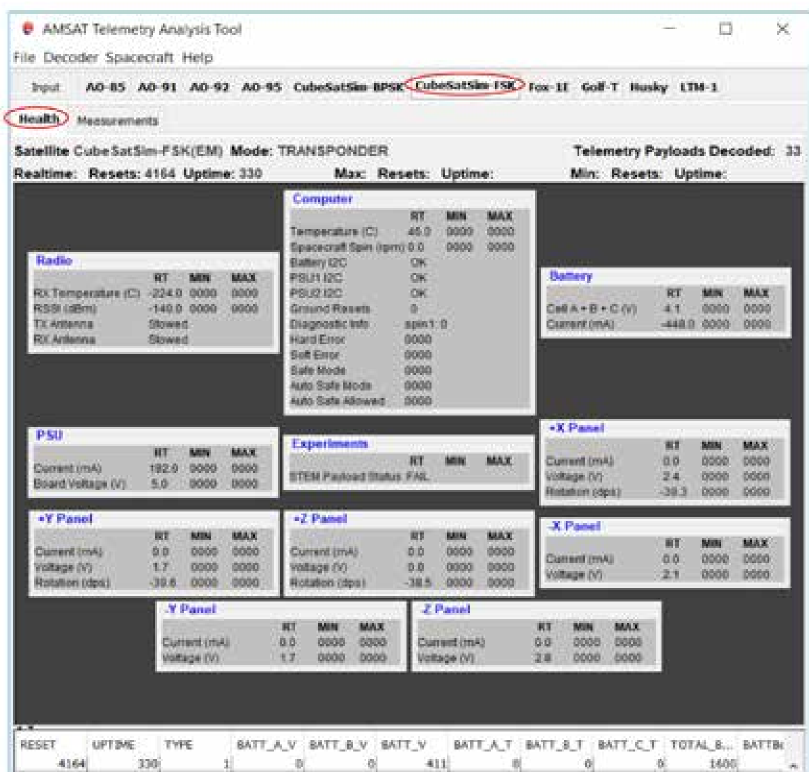


Figure 8 — FoxTelem CubeSatSim-FSK Data, Health Tab.

materials by Mark Spencer, WA8SME, in the *AMSAT Journal* November/December 2009 issue (**www.arrl.org/files/file/ETP/CubeSat/CubeSat-Pt2-NovDec09.pdf**).

Radio and Data Communication

The CubeSatSim uses digital transmission of telemetry data. Data about the health and environment of the CubeSatSim is gathered by the Raspberry Pi in the C&DH using onboard sensors. This includes voltages, currents, and temperatures. This information is then grouped into a "payload" packet of data which is then encoded and modulated as a "frame" and sent over the radio channel as RF (Radio Frequency) signals, and down to the ground station — your computer with FoxTelem and the RTL-SDR USB dongle receiver.

Can you tell the signal received at your ground station is binary data?

If you look at the Sample window in FoxTelem when data is being received and decoded, such as in Figure 5, you can see the binary nature of the data. The waveform looks like a square wave, with the amplitude having only two states: high or low.

Do you have an open eye pattern or a closed eye pattern?

If you look at the Eye Diagram window next to the Sample window in FoxTelem when data is being received and decoded, such as in Figure 5, you will see what communication engineers call an "eye pattern." The eye pattern is generated by superimposing the binary waveform from the Sample window so that it is just one bit wide and repeats over and over again. If the binary waveform is only assuming the high and low values, the lines in the eye pattern will be mainly at the top and bottom, with some going up or down on the sides when the waveform is transitioning from high to low or low to high. If the area in the middle is empty, this is described as an "open eye pattern." Figure 6 shows a "closed eye pattern," where the waveform is just random noise. The eye pattern gives a quick visual view of the quality of the received signal and is a good indication of whether the telemetry signal will successfully be demodulated and decoded. Note that because the CubeSatSim is typically right next to the ground station, this eye pattern is amazingly clear. A real satellite signal such as one from one of the Fox-1 CubeSats will not look quite as perfect.

What is the actual transmit frequency of your CubeSatSim?

If you look at the FFT window at the bottom of FoxTelem, you will see a section of the radio spectrum centered about the Center Frequency. In Figure 5, the Center Frequency is 434.900 MHz, and the FFT shows signals from 434.780 to 435.020 MHz (note that this corresponds to the Sample Rate setting of 0.240 MHz for the RTL-SDR). When FoxTelem is tuned to a signal, it shows the frequency next to Freq. In Figure 5, the actual frequency according to FoxTelem is 434898 kHz or 434.898 MHz.

What does the telemetry signal sound like if you listen to it?

A UHF radio tuned to 434.900 MHz will allow you to listen to the transmitted signal. Instead, if you click on the Monitor Audio button, you can hear the audio of this digital signal. It sounds like a low pitched rumbling sound; some describe it as a "background freight train." The Fox-1 satellites send this when the FM transponder is active in the background of the voices making contacts. You might be able to hear it on the air, although most radios filter out the low frequencies making it difficult to hear. To hear it in the Windows application SDR#, you need to uncheck the Filter Audio option under the Audio settings.

Can you hear the Morse Code CW callsign transmitted by your CubeSatSim?

When the CubeSatSim first turns on, it sends an FM modulated CW callsign. If you watch the FFT window during the CubeSatSim startup, you will see the individual tones being sent. (Using the pushbutton on the CubeSatSim, you can turn on, reboot, or shut down the CubeSatSim.) After a short break, the constant FSK telemetry will start. If you uncheck the Squelch When No Audio button, you can hear the CW tones, but turn down your volume first — loud un-squelched FM can be very annoying!

What is the Signal to Noise Ratio (SNR) of the received telemetry signal?

When the telemetry signal is being decoded, the FFT will indicate the Signal to Noise Ratio (SNR). Figure 5 shows this as 12.8 dB (decibels or dB are a logarithmic scale useful for audio and radio signal intensity levels). The higher this number, the stronger the level of the signal (the peak) over the background noise level (the flat line across the FFT). Another SNR appears in the Eye Diagram window. In Figure 5, this shows as 9.4 dB. This indicates how "open" the eye is. A higher number indicates a cleaner signal with a better chance of decoding.

Basic Power and Electronics

What are the battery voltages and currents used or produced by the CubeSatSim?

The basic power subsystem information on the CubeSatSim is available in the CubeSatSim-FSK tab in the Health tab, after telemetry frames have been received and decoded, as shown in Figure 9. Examine the following fields: under Battery, Cell A + B + C (V) gives the voltage (3.9 V) of the battery pack, the three NiMH AAA cells in series. When you plug in the micro USB power supply to charge, the battery pack voltage will jump to over 4.0 V.

Figure 9 also shows that the battery is supplying a current of 307 mA.

A battery voltage of 3.9 V produces 1.2 W of power. Over a long run, the battery pack voltage averages 3.6 V and the battery current 246 mA. This gives an average power of 886 mW.

When you plug in an external power source for charging, you will see a "negative current" while current flows into the battery to store energy, such as in Figure 8. You may see more than 300 mA of charging current for a battery with a great depth of discharge, dropping to around 90 mA when the battery is nearly fully charged. Charging time is just over two hours for the AAA battery pack.

What are the Power Supply voltage and current of your CubeSatSim?

As shown in Figure 9, under PSU (Power Supply), the Current (mA) gives the Electrical Power Subsystem (EPS) bus current (192 mA), and the Board Voltage (V) gives the EPS bus voltage (5.0 V).

In the CubeSatSim EPS, an electronics circuit known as a Boost Regulator (see Figure 2) turns the battery voltage, varying between 4.2 and 3.2 V, into a constant 5 V needed by the CubeSatSim. You will almost always see 5.0 V for the PSU Board Voltage in your telemetry.

The PSU Current averages about 156 mA over long runs and is about 44 mA less than the original CubeSatSim design. Since the new design also features the new STEM Payload Board, which draws about 35 mA, the real current reduction from the previous design is about 80 mA. The power is about 780 mW.

The efficiency of the CubeSatSim power conversion is approximately 780 / 886 x 100 = 88%.

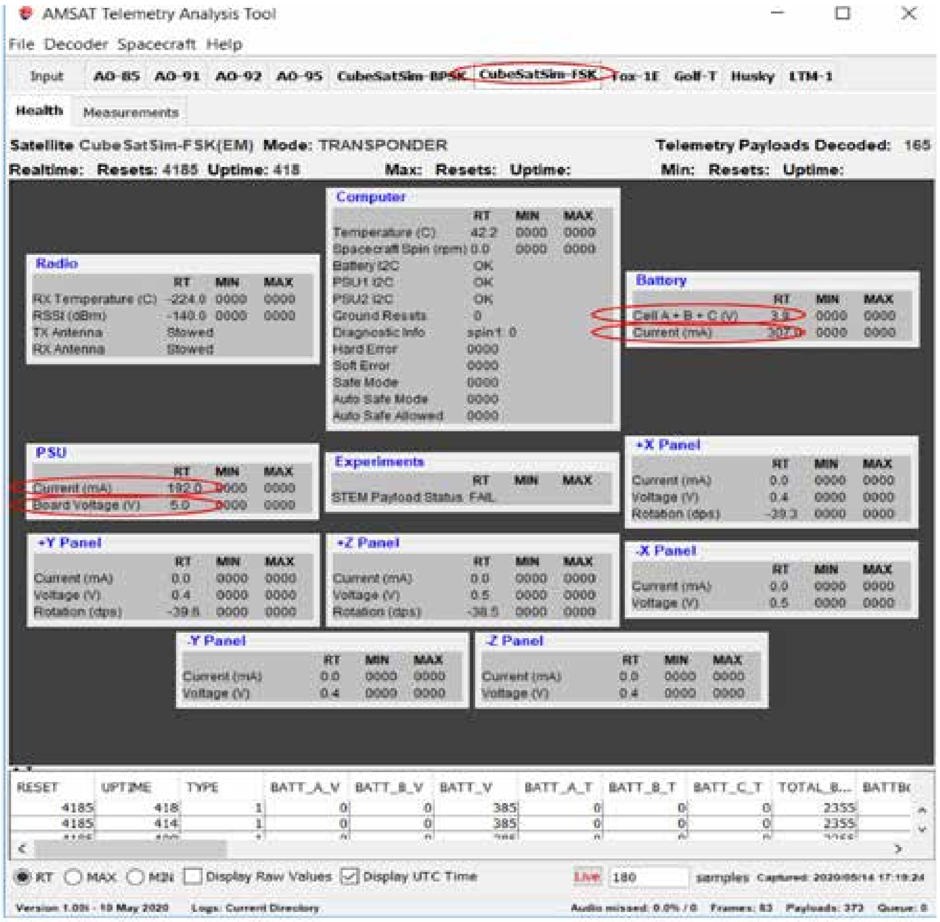


Figure 9 — FoxTelem CubeSatSim-FSK battery and power supply telemetry data.

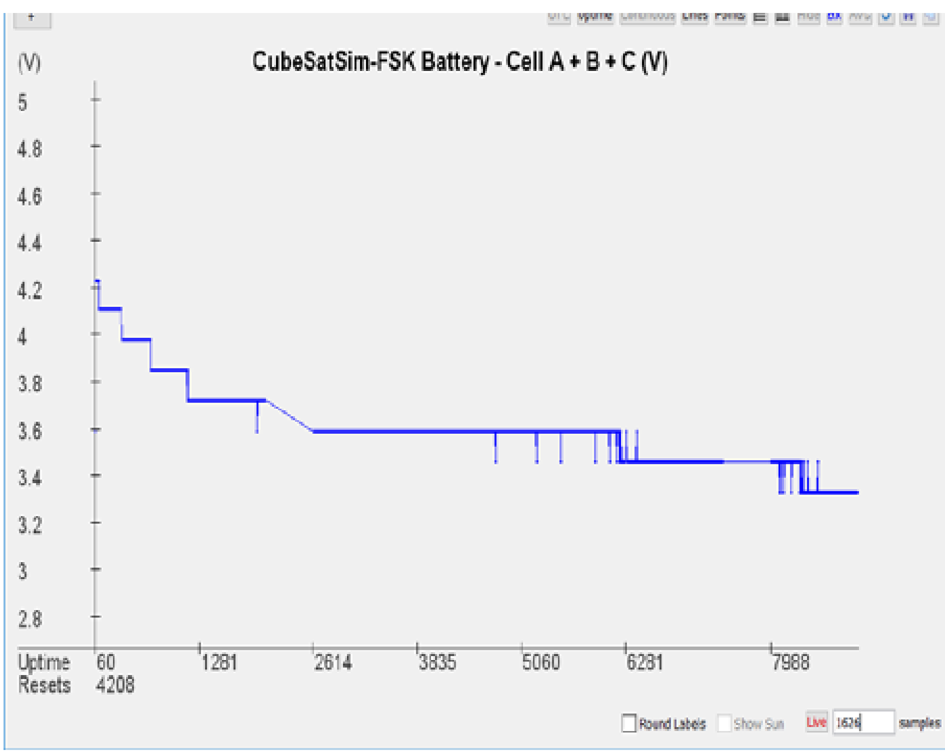


Figure 10 — FoxTelem CubeSatSim-FSK battery and power supply telemetry data.

What is the minimum panel/battery voltage required for the CubeSat Simulator to operate?

While the battery energy depletes, you will discover that the CubeSatSim safely and automatically shuts down (enters its "Safe Mode") when the battery reaches a certain voltage. That minimum voltage is 3.2 V, although the last telemetry frame you see might have a slightly higher voltage.

Satellite Operation Activities

How long will the satellite operate in eclipse?

In eclipse (darkness), the CubeSatSim runs only on battery power. The test run of Figure 10 shows the battery pack voltage versus time until the CubeSatSim automatically shuts down. Over this period, the three AAA cell NiMH battery pack goes from 4.2 V down to 3.2 V. The 3.2 V is the lower limit since it is not recommended to discharge a NiMH cell below 1.1 to 1.0 V. The software shuts down the CubeSatSim safely at that point to protect the integrity of the file system on the Pi's microSD memory card. The time axis of Figure 10 shows Uptime, which is the number of seconds since the Pi powered up. The battery discharge took 9005 seconds or about 150 minutes. For a typical LEO CubeSat, this is more than a complete orbit, which would be a good margin.

