The AMSAT® Journal

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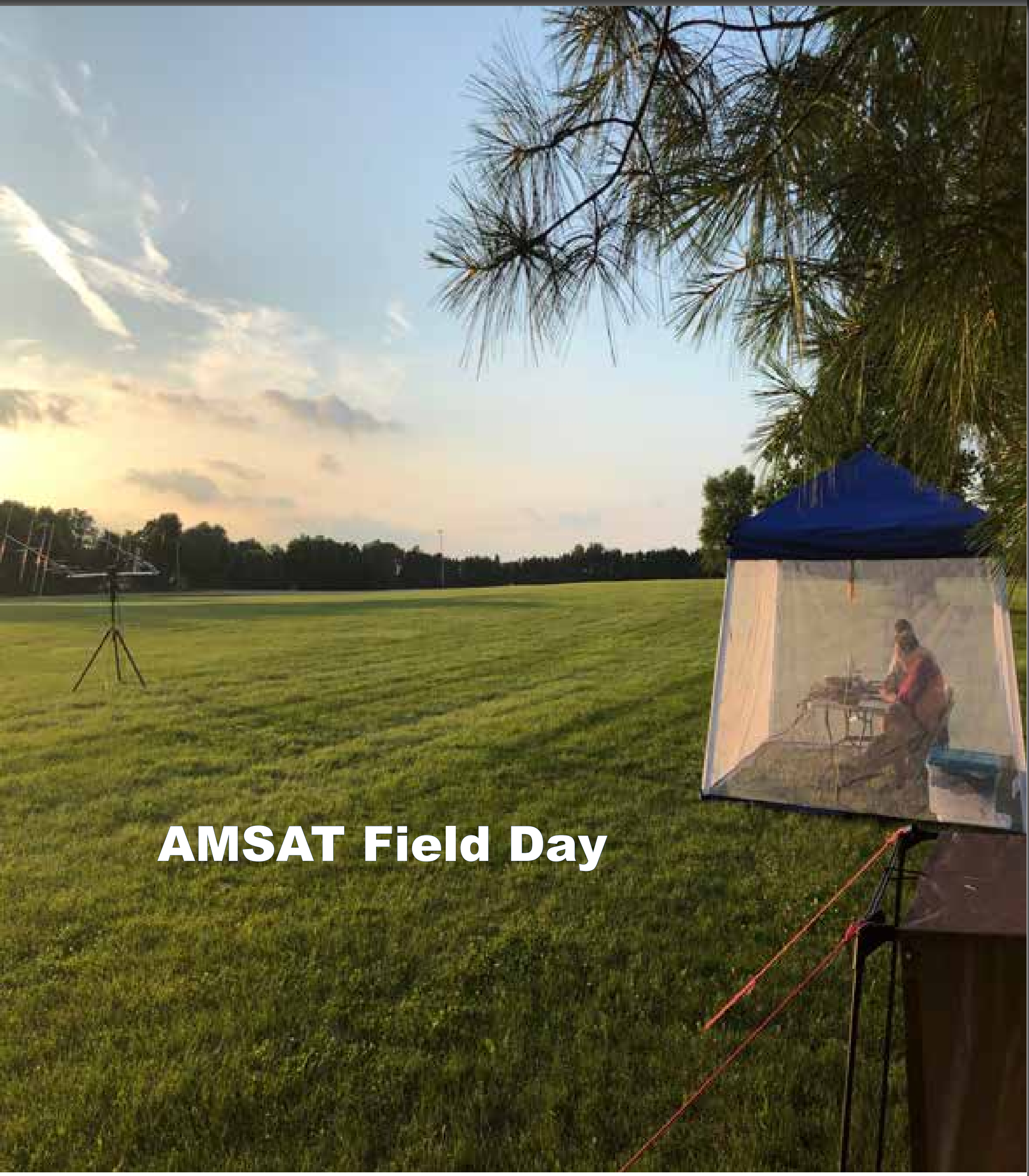

AMSAT Field Day

in this issue …

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AMSAT Announcements

2019 AMSAT 50th Anniversary Space Symposium, October 18-20

AMSAT announces that the 2019 37th Annual AMSAT Space Symposium and General Meeting will be held on Friday through Sunday, October 18-20, 2019, in Arlington, Virginia. The location will be The Hilton Arlington, 950 North Stafford Street, Arlington, Virginia, 22203, 703-528-6000.

The Hilton Arlington is located in the heart of the Ballston neighborhood of Arlington, VA. Connected to the Ballston Metro Station, the hotel offers easy and effortless access to Washington D.C.'s top tourist destinations like the National Mall, Smithsonian Museums and historical monuments. The hotel is six miles from Reagan National Airport and the National Mall.

The AMSAT Board of Director's Meeting will be held just before the Symposium, October 16-17, at the same hotel.

The current plan includes tours of Washington D.C./Baltimore area ton Sunday and Monday, October 20-21. The banquet speakers will celebrate AMSAT's long history, and an OSCAR Park display also is planned, so please plan to join us for the 50th Anniversary Symposium — you would be glad you did.

You can make hotel reservations by calling the hotel directly at 703-528-6000. The group name is AMSAT, Radio Amateur Satellite Corporation.

Attendees may also make their reservations online at **amsat.org**.

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

Joe Spier, K6WAO
President

Since Hamvention, I have traveled to Virginia and Montreal. The purpose of my trip to Virginia was to move the AMSAT historical files from Dr. Bob McGwier's (N4HY) basement to climate-controlled storage in Virginia, nearer to the AMSAT Office. For the past five years — since the move out of the AMSAT office in Silver Spring, MD — Bob has generously stored the AMSAT file cabinets and the Dick Daniels, W4PUJ (SK), photo archive at his home in Virginia. Bob is now selling his house and planning a move. I want to thank Bob for all the help he has provided AMSAT over the years.

I also visited the Hilton Arlington, the site of our Symposium this fall. The 50th Anniversary Symposium — 37th AMSAT Space Symposium and Annual General Meeting — will be held October 18-20, 2019. The AMSAT Board of Director's Meetings will occur on October 16th and 17th at the same hotel.

AMSAT has planned two tours of Washington DC/ Baltimore area. The first of these is a trip to the Smithsonian Air & Space Museum, Steven F. Udvar-Hazy Center in Chantilly, VA, on Sunday, October 20th. The cost is $30 per person for the tour bus; admission to the museum is free. If you drive there yourself, the parking is $15 per vehicle, and you get the experience of driving in the Commonwealth of Virginia. Then, on Monday, October 21st, AMSAT President, I will lead a walking tour of the National Mall. We will meet at the entrance to the Balston Metro. You are on your own for the day, although AMSAT will designate a location for lunch, and meet back at the Smithsonian Metro for the return in the afternoon.

The Symposium banquet speakers will celebrate AMSAT's long history, and an OSCAR Park is also planned. So, if you can, please attend the 50th Anniversary; you would be glad you did. Future announcements will appear on the AMSAT website and through the AMSAT News Service and AMSAT-BB.

Again, the location for the Space Symposium and Annual General Meeting will be The Hilton Arlington, 950 North Stafford Street, Arlington, Virginia, 22203, USA TEL: +1-703-528-6000. The code for the hotel is AMSAT – Radio Amateur Satellite Corp.

The Hilton Arlington is located in the heart of the Ballston neighborhood of Arlington, VA. Connected to the Ballston Metro Station, the hotel offers easy and effortless access to Washington D.C.'s top tourist destinations like the National Mall, Smithsonian Museums and historical monuments. The hotel is six miles from Reagan National Airport and the National Mall and has metro connections to both.

Before I headed back to Reno, I stopped at the Smithsonian Air & Space Museum, Steven F. Udvar-Hazy Center in Chantilly, VA, for an ARISS contact. This was pretty cool as the stage was under the Space Shuttle Discovery. I also met with students from Bishop O'Connell High School, who, with the help of their teacher/mentor, Melissa Pore, KM4CZN, are reviewing and improving the prototype of the CubeSat Simulator. Before I left the east coast, I was invited to NASA Goddard to speak to about 25 interns in the Space Communications and Navigation (SCAN) summer program. SCAN is also a benefactor of ARISS.

At the end of June, I attended the ARISS-I Face-to-Face Conference in Montreal, Quebec, Canada. JVC Kenwood presented two TM-D710GA radios to ARISS Russia to manifest to the ISS. At this meeting, I held talks with Radio Amateurs of Canada (RAC) and the Canadian Space Agency (CSA) about providing linear transponders to Canadian universities. At this writing, the talks are still in process.

I interviewed a candidate for AMSAT Vice-President for Development (Marketing) and am pleased to announce that the AMSAT

BOD has appointed Frank Karnauskas, N1UW, to that position. Frank is also an ANS Rotating Editor. Frank will have more to say about his plans shortly.

Right before Hamvention, I was contacted by CQ-DL to provide a write-up of the 50 years of AMSAT. I was also given the opportunity for an editorial. The 50 Year History of AMSAT appeared last month, but since it was editorially shorted and in German, I am including it below. Please remember this is opinion and is not AMSAT Policy.

For now, I ask that you keep your membership up, recruit new members, contribute what you can, use the satellites, transition to the linear birds, and more importantly have fun!

AMSAT's Next Fifty Years

Predicting what will happen and what technologies will be available in the future is always chancy, and usually wrong. After World War II, all sorts of articles appeared in magazines predicting that, in a few years, we would not be limited to traveling on roads. Everyone would have some kind of convertible car/aircraft and thus be able to soar to and from work above the traffic. How wrong was that? But I still want my flying car!

In those days, some 75 years ago, no one predicted that practically everybody would have computers, particularly with 1930's Dick Tracy wristwatch features, that fit in their pocket. Even 50 years ago, in 1969 when the Radio Amateur Satellite Corporation was formed, did people really think computers would be commonplace, or that people would have access to over hundreds of T.V. channels via a cable, much less satellites 23,000 miles in space. So, with the errors so prevalent in predictions in mind, let's take a brief look at what may lie ahead for the next 50 years of amateur radio satellites, amateur radio in space, and speculate on how such wild prognostications might come about.

One prediction that is already coming true is the cascade of CubeSat development leading to spacecraft constellations and promising to provide worldwide internet access (for a small fee, of course). These constellations are already taxing the international teams of satellite frequency coordinators and the associated government regulators.

Let's go out on a limb and predict amateurs will have some type of 24/7 satellite availability. While not likely to come from a host of LEO CubeSats, 4-5 Amateur Radio CubeSats strategically placed in the GEO parking orbit would meet the orbital debris mitigation rules and would slowly drift across the horizon, needing to be tracked slowly, and connected via inter-satellite links providing 24/7 amateur access to all areas of the Earth, except for spotty reception on the poles. At today's (2019) launch costs of $1 Million (USD) per 3U rideshare, this is a possibility greater than the $6 - $10 million for a regional GEO satellite.

Such a system would provide worldwide emergency communications. Each satellite should also have a SARSat receiver. I call this notion AMSAT TDRS (Tracking, Data, Relay Satellites). The inter-satellite links could also provide lunar, planetary, and deep space links. This idea does not need to stop at GEO, but scales well to Cislunar orbits – Lunar TDRS, interplanetary orbits – Mars Cycler TDRS, Venus TDRS, Jupiter TDRS systems, and further. The future is likely to bring a "Lost in Space" (not really lost) moment of amateur radio satellites heading to Alpha Centauri. Think of the technological leap to perform this weak signal work!

Satellites with high-speed digital communications are the means amateurs have to furnish such capabilities. Greater bandwidth means higher frequencies. So, here's the prediction that the AMSATs will, from some source, obtain the funds necessary to gain rideshares on GEO and beyond missions. Notice, I said AMSATs, for it will take international cooperation among the various AMSAT organizations to design, construct, procure, and operate these satellite constellations. Whether these funds come from governments or wealthy benefactors, the likely funding will come from beyond the amateur radio community. Hams will need to support these communication infrastructures. Half a dozen Deep Space Network (DSN) 34-meter dishes will not suffice, but many small 1-meter and up ground stations are also an untapped resource.

A near term prediction is Deep Space Gateway (DSG). ARISS has been approached by both NASA and ESA to see what capabilities and plans could be provided to DSG. DSG is becoming real.

Another prediction is a lunar repeater if the extreme lunar day/night thermal regulation and a multitude of other issues can be resolved. It's only a 273-degree temperature swing from boiling hot to deep freeze in every 14-day period called a Lunar Day.

Foreign Affairs

AMSAT-NA's entire history has been a foreign affair. Our first satellite project was preparing for launch and finding a ride for a satellite built in Australia. Sir Martin Sweeting from the U.K. attended a number of our early meetings. AMSAT hadn't been in existence very long before beginning to work with Dr. Karl Meinzer and his German associates to place a Mode B transponder into AO-7. Then came the AMSAT-DL cooperation with the Phase 3 series of satellites, culminating with AO-40.

People from Brazil, Argentina, and Yugoslavia (now Solvenia) participated in the MicroSat project. There have been several non-Americans on the AMSAT Board of Directors, including Pat Gowen, from England, Junior deCastro, from Brazil, Haruo Yoneda, JA1ANG, from Japan, and John Henry, VE2VQ, as well as Robin Haighton, both from Canada. Of course, Robin also served as AMSAT President.

AMSAT-NA has welcomed attendees at our annual AMSAT Space Symposium and General Meeting from such diverse countries as New Zealand, Australia, Japan, Mexico, Italy, Russia, South Africa, Germany, Belgium, Austria, the U.K., and the Philippines. These are but a few examples that demonstrate that AMSAT-NA is truly an international organization.

But AMSAT-NA was also classified by the U.S. Government as an "arms dealer." Why? It stems from a thick book of U.S. Code of Federal Regulations called ITAR, which stands for International Traffic in Arms Regulations. These regulations — among other items such as cannons, tanks, and especially ballistic missile technology — classified "satellites" as defense munition items. They did not distinguish the use to which a satellite might be put, its size, or any other attributes. A one-kilo CubeSat built by a university or a non-profit like AMSAT-NA to relay amateur radio signals was treated the same way as a huge spy satellite. If it was a satellite, it fell under ITAR rules. ITAR imposed specific steps that must be taken if any satellite hardware, or hardware/software combination, or design data, or deemed export (a technical discussion) is exchanged by U.S. citizens with citizens of any other country. ITAR did not prohibit such exchanges but made it very difficult and expensive to obtain permission for them to take place. In essence, to work within the ITAR framework, a foreign national had to agree to submit to U.S. law.

Violation of ITAR carried severe penalties, including prison and steep fines, and usually both. AMSAT self-reported on our activities with AMSAT-DL and other AMSAT groups from around the world in connection with our work on AO-40, the Canadian MOST program, and the Phase 3E satellite. AMSAT-NA was found to be in violation, but since this was self-reported, no fines or enforcement action was taken. However, no further violation could occur. Regrettably, this meant AMSAT-NA could only perform projects with U.S. citizens, and this became AMSAT-NA policy.

EAR/ITAR Compliance

For AMSAT-NA, the EAR/ITAR compliance issue must be resolved. These regulations have hampered not only AMSAT-NA in its need to have a free and open interchange of information and material relating to amateur radio satellites with our overseas partners but also U.S. commercial interests. In the fall of 2014, new rules for ITAR concerning satellites as munitions became effective. It has taken some time to decipher these regulations. At the end of 2017, new EAR guidelines for Export Controls for the Commercial Space Industry were released. While open-source software and encryption are exempt, once tied to specific space-related hardware, the EAR/ITAR regulations apply. While most Commercial Off The Shelf (COTS) components of AMSAT satellites fall under the No License Required categories, a policy and process must be in place to comply with U.S. laws. AMSAT-NA has been working through these issues and through a thorough understanding of the law has formulated a draft policy now under legal review with F.D. Associates.

Multilateral Commitments

The United States aligns its export control regulations with several major multilateral control regimes to which the government is committed. Of particular interest to commercial (and non-profit) space companies are the Missile Technology Control Regime (MTCR), which controls items needed for missile development, production, and operation, and the Wassenaar Arrangement (W.A.), charged with promoting transparency and greater responsibility in transfers of conventional arms and dual-use goods and technologies to prevent destabilizing arms accumulations. Additional information on MTCR and W.A., including a list of member states, can be found at **www.mtcr.info** and www.wassenaar.org, respectively.

Since the E.U. and many in the world community are parties to the Wassenaar Arrangement, many AMSAT organizations are now on a level playing field, and co-operative agreements may proceed. Most items on the EAR Commerce Control List are eligible for several license exceptions, including a Strategic Trade Authorization (STA), that allows the unlicensed export, re-export, and in-country transfer of products to 36 U.S. allies. Eight other countries are eligible to receive certain items under STA, provided all terms of the license exceptions have been met.

So, here's the prediction: international cooperation between the AMSATs will be a reality.

The AMSAT Century

In 2069, AMSAT-NA will hold its 100th Anniversary Annual General Meeting and Space Symposium. Most of our current members will not be present, but some of the younger ones will. And, maybe there'll be another update of this book or scan entitled: The AMSAT Century, The First 100 Years

73-Joe, K6WAO

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.

Sometimes we are getting rid of our old equipment, sometimes selling something new. In any case, please consider giving a piece of the pie to a new satellite and choose AMSAT for your eBay Charity.

Engineering Update

Jerry Buxton, NØJY
Vice President, Engineering

The Digital Divide

If you are not familiar with the moniker "Five and Dime," it refers to the choice of 5 GHz for the uplink, and 10 GHz for downlink as a standard for the three satellites AMSAT was working on/toward in early 2015. The ASCENT team working on our new NASA-sponsored Cube Quest Challenge ("CQC") joint project with Ragnarok had initial discussions about which amateur satellite bands to use for the communications package that AMSAT would contribute to a lunar orbiting satellite. Microwave bands were necessary for the required data speed and volume.

Our engineers looked at 3 GHz, and with input from Bob McGwier, we went higher to the 5 GHz band where terrestrial expansion was not so much a threat. If I recall correctly, Tom Clark championed the use of 10 GHz for the downlink because of the availability of existing amateur stations and less expensive options for a ground station, as well as less susceptibility to rain and atmospheric attenuation for command stations when the Moon was at low elevation for the station. Upon settling that, which was right around the time Bob McGwier introduced the Phase 4B opportunity, I discussed frequency choices for the P4B bands being the same as CQC and as the new standard bands for future AMSAT Phase 3, 4, and 5 satellites.

GOLF was not in the picture that early on, but the return to HEO was always in my long-range plan. The aim was setting the use of these new microwave bands and allowing satellite operators to grow into the new bands with the CQC and P4B opportunities. Once settled, the repetition of "5 and 10" so many times in my discussions somehow popped up the old use of "five and dime" which referred to the five and ten-cent stores that the oldsters here will recall, and I started using "Five and Dime."

Digital modulation techniques were a requirement for CQC because of the long distances and path loss and were the choice that many desired for P4B to integrate the complex handling of designated channels for emergency communications backup, which was part of the basis for funding of the payload and project. Early on, that became a hot topic among amateurs of all types who for various reasons preferred one or the other in the sense of digital or analog modulation

— the "digital divide," if you will.
Hearing the number of arguments for both sides of the analog/digital debate, I then considered the "who is our customer" point of view in terms of future AMSAT satellites. I was convinced that, while digital is the clear winner for long-distance low signal-to-noise satellites, the best path for the future AMSAT satellites would be to allow operators to grow into digital satellites in the same way as I saw moving to the microwave bands. The transition applies to both microwave and digital in considering the opportunities we bring to hams worldwide as well; it's not just local users who want to get on the birds.

Another factor in the balance is the desire of available volunteer engineers. As I like to say, we build what the engineers are interested in building or else we will have no one to build it. From that standpoint, the AMSAT Ground Terminal team, which was first tasked with P4B, since it was the frontrunner for launch back then, went with all digital even though the original payload concepts were to have both analog and digital portions in the available bandwidth. The payload belonged to Virginia Tech, and that was their choice as well. The ground terminal would be able to support CQC with perhaps minor adaptations.

Also in early 2015, AMSAT and Virginia Tech agreed that, since AMSAT was funding the development of the ground terminal, AMSAT would be involved in the development of the project. The common core of the Five and Dime uplink/downlink would be used as a basis for ground stations for the new Phase 3E opportunity that Bob McGwier was working on as well as future AMSAT HEO satellites.

Then the many opportunities for Five and Dime, unfortunately, began to disappear. The P4B launch was uncertain and that put CQC at the top of the list of uses for the ground terminal. That, too, did not last long. The GOLF opportunity came along at Symposium 2017, which sadly was also the final announcement by Virginia Tech that P4B had no launch opportunity.

In keeping with the goal of microwaves and digital, GOLF does incorporate both albeit on a sliding scale along with the incremental development of our capability to put robust CubeSat in HEO. GOLF-TEE is intended to provide the opportunity to receive a telemetry downlink in the 10 GHz band and may include the transponder voice downlink. GOLF-1 is targeted to provide analog Five and Dime transponder capability as well, albeit the ground terminal did not keep track with this use case, so there is an opportunity to fill that piece. I have talked with Phil Karn, KA9Q, about digital opportunities on GOLF-2 with the SDR being capable of both digital and analog modulations, as part of the transition. Phil is keen on digital and a great resource, although we don't see eye to eye on an all-digital bird just now, nor are there any great orbit opportunities for one. Meanwhile, both GOLF-TEE and GOLF-1 will provide V/u linear transponder capability as the GOLF program begins the transition to microwave and HEO.

The plan for the GOLF program progressing to higher orbits in the path back to HEO is faced with a tough challenge, though, as we found in our quest for a 1000+ km orbit for GOLF-1. I am confident that we can move beyond LEO through innovations by CubeSat hardware providers, rideshare opportunities that offer an increasing number of satellites going to at least the AO-7/FO-29 altitudes, and our excellent reputation and relationship with NASA CSLI/ELaNa. It may be that, in working with NASA, we can find an elliptical orbit with a desired apogee and a required perigee where a deorbit device would not be required. Perhaps that's a long(er) shot, but I am an optimist.

A more recent project that I am involved in, the Amateur Radio Experiment (AREx) of ARISS International, aims to put amateur radio on the Lunar Gateway in a similar fashion to SAREX, MIREX, and ARISS. AMSAT-UK, AMSAT-DL, and others are involved in the planning and working with NASA to propose such operations. Digital techniques are an essential part of such a concept, and opportunities ranging from on-station experiments to transponders and astronaut contacts are in the mix. This is something that began formulating a while ago, and band planning and the use of Five and Dime were discussed. I encourage you to visit ariss.org to find out more about the whole project, and you will undoubtedly hear more from me about it in the near future.

One more opportunity came to us at the Symposium in Huntsville last year. NASA's encouragement of commercial development of small landers for part of the overall return to the Moon will create ongoing opportunities for payloads on various lunar landers. The opportunity we explored would have allowed a payload on a lander, and the obvious choice for a good two-way amateur capability would be digital voice codec. I also saw this as a way to develop and test both space and ground equipment for lunar distance communications, coincident with the ARISS AREx.

Working with a small team of engineers, we set out to come up with a quick but best look ConOps (Concept of Operations) that I would present to the AMSAT Board of Directors for funding the project. The entry deadline was a short window, as the solicitation sought existing projects that were nearly ready to fly. Our initial proposal was accepted, and we were encouraged by the program to continue. So, we worked to get board approval.

The requirements for participation in the program limit what I can share publicly, but as we looked at the physical location and especially the power budget, we determined that a transponder would be difficult to access and the duty cycle for use would be very limited. The lander project was designed for hosting short duration experiments with a duration of about seven days. The uncertainty of any measure of success with radios and the cost for supporting hardware en route and special handling for landing on the Moon was determined to be much too high for a single project with so much uncertainty and so little uptime. However, just as happened here, we are always looking at and for potential opportunities. With the help of our latest volunteer, Frank Karnauskas, N1UW, who stepped up to a position that we have sought for years, hopefully, AMSAT will be able to engage in more of these great opportunities in space.

User Services Update

Robert Bankston, KE4AL
Vice President, User Services

It's hard to believe that summer is already over. While I look forward to some cooler temperatures, I know it's time to start gearing up for this year's Symposium. As I am sure you are all aware, 2019 marks AMSAT's 50th Anniversary. While the year already has been filled with events and moments to recognize this special occasion, this year's Symposium will effectively mark the culmination of everything we have been celebrating. First, the 2019 AMSAT 50th Anniversary Space Symposium and General Meeting, to be held October 18-20, will return to its birthplace, Washington, D.C. Well, it's actually going to be in Arlington, Virginia, but anyone who has been to our nation's capital can tell you that one town flows right into another. In addition to the usual Symposium fanfare and presentations, we will host special guests, displays, and events to commemorate 50 years of keeping amateur radio in space. This undoubtedly will be the Symposium you do not want to miss.

Speaking of summer, where did it go? It flew by way too quickly, but I guess that's what happens when you are having so much fun.

My summer officially started in May with hosting an AMSAT Academy in Dayton, Ohio. The day before Hamvention, I had the unique privilege of sharing my passion for amateur radio satellite operations with 38 attendees. Our infamous "El Presidente," Joe Spier, K6WAO, managed to sneak away from his Hamvention setup duties to cover AMSAT's rich history, while I unraveled the mysteries of doppler effect and antenna polarization, and instructed the attendees on how to work FM, linear, and digital satellites, including live demonstrations in the parking lot. In addition to the in-depth instruction, each attendee received a one-year basic membership in AMSAT and a digital copy of AMSAT's hot-off-the-presses *2019 Getting Started Guide*.

AMSAT Academy was a great success, and, when I finally got home, I had an inbox full of emails from attendees thanking me for hosting the AMSAT Academy and telling me how much they learned. AMSAT Academy is an excellent opportunity to learn not only the basics but also all of the tips and tricks that would take you months to learn on your own. I certainly hope that we can offer these full-day classes more often and across the nation.

I would be remiss if I failed to thank our gracious hosts, the Dayton Amateur Radio Association (DARA), who generously shared their magnificent facilities with us. For those who have never been to the DARA Club House, I highly encourage you to visit it the next time you are in town. DARA has been around long enough, as evidenced by the ARRL Affiliated Club certificate signed by Hiram Percy hanging in their entranceway, to know how to do it.

Ed Collins, N8NUY, a DARA and fellow AMSAT member, was my host. Ed not only gave me the grand tour of Dayton and introduced me to the famous Bill's Donuts in Centerville, but he also made sure we had everything we needed to make AMSAT Academy a success. Thank you, Ed and DARA. Your support was truly appreciated.

With what seemed like only a moment to catch my breath, I was at the Greene County Fairgrounds & Expo Center the next morning to kickoff AMSAT's participation at Hamvention. This was my first time at Hamvention since it moved from Hara Arena and my first time supporting AMSAT. To say there was a lot to take in would be an understatement. I was instantly impressed to see all of the hard work our volunteers did to set up the AMSAT area, especially the stunning OSCAR Park.

The whole weekend went by in a blur — meeting so many AMSAT members, having eye-ball QSOs with the operators I have worked on the satellites, and presenting at my first AMSAT forum. The constant crowds in AMSAT Engineering, AMSAT Education, AMSAT Getting Started, AMSAT Sales, ARISS, and Satellite Demo areas were a testament to how popular and essential satellite operations are to amateur radio. Phil Smith, W1EME, AMSAT Hamvention Chair, along with too many volunteers to name here, did a phenomenal job in setting up and running the AMSAT booths at Hamvention.

In June, we kicked off the "Take W3ZM on the Road" campaign, as an effort to operate with AMSAT's club call sign, W3ZM, from all 50 states leading up to the 2019 AMSAT 50th Anniversary Space Symposium and General Meeting. To make this happen, we need your help! Please volunteer to get on the air and activate your state, using AMSAT's W3ZM call sign, as well as to cover those states without an active AMSAT member. Activations of other United States Territories, including Guam, American Samoa, the U. S. Virgin Islands, and the Commonwealth of the Northern Mariana Islands, are also welcome. Full details are available on the AMSAT website at **www.amsat.org/events/was-w3zm/**.

In July, I relaunched the AMSAT Ambassador program to regain control of the program and ensure we had an accurate roster of active volunteers willing to represent AMSAT and its mission and vision. Back in 2018, AMSAT retired the Area Coordinators program and launched AMSAT Ambassadors. Unfortunately, by automatically enrolling all previous Area Coordinators, who may or may not have wished to continue their service, we lost the ability to know who was available and how to communicate with them.

The new AMSAT Ambassador program requires interested AMSAT members to apply, outlining their experience and areas of interests. AMSAT Ambassadors will receive the latest updates as to what AMSAT is working on and have access to a library of presentations, designed for various audiences. If you are willing to share what you have learned about amateur radio in space with others, and, in the process, help inspire the next generation of AMSATers, please consider becoming an AMSAT Ambassador. Additional information and the application process are available at **www.amsat.org/ambassador/**.

In my free time, I continue getting to know the countless volunteers who quietly serve in the shadows to deliver quality services our members deserve — the AMSAT Journal editors, AMSAT News Services staff, and all the folks who work on the AMSAT website, AMSAT store, AMSAT mailing lists, Hamvention, AMSAT Awards Program, and AMSAT social media accounts. Your efforts and personal sacrifice are much appreciated.

I hope to see all of you at the 2019 AMSAT 50th Anniversary Space Symposium and General Meeting and look forward to continuing to serve you!

Educational Relations Update

Alan Johnston, Ph.D., KU2Y

One year ago, I wrote my first Educational Relations Update column for *The AMSAT Journal*. I was recently back from my first Hamvention, a whirlwind of meeting people and learning about projects and plans. Hamvention last year is where I first heard ideas for a new CubeSat Simulator, and I wrote about it in my first column. Thanks to many AMSAT members and especially Pat Kilroy, N8PK — together, we have made a lot of progress on the project in the last year!

I was delighted with the "launch" of the CubeSat Simulator program at Hamvention during the AMSAT Update Forum in May 2019. Figure 1 shows me presenting and explaining the simulator on the big stage with a halogen lamp and turntable used to simulate rotation in the sunlight.

A big thanks to four Villanova University CubeSat Club members who helped staff the Education table at the AMSAT booth. They all passed their license tests at Hamvention, and are looking forward to getting on the air!

AMSAT now has four CubeSat Simulators which are available for loan, shown in Figure 2, and were built by freshman electrical and computer engineering students at Villanova University as part of a CubeSat Mini Project during the Spring 2019 semester.