The NiMH AAA batteries are rated at 600 mAh in capacity each, which means the three have a stored energy of 600 mAh x (0.001 A/mA) x (3 batt/pack) x (1.2 V/batt) x (3600 sec/h) = 7800 Joules. During the CubeSatSim eclipse run, we had an average battery voltage of 3.6 V and an average current of 245 mA over 150 minutes, which is about 7900 Joules. This is very close to the rated stored energy.

How can you use the telemetry data to determine the rotation rate of the satellite?

The rotation rate can easily be determined by studying the graph of any one of the solar panels. If the CubeSatSim is nearly in darkness, it can be calculated from the solar panel voltage peaks. If rotating in sunlight or in front of a halogen lamp, it can be calculated from the solar panel's current peaks. Figure 12 shows a solar panel voltage graph of the CubeSatSim rotating in front of an LED lamp. There is a separate plot of the voltages for each of the six solar panels, which are labeled using the spacecraft X, Y, and Z axes.

In three dimensional space, the spacecraft X, Y, Z axes are useful, since you can't say

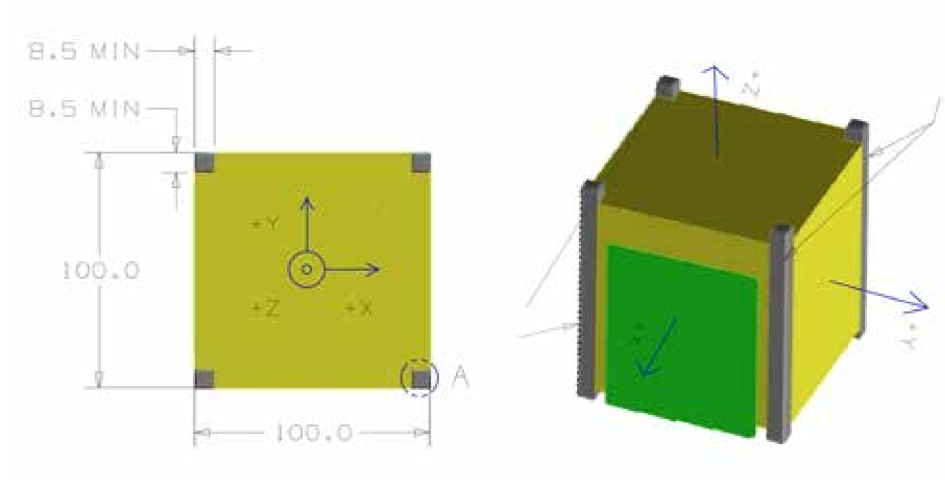


Figure 11 — Figures from the CubeSat Design Specification Standard document Rev 13 showing the +X, +Y and +Z axes on a CubeSat. Source: www.cubesat.org/resources.

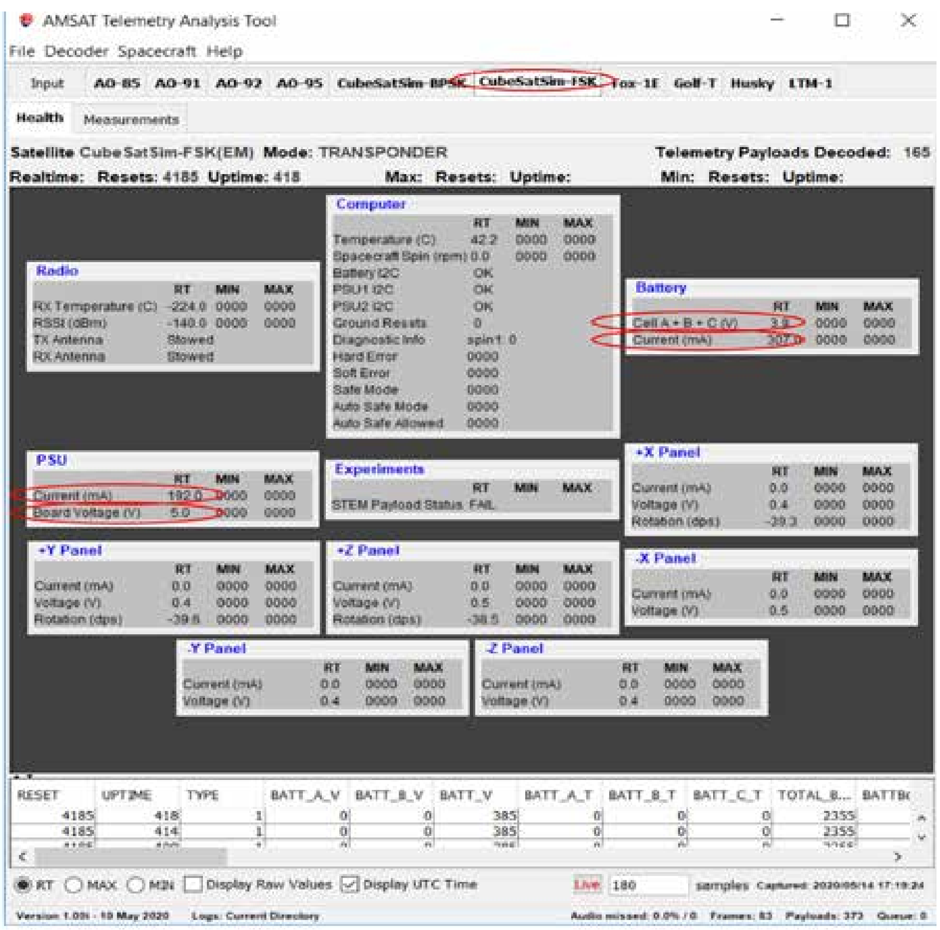


Figure 12 — FoxTelem graph of CubeSatSim solar panel voltages on the X, Y, and Z axes.

up or down very well. Figure 11 is from the CubeSat Design Specification Standard and shows the X, Y, and Z axes as labeled. The left figure shows a view looking down on the CubeSat, showing the X and Y axes as used for dimensional graphs. Typically, the +X axis points to the right on the page while the +Y axis points up on the page. The third dimension, +Z, can be thought of as pointing out of the page, as given by the Right-Hand Rule. The -X, -Y, and -Z axes are in the respective opposite directions. The right figure shows these on a CubeSat space frame.

Furthermore, some spacecraft coordinate system's naming convention requires, for example, their +X to face into the "Ram" or the velocity vector, or the radiator on the +Y side to be facing deep space (or opposite the -Y solar array side), or the +Z to be Nadir pointing (earth facing side). Or a combination of the above, but your mileage may vary based on your mission requirements.

In closing the point of analyzing satellite rotation rate for a point on its orbital track using solar panel peaks, we assume that a peak occurs when the plane of the panel is normal to the source of the light, or closest to it. At the next peak for the same panel, one only needs to extract the timing between the two peaks to obtain the average rate in Rotations Per Minute (RPM). But be aware of potential ambiguities, such as the correct answer could be masked in an integer multiple of the RPM figure depending on one's sampling rate and telemetry reporting rate. Furthermore, inspecting the peak sequence in more than a single panel might reveal additional information (or confusion) on any tumbling rate or orientation. Fortunately, one need not worry about these higher-order challenges with your CubeSat simulator situated on a lab table and turntable. Unless, of course, your instructor mounted the simulator on the turntable in an uncharacteristic orientation, and without allowing a visual of it, challenged you to try to determine its rate and position, only by the telemetry at hand.

As you can see, depending on how precise your housekeeping sampling rate is, and the downlink frequency of the data of interest, rotation rate determination from solar panel performance is an excellent educational exercise. A flight model, however, might require a means a little more elegant and reliable. Note that when the Gyro on the STEM Payload Board is running, this could be seen directly in the Rotation field.

Conclusion

We have shown several activities that can be performed using FoxTelem to analyze CubeSatSim housekeeping telemetry. These are critical lessons to help you understand your satellite in orbit, and in the care and feeding of it, which will guarantee the longest lifetime possible. Developing skills like these will make you more marketable and valuable in the aerospace industry throughout your career.

In a future article, we will focus on interfacing new sensors, experiments & payloads with the AMSAT CubeSatSim.

How-to Options to Make Your Own

The opportunities to learn CubeSat design and fabrication abound for AMSAT members. From Maui to Maine, and from the tip to toe of North America, AMSAT members and university students possess a gold mine of demystifying satellite design details to start a design of their own. The stepping stones of the engineering processes, from a fully functional satellite simulator (Sim) to an Engineering Development Unit (EDU) to an actual Flight Model (FM), are at your fingertips with your personal AMSAT resources.

Example 1:

Run, don't walk, to the AMSAT Annual Meeting & Space Symposium Proceedings for six years in a row starting with Orlando (2012) and completing in Reno (2017). Substantial engineering documentation for the five Fox-1 flight models is laid out in the latter pages of each publication. You'll see Concept of Operations (ConOps), requirements specifications, Interface Control Drawings (ICDs), subsystem design specs and schematic diagrams, Flight Software (FSW) Architecture Specs, Mechanical Drawings, Bus Pin Assignments, experiment/payload details and so much more. It's the real deal!

Example 2:

The seeds of the low-cost, high-educational value AMSAT CubeSat Simulator (CubeSatSim) were sown at that very AMSAT Symposium in Reno. One year later, in Huntsville, we unveiled the AMSAT CubeSat Sim proof of concept model. Then last year, in Arlington, we demonstrated the first CubeSat Simulator for beta testers to build, and simultaneously released four completed & tested kits along with ground station components to the AMSAT public, shipping them all around the country for inspection, orientation, education and outreach demonstrations. In between the AMSAT space symposia, we published details of building and operating them in parts, via sequential issues of the AMSAT Journal. A repository of these issues and proceedings papers is found at CubeSatSim.org. Our CubeSat Simulator developments continue.

Example 3:

In the previous issue of the AMSAT Journal, March/April 2020, George Downey and Bob Bruninga, WB4APR, shared a seriously intriguing and totally amazing CubeSat flight model they built and tested. They offered hints on how to scale back the flight model to behold a "LabSat" for classroom and public demo use, not unlike our CubeSatSim. Bob released an ocean of additional technical details to his "PSAT-1U" model online at aprs.org/psat1u.html.

Epilog

An exercise left to the "student" is to inspect each of the three examples for the processor type used in each example above in the respective Internal Housekeeping Unit (IHU) — or Command & Data Handling (C&DH) subsystem as some call that part holding the central "brains" of a satellite. Because we engineers must function in the real world where it is the scientists who often create the purpose of a given satellite mission, we ought to consider how ready and capable the interface is to accommodate a scientist's payload experiment to the satellite bus. "The payload is the reason for the season." And the budget. A key to this accommodation is in the critical design of the C&DH.

Share Your Experiences as an AMSAT Member

The AMSAT Journal is looking for you to share your satellite radio experiences, likes and dislikes, how you work the birds, and what you like about *The AMSAT Journal*. We'll publish a selection of responses in upcoming issues of the Journal under a column we're calling "Members Footprints." Photos are strongly encouraged! Thanks!

Please send the information requested below to journal@amsat.org --

- Your Name
- Call Signs Held
- Primary Grid Square
- Favorite Satellite Contact
- First Satellite Contact
- First Satellite Ground Station Description
- Current Satellite Ground Station Description
- Reasons You Are an AMSAT Member
- Favorite AMSAT Memory (a satellite contact, symposium, engineering project, etc.)
- Favorite Topics Appearing in The AMSAT Journal

Please Provide a Hi-Resolution Photograph (see www.amsat.org/?page_id=1709).

The Recovery of LES-5

Scott Tilley, VE7TIL

On the afternoon of March 24, 2020, EDT, I noted a modulated carrier on 236.7487 MHz. I wasn't looking here by accident. I was searching for LES-5; and, after almost 53 years in space and 49 years since it was supposed to have been switched off, LES-5 [2866, 1967-066E] had been discovered alive.

What follows is a discussion of the methods used to identify the satellite as LES-5 and determine that the telemetry transmissions may have scientific value as if the spacecraft is sending meaningful telemetry. Researchers may be able to obtain valuable information on how hardware launched into a high Earth orbit 53 years ago has faired.

LES-5

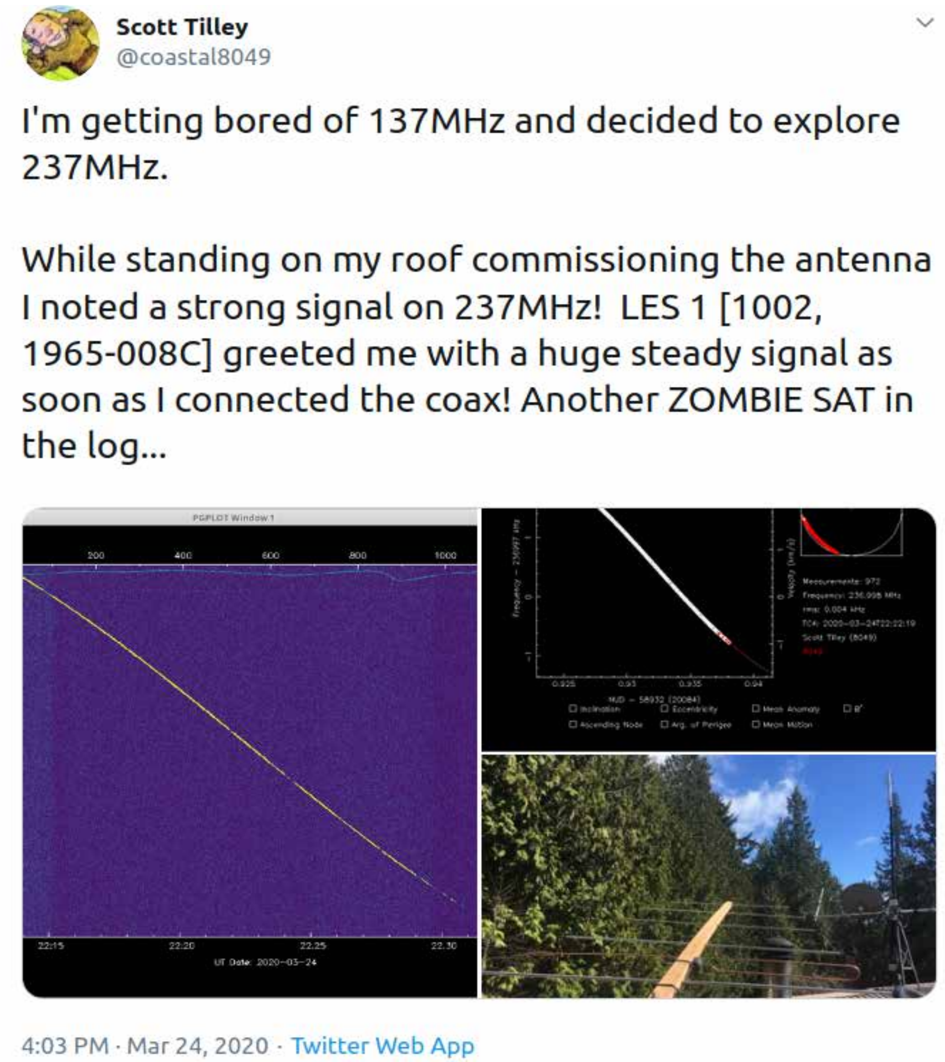
LES-5 is an experimental communications satellite developed by MIT Lincoln Laboratory to test the viability of a UHF communications satellite in a near geostationary class orbit.