As I write this column, all four of them are out at various schools and events. Warren Ziegler, K2ORS, a teacher at Fryeburg Academy in Fryeburg, Maine, has been using one with his high school students. Next, he plans to help his students build their own. Another is with Melissa Pore, KM4CZN, a teacher at Bishop O'Connell High School in Arlington, VA. Students in her DJO Engineering Club demonstrated it at the Innovations in Flight — Family Day and Outdoor Aviation Display at the Udvar-Hazy Smithsonian National Air and Space Museum. Tom Schuessler, N5HYP, has the fourth simulator and will show it off during a presentation for the Dallas/Fort Worth, TX, chapter of the National Space Society and at a Moon Day STEM event at the Dallas Frontiers of Flight Museum.

Figure 2 — Four AMSAT CubeSat Simulators are available for loan. Contact ku2y@amsat.org for information.

In addition, a loaner CubeSat Simulator was demonstrated by Joe Erlewein, N8CN, at the recent successful ARISS contact at the Public Library in Traverse City, MI. I am very interested to see the interplay between the CubeSat Simulator program and ARISS, the other major educational initiative that AMSAT supports. Will an ARISS contact interest students in building a CubeSat Simulator, or will building a CubeSat Simulator eventually lead to an ARISS contact? Or both?

Other Beta Builders have been hard at work. As I mentioned in my last column, CubeSat Simulators have been built at the University of Tennessee, Knoxville, under Gould Smith, WA4SXM. At the University of Texas, El Paso, a Simulator has been produced by Chris Roberts, KC8GOQ, and his students. See Figure 3.

Figure 3 — CubeSat Simulator built at the University of Texas, El Paso. [Photo courtesy of Chris Roberts, KC8GOQ.]

Figure 1 — AMSAT CubeSat Simulator "launch" at Hamvention 2019 AMSAT Update Forum. Alan Johnston, Ph.D., KU2Y, wearing an AMSAT 50th Anniversary lab coat and the CubeSat Simulator.

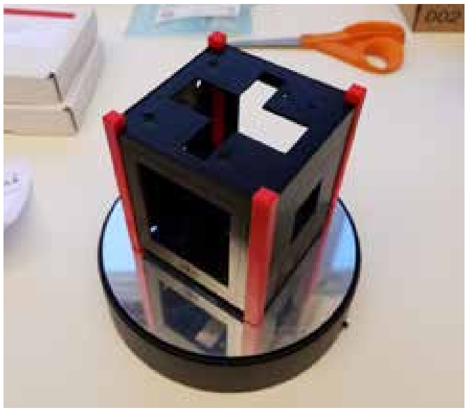

Figure 4 — CubeSat Simulator 3D Printed Frame from Grace Brethren High School in Simi Valley, CA. [Photo courtesy of Eric Tapper.]

At Grace Brethren High School in Simi Valley, CA, Eric Tapper has been building a CubeSat Simulator in his STEM course. One of their 3D printed frames is shown in Figure 4.

As you plan your late summer and fall activities, keep in mind a CubeSat Simulator. If you like 3D printing, you can print your own frame — makes a great conversation piece! Add any Raspberry Pi, and you can have a CubeSat Simulator Lite! Building a full CubeSat Simulator is a fun little project – it costs about $400 in parts and takes about 20 hours. Only basic soldering and computer skills are needed. All the instructions are available on GitHub **cubesatsim.org/wiki**. If you don't have access to a 3D printer (check your local library!), you can order a print on the website Thingiverse. In the future, we may have kits available — stay tuned!

If building isn't your thing, but you have a presentation, whether at hamfests and conventions or an opportunity to talk about amateur radio satellites in a classroom, contact me about borrowing one of the AMSAT loaners. I am especially interested if anyone is attending a maker event; that seems like an excellent opportunity to introduce amateur radio and satellites to a broader audience.

We will have CubeSat Simulators on hand at the AMSAT 50th Anniversary Space Symposium in Arlington, VA, in October. Pat Kilroy, N8PK, and I will be giving a presentation on the CubeSat Simulator program. Hope to see you there! As always, questions, suggestions, or help is just an email away **ku2y@amsat.org** or on Twitter **@alanbjohnston**.

AMSAT Field Day 2019 Results

Bruce Paige, KK5DO
Director, Contests and Awards

I thought this year's Field Day was going to be even better than last year. It seems things were skewed a little. Last year there 32 stations participating, and this year there were 26. Last year we had 33 different satellites (more on this below,) and this year only 28. Though not a significant change, I thought we would see a bit more participation.

As with every year, we count the number of satellites according to their modes. SO-50 has one FM transponder which I count as one satellite, whereas AO-7 has two modes, SSB and CW, and gets counted as two satellites. AO-92 has two modes, U/v and L/v, and thus counts as two satellites. We count by mode because an operator can work the same station on the same satellite in each mode available for that satellite.

	Phone	CW/Digital
AO-7	31	20
AO-73	54	1
AO-85	7	
AO-91	9	
AO-92	8	
CAS-4A	93	1
CAS-4B	98	1
EO-88	4	
FalconSat		5
FO-29	111	17
IO-86	2	
PO-101	8	
SO-50	7	
XW-2A	74	2
XW-2B	85	1
XW-2C	66	1
XW-2D	1	
XW-2F	37	2

Table 1.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Satellite	12	9	9	8	12	9	16	21	33	28
QSOs	387	335	263	443	305	316	424	728	945	746
Stations	18	14	19	23	21	21	22	27	32	26
Points	505	455	329	613	357	386	448	778	995	848

Table 2.

We had 28 satellites in operation this year as evidenced by Tables 1 and 2. With only a couple of entries from AO-92 L/v, I incorporated them in with the U/v for the chart. The breakdown of satellite usage appears in Table 1.

This year twenty-six stations participated in AMSAT Field Day. They reported 746 QSOs with a total of 848 points, with 695 phone QSOs and 51 CW/digital QSOs. Based on the numbers, FO-29 SSB appears to have been the busiest satellite. Next up were CAS-4A and CAS-4B followed by XW-2B and XW-2C. The preferred choice for CW contacts this year was AO-7 followed by FO-29 (see Table 2).

We had several stations operating from home with both emergency power and commercial power. They were (by call area, then alphabetical) NA2X, K5TA, AI6DO, N8HM, WD9EWK, N0RC, N9IP/KL7.

Here are this year's winners; all will receive certificates at the AMSAT Symposium in Washington, DC, later this year. In first place, no stranger to Field Day and knocking out last year's first-place winner, K4BFT, is W5RRR, Johnson Space Center Amateur Radio Club with 172 unbeatable points. Last year, they took third place. They operated almost every pass of every satellite they could. In fact, they made more satellite contacts than their 6 M, 10 M and 15 M stations combined. Photo 1, Photo 2 Tanner, W9TWJ.

W9LDX, Lafayette DX Association, finished in second place. They moved up from fifth place last year with 114 points this year. If we were awarding a prize for best Field Day photo, it would go to Photo 3, the W9LDX site. The lighting is just perfect. Photo 4 is their equipment.

Third place this year is W4MLB, Platinum Coast Amateur Radio Society, which finished sixth place last year and came in with 74 points this year. Greg, N4EN, was able to work AO-73 and IO-86 this year.

Finally, the top home station operating on

Photo 1 — At W5RRR, Johnson Space Center Amateur Radio Club, with John, AB5SS, and Andy, W5ACM.

Photo 2 — Tanner, W9TWJ, operating W5RRR.

emergency power with 54 points (nearly doubling last year's points for the home station) is K5TA, Scott (see Photo 5).

I was a player again this year with the Texas Emergency Amateur Communicators operating as W5SI. With only a clear shot to the North, South, and East (last year was North, South, and West), we were able to work two stations on SO-50 for a reporting total of one point. This year was easier with a G-5500 rotor instead of the "arm strong" rotors we used. I also got to sit in air conditioning instead of outside in the nice Texas summer weather. Let me tell you, trying to learn SATPC32 Doppler correction for the SSB satellites at field day was not a good idea.

Photo 6 and 7 are from the Nashua Area Radio Society operating as N1FD. Although they did not submit their score for this year, they did forward pictures of their satellite station and antenna.

Patrick, WD9EWK, was out and about operating, and Photo 8 is a beautiful picture as he was awaiting PO-101 AOS.

The Fullerton Radio Club operating as W6ULI, had Joe, K0OV, working the radio and Tom, WB2LRH, turning the antenna. Check out their station in Photo 9. This photo would have been my runner up for the neatest picture.

Over at the York Region Amateur Radio Club, VE3YRA, was Alex, VA3ASE, Ian, VE3ISG, and Terry, VA3TYB. They focused

Photo 3 — W9LDX, Lafayette DX Association.

Photo 4 — W9LDX, Lafayette DX Association.

Photo 5 — Scott, K5TA.

Photo 6 — Nashua Area Radio Society, N1FD.

Photo 7 — Nashua Area Radio Society, N1FD.

Photo 8 — Patrick, WD9EWK, awaiting PO-101 AOS.

on the SSB satellites this year. Photos 10 and 11 depict Alex, VA3ASE, and third harmonic, George.

Photo 12 is at the Irving Amateur Radio Club, N2BB, site. The club did not provide a submission, but we did receive a photo of their site from Tom, N5HYP. Tom also provided Photo 13 of the Dallas Amateur Radio Club, W5FC, site where he logged his first-ever contacts on PO-101 and EO-88.

Ryan, AI6DO, submitted a report that worked 20 satellites, although he had only 6 qualifying QSO's, and half of them were with WD9EWK. He was also operating pedestrian mobile.

We noticed the San Lorenzo Valley Amateur Radio Club, K6MMM, was missing from the top 10. The good reason was that they could not even set up this year until after 5:00 PM on Saturday. They suffered two broken antennas, errors in their software and still managed to have a great visitor turn out to watch the satellite station. They even got a few bold and curious folks to work the satellites.

Lake Monroe Amateur Radio Society, N4EH, experienced rain all week but, when Field Day showed up, no rain appeared until it was time to tear down — great timing for mother nature. Glen, NK1N, operating the station for the Delaware Valley Radio Association, W2ZQ, had a separate speaker away from the operating station in a park so passers-by could listen, too. Great idea, Glenn!

Marcus, N5ZY, was operating for the Edmond Amateur Radio Society, K5EOK. They got set up and scored a contact, but then strong winds forced them to dismantle their station, and that was it for them. Their operation attracted a large gathering as there is something about our satellite antennas that people are drawn to.

Over at the Montreal Amateur Radio Club, VE2ARC, Patrick, with no call sign yet, made a contact on an FM sat, their first L-band contact and their first CW contact (see Photo 14). He will have a lot of fun when his call sign arrives. Look for him to be very busy on the satellites.

And wrapping up this year's report, Tim, N8DEU, had trouble getting back to Huntsville, AL. And when he finally got back, mother nature kept him off the air for 3 hours with lots of lightning. Nevertheless, he was still able to log a fair number of contacts. And operating from a campground

Photo 9 — Fullerton Radio Club, W6ULI.

Photo 10 — York Region Amateur Radio Club, VE3YRA; Alex, VA3ASE, holding George.

Photo 11 — Alex, VA3ASE, with George.

Photo 12 — Irving Amateur Radio Club, N2BB.

Photo 13 — Dallas Amateur Radio Club, W5FC.

Photo 14 — Montreal Amateur Radio Club, VE2ARC.

in Copper Center, Alaska, was Steve, N9IP/KL7. Being so far north, he operated three passes of PO-101 talking with himself.

For next year, remember, Murphy will somehow visit someone and spoil the day. Be prepared and have extra equipment, cables, and connectors. Writing this article is always the most fun for me, and I hope you enjoyed it.

Here is a table of all entries received. In the case of a tie, call signs are listed alphabetically.

1	W5RRR	172	12F
2	W9LDX	114	1A
3	W4MLB	74	2F
4	VE3YRA	65	5A
5	K5TA	54	1B
6	W6ULI	52	2A
7	K6MMM	45	3A
8	K4BFT	44	4A
9	W2ZQ	40	2A
10	W5FC	39	3A
11	N4EH	28	5A
12	K4JJ	26	3A
13	VE2ARC	16	1A
14	N8HM	13	1B
15	WD9EWK	13	1B
16	K8UNS	8	4A
17	W4YY	8	2A
18	AI6DO	6	2B
19	N9IP/KL7	6	1B
20	N0RC	5	1D
21	NA2X	5	1E
22	W2RS	3	2A
23	N7GV	2	2A
24	K0AJW	1	1F
25	KE5OK	1	7A
26	W5SI	1	4F

Take W3ZM on the Road!

Robert Bankston, KE4AL
Vice President, User Services

Leading up to the 2019 AMSAT 50th Anniversary Space Symposium and General Meeting, to be held in Arlington, VA, October 18 – 20, 2019, AMSAT's call sign, W3ZM, will operate from all 50 States, the District of Columbia, and Puerto Rico. Not only is this your chance to get Worked All States-Satellites under the W3ZM call sign, but, also, your chance to be a part of this historic effort.

Note: When operating outside of the "3" call area, operators will append the W3ZM call sign with "/(call area)." As an example, someone operating from Texas will use W3ZM/5; from Hawaii, W3ZM/KH6; from Alaska, W3ZM/KL7; and from Puerto Rico, W3ZM/WP4.

To make this happen – we need your help! Please volunteer to get on the air and activate your State, using AMSAT's W3ZM call sign, as well as to cover those States without an active AMSAT Member. Activations of other United States Territories (i.e., Guam, American Samoa, the U. S. Virgin Islands, and the Commonwealth of the Northern Mariana Islands) are also welcome.

To volunteer and operate using AMSAT's W3ZM call sign, you must:

- Be a current member of AMSAT;
- Obtain permission by emailing AMSAT VP of User Services, **ke4al@amsat.org**
- specifying the requested date(s) and location(s); and
- Submit an ADIF log of contacts made for upload to LoTW by AMSAT, as instructed in your notice of approval to use the W3ZM call sign.

For more information, see
www.amsat.org/events/was-w3zm/

PSAT2 and USNAP1 Added to the APRS Digipeater Constellation

Bob Bruninga, WB4APR
U.S. Naval Academy Satellite Lab

With the launch of PSAT2 and USNAP1 on June 25, 2019, these two satellites become the sixth and seventh APRS digipeaters in space. The overall goal is to have enough digipeaters so that Ham users around the world are never more than a few minutes from position/status reporting and two-way text messaging anywhere on Earth. We once calculated that having ten would get close to being no more than about ten minutes from any next pass.

The re-packaged Byonics TT4 APRS transceiver that we call the SATT4 is the basis for a single card implementation in any CubeSat as shown in Figure 1. It even has room for a CANSAT/STENSAT 9600 baud auxiliary experimental downlink on the top half of the board (not populated on PSAT2).

CONOPS

The Concept of Operations shows in Figure 2 the various modes and transponders on PSAT2. To give users immediate access while we did the first week or so of on-orbit checkout on VHF, the UHF and ten-meter band links were the first to be activated.

PSK31 and SSTV

Listen for PSAT2's PSK31 and SSTV

Figure 1.