LES-5 was launched along with IDCSC 16-19 and DODGE 1 into a nearly circular orbit with a nominal altitude of 33,000 km on July 1, 1967.

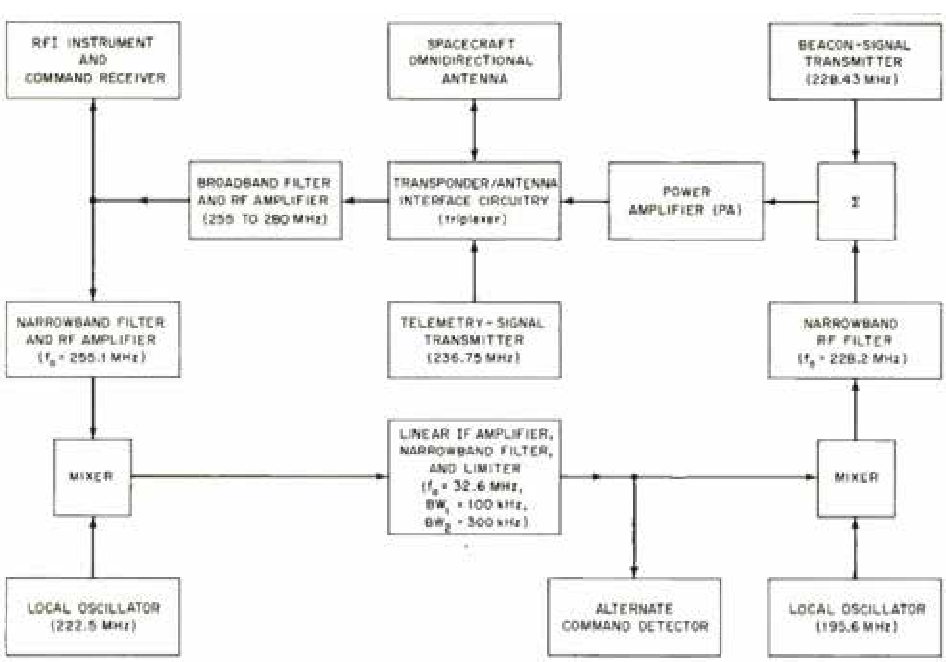
An old U.S. government documentary on LES-5 called, "The Tactical Satellite Communication Program, Part 1, Program 591," can be viewed at www.youtube.com/watch?v=TtDA-OjQ6yg. In this documentary, the filmmakers outline the value of a UHF communications satellite in geostationary orbit and how LES-5 was built, launched and tested to understand the requirements of each sector of the armed forces. It should provide the reader with a wealth of historical information for context.

Finding Something the Old Fashioned Way, "Doing the Homework"

Lincoln Experimental Satellite 1 (LES-1) was recovered on the 237 MHz band by Philip Williams, G3YPQ, in 2013. This curiosity piqued my interest as to what else may be emitting signals in this now largely unused portion of the radio spectrum. As 237 MHz is far away from most active amateur radio bands, with only limited use of the band for satellite operation dating back decades, and few having seriously studied it for satellite emissions, this band seemed like



LES-1 captured literally as I plugged in the coax for my 237 MHz 6 element yagi antenna.



LES-5's communications system block diagram showing references to telemetry and transponder frequencies.

a good place to search.

Upon setting up my 237 MHz antenna, I was greeted instantly to emissions from LES-1 on 237.0 MHz.

Some years ago, I had noted the S-band emissions of LES-9, a nuclear RTG powered communications test satellite launched with LES-8 in 1976, and my interest was piqued about the history of the MIT Lincoln Laboratory series of satellites. I gathered many papers published online, and, over time, began digesting the program's history and operational characteristics.

I then tracked down an old paper on LES-5 and noted with interest that LES-5 had beacons on 236.75 and 228.43 MHz.

A quick check of the position of LES-5 on the afternoon of March 24, 2020, revealed it was in my sky to the southeast. So, I aimed the antenna and went back inside.

A Needle in a Haystack

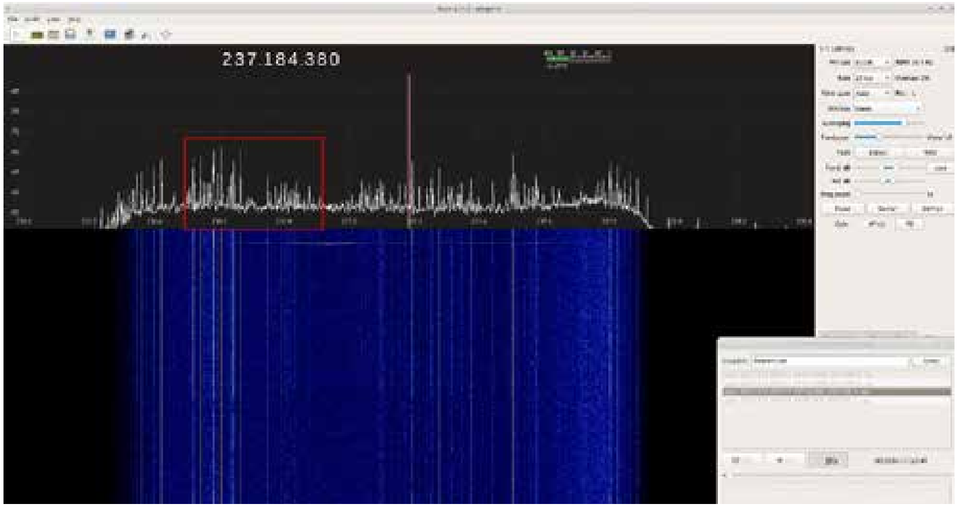
Knowing where to look greatly simplified discovering LES-5. The VHF radio bands have become a clutter of radio frequency interference from all the modern conveniences of life. As LES-5 is in a sun-synchronous orbit, the Doppler effect on the satellite's signal is negligible over time. So, the techniques I commonly use to find and identify a satellite are largely ineffective.

Even with knowing where to look for LES-5, the challenge of finding the signal in the thicket of noise on the 237 MHz band was a challenge. As I sifted through the noise, I noted one "carrier" that slightly stood out from the others and zoomed in, increased the FFT size until I could resolve the modulation on the carrier, and suspected I had detected something other than radio frequency interference.

Once I began to suspect I was detecting LES-5, I went outside and turned the antenna orthogonally to the heading that LES-5 was on and the signal completely disappeared while most of the noise signals remained. I repeated this test several times with different headings and found that the signal peaked to my southeast in roughly the spot LES-5 should be.

Timing an Eclipse of LES-5

Doppler analysis of an object in near geostationary orbit can be difficult or impossible as the Doppler effect is overwhelmed by other factors such as the stability of the spacecraft oscillator and

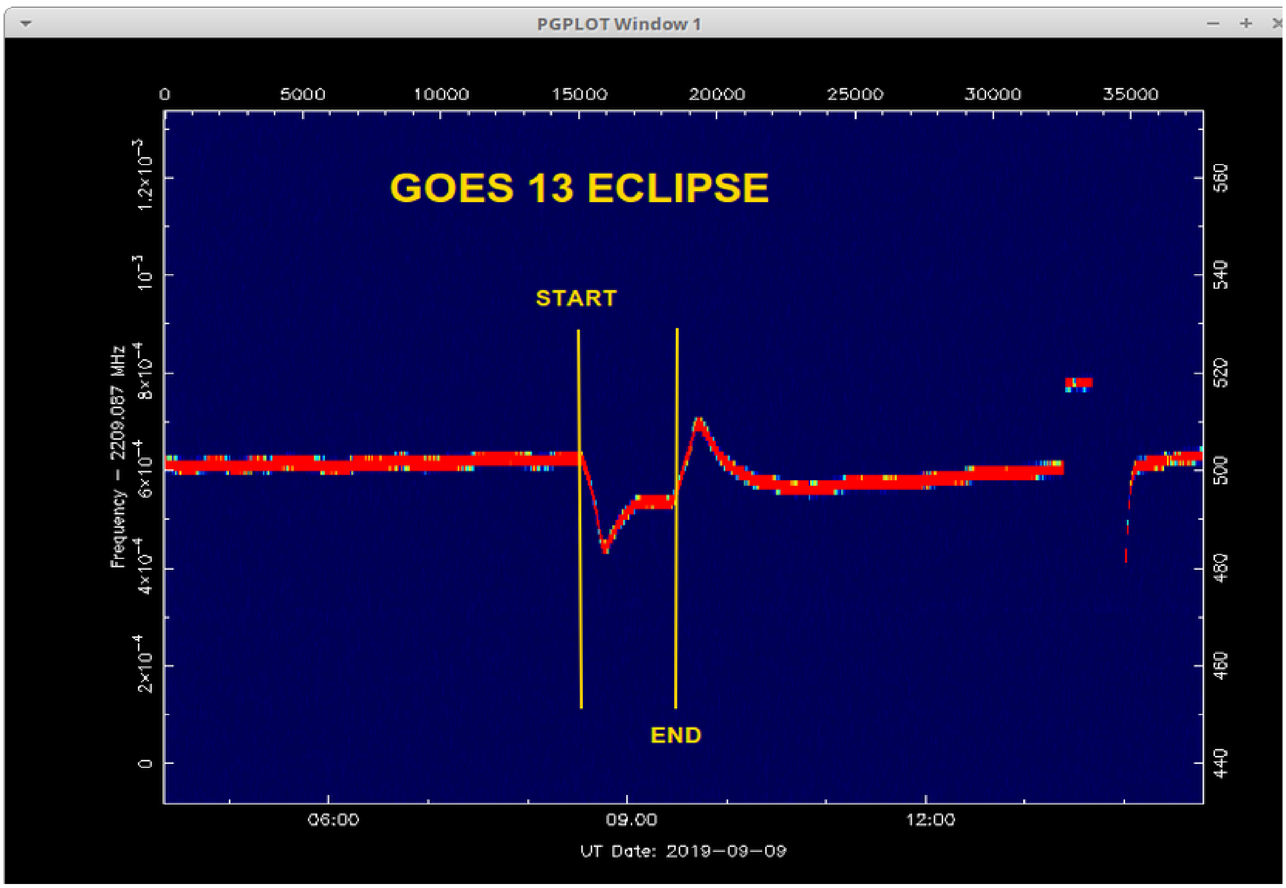


Zooming in on LES-5's signal in the noise found on the 237 MHz band. It was like finding a needle in a haystack.

LES-5 never had a battery that supplied the payloads (i.e. transponder and telemetry beacon). Ironically, the only battery onboard was supposed to turn off the satellite after five years. I guess this is one of those "You only had one job!" meme moments!

LES-5's battery had "Only One Job", to turn off the satellite after 5-years.

Many old decommissioned missions still emit RF, and I have observed them over the years and used the phenomenon to identify them before many of the objects were declassified. Recently, I used the technique to confirm GOES-13 wasn't decommissioned as it stealthfully left its perch over North America and headed to a new home over the Indian Ocean last year.



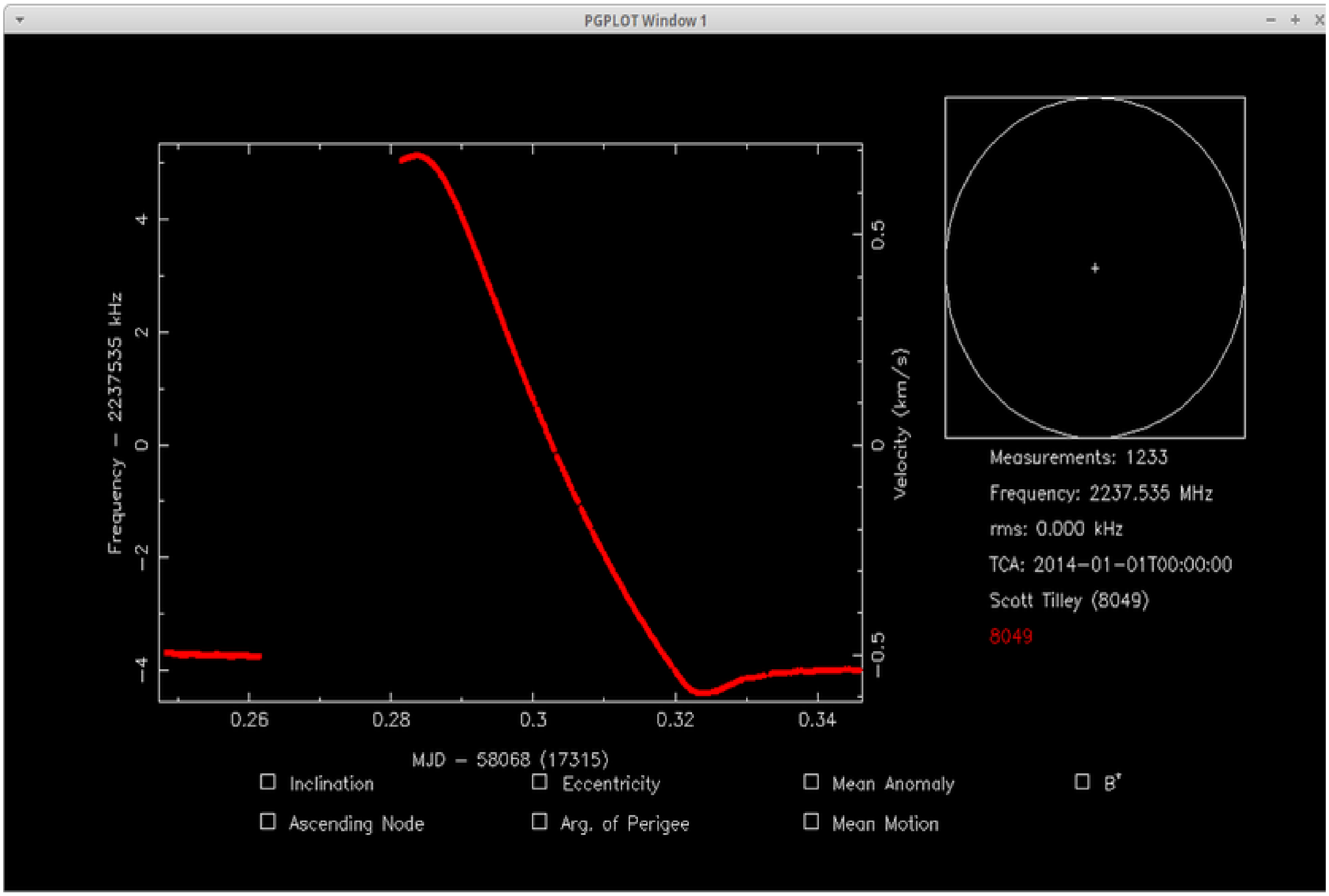
GOES-13 undergoes a solar eclipse and displays a carrier frequency anomaly. Timing the anomaly allows an observer to locate the spacecraft. Given knowledge of the expected orbit, one can accurately confirm the identity of a spacecraft using this technique.

perturbations to the satellite's velocity relative to the observer by the Sun and Moon's gravity tugging on it. But as fate would have it, we have another reliable technique to locate a satellite very accurately in a geostationary class orbit.

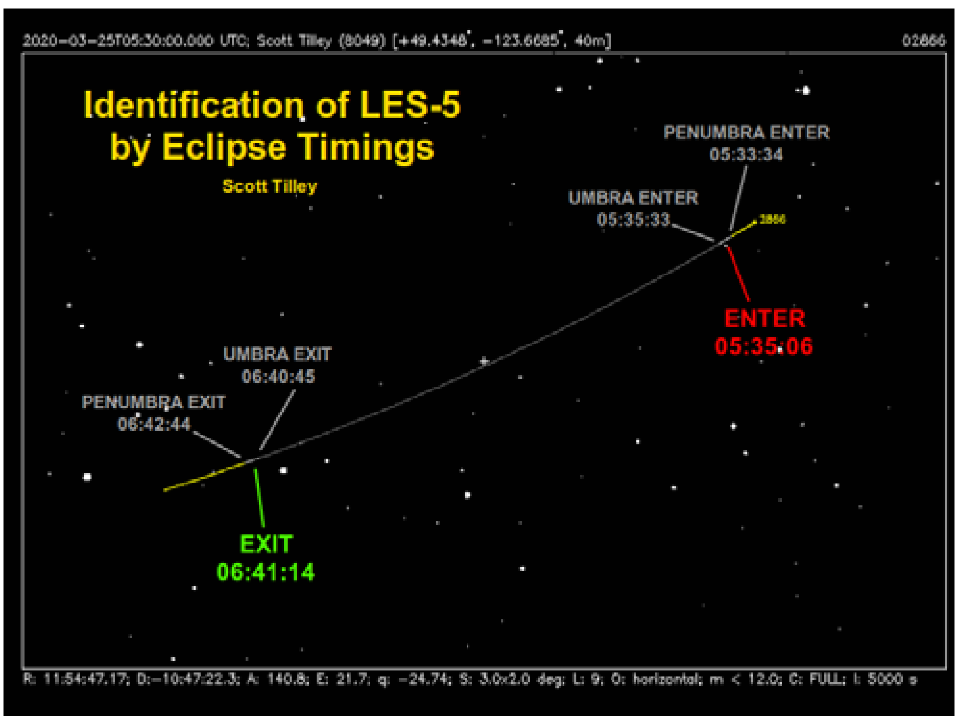
During the equinoxes, satellites in geostationary and similar orbits undergo nightly solar eclipses and we just so happen to have arrived at the spring equinox so nature was co-operating.

Spacecraft with good batteries usually display some sort of carrier frequency anomaly as they pass through eclipse.

Armed with the knowledge to wait for the eclipse, I set out to predict the timings and set up to record the data. For fun, I shared the moment LIVE on Twitter with a number of interested people. You can enjoy the moment of discovery shared with a few hundred of my Twitter followers at: **www.youtube.com/watch?v=pCGUfySxUOU&t=50s.**



DSP-F15 a retired missile early warning satellite undergoing a solar eclipse.



Summary of the LES-5 eclipse monitoring results. As you can see the spacecraft signal disappeared and returned as predicted.

LES-5's signal disappeared partway through the penumbra portion of the eclipse and then reappeared also in the penumbra portion of the eclipse. Perhaps this is a good indication of the health of the solar array.

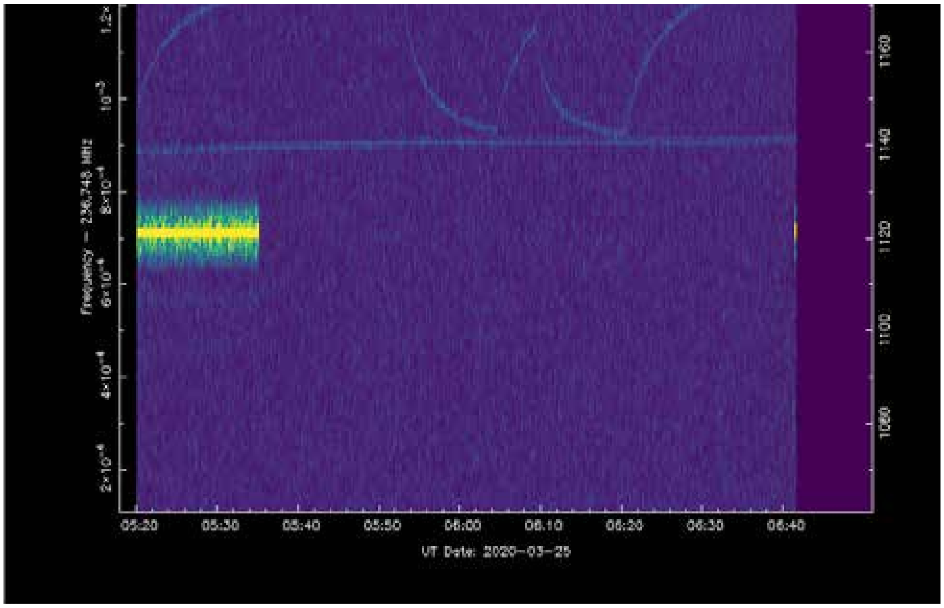
Interestingly, the stability of the LES-5 local oscillator is rather amazing. Other than a brief transient drift in frequency during the power off/on segment, the carrier returned to 237.7487 MHz very quickly without the usual recovery period seen in more modern satellites.

On March 27, 2020, the Twitter user Fer @supertrack_it, 45.3N 7.7E, reported the LES-5 signal as the satellite drifted into view over Italy. He provided signal reports and repeated the eclipse timing experiment.

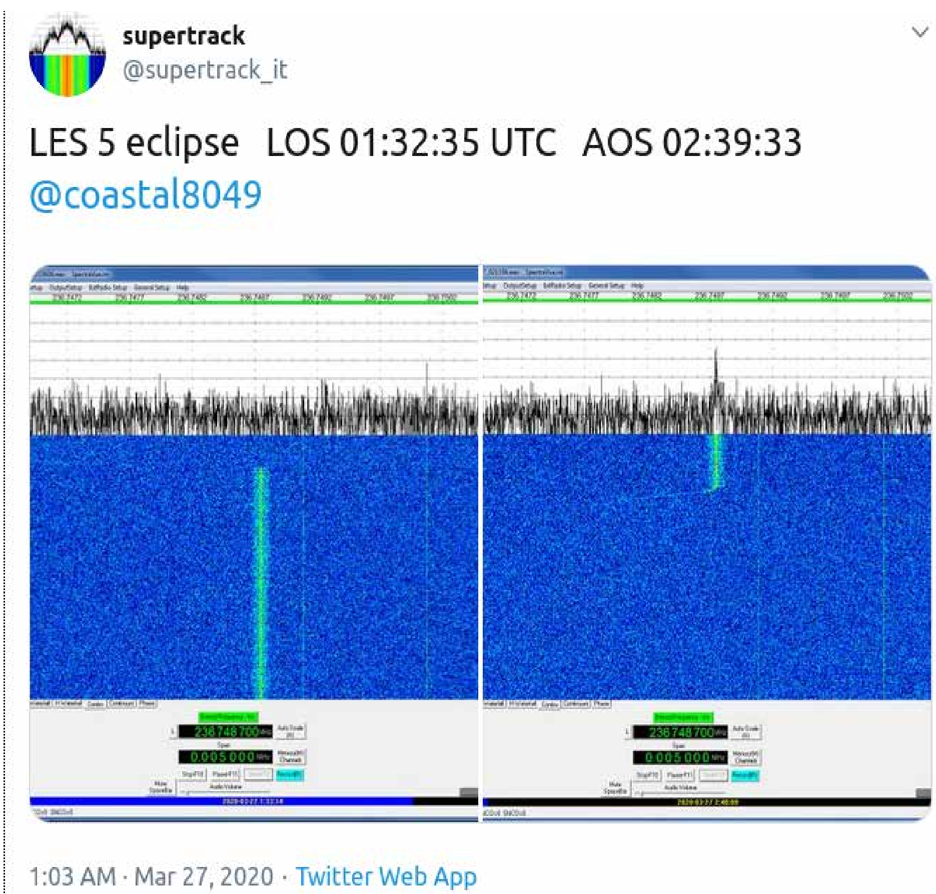
The Space-Track TLE used for generating the eclipse timings used in this report was EPOCH 20086.84975933. The Italian observer's results matched mine. I believe this confirms the identity of the spacecraft.

Is LES-5 Saying Anything Meaningful?

I recorded a fair amount of IQ and .WAV



LES-5 frequency vs. time plot of the eclipse. Note the remarkable stability for the carrier frequency.



LES-5 observed from Italy entering and exiting eclipse on March 27, 2020.

audio data files of the LES-5 signal before it set over my eastern horizon. I sent those files to Dr. Daniel Estévez, EA4GPZ, who specializes in the decoding of satellite signals.

Daniel decoded the 100bps BPSK telemetry into readable bitstreams and concludes that, with documentation, the contents of the telemetry could be understood to determine spacecraft health.

Daniel's results are interesting as he concluded the following in his blog post – Decoding LES-5:

> *So far, my impression is that the data is valid, so at least a good part of the onboard computer is working. It would be very interesting to decode it, as probably it can show us something about the spacecraft's health. However, this might not be so easy, as the documentation from this very old satellite might be long gone.*

March 27, 2020, Dr. Daniel Estévez

Conclusion

Based on the results of amateur observers, LES-5 has been confirmed to be sending telemetry on 237.5487 MHz. The telemetry appears to indicate deciphering it may provide a means of determining satellite health. I have posted this information to help obtain support from persons involved in the LES-5 mission so that further research can be conducted to determine the health of the spacecraft and see if anything can be learned from a mission that has been in space for 53 years.

Operating WSJT-X FT4 on Satellites

Dave Beumer, W0DHB
Alan Bowker, WA6DNR
Carlos Cardon, W7QL
Ronald G. Parsons, W5RKN
Brad Schumacher, W5SAT
Robert Wright, N7ZO

Introduction

Many amateur radio satellite operators have attempted to operate digital communication via linear transponder satellites with mixed results. Problems with the constantly-changing satellite Doppler shift and weak and varying signal strength hindered their efforts.

With the advent of the FT4 mode available in the WSJT-X weak signal program, we were provided with an impetus to try anew. The FT4 protocol is fast with excellent weak-signal capabilities. A complete, confirmable contact requires only six transmissions, just 45 seconds if no retries are required, including the initial CQ and the final 73, such as:

CQ WA6DNR CM87
WA6DNR W5RKN EM10
W5RKN WA6DNR +03
WA6DNR W5RKN R+07
W5RKN WA6DNR RR73
WA6DNR W5RKN 73

The major problem has been to compensate for the Doppler shift of the satellite's signal as accurately as possible. SatPC32 calculates the Doppler shift once per second but provides a temporary 5x or 10x increase in this speed. Future versions will allow saving this speed. FlexSATPC by W0DHB for satellite use with FlexRadio transceivers also allows saving increased speed (up to once every 100 msec). We have found excellent decoding at 100 msec intervals of FT4 signals by WSJT-X even at the Time of Closest Approach (TCA) of low-Earth-orbit satellites.

Testing

We used WSJT-X v2.2.1. for the tests. The FlexRadio users in our group used FlexSATPC. All used SatPC32. To avoid interfering with other users of the satellites, we used the minimum power practicable and used 3 kHz of the satellite's passband starting 2 kHz above the bottom of the satellites receive passband. In the rare instance when other users were present in the WSJT-X passband, CW or voice, we noticed no interference to our reception, so the FT4 protocol is quite tolerant of other signals present. A decode often occurs of an FT4 station right at AOS when the signal is not yet visible on the receive panadapter.

For the past month or so, the authors and others have been testing WSJT-X FT4 on a variety of satellites including the XW-2 series, CAS-4A and CAS-4B and especially RS-44. The new satellite RS-44 was an especially attractive vehicle. Its orbit is higher than the XW and CAS satellites, and its receiver is very sensitive and the downlink signal strong. Its 60 kHz wide passband leaves room for lots of users to spread out. Its high orbit should enable setting some new distance records.

On the test pass illustrated in this paper, we had five of the authors of this paper simultaneously active during the entire pass, trying to make as many QSOs as possible. Combined we logged about 36 QSOs.

Doppler Shift Correction

The FT4 protocol was designed to extract data from weak signals, not from a signal with a center frequency that changes constantly or erratically. Thus, the smoothness and accuracy of the Doppler correction is a critical factor that relies on two variables:

1. Accurate knowledge of the orbit. This requires the use of the most recent available keps (Keplerian orbital parameters).
2. Frequent and accurate calculation of the Doppler correction. We have found that 100 msec intervals to be sufficiently often.