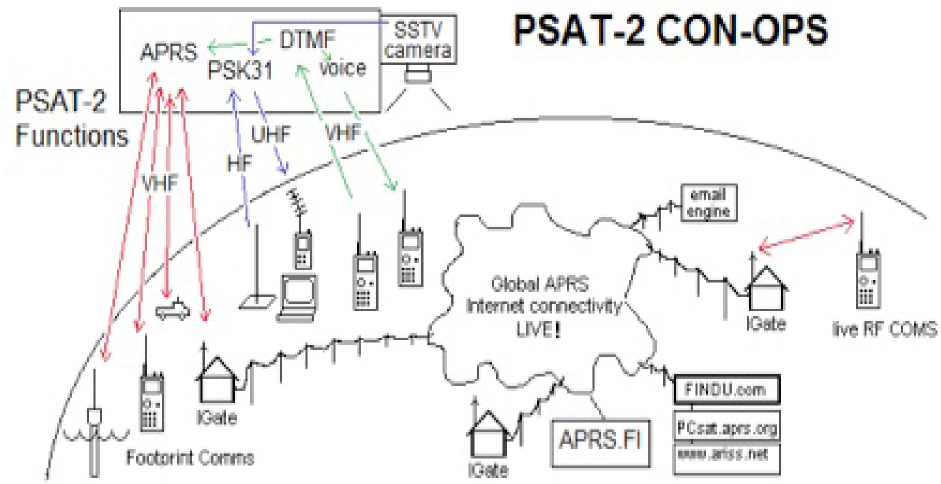

Figure 2 — PSAT2 has Packet, PSK31, SSTV, Voice Synthesis, and DTMF transponders.

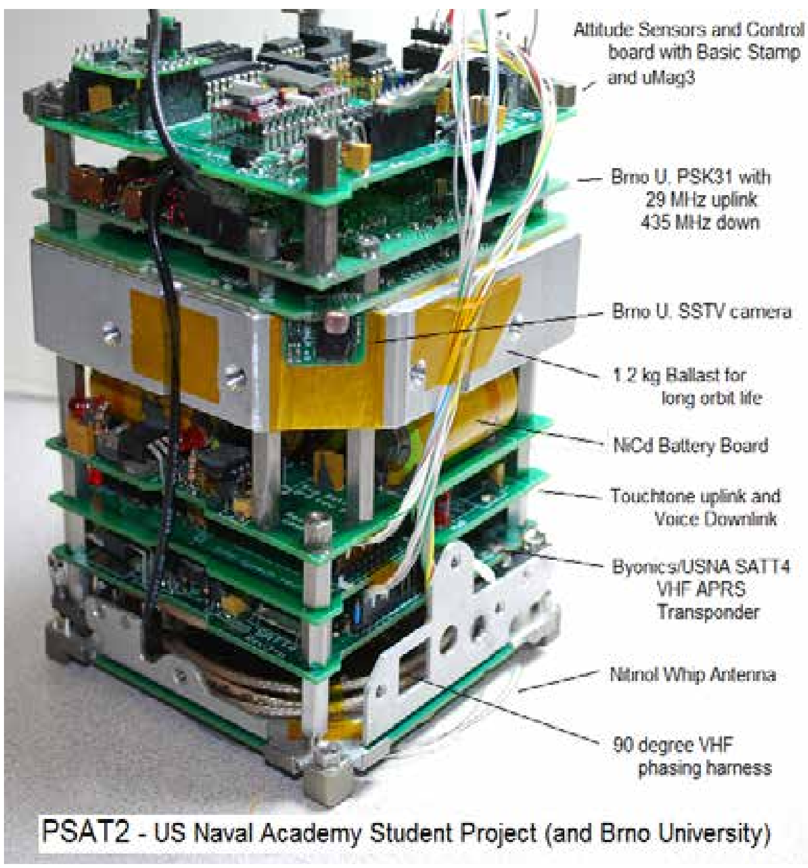

Figure 3 — The complete board stack and massive ballast.

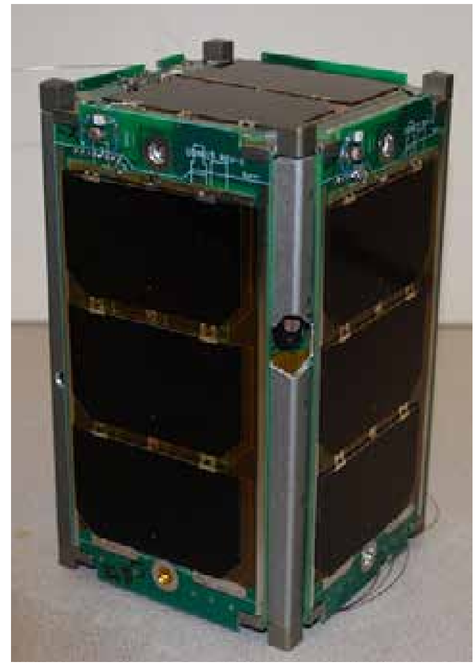

Figure 4 — The SSTV camera view port.

downlink on 435.350 +/- Doppler using any UHF FM receiver. You will see the audio waterfall with satellite telemetry at around 280 Hz, PSK31 users between 550 to 950 Hz and occasional SSTV images between 1200 to 2300 Hz. Using SSB uplink on ten meters and UHF FM downlink, the total Doppler shift of PSK31 users is only about one Hertz per second average. On approaching and receding passes for a user, where Doppler changes very little, conventional PSK31 decoders will work OK.

Figures 3 and 4 show the internal and external views. The camera peeps through a hole in the rail.

Full Duplex, Doppler Corrected Uplink

For serious two-way contacts, users should download the special Doppler corrected PSK31 uplink program written by Andy Flowers, K0XY. It not only adjusts your uplink Doppler automatically so you stay at a fixed location in the passband, but it also allows you to operate full duplex with your HF uplink for the complete duration of the pass. You can chat with everyone as fast as you can type!

Operating Modes

PSAT2 consists of a number of exciting and unique Amateur Radio Communications experiments sketched in Figure 2 above:

- A new PSAT type PSK31 29 MHz uplink/UHF FM downlink from Brno U.
- A new Brno University SSTV camera downlinks in the same UHF FM audio
- A conventional APRS digipeater (ARISS and APRSAT aliases)
- Voice Synthesizer to speak special APRS-to-Voice text messages to everyone.
- A unique DTMF grid and message uplink for translation to voice and APRS.

The only user mode in USNAP1 is the digipeater (when enabled).

Elliptical Orbit

PSAT2 and USNAP1 successfully launched at 0630Z on June 25, 2019, on the Falcon Heavy STP-2 mission into a 28-degree elliptical orbit with apogee at 860 km and perigee at 300 km. The 28-degree inclination makes it difficult to work over northern Europe, but the significant difference in

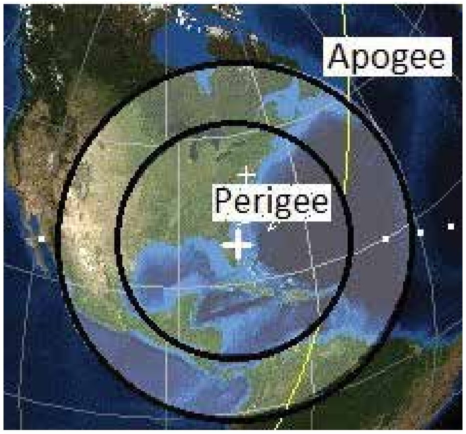

Figure 5 — PSAT2 Footprints.

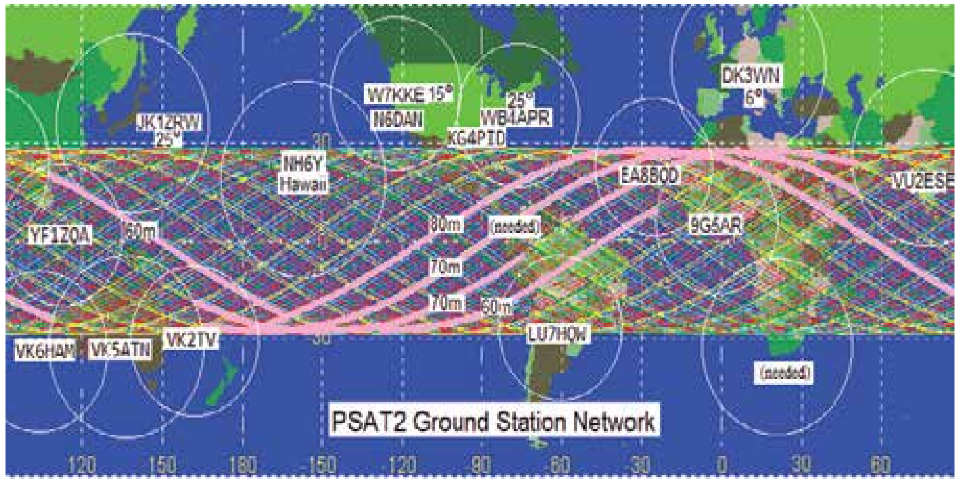

Figure 6 — Shows the orbit tracks for the 28-degree inclination orbit.

apogee/perigee shown in Figure 5 can make a 20-degree or so elevation difference on the horizon. When apogee circulates to be over the northern hemisphere, then more northern stations can work it. When perigee occurs over the northern hemisphere, it can only be seen easily in Spain and Italy latitudes in Europe, and only mid-latitudes in the U.S., as shown in Figure 6.

Fortunately, this changing apogee/perigee dynamic will move earlier each day and two weeks later, will have reversed, and so forth on a monthly cycle or so. Everyone gets a chance.

Pass Timing

Another interesting thing about the orbit is that it is almost time-synchronous, meaning that a pass will occur at nearly the same time every day (though five minutes later). But then, an earlier pass will appear 90 minutes or so earlier every other day. This makes it very easy to do mobile/portable operations without any computer once you hear one pass and remember the offsets (Figure 7).

Camera

Initially, the HF/UHF PSK31 and SSTV modes were enabled from launch and available to users. During the initial activation, the camera took some images to file. It has been sending them down over time. The best Earth photo is shown in Figure 8. Later, live camera and other modes may be enabled.

Mode Status Bits

Initially, the VHF modes were off to allow for on-orbit checkout of the attitude determination and control system (ADCS) and other functions. In this SAFE mode, the call sign is PSAT2-1. The ADCS mode reported sun vectors showing about a 1.3 RPM tumble including all 3 axes. By a week later, the digipeater was enabled, as indicated by the change to the PSAT2 call sign on the downlink. The APRS-to-voice synthesizer was also enabled. It is easy to see the PSAT2 modes by looking at the packet status bits. Normal digipeater operations with DTMF off will show a pattern of 01000111. The status bits in USNAP1 are entirely different. The only bit of significance is the 01000X00 bit where the X bit will be "0" if the digipeater is enabled.

The DTMF Grid report mode is enabled and seems to be working even on fast DTMF keying speeds. Users encode their Grid and Call using the special translator on the PSAT2 web page and store it in their radio memory and then users without any special APRS radio can uplink their grid and get a voice and packet acknowledgment. See **aprs.org/psat2.html.**

Narrowband Uplink Modulation is Required

PSAT2 uses a low-cost off-the-shelf receiver with modern narrowband channelization. This distorts all uplinks that are not Doppler compensated. Don't even think about transmitting to PSAT2 with a standard U.S. model radio not set to narrowband and using 5 kHz channel steps except for the center few seconds as the Doppler passes

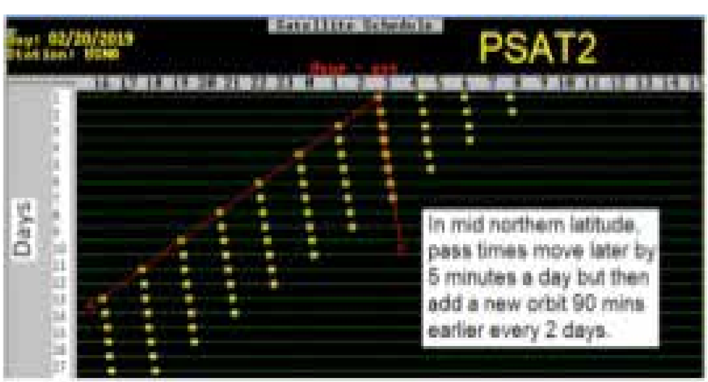

Figure 7 — PSAT2's easy to remember pass times.

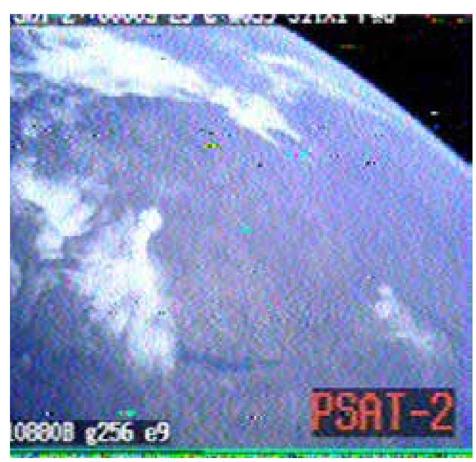

Figure 8 — One of the best early SSTV camera images from the Brno University camera.

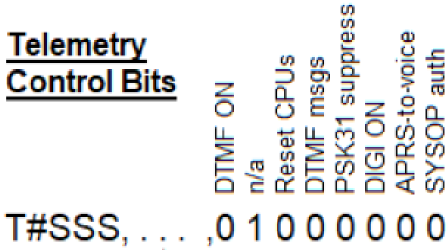

Figure 9 — Safe mode Status Bits.

rapidly through zero offset. Do not transmit otherwise because PSAT2 will never decode you, and you are only jamming others.

Ballasted Mission Life of Five Years

PSAT2 is designed for maximum orbit life compared to other similar-sized CubeSats because it is flying with the maximum allowable CubeSat mass. Almost a kilogram of lead ballast about 2cm x 8cm x 8cm is located in the center of the CubeSat shown in Figure 3 and constitutes nearly HALF the satellite's mass to give it a high ballistic coefficient to last longer in orbit. Initially, the ballast was made of stainless steel, but that would have survived re-entry and been a missile hazard. So, it was re-built as a ¼" aluminum shell around a 1" thick chunk of lead which would demise (burn up) by the time it got to 60 miles or so altitude on re-entry.

It will be interesting to watch PSAT2 and USNAP1 separate on orbit as USNAP1 has an identical drag cross-section but weighs only 1.7 kg compared to PSAT2's 2.8 kg. Due to orbital mechanics, this makes USNAP1 slow down which makes its orbit lower, and then actually faster. So, you will see USNAP1 move out ahead of PSAT2 as it decays.

Operating Frequencies

- APRS Up/Down:145.825 1200 baud APRS (like PCSAT, ISS, PSAT, AISAT-1, USNAP1)
- PSK31 Downlink: 435.350 MHz +/- 5 kHz FM (300 mW)
- PSK31 Uplink: 29.4815 MHz PSK31 SSB (25 W and omni vertical typical)

Digipeater Standard Aliases

To join the existing APRS satellites on orbit and operate as a seamless constellation, both PSAT2 and USNAP1 support the same APRSAT and ARISS generic aliases as the original PCSAT (NO44), PSAT and the packet system on the ISS and subsequent APRS satellites. With these standard aliases, users do not have to change any parameters when using any of these five APRS transponders.