To test the accuracy of the Doppler correction, we tracked the CW beacon of RS-44. The keps were the most current at that time on nasabare. We measured two passes with maximum elevations of 9 and 85 degrees. The beacon signal audio after Doppler shift removal was passed to WSJT-X and plotted on its Wide Graph. The deviation over the passes is shown in Figure 1. The left part shows the maximum deviation from the value at TCA was about 350 Hz for the 85 deg pass. The right part shows 200 Hz maximum deviation for the 9-degree pass. We found that WSJT-X had no problem decoding FT4 with this amount of data frequency shift.

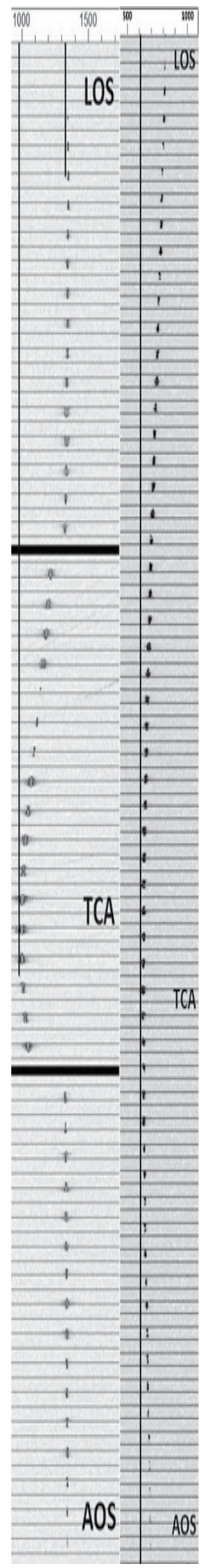


Figure 1 —Residual Doppler Error.

Equipment Configuration

W0DHB, WA6DNR and W5RKN operated FlexRadio transceivers with minor variations of the same configuration.

The transceiver used two transverters, 144 MHz and 435 MHz, connected to steerable antennas. SatPC32 steered the antennas. FlexSATPC provided Doppler correction, uplink calibration and other control functions. Two SmartSDR slices were used, A for receive and B for transmit. The receive audio was sent to WSJT-X via a DAX audio channel. The transmit audio also was sent to SmartSDR via a DAX audio channel. PTT was controlled by a CAT TCP port.

W7QL, W5SAT and N7ZO used an Icom IC-9700 with similar configurations. The IC-9700 Transceiver, with V 1.24 firmware, was controlled by SatPC32 via the standard USB Port. SatPC32 steered the antennas. SatPC32 with support for the IC-9700 was used for testing. WSJT-X received audio from the 9700 USB audio output and controls FT4 signal transmission PTT via the 9700 USB (B) port.

The FT4 Jamboree

On June 21, 2020, five of us gathered at our respective QTHs for the Grand Jamboree test pass. From approximately 2350Z to 0015Z, we made QSOs with the other members of the group. We completed a total of about 36 QSOs.

The coverage area of the middle of the pass is shown in Figure 2.

A two-minute excerpt from N7ZO's Band Activity display from WSJT-X is shown in Figure 3. This display is

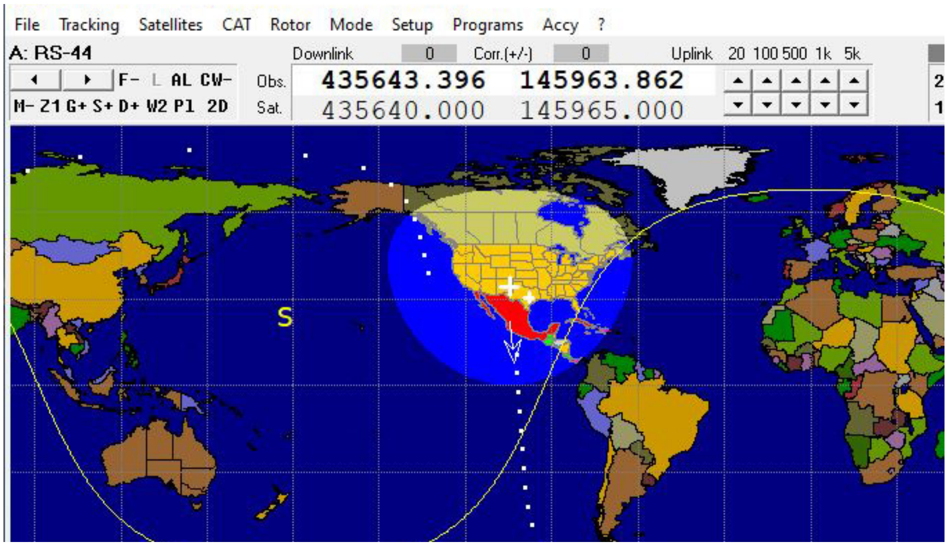


Figure 2 — Jamboree Coverage Area.

```
000345 1 0.2 2175 + W5RKN W0DHB R+11
000352 2 0.2 1578 + CQ WA6DNR CM87
000352 9 0.0 1845 + W5SAT N7ZO CN85
000400 7 0.0 1239 + W5RKN W5SAT DM26
000400 2 0.1 2173 + W5RKN W0DHB R+11
000407 4 0.2 1573 + CQ WA6DNR CM87
000407 5 0.0 1846 + W5SAT N7ZO CN85
000407 0 0.1 2337 + CQ W5RKN EM10
000415 8 0.1 1238 + N7ZO W5SAT +14
000415 2 0.1 2174 + W5RKN W0DHB R+11
000422 -2 0.2 1579 + CQ WA6DNR CM87
000422 4 -0.0 1847 + W5SAT N7ZO R+08
000422 4 0.1 2346 + CQ W5RKN EM10
000430 5 0.1 1236 + N7ZO W5SAT RR73
000430 3 0.1 2167 + W5RKN W0DHB R+11
000437 -2 0.2 1576 + CQ WA6DNR CM87
000437 5 0.0 1847 + W5SAT N7ZO 73
000437 2 0.1 2357 + CQ W5RKN EM10
000445 8 0.0 1238 + W5RKN W5SAT DM26
000445 -1 0.1 2166 + W5RKN W0DHB R+11
000452 -5 0.2 1577 + CQ WA6DNR CM87
000452 1 0.0 1847 + CQ N7ZO CN85
000452 -3 0.1 2355 + CQ W5RKN EM10
000500 5 0.0 1239 + W5RKN W5SAT DM26
000500 1 0.1 2165 + W5RKN W0DHB R+11
000507 7 0.1 2366 + CQ W5RKN EM10
000515 4 0.1 1240 + W5RKN W5SAT DM26
```

Figure 3 — N7ZO's Band Activity display excerpt.

```
000231 Tx 1780 + WA6DNR N7ZO CN85
000252 10 0.2 1884 + N7ZO WA6DNR +08
000300 Tx 1780 + WA6DNR N7ZO R+10
000307 7 0.1 1885 + N7ZO WA6DNR RR73
000315 Tx 1780 + WA6DNR N7ZO 73
000245 10 0.0 1239 + CQ W5SAT DM26
000326 Tx 1780 + W5SAT N7ZO CN85
000330 10 0.0 1237 + CQ W5SAT DM26
000337 Tx 1780 + W5SAT N7ZO CN85
000345 8 0.0 1239 + W5RKN W5SAT DM26
000352 Tx 1780 + W5SAT N7ZO CN85
000400 7 0.0 1239 + W5RKN W5SAT DM26
000407 Tx 1780 + W5SAT N7ZO CN85
000415 8 0.0 1238 + N7ZO W5SAT +14
000422 Tx 1780 + W5SAT N7ZO R+08
000430 5 0.0 1237 + N7ZO W5SAT RR73
000437 Tx 1780 + W5SAT N7ZO 73
000445 9 0.0 1238 + W5RKN W5SAT DM26
000452 Tx 1780 + CQ N7ZO CN85
000500 5 0.0 1239 + W5RKN W5SAT DM26
```

Figure 4 — N7ZO's Rx Frequency display excerpt.

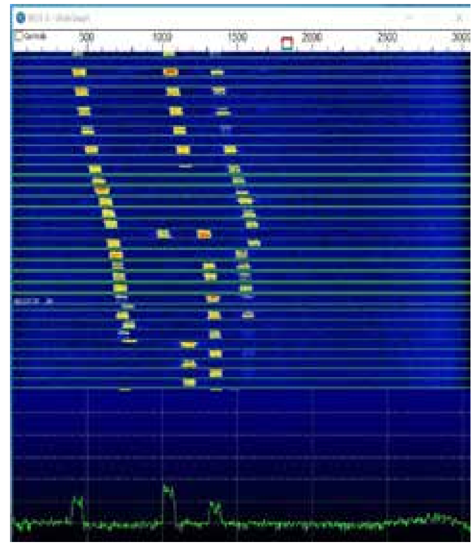


Figure 5 — W5RKN's WSJT-X Wide Graph display.

from a receive-only instance of WSJT-X, which includes decoding himself.

The same period of N7ZO's Rx Frequency display from WSJT-X is shown in Figure 4. This is from the Tx instance of his dual WSJT-X installation.

An example of W5RKN's WSJT-X Wide Graph, which shows the waterfall display of approximately the same time period as the two N7ZO displays above, is shown in Figure 5.

Conclusion

We have shown that weak-signal digital communication using the WSJT-X FT4 mode is not only possible but also useful. Make use of its excellent weak-signal capability — go out and make some new distance records. Be considerate of other users on the satellite. Keep to the low end of the passband. Don't drift around, but compensate for Doppler shift. Use the lowest power possible. Have fun.

For Beginners - Amateur Radio Satellite Primer (Part V)

Keith Baker, KB1SF/VA3KSF
kb1sf@amsat.org

[Portions of this column previously appeared as "How To Use The Linear Amateur Satellites" in the November 2010 edition of Monitoring Times Magazine. *Thank you* MT*!]*

A cooperative effort between the JARL and the JAMSAT, JAS-2 (which later became Fuji OSCAR 29 (FO-29) on-orbit) is a linear transponder satellite shown here just before its launch in 1996. The satellite remains semi-operational to this day. (Courtesy: JARL.)

In previous columns, I've discussed ways to find, track, listen for, and then communicate through our expanding fleet of amateur radio satellites. In this installment, I'll introduce you to another (non-FM) type of satellite transponder called a linear transponder that is carried aboard many of our current amateur satellites.

Transponder "Flavors"

You'll remember from previous columns that a transponder is a circuit in a satellite that receives an uplink signal and then retransmits what it hears via its downlink transmitter, much like your local FM repeater does. However, unlike your local FM repeater (and most of our FM satellites), which has a specific input and output frequency, most so-called "linear" satellite transponders (sometimes also called "analog" transponders…the terms are often used interchangeably) receive and then retransmit a whole band of frequencies commonly called a passband.

What's more, linear amateur satellite transponders come in one of two flavors. These transponders are usually classed as inverting or non-inverting. If the satellite has a non-inverting transponder, when an operator's uplink signal frequency is on the high end of the uplink passband, their downlink signal will also be in the high end of the downlink passband.

Conversely, in an inverting transponder, when an operator's uplink frequency is on the high end of the uplink passband, it will become inverted (hence the name) and come out on the lower end of the downlink passband. Put another way, inverting transponders make mirror images of the signals they pass.

This holds true for the sideband sense as well. In a non-inverting transponder, the signals an operator sends up to the satellite (USB or LSB) will come out the same way on the downlink. However, in an inverting transponder, a USB uplink will be inverted and come out as LSB on the downlink. Conversely, a LSB uplink will be inverted and come out as USB on the downlink. The latter approach (USB signals on the downlink) is also what's most preferred by operators using our linear satellite transponders today. Fortunately, CW will be CW regardless of the transponder's variety!

Note that most linear-transponder-equipped satellites currently in orbit, (including FO-29, AO-73, RS-44 as well as the CAS and XW series of satellites) contain inverting linear transponders. The one exception is our old AO-7 satellite launched back in 1974 and which is still "sort of" operational. It uses a non-inverting, linear transponder while in Mode V/H (the old Mode A).

As with the FM birds, common operating practice on amateur satellites with linear transponders is to first listen for your own signal on the downlink. You'll remember from my previous columns that working through a satellite transponder is usually a full-duplex operation, much like talking on a telephone. This means that others can usually hear you while you are hearing yourself.

Finding your own signal in the downlink passband of a satellite with a linear transponder the first few times can be tricky. However, I've found that placing your transmit frequency somewhere in the middle of transponder's passband and then sending a few (widely-spaced) "dits" of CW while tuning your receiver to find your downlink signal works best. This approach causes minimal interference to others who are then working through the transponder. Once you've located your signal, you're ready to try making a contact.

Unlike the FM birds, calling CQ on these satellites is acceptable, and you'll usually find the convention of CW operations in the low end of the passband with phone operation in the upper part of the passband (an arrangement common to High Frequency (HF) amateur radio operation) generally holds true for satellite work as well.

As I have also noted in previous columns, since a satellite is a moving target, its downlink signals will exhibit a pronounced Doppler shift, just like the changing pitch of a train whistle as it approaches and then passes. During a satellite QSO, the "old" (that is, before computer frequency control) so-called "one true rule" of thumb for linear satellite operation is that if the uplink band is higher in frequency than the downlink, you should slowly shift your transmit frequency on the uplink as the Doppler effect changes the frequency of your downlink signal.

Conversely, you should shift your receive frequency if the uplink band is lower in frequency than the downlink. Or, to put it another way, the highest frequency band in use (uplink or downlink) is what you should shift as Doppler affects your signals. This approach will usually help prevent an inadvertent shift of your conversation into someone else's on the transponder. However, in the heat of the moment with everyone frantically searching through the passband for their own downlink signals, these conventions are often ignored.

Technicians make a final adjustment to JAS-2's (FO-29's) upper stage attachment mechanism just prior to the final integration and eventual launch of the satellite. (Courtesy: JARL)

Keep The Power Down!

Also, because it is generated from the Sun, satellite power is a finite (and, therefore, scarce) resource. That's why it is very important to use only enough power on your uplink transmissions to produce a readable signal on the downlink.

As I've said, you need to get used to the idea that satellite work is weak signal work. It's not like operating on HF (or terrestrial VHF or UHF) where the use of more power is usually better. Besides being potentially harmful to a satellite's battery life by using more uplink power than is necessary, overpowering your uplink signal beyond the point of creating a discernable signal through the satellite's transponder on the downlink will not appreciably improve the overall strength of your downlink signal.