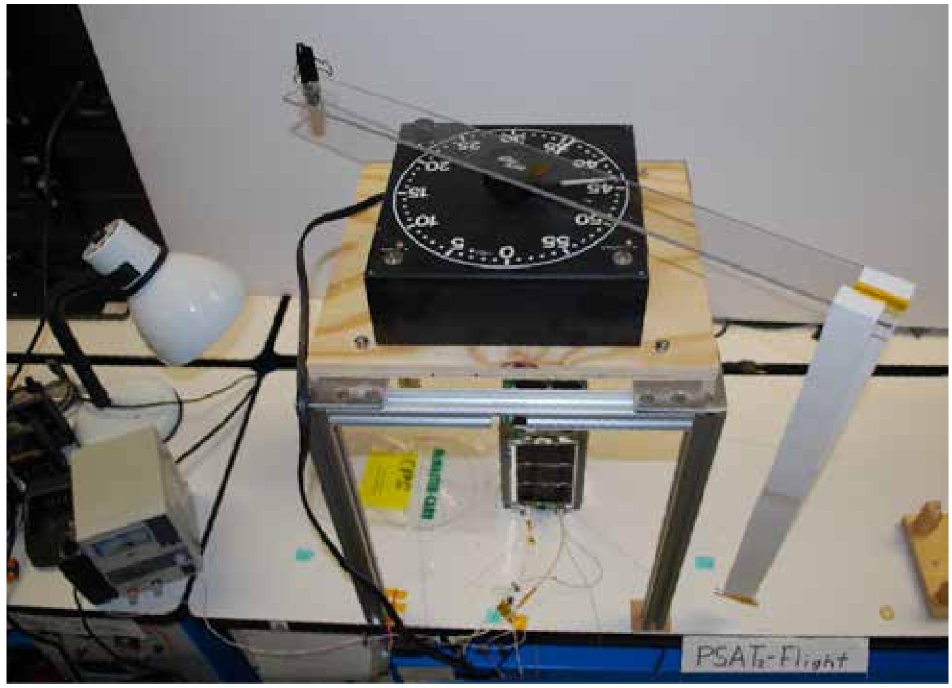

Figure 10 — Poor man's ADCS test set. Notice the magnet on the right suspended from an arm rotating at one rpm by the dark-room timer motor.

Overall APRS Satellite Web Page

PSAT2 and USNAP1 now bring the total of operational APRS satellites on orbit to seven (though FalconSAT is on a different frequency and alias). The processing load on the original PCSAT.FINDU.com data server was getting too big because the satellites have multiple callsigns, and the FINDU.com web pages for satellite data and user downlinks needed to be better organized. To reduce the processing load, we now have a top-down APRS satellite page for all users and all APRS satellites.

Start Here for All APRS Satellite Data: aprs.org/sats.html

This page will let you select USER digipeated packets or telemetry packets from each satellite, as well as some simple links to other info.

Attitude Determination and Control System (ADCS)

The ADCS on PSAT2 was designed for several modes. First is the passive radiative solar pressure spin mode accomplished by the differential color surfaces on the side panels. Notice in Figure 10, below the platform, that the solar cells are offset about 3/16ths of an inch to the right and a reflective (or white) strip provides a color imbalance to solar radiation. On our original PCSAT, we got it right, and for 18 years, PCSAT spins at about 0.6 RPM. On PSAT, we overdid it (about 1/4" of white), and it turns at from 6 to 10 RPM! On PSAT2, we reduced that a bit and also added our first ADCS system with active torque coils that can change the spin if needed.

The active ADCS command modes are: a B-dot to despin rates if they get too high; a modified B-dot that can set a constant spin about any axis; a barrel-roll mode that will attempt to spin the CubeSat about the Z-axis to maintain full sun on the larger side panels; and finally a Z tumble mode to make sure that both Z panels get equal illumination.

To test the ADCS, we rigged up the arrangement in Figure 10. First, on the shelf below the satellite, (not visible) we moved some magnets around until we pretty much canceled out the Earth's magnetic field as sensed by the satellite. Then we placed a magnet suspended by a strip of paper (on the right) hanging on an arm balanced on the rotating knob of a darkroom timer. We adjusted the length of the arm so that the field sensed by the satellite was the same magnitude we get from Earth. Then we could move the magnet around and calibrate all of the axes of the magnetometer sensor.

To test the dynamic response of the CubeSat, we could turn on the timer to rotate the magnet at one RPM simulating the spacecraft rotating in the opposite direction. Each of the torque coils on each solar panel

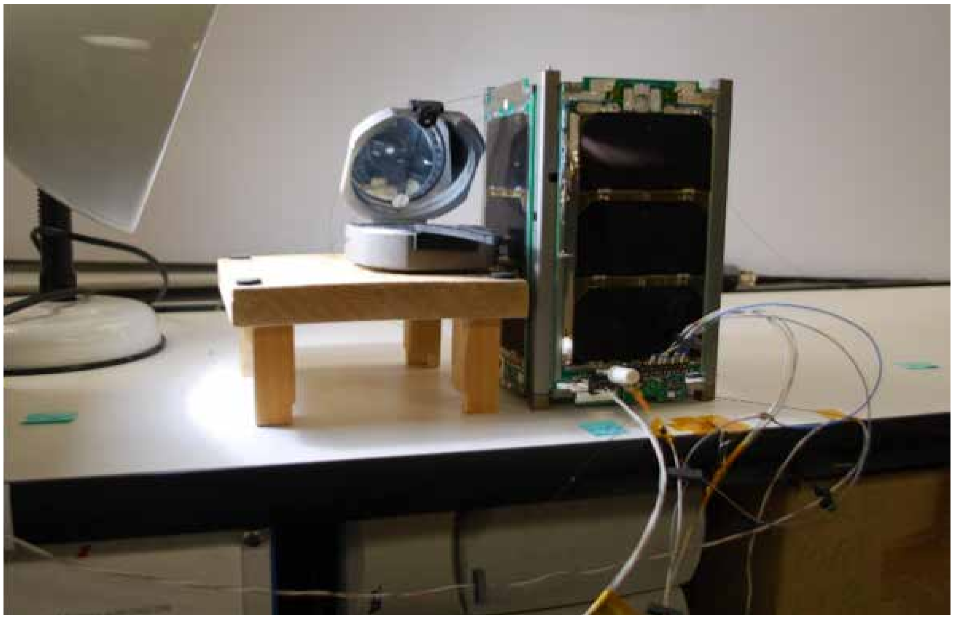

Figure 11 — Compass used to verify torque coil operation.

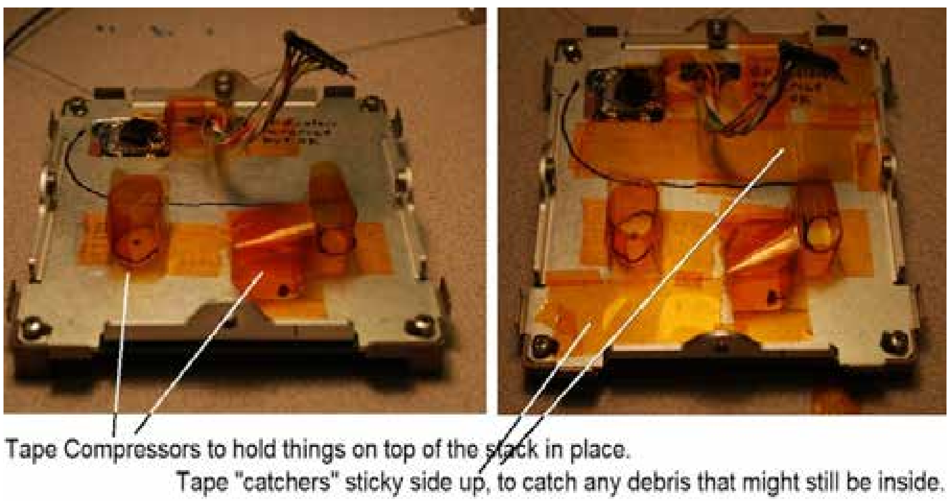

Figure 13 — Use of Kapton Tape on top panel for connector pressure points and debris collection.

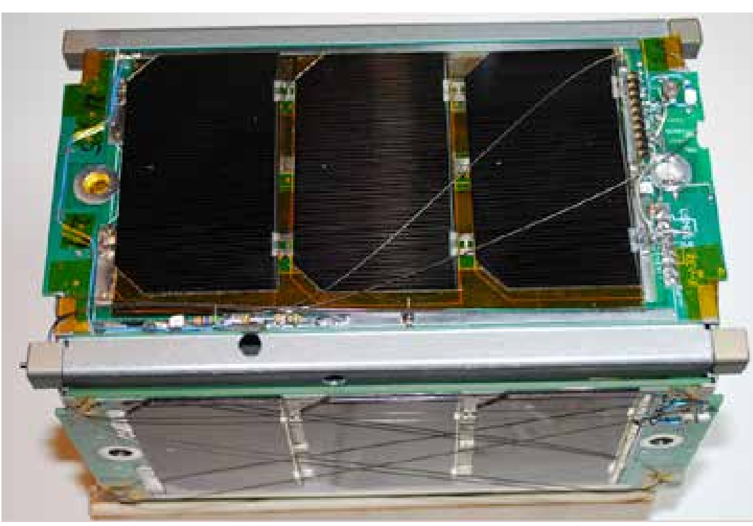

Figure 14 — Wrapping of the five antennas and then burn resistor placement where they all end.

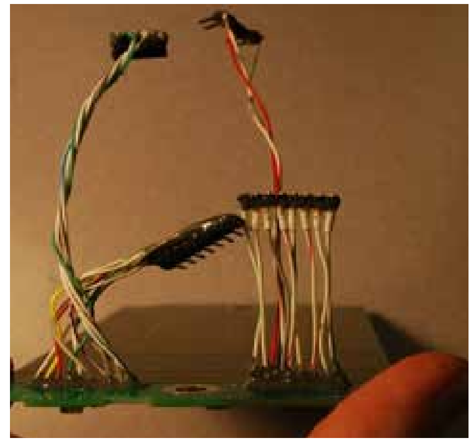

Figure 12 — Various views of the Y+ panel that also has Umbilical connections.

also has an LED illuminated when the torque coil is energized. This lets us visually interpret the reaction of the satellite in its various ADCS command modes. We put this test setup together in only an hour or so, and it was invaluable over several days in giving us confidence that everything was wired with the correct polarity, and the ADCS CPU was commanding the right response.

In the same Figure 10, you can see the six-foot HF wire antenna coiled up in the McMaster-Carr plastic bag, and the two UHF right angle crossed polarized whips coming off the front. The pair of two-meter 20" whips are not visible.

Figure 11 shows the compass used to verify torque coil pulsing and direction. The umbilical wires all have ferrite beads and chokes on them to prevent RF from getting into the control lines. The torque coils on each axis are four separate coils, one each on the top and bottom of each solar panel in series with the similar pair on the solar panel on the opposite side. We wanted to make sure they were all working together in the right direction. The coils are spiral rectangular traces etched onto the solar panel front and back to make construction trivial. The back of a solar panel is shown in Figure 12.

There are 60 turns of torque coil traces on the front and back of each solar panel, and when connected in series with the opposite panel on that axis, the resistance is about perfect for the maximum rating of an Arduino output pin (40 mA), so no H-bridge or other hardware drivers were needed.

We make common use of simple pin-headers for all connections because the number of pins needed always seems to grow as the design progresses. By flight time, the +Y panel had not only the same eight pins for all the devices on each panel but also another 18 pins for the umbilical test connections.

The pins and wires are stress-relieved by Scotch-Weld epoxy. Since all of these solar panel connections plug into the top of the card stack, cylinders of Kapton tape are used to provide a crushable pressure point to hold things in place during vibration. We also use copious amounts of exposed tape wherever it will fit to collect any floating debris that might result due to vibration (Figure 13). This is a cheap substitute for, though not as good as, conformal coating of all boards. But it fits our last-minute-hack style of construction.

Mitigating Student Design Techniques

Two other design shortcut techniques avoid costly interactive interferences. First, any exterior viewports are placed in the corners of boards. Since the final stacking is never known until well on into the student design and integration process, having access ports in the corners of the CubeSat avoids any impact on the most expensive components of the satellite, the solar side panels. These holes are drilled last. Second, the antenna release mechanism is not finalized until after integration. This is because the length of the five antennas from 6" for UHF, 20" for VHF and 72" for HF cannot be known until final integration and careful tuning. Therefore, the location of the burn-release resistor is not known until the spacecraft is built.

We design for this by placing burn-resistor traces along the edges of all solar panels. After all antennas are tuned, we can play the origami challenge of finding one place on the entire CubeSat where the ends of all antennas can come together in one spot. This is where the burn resistor is finally soldered. Then a few small bent wire clips can keep the windings of the antennas in place during vibration and launch. The burn resistor is in the left middle of Figure 14. This is also near two viewports in the corner rail to see the EPS status LEDs. Another last-minute add was a small LED at the burn resistor so we could see when it was energized for final pre-ship verification testing. We use a ¼ watt resistor driven with about 3.5 W to get a good reliable (and repeatable) burn in under 3 seconds. One second tests verify coding without deploy.

Complete PSAT2 information is available at **aprs.org/psat2.html.**

An Easy Way to Work the L-Band Satellites

Ronald G. Parsons, W5RKN

In a recent *AMSAT Journal* article[1], I described my initial implementation of an L-band enhancement to my satellite station. I mentioned a future product from Down East Microwave. Inc. (DEMI), a Transmit Converter which would convert a low-level 10 MHz wide signal at 28, 50 or 430 MHz, and generate a 10 MHz wide output on 1260-1270 MHz (L-band) with up to 25 W power. That product now has been released as Model L24TX.

All three regions of the IARU define a world-wide amateur satellite segment on 1260-1270 MHz that is uplink only. Thus, the downlink will be on other bands. But the limitation to uplink-only simplifies the design of modifications to current U/v satellite stations to encompass L/v capability. In the following, I will describe a modification that, with only minor changes, can be applied to most current U/v stations. I will use two examples: (1) my FlexRadio system, and (2) a generic U/v transceiver. Modifications to other systems should be very similar. Two satellite tracking software programs widely used, SatPC32 by Erich Eichmann DK1TB and MacDoppler by Dog Park Software, have a built-in capability to correctly calculate the Doppler shift of the L-band signal, which is about three times larger than the Doppler shift in U-band signals.

Current and Future L-band Satellites

Right now, we have only one satellite with active L-band use. AO-92 is commanded into L/v mode using FM every Saturday for 24 hours. I regularly work an average of seven contacts each pass with an elevation of at least 30 degrees. So, with each of us trying to work all the others, the pass can be very busy. We had high hopes that Fox-1 Cliff, AO-95, would provide another L/v satellite but, sadly, AO-95 failed to achieve operational status.

ESEO, currently in commissioning by AMSAT-UK, has the capability for a single-channel L/v FM transponder. Its IARU Coordinated Frequencies are FM Uplink 1263.500 MHz CTCSS 67 Hz and FM Downlink 145.895 MHz.

GOLF-TEE/-1, currently in development by AMSAT-NA, includes the possibility of L-band up with U/S/X down.

Implementations

I won't repeat the description of the FlexRadio-based system detailed in footnote 1, but I will make note of the changes. Fortunately, the modifications using this DEMI Transmit Converter are simpler than the previous description. The former implementation used a complicated series of devices, a 28-144 MHz transverter, a 144-1260 MHz transverter, optionally followed by a 1260 MHz amplifier, each requiring power, PTT control, and interconnecting cables. This new implementation uses a single device, greatly simplifying the design.

The only difference between the FlexRadio implementation and the generic U/v radio is the method used to specify the offset frequency between the IF and L-band frequencies. FlexRadio provides a construct called a transverter band (XVTR) which is a named translation definition between the IF frequency and the output frequency and some other parameters such as IF drive level, as described in the article in footnote 1. For other radios using SatPC32 software to control the radio, a parameter in the Doppler.sqf file entry for a satellite defines the difference between the IF frequency and the output frequency.