On the contrary, such activity will do little more than "pump" the satellite's automatic gain control as it tries to compensate for the onslaught you are creating with your overpowered uplink signal. Such activity will only gobble up yet more of the satellite's precious available power, not to mention limiting the overall downlink power available for others using the transponder.

Unfortunately, all it takes is one overpowered uplink signal in the passband to drastically cut the strength of everyone else's downlink signal. As you might expect, such activity will not make you a popular camper on the satellites as crocodiles — those who operate with "all mouth and no ears" — are about as welcome on the birds as lids are elsewhere in amateur radio.

FM Is Particularly Unwelcome

In addition, because satellite power is such a scarce commodity, most linear satellite transponders are built to use the most efficient operating modes possible. Normally, this equates to single sideband (SSB) voice and/or Morse (CW).

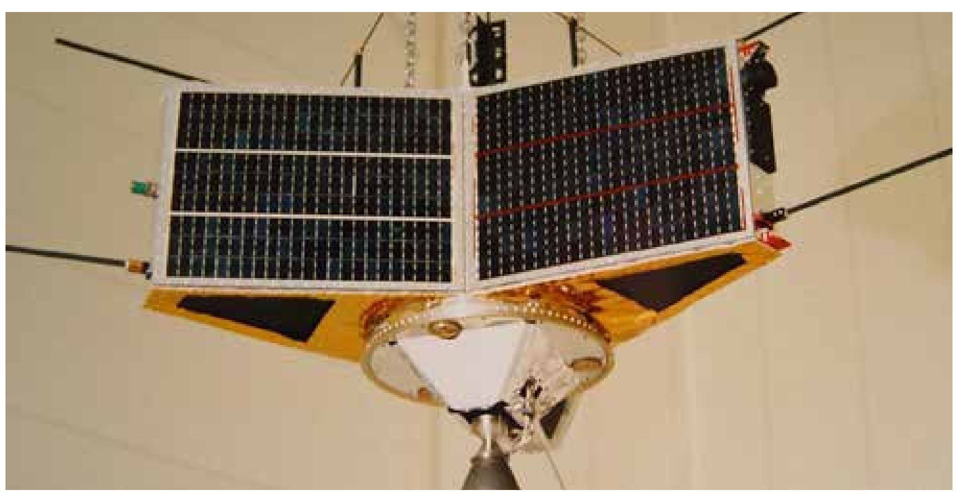
Therefore, it should also come as no surprise that another big "no-no" is running FM through linear satellite voice transponders. FM signals occupy a much larger bandwidth and take a significantly greater portion of a transponder's precious output power to re-broadcast than do CW and SSB signals.

Your FM signals will gobble up lots of downlink power, not to mention causing your transmissions to stick out like a sore thumb. Just imagine how obnoxious you'd sound running SSB signals through your local FM repeater, and I think you'll agree that all use of FM should be avoided when operating through one of our linear satellite transponders.

Wrap Up

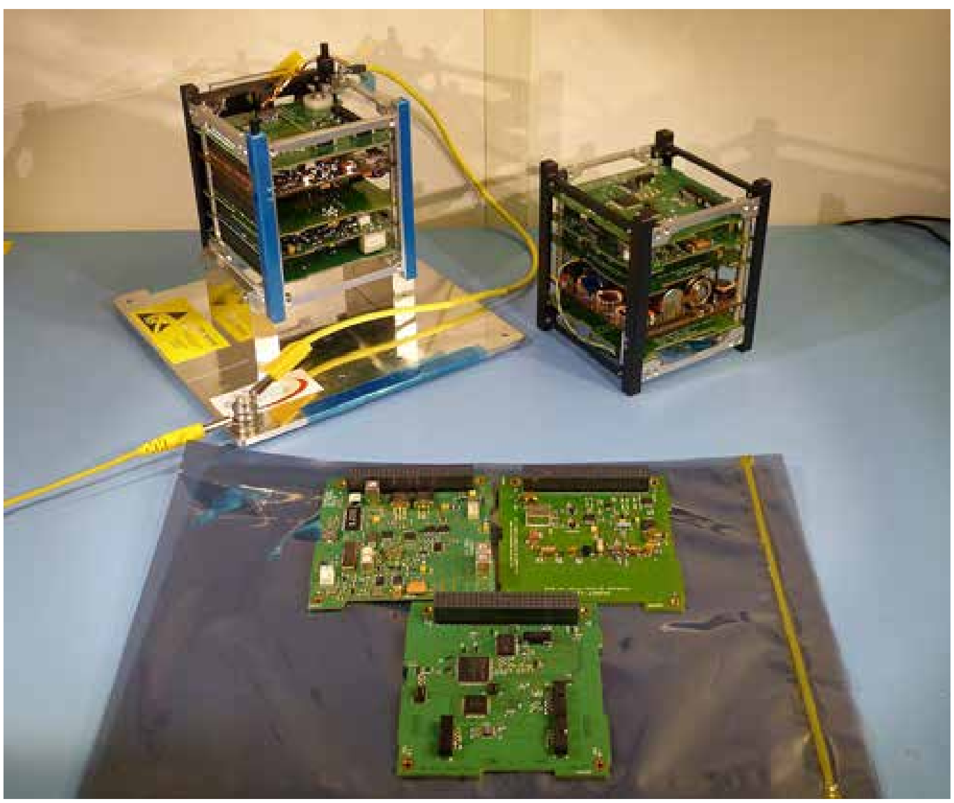
That's all for this time. In future installments, I'll be discussing some more detailed aspects of this unique part of our amateur radio satellite hobby by shining the spotlight on several of our satellites now in orbit. See you then!

JAS-2 (FO-29) is shown here just after final assembly and integration of the satellite were completed. (Courtesy: JARL)



AMSAT-Germany's Phase 3-C satellite (which later became AMSAT OSCAR 13 (AO-13) on-orbit) was a very popular linear transponder satellite that provided amateurs with near worldwide coverage before its (unplanned!) de-orbit in late 1996. (Courtesy: AMSAT-DL)

AMSAT OSCAR 7 (AO-7) another satellite carrying linear transponders was launched in 1974 and went silent in 1981 due to battery failure. Then, after 21 years of apparent silence, the satellite was heard again on June 21, 2002, and remains semi-operational to this day when sunlight illuminates its solar panels. (Courtesy: AMSAT)



A working engineering model of AMSAT-UK's FUNCube-1 is shown here on the left along with the actual flight model (minus its solar panels) on the right. FUNCube1 (which later became AMSAT OSCAR 73 (AO-73) on-orbit) was successfully launched in 2013. The satellite carries both a linear and an FM transponder. (Courtesy: AMSAT-UK)

OSCAR Who?

Since 1961, some 100 plus "OSCARS" (short for Orbital (or Orbiting) Satellite Carrying Amateur Radio) have been built and launched by a number of amateur radio-related organizations worldwide. And just like their Hollywood counterpart of the same name, there are some very strict rules as to how our amateur satellites get to be so honored.

First, they have to be capable of transmitting and/or receiving in the amateur radio bands. They also have to successfully achieve orbit and be activated in space. And, lastly, the builders of the satellite have to formally request that an OSCAR number be assigned to their orbiting handiwork.

Today, by mutual agreement between AMSAT and the original Project OSCAR team (who built and launched the very first OSCAR satellites), those formal requests all go to our AMSAT Board of Directors and Vice President of Operations member Drew Glasbrenner, KO4MA, who then determines the "amateurness" of the payload before he assigns an OSCAR number.

Most amateur satellites have other names before launch. For example, AMSAT-North America has chosen to use sequential alphabetic characters for their satellites. One of AMSAT's current (and very popular!) FM birds, AO-91, was dubbed "Fox-1B" before its successful launch and activation on orbit. The fleet of Japanese amateur satellites uses "JAS" (Japan Amateur Satellite) followed by a sequential number for their amateur satellites. Their current, semi-active amateur satellite, FO-29, was called "JAS-2" before its successful launch in 1996.

Usually, the "O" stands for "OSCAR", while the number following it is sequentially assigned, depending on when the satellite's transponder is activated on-orbit or when its builders request that an OSCAR number be assigned. What's more, the first letter of the OSCAR designator usually is suggested by the satellite's builders or sponsors and often gives a hint about its heritage.

For example, the "F" in FO-29 stands for "Fuji" (for "Fuji OSCAR") while the "A" in AO-91 stands for "AMSAT" (as in "AMSAT- OSCAR 91"). The "S" in SO-50 stands for "SaudiSat" as a university team in Saudi Arabia sponsored the building and launch. Just remember that the letter "O" in a satellite's official, on-orbit name followed by a dash, and then one or two numbers, usually indicates that the satellite is one of our fleet of amateur radio (OSCAR) satellites.

Using the Kenwood TM-D710GA's Internal TNC with the FalconSat-3 BBS

Kevin Zari. KK4YEL

Introduction

I am an engineer, an amateur radio enthusiast, and somewhat of a perfectionist when it comes to figuring out things that interest me. Sometimes, as I am struggling with challenges, I wonder to myself, "How many other folks have quit along the way because there wasn't an easy-to-find guide?" "How many folks figured this out before me, but either didn't share the knowledge, or the info isn't easy to find?" That is my motivation for writing this article.

There are plenty of great guides out there about making a QSO through a satellite that has an APRS digipeater. I started with JoAnne Maenpaa's (K9JKM) excellent article entitled "Add ISS Packet Operation to Your Satellite Activity." (See **www.ariss.org/uploads/1/9/6/8/19681527/k9jkm_2012_symposium_ver2.pdf.**)

After making a few QSOs by the method JoAnne outlined, I satisfied my curiosity. But then I read, "Working Digipeaters with the Kenwood TH-D72A and TH-D74A" by Joe Kornowski (KB6IGK) and Patrick Stoddard (WD9EWK). (See **www.amsat.org/wordpress/wp-content/uploads/2014/01/AMSAT_Journal_KenwoodHT_Packet.pdf.**)

I liked the article because I owned some of the radios described, and the authors walk you through specific menu settings needed to be successful. As a result, I also made my first 9600 baud APRS QSO through the FalconSat-3 satellite.

Unlike the 1200 baud APRS digipeater on the ISS, FalconSat-3's APRS digipeater is 9600 baud. When I made my APRS QSOs through FalconSat-3, I saw all sorts of non-APRS packets via the packet monitor (PMON) function of my Kenwood TM-D710GA radio. They were appearing to cause collisions and making APRS QSOs difficult on that satellite. What the heck was happening? Did another station have its radio misconfigured, beaconing away in rapid succession? I looked at the raw packets, did some Internet searches, and discovered that FalconSat-3 also has a 9600 baud Bulletin Board System (BBS).

Most of the information available online about using FalconSat-3 was pointing to various procedures for tapping off the radio's 9600 baud pins in the data port, pulling it into a computer via a sound card, using software to act as a Terminal Node Controller (TNC), and then feeding that into applications to make use of the BBS. That seemed fine, especially if the radio didn't have a built-in hardware TNC. But the Kenwood TM-D710GA did, so I wanted to use it. Even more daunting, the suite of software referenced in many online mailing list posts was originally written for Windows 3.1 and later for Windows 95/98/NT. I'm not knocking the app suite in any way, but the idea of trying to get decades-old software to run on a modern operating system wasn't how I wanted to spend my time. Luckily, I would find a better solution. More on that in a bit.

My radio, the Kenwood TM-D710GA, has a built-in TNC. I wanted to leverage that feature by feeding the data directly into the computer, having software communicate directly with the TNC in the radio to access the BBS on FalconSat-3. Here is how I set up my TH-D710GA to work with the BBS on FalconSat-3.

Kenwood TM-D710GA Internal TNC Setup

Serial Port Baud Rate Versus Internal TNC Baud Rate

I just want to point out that the default baud rate used in the serial connection from the radio to the computer through the comm port is 9600 baud. This is seen in Menu 929, COM Port Baudrate. Don't confuse this with the baud rate you want the internal TNC to communicate to the satellite with. They are two separate things. Leave the COM Port Baud rate at its default of 9600. You will need to know that later when setting up software to communicate over the COM port to the TNC.

Setting Internal TNC to 9600 Baud

When you press the TNC button on the radio, it toggles between three states: the internal TNC configured for APRS, the internal TNC configured for AX.25 packet, and the internal TNC off. When you cycle through these, you will most likely see PACKET12 displayed on the screen. Reference Figure 1 - Radio in PACKET 1200 mode. The 12 represents 1200 baud. But FalconSat-3 is 9600 baud. Unlike other parameters, you cannot change the internal TNC's packet baud rate through the menu in the radio. One way to set the TNC packet baud rate is through a serial port connection via a terminal emulator running on your PC. Make sure you have the Kenwood serial communications cable plugged into the back of the control head of your radio. This is the component of the radio that has the amber (or green) backlight. Do not have the serial communications cable plugged into the back of the main body. When using the built-in TNC, you must connect the serial communication cable to the control head. On the other end of the cable is a DB-9 connector, which for me, I connected to my computer through the use of a USB to serial port adapter (I use the Tripplite USA-19HS). Anyway, if you have to, use device manager to find which COM port is assigned to that adapter.

Next, you will need to use a terminal emulator. I like Putty (www.putty.org/). With the Kenwood using its internal TNC in the PACKET mode (with PACKET12 displayed), open up a session in Putty and connect to the COM port your USB to serial adapter is assigned to. Remember to set Putty for the COM Port Baud rate of 9600, assuming you left it at the default, as I recommended. Once it connects, you may have to hit the Enter key a few times on your keyboard, but you should see the term "cmd:".

Next, let's type this command. Be careful, as the terminal doesn't like the backspace. If you type an unknown command, you will

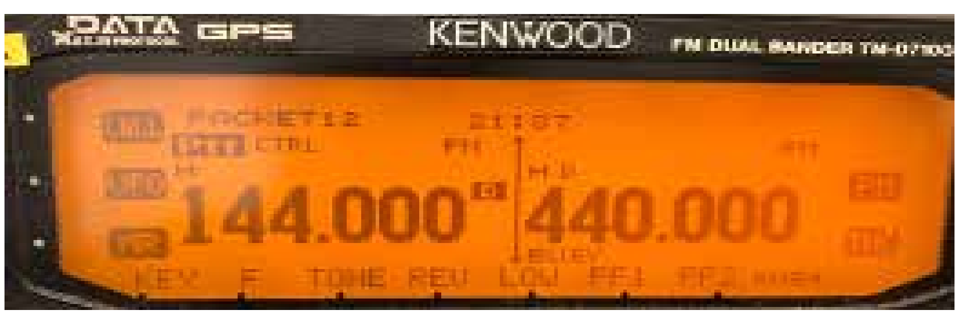


Figure 1 — Radio in PACKET 1200 Mode.