Specifying the LO Offset with SatPC32

SatPC32 uses an auxiliary file Doppler.sqf to define all necessary parameters for a satellite's frequency and mode parameters. For example, the nominal data line for AO-92 for a U/v capable transceiver is:

AO-92,145880,435350,FMN,FM,NOR,0,0,Voice U/V 67 Hz tone required

where 145880 is the downlink frequency and 435350 is the uplink frequency in kHz. For the L-band mode, the nominal uplink frequency is 1267359 kHz.

The FlexRadio version of my satellite station has a built-in frequency converter that can use the nominal form of the data line with the actual uplink frequency. Flex has a construct called an XVTR band definition which specifies a LO frequency for the difference between the output frequency of the Flex radio and the transmitted frequency after being converted to the actual transmitted frequency from the antenna. This allows SatPC32 to calculate Doppler frequency corrections at the actual frequency.

So, the Doppler.sqf data line is:

AO-92,145880,1267359,FMN,FM,NOR,0,0,Voice L/V 67 Hz tone required 1267359 actual uplink.

But for a generic U/v capable transceiver, SatPC32 must send the UHF frequency to the transceiver but with the Doppler correction based on the actual uplink frequency. To do that, SatPC32 provides two parameters in the data line to specify the difference between the radio frequency and the satellite frequency. The two parameters normally are both zero. The first is for the downlink and the second for the uplink. For the U/v transceiver, I will be converting the 10 MHz segment from 430 MHz to 1260 MHz. The offset between radio and satellite frequency is 830 MHz. The parameters must be specified in kHz without commas. Thus, the two parameters 0,0 must be changed to 0,830000.0 with the optional fractional kHz separated with a period. So, the adjusted Doppler.sqf data line is:

AO-92,145880,1267359,FMN,FM,NOR,0,830000,Voice L/V 67 Hz tone required.

Specifying the LO Offset with MacDoppler

The process is similar in MacDoppler. In the Modes Preferences panel for a given satellite, put an entry in the Txverter column for the uplink offset. The Doppler shift is calculated for the actual frequency of the satellite, but the shift is applied to the IF frequency data sent to the radio. The offset is in decimal Megahertz.

The DEMI 24 cm Transmit Converter

The Down East Microwave 24 cm Transmit Converter, Model L24TX, is a highly configurable transmit-only product with up to 25 W output between 1260-1270 MHz designed specifically for the Amateur Radio satellite service. See Figure 1. It has options that enable the use of selectable IF frequency ranges and drive levels to work with an existing satellite system or a newly designed set-up. The converter takes a 10 MHz user-selectable range and up-converts it to the 23 cm worldwide satellite sub-band at 1260 MHz. Frequency accuracy is obtained with an on-board synthesizer locked to an external standard 10 MHz source. There are options for various drive levels from -20 dBm to 10 W and for transceivers that do not have continuous 10 MHz wide output at 10 m and 6 m. The output power can be monitored by a reference voltage available through an auxiliary connector.

Figure 1 — DEMI 24 cm Transmit Converter.

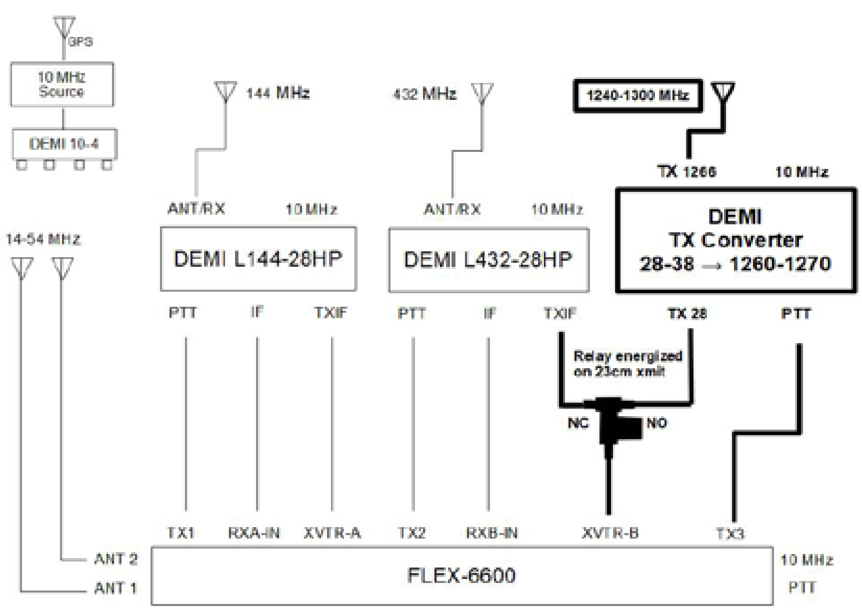

Figure 2 — Block diagram of the interconnections for the FlexRadio implementation. The parts in bold are changes from the paper in footnote 1.

There is an optional model, L24TXMM, which is mast-mountable and has provisions for monitoring all necessary functions. There is also an option to use a single coax which shares the 10 MHz and IF frequency signals.

The converter has a control wire (Pin 4 Power On) which enables the converter to be connected to its power supply continuously and turned on with a positive voltage applied to this control wire. The transceiver can supply this, so the converter is turned on when the transceiver is turned on or by an external switch. This would be especially useful for the mast-mountable model.

Using the Transmit Converter with My FlexRadio-based U/v Satellite System

The Transmit Converter was added to my Flex-based satellite system, as shown in Figure 2. The changes are highlighted with bold lines. When used with W0DHB's FlexSATPC program, the relay is energized automatically when the transmit frequency is in the 23 cm satellite sub-band. I use the same switched power line, controlled by FlexSATPC, which controls the coax relay that switches the output of the transceiver between the UHF transverter and the Transmit Converter, to control the Pin 4 Power On line to the Transmit Converter.

To associate the converter's base frequency of 1260 MHz with the IF base frequency of 28 MHz, I defined the XVTR Band named L/v, as shown in Figure 3. The maximum power output from the FLEX-6600 on 28 MHz is set to 10 dBm. This power is associated with the RF Power slider set to 100 in SmartSDR. Thus the converter option "MAX IF Drive Range" was chosen to be +10dBm when ordered.

The receive and transmit slice flags in SmartSDR are shown in Figure 4 using the XVTR band L/v definition, the association of the TX3 PTT connector with the L/v mode, and the SatPC32 Doppler.SQF L/v mode definition of the uplink and downlink frequencies for the satellite AO-92. These slice pictures were recorded with SatPC32 and FlexSATPC controlling the satellite system.

Figure 4 — FlexRadio SmartSDR Slice Flags showing frequencies and modes.

Figure 3 — FlexRadio SmartSDR XVTR definition for L/v mode.

Using the Transmit Converter with a Generic U/v Satellite Radio

Figure 5 shows the interconnections for the generic U/v transceiver. The DEMI Transmit Converter must be optioned for 430-440 MHz IF frequencies. If the generic radio has a dedicated low-power output, the Transmit Converter should be optioned for "IF Drive Range" compatible with the radio, and this output used to drive the Transmit Converter. If the generic radio does not have a dedicated low power output, the Transmit Converter should probably be optioned for "IF Drive Range" of "10 Watt max." Carefully adjust the RF power output of the transceiver to be within the optioned drive range.

The coax relay or switch must be set to the NO connector when in L/v mode. Most transceivers will have an output

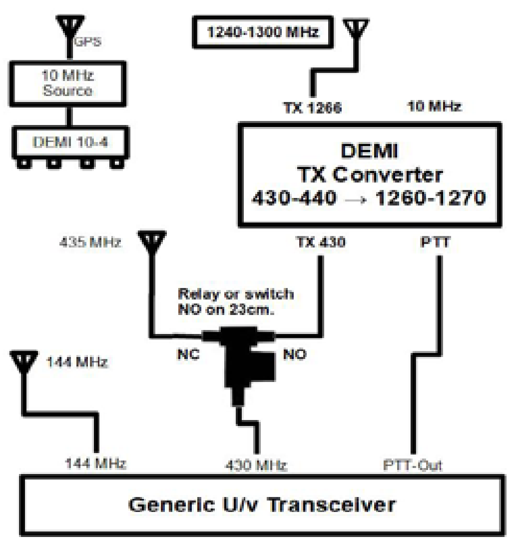

Figure 5 — Block diagram of the interconnections for the generic U/v transceiver implementation.

which is grounded when the transceiver transmits. This must be connected to the PTT connector on the converter.

Be sure to configure SatPC32, MacDoppler or whichever program you use to adjust frequencies as discussed in specifying the LO offset with SatPC32 above so the Doppler shifts will be correctly calculated.

When in use, the display of the radio will look like it is operating mode U/v. But the UHF frequency will be changing about three times more than usual as the Doppler shift is about three times larger for L band than U band.

Operation

With either of these two configurations, operating L/v mode is just like operating U/v mode. Consistent with good operating practice, you will want to use the lowest power output that will provide good communication. Since the power output of the L24TX is more or less proportional to the drive level, you can use your usual methods of adjusting power output. The output power can be monitored by a power meter in the antenna feed line or use the monitoring provided by a reference voltage through the auxiliary connector.

To switch to L/v, just power on the L-band equipment, choose the appropriate Doppler.sqf line or equivalent in MacDoppler, switch the coax relay/switch and operate. For the 23 cm uplink, I use the M2 Antenna model 23CM22EZA. It has a 70" boom and is rear-mounted — very easy assembly. Received signal reports have been good.

Footnotes

1. Parsons, Ronald G., "L/v Mode Enhancement to SDR Satellite Station," *The AMSAT Journal*, November/December 2018, p. 13.

AMSAT CubeSat Simulator Part 4: The Ground Station

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Introduction

We feel that, to the general public, the key concepts of a satellite ground station are akin to the line from *The Wizard of Oz*, "Pay no attention to that man behind the curtain!" Not so for CubeSat developers! The ground station is essential in any space mission, as it is the only way to communicate with and command a satellite after launch. However, we are surprised by the number of CubeSat teams that do not have a properly functioning ground station by the time their satellite is deployed on orbit. Just as we believe building a CubeSat Simulator is an important step towards developing a successful CubeSat flight model for a launch, we believe that setting up and using a CubeSat Simulator Ground Station is a vital step towards being able to communicate with one's CubeSat after launch.

In Huntsville, Alabama, in November 2018, we introduced a proof-of-concept prototype model of the new AMSAT CubeSat Simulator as a tool for satellite technology education and demonstrations. We initiated a Beta Builder & Beta Tester invitation to AMSAT members. Shortly after, we officially launched the core of an encompassing STEM program at Hamvention 2019 in Dayton, Ohio during the AMSAT Update forum. We loaned all four of the complete, working CubeSat Simulator models that debuted at the Hamvention to AMSAT members to take home to demonstrate at a high school, club meeting or public function. The results so far have been highly successful and quite encouraging.

This article is the fourth in a series introducing the AMSAT CubeSat Simulator. The first article explained the philosophy and design of the simulator (*The AMSAT Journal*, Part 1, Nov/Dec 2018). The second showed some educational activities that can be performed with the simulator, starting with activities designed for the original ARRL ETP CubeSat Simulator, as described by Mark Spencer, WA8SME, (*The AMSAT Journal,* Part 2, Jan/Feb 2019). The third article described some interesting failure simulations, efficiency and maximum power point calculations, and using an Arduino platform as a payload interface for the simulator (*The AMSAT Journal*, Part 3, May/June 2019).

This article introduces the CubeSat Simulator Ground Station and discusses the various options and tradeoffs in station design. It includes a choice between a Windows PC ground station and a Raspberry Pi ground station.

Background

The new AMSAT CubeSat Simulator, shown in Figure 1, features a Raspberry Pi Zero W-based multi-board stack and a 3D-printed frame structure. These serve as a functional CubeSat model in a 1U form factor, less the

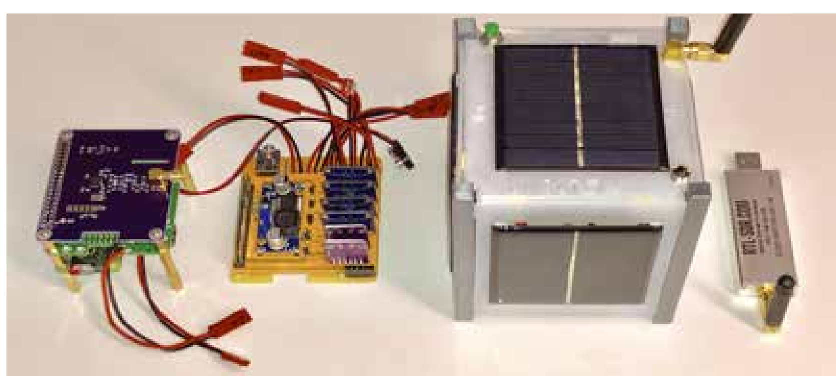

Figure 1 — An AMSAT CubeSat Simulator showing the components. From left to right: three board stack including Brandenburg Digital Transceiver Board, MoPower UPS V2; Raspberry Pi Zero; custom AMSAT solar power board with current and voltage sensor; 3D printed CubeSat frame with solar panels; and RTL-SDR USB dongle with antenna for the ground station.

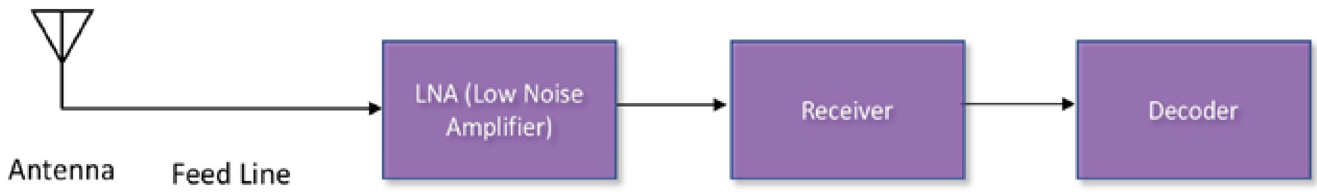

Figure 2 — Functional blocks in a Satellite Ground Station.

ground station component. It is designed as closely as possible to act as a standard 10 cm (4 inch) cube-sized satellite flying in Low Earth Orbit (LEO). The purpose of this system is to demystify how satellites work. Like typical LEO satellites, this simulator runs on rechargeable battery power and solar cell panels. Our model currently transmits telemetry on the UHF band using the AMSAT OSCAR 7 (AO-7) format using AFSK AX.25 1200 bps modulation. For details on the design and construction of the simulator, see our paper in the 2018 AMSAT Annual Meeting & Space Symposium proceedings[1] or as updated and edited for the Nov/Dec 2018 issue of *The AMSAT Journal*.

The remainder of this article describes a ground station for the CubeSat Simulator.

Ground Station Requirements

The main requirement of the CubeSat Simulator Ground Station is to receive telemetry transmitted by the CubeSat Simulator and enable the decoding and display of the information contained in the telemetry. Telemetry, of course, includes the satellite's health and welfare or "housekeeping" data downlinked, as well as the science data from each payload or instrument on the spacecraft bus. For simplicity, most of our telemetry discussions tend to be of the common housekeeping variety because each instrument is so unique. Other requirements include that the ground station be reasonably low in cost, easy to set up and configure and be similar to a real satellite ground station.