Figure 2 — Kenwood TM-D710GA in PACKET 9600 Mode.

Figure 3 — Default Setting for Internal TNC.

Figure 4 — Internal TNC Set for Full Duplex.

Figure 5 — Display with Squelch Set Up Properly and Downlink Signal Present.

see "?EH" displayed in the terminal. Don't worry, just type the command again. Type HBAUD (and then hit the ENTER key). The terminal window should echo back the words "HBAUD 1200." But we want 9600, so type the following HBAUD 9600 (then hit the ENTER KEY). So, the screen should read as follows:

```
cmd: HBAUD
HBAUD 1200
cmd: HBAUD 9600
HBAUD      was 1200
cmd:
```

Take a look at your radio, and you should see PACKET96 displayed now. Refer to Figure 2 - Kenwood TM-D710GA in PACKET 9600 mode. Congratulations, you just set the Internal TNC's baud rate to 9600. You can exit out of Putty now. This is important because we need to free up the COM port for the BBS software.

Setting Internal TNC for Full Duplex

The default mode for the internal TNC is to have VFO A be used for both TX and RX. You need to change that. Enter the Menu by hitting the F key, then push in on the leftmost knob on the radio, rotate that leftmost knob until you get to AUX, and again push in the leftmost knob. Rotate the leftmost knob to find menu item 930, Int. Data Band (PACKET). You will notice it is defaulted as in Figure 3 - Default Setting for Internal TNC. Push the leftmost knob in, then rotate it until you can select TX: A-BAND RX:B-BAND as shown in Figure 4 - Internal TNC Set for Full Duplex. Push the knob in, to confirm your choice, and then hit ESC. It is important to note that I have set my radio up so that I can TX on VFO A and RX on VFO B.

Squelch Settings

As I stated, I chose to have my VFO A be used for TX, so I kept its squelch all the way closed. For my VFO B, used for RX, I opened the squelch all the way up, similar to how you would configure a radio for full-duplex for FM voice. Unlike for FM voice/phone birds, you do not need to have the volume on, as the TNC is what is listening, regardless of the volume to the speaker. In fact, you won't hear much of anything but will see VFO B's S-meter level displayed on the TM-D710GA when there is data on the downlink. Refer to Figure 5 – Display with Squelch Set Up Properly and Downlink Signal Present.

Memory vs. VFO

It is up to you whether you preprogram your radio to have presets for FalconSat-3 frequencies, or if you just use the VFO and manually enter the frequencies. Refer to the Kenwood TM-D710GA manual if you want to store them in memory locations. FalconSat-3 values for presets are documented in the frequency chart by Patrick Stoddard (WD9EWK) at **www.amsat.org/wordpress/wp-content/uploads/2018/03/FalconSAT-Stoddard-pdf.pdf**.

Saving Your Settings – Programmable Memory (PM)

The Kenwood TM-D710GA has an amazing feature that I was so happy to learn was there. It can save a snapshot of the entire radio for quick and easy recall. Think about this for a second. If you have ever played around with 1200 APRS on ISS and then switching to 9600 APRS on FalconSat-3, you know you have to change a bunch of parameters. You could configure the radio with the settings

Figure 6 — Different PMs Startup Screens.

you need for one application, let's say ISS APRS and save the state of the radio into a PM. You can then make changes to the radio for another application, let's say FalconSat-3 APRS, and save that. Remember, it is a snapshot of the radio at that time. So, if you have the TNC off, it will be off when you recall that PM. If you have it in APRS96 it will be in APRS96 when you recall that PM. This allows you to easily switch between the different configurations needed for different modes/satellites very rapidly. Furthermore, you can save different startup images and messages for each PM. Details on how to do this are in the Kenwood TM-D710GA user manual. I use four PMs: Off (for regular terrestrial use), ISS APRS, FalconSat-3 APRS, and FalconSat-3 BBS. See Figure 6.

Modern Software for FalconSat-3's BBS AMSAT PACSAT Ground Station

Remember when I said I found a much better solution than trying to make software for Windows NT work on a modern OS? I found the easiest software to use on a modern MS Windows-based PC is AMSAT PACSAT Ground Station software, by Chris Thompson (AC2CZ/G0KLA), located at **www.g0kla.com/pacsat/**.

The manual is great, and the software is solid. Give it a read and follow the instructions about Using a Hardware TNC. I'm not going to go into details here, but it involves selecting the comm port to find your TM-D710GA on, just like you did in Putty. Listen for a few passes, remembering to adjust for Doppler, especially on the UHF downlink side. Again, follow the excellent instructions Chris has in the manual.

Conclusion and Acknowledgements

Using a BBS on a satellite circling the Earth every 90 mins is another fun way to enjoy the amateur radio hobby. I am certain a similar approach can be used with the Kenwood TH-D72A full-duplex HT. I may update this article if I decide to test that.

I'd like to thank the authors of the referenced papers and software, and also Scott Chapman (K4KDR), Stephen DeVience (N8URE), Harikrishnan Nair (A65GR/NA1RH/VU2TG), and Shin Aota (JL1IBD). I encourage you to support AMSAT with your monetary donation, time, or sharing of knowledge.

Feel free to contact me on Twitter (@supercazzola). Remember, once you connect to the FalconSat-3 BBS, send me a message through the BBS if this guide was helpful.
73 and GL
KK4YEL

Comparison of Omnidirectional VHF Antenna Construction and Performance for LEO Satellites

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Abdus Saboor Zubair, KD9NNV
Dan White, Ph.D., AD0CQ

Abstract

Lowering the barriers of entry with regards to building a satellite ground station is central to why a comparative analysis of easy-to-build antennas is needed. Easing access to the experience of setting up a ground station and observing passing satellites is a valuable asset to any community and allows those who are interested in the data being transmitted, more opportunities to receive said data. The study compares the receive performance of two omnidirectional VHF antennas. Antenna performance metrics include SWR, return loss, decoded images, impedance in the VHF band, and more. Understanding which antenna performs best with minimal tedium during setup can be accounted for as a significant barrier lowering factor. As such, the study also compares the ease and practicality of each antenna build, considering skill level, cost, access to materials, and other relevant factors. The antennas under test include the crossed-dipole and quadrifilar helix (QFH or QHA), both of which are omnidirectional VHF and relatively easy to build. Both of these antennas were to operate in the two-meter band, between 146-148 MHz. Preliminary results suggest the QFH receive performance is stronger than the crossed-dipole.

Background

Assessing antenna performance and constructability are the fundamental criteria by which completion of our objective will be measured, therefore, the ensuing analysis considers the performance of two antennas operating in the two-meter band that were constructed using materials purchasable at any hardware store and tested using a VNA as well as other equipment and techniques. A quantitative comparison of homemade, LEO reception antennas is not present in any existing published material, therefore, data acquisition for the purposes of comparing the antennas had to be done. This was accomplished by ensuring that both

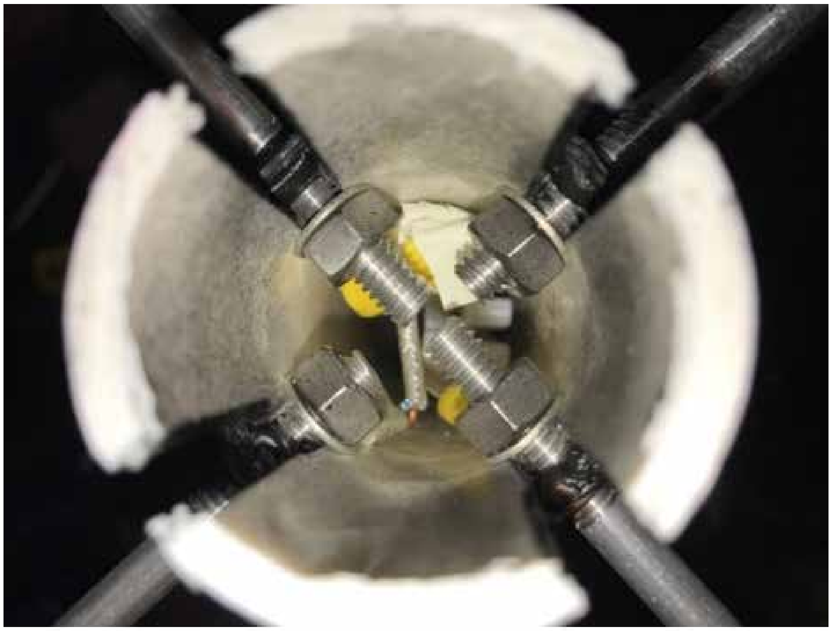

Figure 1: Crossed-dipole feed point.

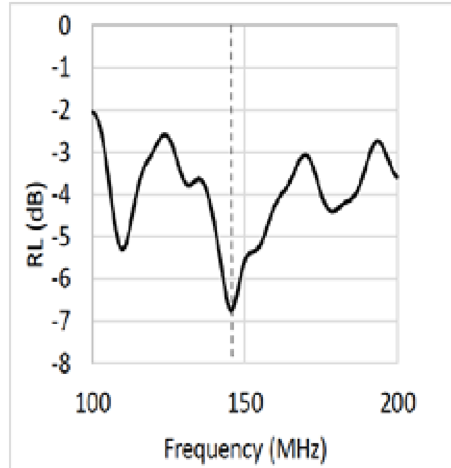

Figure 2: Measure of turnstile return loss over 100 MHz frequency sweep (dashed line denotes 146 MHz).

antennas operated in the same conditions, which included location, environment, builders, measuring devices and receive parameters such as gain, orientation in space, and reception frequency.

The missions of SatNOGS, an open-source hardware platform for networking satellite ground stations, the Libre Space Foundation, and our own objective of accessibility informed our choice of which antennas to build. In compliance with our objective, the chosen antennas had to be omnidirectional, as this is the most cost-effective, and requires minimal construction experience on the part of the builder. Thus, the chosen antennas were the crossed-dipole or turnstile antenna and the quadrifilar helix (QFH or QHA) antenna. Our intended receive frequency was to be at 146 MHz. This frequency would allow us the flexibility to downlink data from the NOAA weather satellites at 137 MHz, the Fox satellites, and many others operating in the two-meter amateur band.

Crossed-Dipole – Characteristics & Construction

The first antenna to be considered will be the half-wave crossed-dipole (or turnstile) antenna. The materials needed for construction included 1¼" PVC, 13 feet of ¼" aluminum rod, ¼" nuts, ring terminals, terminal blocks, LMR-195 coaxial cable, and terminating SMA connectors. The desired reception frequency of 146 MHz dictated the length of each half of the dipoles to be 18.4" and reflectors to be 36.94". The construction process consisted of creating four through-holes perpendicular to each other in the PVC pipe through which the halves of the driven elements were secured. Then, four more holes were drilled into the PVC, a quarter wavelength, or 18.4", from the driven elements; each pair of holes were drilled in planes offset by a quarter-inch such that the two reflectors could pass through the PVC without coinciding. Next, the driven elements had to be wired. This was done by separating the inner and outer conductors and connecting them to the driven elements 180° apart. Then, the 90° phase line was cut to 18.4", where one end was spliced with the feedline and the other end was connected to the remaining driven elements [1]. The manner in which these connections were made resulted in the intended left-handed polarization [2]. The challenge of this build was with respect to the congestion of the feed point. Feed point congestion, as seen in Figure 1, is a challenging problem to remedy because antenna theory requires that the dipole is continuous from end to end despite the obvious impossibility of this in reality. Perhaps, the feed point could be a separate

Figure 3: QFH feed point assembly. [David P. Finell; *Build a 2-Meter Quadrifilar Helix Antenna,* 9 July 2019].

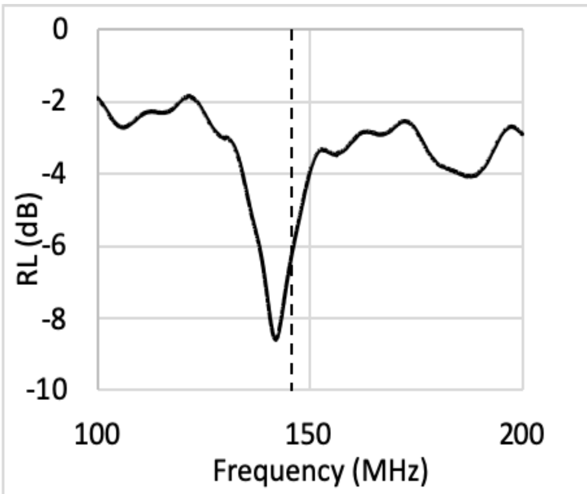

Figure 4: Measure of QFH return loss over 100 MHz frequency sweep (dashed line denotes 146 MHz).

assembly which could be coupled to the main post in future builds.

Crossed-Dipole – Performance

Antenna elements for the turnstile were iteratively tested with a VNA during the building process. Since a turnstile is comprised of two dipoles 90° out of phase, each dipole was tested to verify if it was receptive at 146 MHz. For the first dipole to undergo VNA testing, the VNA plot of return loss vs. frequency revealed a dip at 138.4 MHz instead at 146 MHz. This result sparked the realization that theoretical conditions make assumptions that cannot be ignored in application; frequency has a linear relationship with the length of the dipole, hence the concept of proportionality was used to make the dipole resonant at 146 MHz.