A student recently asked innocently enough, and quite insightfully, "Why not just have the satellite send down its data directly without all the complexity of modulating, demodulating, encoding and decoding"? Well, we wish the current state of the art in technology would permit that to happen. It does not, and for a number of reasons. So, such an investigation is left for the student to explore, and perhaps one day to develop a simpler solution for humankind.

The functional blocks of a ground station are shown in Figure 2. They are antenna electrical and mechanical subsystem, feed lines, low noise amplifier, receiver, and decoder. We will discuss each in terms of the requirements for the CubeSat Simulator Ground Station.

In an orbital satellite ground station, the antenna is a critical and complex part of the station. However, since the CubeSat Simulator is usually in the same room as its ground station, the antenna can be very simple, even a short piece of wire. And since the antenna can be co-located with the ground station, the feedline for the Simulator Ground Station can be a connector. Again, due to the simplicity, a low noise amplifier is not needed for the simulator.

The receiver for the ground station also has simple requirements. Any UHF FM receiver or scanner would work, as would a software defined radio (SDR) receiver USB dongle, plugged into a laptop or PC or Raspberry Pi.

The following sections will discuss the details. The decoder takes the output of the receiver and translates it to display and analyze the satellite telemetry. Also, the output from the receiver might be speakers or headphones, or an audio recording device.

Radio Receiver Options

To receive the AFSK 1200 bps telemetry, almost any UHF FM transceiver or handie talkie (HT) will work, including the ultra-low-cost Baofeng HTs which sell for as little as $20. An audio cable is needed to input the signal to a computer for telemetry analysis. This cable transfers the line-level headphone audio output from the radio to an audio input on the computer. If the computer does not have a line-level audio input (but only a low-level microphone input), then adjustments with the HT volume knob or PC mixer controls might be required to avoid a distorted signal. Otherwise, a small series resistor might serve well as an attenuator if needed.

SDR Receiver Options

Since the intent of the ground station is to analyze the telemetry, using an SDR receiver dongle is an obvious choice. A wide range of SDR USB dongles is available today. We use the cheapest RTL-SDR dongle which sells for about $20. The "RTL" in RTL-SDR refers to the RTL2832U chip, which functions as a wideband radio tuner. It can be plugged into a Windows or Linux computer, such as a Raspberry Pi. We will discuss the pros and

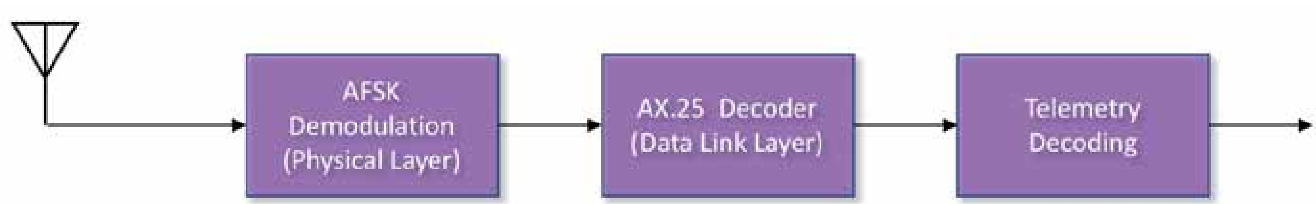

Figure 3 — Block diagram of demodulator and decoder.

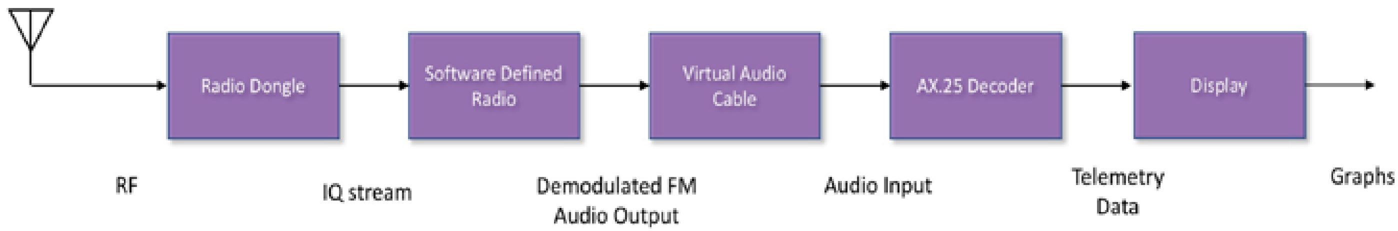

Figure 4 — Ground station implementation of demodulation and decoding of telemetry.

cons of each computer configuration in the following sections.

Demodulation and Decoding

The current version of the AMSAT CubeSat Simulator uses AFSK AX.25 1200 bps encoding of AO-7 formatted telemetry. We chose AFSK AX.25 as it is simple, common, and easy to decode. It is compatible with APRS (Automatic Packet Reporting System) decoders. Future software updates may also support other modulation schemes, such as the DUV FSK (Data Under Voice Frequency Shift Keying) of the AMSAT Fox-1A, 1B, 1C, and 1D satellites or the BPSK (Binary Phase Shift Keying) of the soon to be launched Fox-1E satellite.

To understand the requirements of the Decoder and Demodulator, let's break down what "AFSK AX.25 1200 bps" means. Note this is also sometimes written as AFSK AX.25 1k2. We will start with the radio signals received from the CubeSat Simulator on the UHF band. The block diagram of this process is shown in Figure 3.

The radio signal sent by the CubeSat Simulator is an FM modulated digital signal. A normal narrow-band FM demodulator is first used, at the carrier frequency of the RF signal. The resulting audio after demodulation is a series of tones which represents the stream of 1's and 0's — the binary data. A 1200 Hz tone represents a 1 (a "mark"), and a 2200 Hz tone represents a 0 (a "space"). The data rate is 1200 bits per second, so the tone can change up to 1200 times each second. For each period of 0.833 ms, the tone is detected to determine if a 1 or a 0 is being sent. This is how demodulation of an AFSK (Audio Frequency Shift Keying) signal is performed. The output from an AFSK demodulator is a stream of 1's and 0's.

Next, the AX.25 decoder will take this stream of 1's and 0's. The AX.25 decoder removes the AX.25 header, which is at the start of the frame and contains fields such as the source and destination call signs, etc. The rest of the frame is the string of telemetry data. For more information on the complete satellite telemetry decoding protocol stack, see this excellent summary of these and other protocols such as HDLC and KISS that are used in satellite telemetry decoding by Daniel Estevez, EA4GPZ / M0HXM[2].

This telemetry data represents encoded values of measured voltages, currents, and temperatures on the CubeSat Simulator. Each of these values is a coded number. We chose to encode them in a format in which AO-7 and later AMSAT satellites — including AO-8 which Alan KU2Y worked back in the 1980s — encoded this information suitable for transmission over CW. This is the memorable "hi hi 156 199 …" format where "hi hi" indicates the start of a packet frame of information, which is then followed by sets of three-digit numbers separated by a blank space. The first digit represents the channel number, and the next two digits are the encoded telemetry value. For example, the solar panel electrical current channels are encoded by this formula where "value" is a two-digit number, and "current" is the current in mA. Previous articles discuss interpreting this data.

Ground Station Manual Implementation

The steps in manually demodulating and decoding telemetry from the CubeSat Simulator are shown in Figure 4. It begins with an RF (Radio Frequency) signal from an antenna on the left and ends with graphs displayed of telemetry data on the right. A radio dongle produces a stream of IQ (In-phase and Quadrature) data centered about the carrier frequency of the CubeSat Simulator telemetry, around 440 MHz. An SDR receiver application is then used to perform the FM demodulation. A virtual audio cable (VAC) loops back the playback audio to the recording microphone input for the AX.25 decoder which outputs the telemetry data. The display function processes the mathematical formulas that convert the coded data into the originally measured voltages, currents, and temperatures, which are then graphed.

For Windows, the applications are as follows: an RTL-SDR receiver dongle, the SDR# Software Defined Radio package, the VBCable (which provides a virtual audio cable from the

Are you planning to build a CubeSat flight model? Here are a precious few professional ("Been there, done that, failed a few times ourselves!") advice snippets to consider before holding your Preliminary Design Review (PDR). Can you incorporate any of these tips into the AMSAT CubeSat Simulator project that you are about to get underway?

NASA Advice Given to CubeSat Developers:

1. "Test early and test often." Very important! Cannot be overemphasized. Negotiate diligently for the required schedule or budget. Start from your component and subsystem level units at your incoming inspection upon procurement. Verify the operation of each part or unit, comparing to the related spec sheet. Contact the vendor about any discrepancy.

2. "Test as you fly." That is, activate your ground station and converse with your satellite while it sits on a lab bench only a meter or two away. Celebrate its responses. This is called a Compatibility Test. Perform DITL ("Day In The Life") tests and deployment tests in the configuration as close as possible that you expect the satellite to experience on orbit, all on an open lab bench. Accumulate hours of operation and log them. Good job! Then do the same under stresses, such as thermal, mechanical, and RF emission environments. Have any CubeSat developers cut way back on proper testing for any number of reasons? Unfortunately, those are the ones who also have issues and challenges once on orbit and wonder why. Hard facts. Tough love?

3. "Analyze your housekeeping telemetry closely and look for trends in your data." Learn all the characteristics of your satellite almost as though it were a newborn baby growing to a toddler through your telemetry data. Watch for good trends. Watch for not-so-good trends and learn to perform troubleshooting on the ground, as opposed to in low earth orbit.

4. "Develop a properly functioning ground station." Don't rely solely on a distant, outside source or group. Otherwise, hold a sufficient number of comprehensive Compatibility Tests with your remote ground station or stations, or network. One's ground station or network seems to be too often a late oversight. Don't let it happen to you. Plan early.

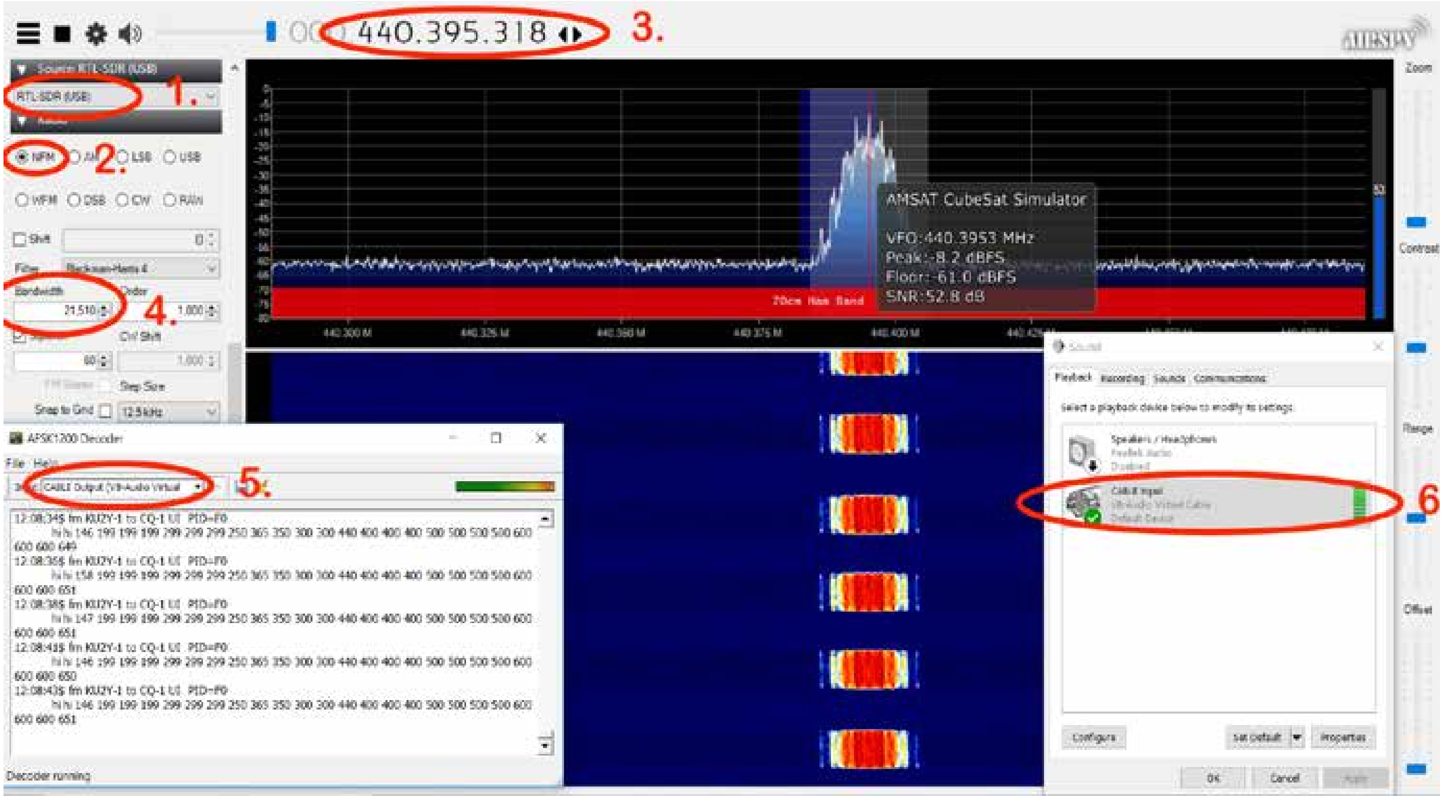

Figure 5 — Windows screenshot showing key settings in applications.