It was determined that the dipole should be shortened by 5.2% after calculating the percent difference in the frequencies. After cutting down the length, the dipole was tested again with the VNA, and successfully obtained a dip at 146 MHz. Then the cross dipole was cut to the same length and verified with the VNA to ensure resonance at 146 MHz. After adding the quarter wavelength phase line and reflector, the newly assembled turnstile was tested. The return loss vs. frequency plot for the turnstile revealed a dip at 146 MHz. Although the dip's position was right, it was not as deep as the dips of the individual dipoles. The return loss was -6.73 dB, as seen in Figure 2, for the turnstile, while the dips of individual dipoles were -27.09 dB. SWR for the turnstile at 146

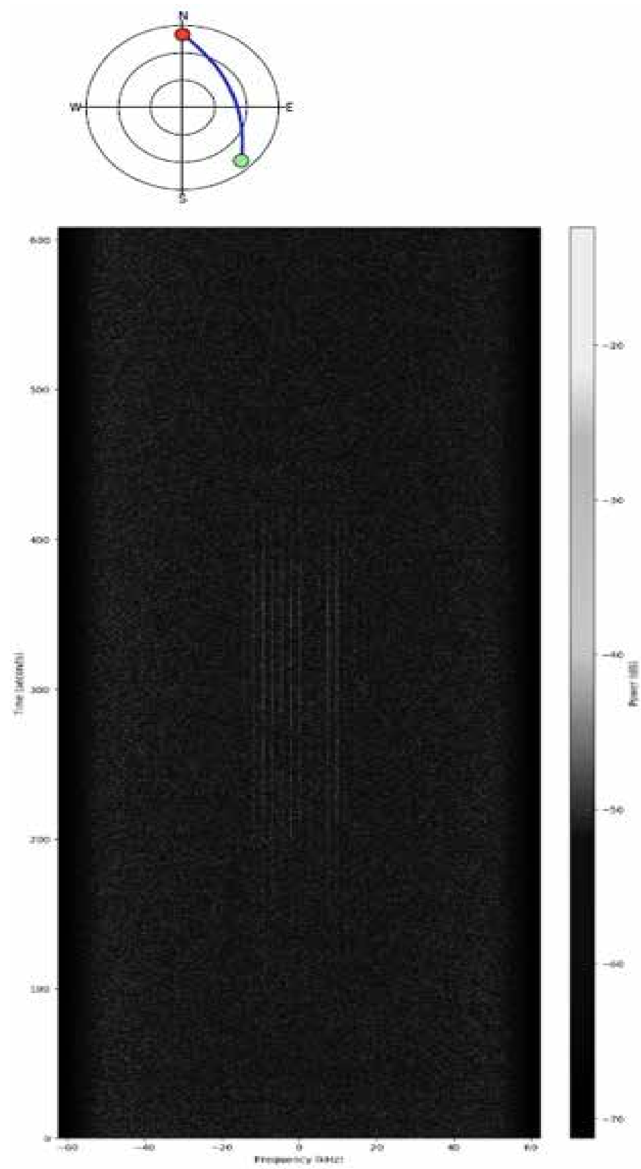

Figure 5a: Crossed-dipole waterfall representation of observation taken during a NOAA-18 pass.

MHz was 2.71 and resistance and reactance at 146 MHz for the turnstile were 31.2 Ω and 36.4 Ω, respectively. After this, we scheduled observations through SatNOGS for weather and amateur satellites to obtain the waterfall spectrum and decoded images.

QFH – Characteristics & Construction

Constructing the QFH antenna was done by following instructions written in the journal *QST* by David P. Finell, N7LRY, titled Build a 2-Meter Quadrifilar Helix Antenna [3]. The materials required for this build included 2¼" PVC, 2" PVC, 2¼" to 1¾" adapter, 2 feet of ¼" aluminum rod, 12 feet of ½"-width aluminum strips, ¼" nuts, and ring terminals. The desired reception frequency of 146 MHz dictated the physical parameters of the antenna, like helix diameter and length. Two sets of four holes were drilled 18.4" apart, which set the length of each helix. The helices were made by cutting two 10" aluminum rods and securing them to each end of two of the aluminum strips. This formed a rectangle which was then twisted by stepping on one end of the assembly and turning the other end 180° by hand. This formed one of the helices and was repeated to form the other helix. The feed point of the antenna consisted of a 1" PVC cap which was affixed concentric with a coupler at the bottom end of the helix, as seen in Figure 3. The inner and outer conductors of the LMR-195 coaxial cable were then separated and connected to the elements 90° offset from each other. A 90° phase line was then spliced to the feedline connections on one end, and connected to the remaining two elements on the other end. The challenge in constructing the QFH had to do with screwing the nuts onto the aluminum rods onto which threads

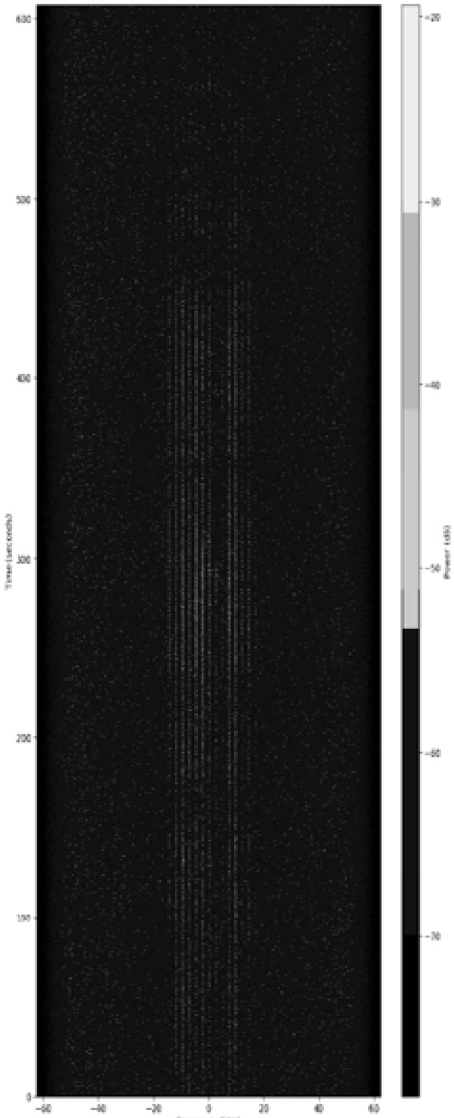

Figure 5b: QFH waterfall representation of observation taken during a NOAA-18 pass.

were cut using a tap and die set; the softness of aluminum would yield to the hardness of the steel nuts when screwed on. This made fine adjustments of the nuts (to adjust the helix diameter) difficult.

QFH – Performance

The QFH cannot be tested in a piece-wise fashion as the turnstile was, so the QFH was tested only once it was completely assembled. Once the QFH was put together, it was tested with the VNA. The return loss vs. frequency plot revealed a dip of -6.08 dB at 146 MHz, as seen in Figure 4. Also, the .csv file from the VNA test revealed a SWR of 2.97, real impedance of 18 Ω, and reactance of -12.5 Ω. Our rudimentary application of impedance matching using a choke balun did not prove to be very effective. After the VNA testing, observations were then scheduled through SatNOGS for weather and amateur satellites to obtain the waterfall spectrum and decoded images.

The waterfalls in Figures 5a and 5b illustrate the disparity in the receive quality between the turnstile and QFH antennas upon reception from a NOAA-18 weather satellite. It can be seen that the turnstile's downlink strength was weaker than the QFH which maintained a reception quality of -35 dB throughout most of the pass. This comparison, however, is an ongoing process, as neither antenna is equipped with an LNA or band-pass filter.

Conclusion

This study provides a comprehensive analysis of the ease of construction and preliminary performance of the omnidirectional VHF crossed- dipole turnstile antenna and QFH antenna. To provide a standardized analysis we controlled the conditions and operating environment under which both antennas were tested. Difficulties during construction were experienced during both antenna builds; an iterative approach will be taken to solve these issues to improve constructability. The initial data suggests that, through VNA plots and waterfall spectrums, the QFH exhibits better receptivity. It must also be noted that this study is ongoing and that any substantial claim on the performance of either of the antennas is dependent on the completion of a satisfactory number of test observation.

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[1] Cebik, L.B. "A Simple Fixed Antenna for VHF/UHF Satellite Work." *QST*, Aug. 2001.

[2] Alicajic, Adam 9A4QV. "DIY 137 MHz APT Weather Satellite Antenna – Or, Do We Need a Circular Polarization?" **http://rfelektronik.se/manuals/Datasheets/.**

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Regulatory Update

Paul Stoetzer, N8HM
Executive Vice President

AMSAT faces many challenges in our efforts to Keep Amateur Radio in Space. Most members are familiar with the technical challenges involved in satellite development and financial challenges involved in a small non-profit organization funding the hardware, development, testing, and launch costs associated with amateur radio satellites. However, changing regulatory requirements also has had a big impact on our mission. In fact, in my report to the Board of Directors that I delivered at the 2019 meeting, I stated that increased regulatory requirements were the number one threat to AMSAT's mission. Fortunately, with strong support from the ARRL and others in the small satellite community, I am confident that we can avoid the most serious of the regulatory hurdles we face.

First, some good news. On May 20th, NOAA published a final rule on the Licensing of Private Remote Sensing Space Systems. This rule places remote sensing space systems into tiers based on differing capabilities. Given that AMSAT only operates a very low-resolution camera system on AO-92, this should relieve some of the regulatory burdens that we have faced operating the camera and maintaining the license. This new rule should also streamline the process of licensing the camera proposed for GOLF-1.

One of the more serious threats to AMSAT's mission is the pressure for more spectrum, especially microwave spectrum, for commercial uses such as 5G. In December 2019, the Federal Communications Commission proposed the deletion of the 3.3 GHz – 3.5 GHz amateur band to make room for commercial applications. This band includes an amateur satellite service allocation at 3.4 GHz – 3.41 GHz. In February, AMSAT filed comments opposing the deletion of this band noting the necessity of adequate microwave spectrum for future amateur satellite projects, including AMSAT GOLF and the Lunar Gateway. We also noted that many of our members are engaged in non-satellite activities in the broader amateur allocation, including mesh networking, EME communications, and contesting. As of this writing, the FCC has not finalized action on this rulemaking.

New rules surrounding orbital debris mitigation remain the biggest threat to AMSAT's mission. Amateur satellites authorized in the United States have been subject to orbital debris mitigation regulations since 2004. The basic requirement under the rules currently effective is that AMSAT's satellites are required to either deorbit or move to a parking orbit within 25 years following the completion of their mission. From a practical perspective, this means that even if an appropriate launch were available to us, we could not simply launch another AO-7 or AO-10 as those satellites will remain in orbit for hundreds or thousands of years. AMSAT Engineering is working on various solutions to this issue as part of the GOLF program, but it remains one of the most significant hurdles we face in launching to high LEO or HEO.

In April 2020, the FCC released a draft Report & Order revising the orbital debris mitigation regulations for the first time since 2004. Most of the changes made to the amateur satellite service rules involve more stringent certifications and increased documentation when requesting authorization of amateur satellite operations and are not a significant burden to our operations. However, two of the proposed rules would have a serious effect. First, the draft rules would have required all amateur satellites authorized after 2022 in LEO above 400 km to have maneuvering capability. Given the current state of development of propulsion systems for CubeSats, this requirement would be impractical and would have the effect of limiting AMSAT's future LEO spacecraft to orbits of under 400 km until we were able to include adequate propulsion. Second, the licensee of each satellite would be required to indemnify the government against any claims made against the United States under various international treaties related to the operation of that satellite. Given that amateur satellite licensees can only be individuals, this would have required an individual to personally indemnify the government for these costs. While the chances of such a claim is small, it is unlikely that any individual would be willing to indemnify the government for claims that could easily be millions of dollars.

Upon release of these draft regulations, AMSAT sprung into action. With the assistance of the ARRL and their Washington Counsel, Dave Siddall, K3ZJ, we requested two changes to the new rules: 1. That amateur satellite owners be permitted to make the indemnifications, which would permit AMSAT as a corporation to take on this risk rather than an individual, and 2. That the effective date of the maneuverability requirement be delayed until 2025. Due to the near-unanimous pushback to these proposals, the Commission's final Report & Order moved the issues of maneuverability and indemnification out of the final adopted rules to a Further Notice of Proposed Rulemaking. The Commission also modified the proposed indemnification rule in the manner that we requested and seeks comment on this approach.

As of this writing, the final Report & Order has not yet been published in the Federal Register. We are working on our comments, which will be due 30 days after publication.

AMSAT will remain vigilant in monitoring regulatory developments and will continue to participate in this process. Anyone who wishes to help with these crucial activities is invited to contact me at **n8hm@amsat.org**.

AMSAT GOLF $125,000 Development and Launch Initiative

AMSAT is excited about developing and launching the next generation of Greater Orbit Larger Footprint ("GOLF") satellites. AMSAT has an immediate need to raise funds to cover development, launch and related expenses for GOLF-TEE and GOLF 1. We have set a fundraising goal of $125,000 to cover these expenses and help us to continue to keep amateur radio in space.

GOLF-TEE (Technology Exploration Environment) will be a rapid deployment to LEO to establish/verify/learn ADAC, Deployable Solar Panel Wings, Radiation Tolerant IHU, SDR.

GOLF-1 is planned as an approx. 1300 km LEO, progression of GOLF-TEE technology, first STEM mission with VU and APS, AO-7/FO-29 supplement, and our first "High LEO" CubeSat.

Donations may be made through the AMSAT webpage at **www.amsat.org**, by calling (888) 322-6728 or by mail to the AMSAT office at 10605 Concord Street, Kensington, MD 20895, USA. Please consider a recurring, club, or corporate donation to maximize our chance of success with this mission.

AMSAT President's Club
Support GOLF-TEE and GOLF-1

Contribute to AMSAT directly through easy, automatic charges to your credit card. Since AMSAT is a 501(C)(3) organization donations may be USA tax deductible. (Check with your tax advisor.) To join contact Martha at the AMSAT Office by phone (888) 322-6728 in the US, or (301) 822-4376; e-mail **martha@amsat.org**.

Titanium Donors contribute at least US $400 per month	❒ $400 / month ❒ $4800 one time
Platinum Donors contribute at least US $200 per month	❒ $200 / month ❒ $2400 one time
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Your help is needed to get the AMSAT GOLF-TEE and GOLF-1 Cubesats launched.

For the latest news on GOLF watch our website at www.amsat.org, follow us on Twitter at "AMSAT", or on Facebook as "The Radio Amateur Satellite Corporation" for continuing news and opportunities for support.

With a 50-year Legacy of Success, AMSAT Volunteers …

Build satellites that Keep Amateur Radio in Space!

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Manage satellites in orbit and ensure they are available for public use.

Create and maintain vital partnerships with government, industry, educational institutions, and amateur radio organizations to foster space research and communication.

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