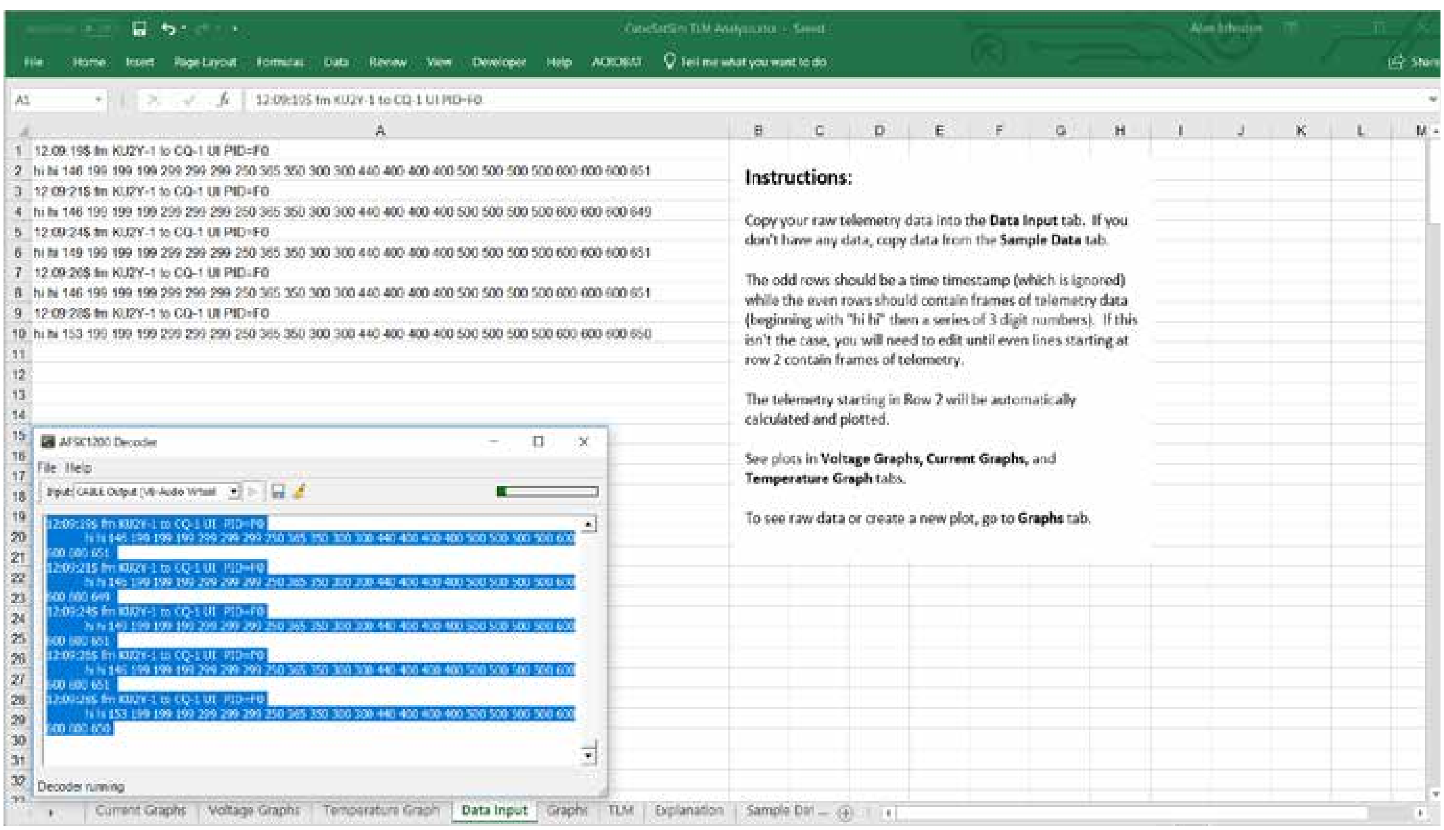

Figure 6 — Windows screenshot showing cut-and-paste from the decoder to spreadsheet.

Sound Playback in Windows to the Sound Recording) and the Qtmm AFSK 1200 Decoder. Then the user performs a manual cut-and-paste of the telemetry data into a spreadsheet for calculation and graphing. The detailed process of how to do this in Windows is described in our project Wiki[3].

A screenshot showing all these applications working is in Figure 5. You can see the key settings circled in red and labeled with a number:

1. SDR# Source set to RTL-SDR (USB)
2. SDR# Radio set to Narrow Band FM (NFM)
3. SDR# Frequency set to 440 MHz, centered about the telemetry signal
4. SDR# Bandwidth set to cover the entire signal (about 20 kHz)
5. AFSK1200 Decoder Input set to CABLE Output (VB-Audio Virtual Cable)
6. Windows Sound Playback set to CABLE Input VB-Audio Virtual Cable

And note that when the signal is received, the Sound Playback CABLE Input, Sound Recording CABLE Output, and AFSK1200 Decoder all show full scale (green bars). The cut-and-paste between the Qtmm AFSK 1200 decoder application and the spreadsheet is shown in Figure 6, where the telemetry is pasted into the Data Input tab of the spreadsheet. The telemetry graphs are then displayed in the other tabs of the spreadsheet.

We realize some steps in our set up procedures are more challenging than others, but please bear with us. We will provide support and encouragement along the way!

Our experience with this ground station setup with Windows has shown the main benefit to be low cost, with only an RTL-SDR dongle and a simple antenna needed, as most people have easy access to a Windows computer. However, it has not proven to be easy to set up. Here are the main issues we have encountered:

1. Installing the RTL-SDR drivers can be difficult. The RTL2832U chip was designed for Digital TV using the DVB-T standard used in Europe. The use of this chip as an SDR is essentially a hack, and to make it work, the official drivers that ship with Windows and Linux must be replaced. This is a simple command line in Linux, but on Windows, it is a procedure involving running a piece of software known as Zadig. You can see the number of steps involved here[4]. Also, this installation requires administrator privileges. Some teachers do not have these rights on school-issued laptops and computers, so this can be annoying. Also, occasionally, the driver installation simply fails for unknown reasons, which is a frustrating experience.

2. Configuring VBCable is a bit complex. Differences between Windows computers means that a set of instructions can't always be followed precisely. Different names and devices also complicate the configuration. In the Wiki instructions[3] we show eight different screenshots of the Windows Sound control panel to try to explain the steps, showing how complex it is.

3. Tuning SDR# can also be a source of problems. If the tuning isn't centered about the telemetry signal, or the bandwidth not set wide enough, decoding may fail even though there is a signal. However, this issue at least has educational value, in that it teaches the importance of correct receiver tuning, a useful skill.

Function	Option	Pros	Cons
Radio	RTL-SDR	Cheapest SDR	Installation of Windows drivers is tricky
Radio	FUNcube Dongle	No driver install, high-quality SDR	More expensive
SDR	SDR#	Free, easy to use, many plugins	Windows only
SDR	HDSDR	Free, used by many satellite operators	Windows only, complex user interface
VAC	VBCable	Works	Windows Sound configuration not easy
VAC	Virtual Audio Cable	Works	Not free, Windows Sound configuration not easy
Decoder	Qtmm AFSK 1200 Decoder	Simple User Interface	
Decoder	UZ7HO SoundModem	Used by many satellite operators	Complex User Interface
Display	MS Excel Spreadsheet	Commonly used	Not free
Display	LibreOffice Calc Spreadsheet	All platforms, Free	Functions slightly different from MS Excel
Display	Google Docs Spreadsheet	Easy to share, Free	Web-based

Table 1 — Windows application options.

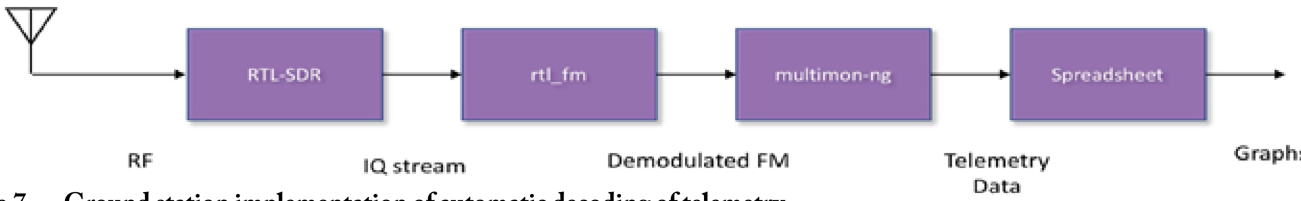

Figure 7 — Ground station implementation of automatic decoding of telemetry.

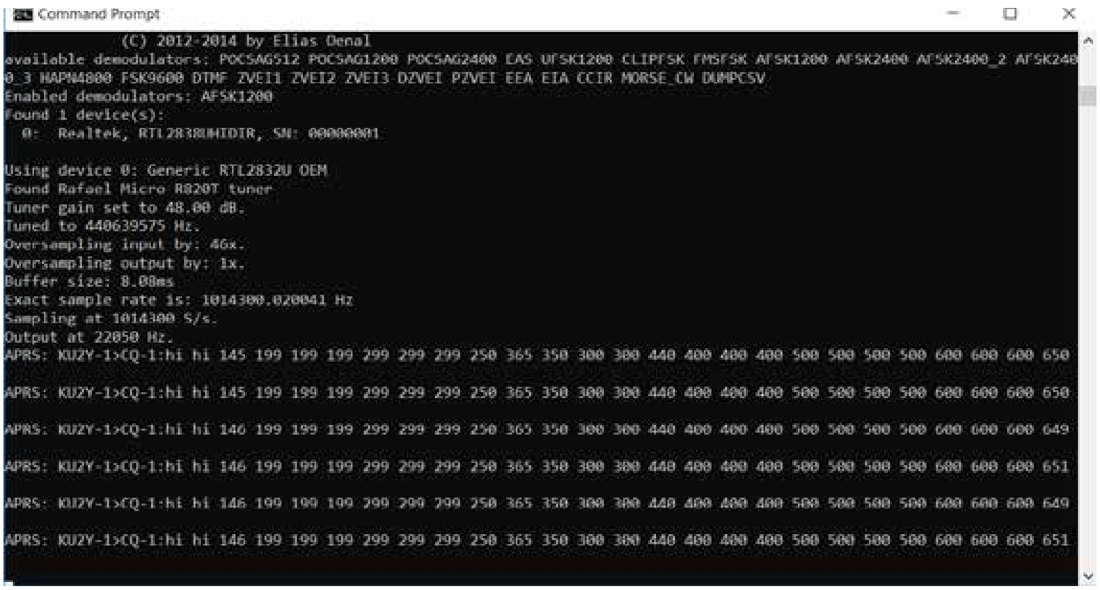

Figure 8 — Automatic telemetry decoding in Windows with multimon-ng.

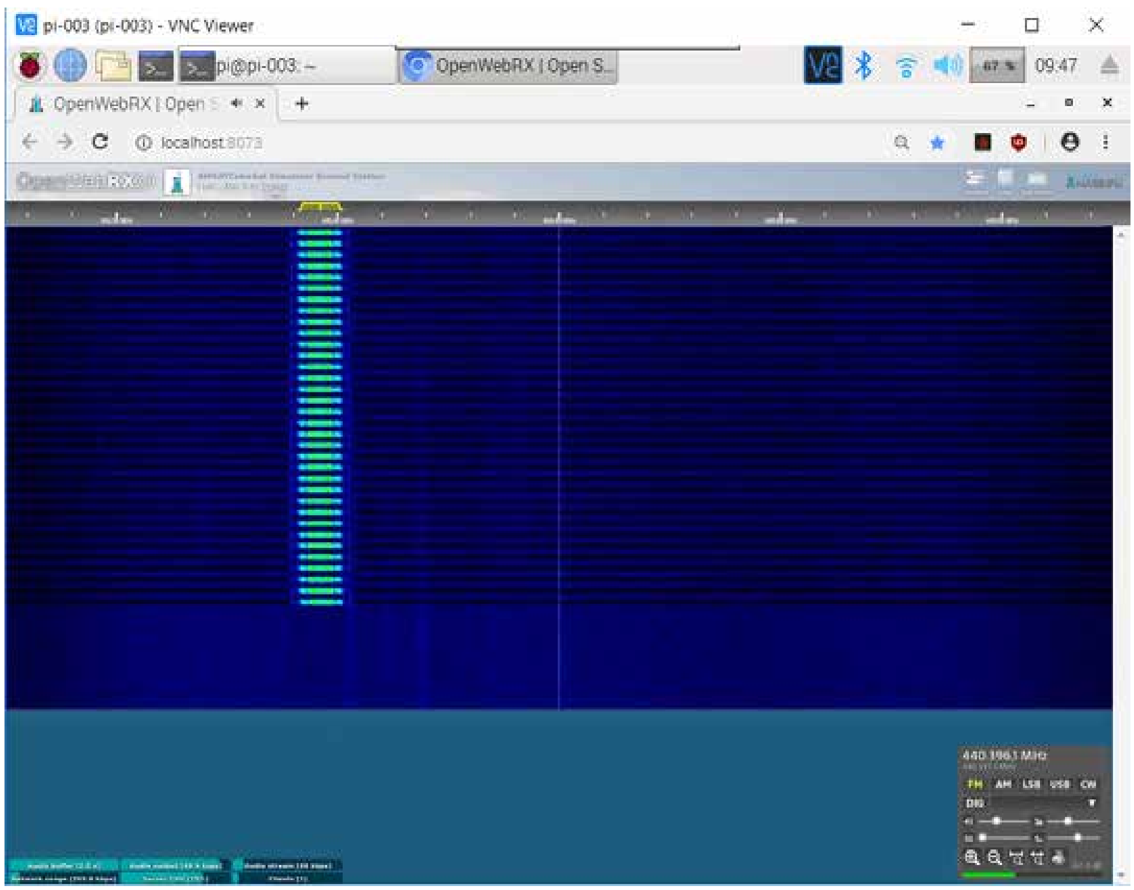

Figure 9 — OpenWebRX on a Raspberry Pi.

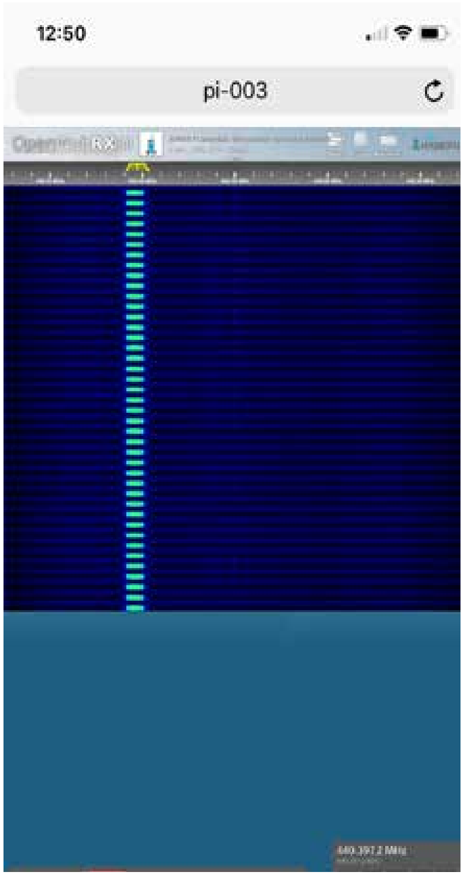

Figure 10 — OpenwebRX on iOS.

Issue #1 can be eliminated by using an SDR dongle which does not require driver installation, such as the FUNcube USB dongle. However, the FUNcube dongle is much more expensive and does not have the broad software support that the RTL-SDR has. There is a no-install RTL-SDR approach that works for Windows, Linux, and even Android and iOS. It is described in the Appendix to this article.

We have not yet found a simple solution to Issue #2 in this configuration. One option might be making a physical loopback plug that connects the speaker to the microphone through the headset jack on a PC. The best solution would seem to be to avoid generating audio that must be ported internally.

Issue #3 can be solved by providing an XML file with the CubeSat Simulator frequency, bandwidth, and modulation pre-configured as a frequency pre-set. Just clicking on the name in the Frequency Manager in SDR# will correctly tune the signal. These and other Windows alternatives for the various applications are listed in Table 1.

Note that if running on Linux, the same flow can be used, although different applications will be used. For example, instead of SDR#, Gqrx could be used, and instead of VBCable, a Virtual_Sink can be configured with PulseAudio. However, we suspect few teachers have access to a Linux desktop. A bootable USB with Ubuntu could be used to allow any laptop to run Linux, but this is a bit advanced. Soundflower provides Virtual Audio Cable functionality for Mac OS.

Ground Station Automatic Implementation

A recent CubeSat Simulator Ground Station approach that we have come up with is an automatic approach. It simplifies the process considerably. It uses two command-line applications: rtl_fm and multimon-ng. The first, rtl_fm is a simple demodulator application that comes with the RTL-SDR drivers and runs on Windows or Linux. Settings such as center frequency, bandwidth, and demodulation are set using command line parameters and options, and the output can be sent to an audio driver, a file, or piped to another command-line application. The other, multimon-ng is a command-line demodulator for a variety of digital encodings, including AFSK AX.25 1200. The input signal can come from another program, and the output is the decoded text.

This single command both demodulates and decodes the CubeSat Simulator telemetry:

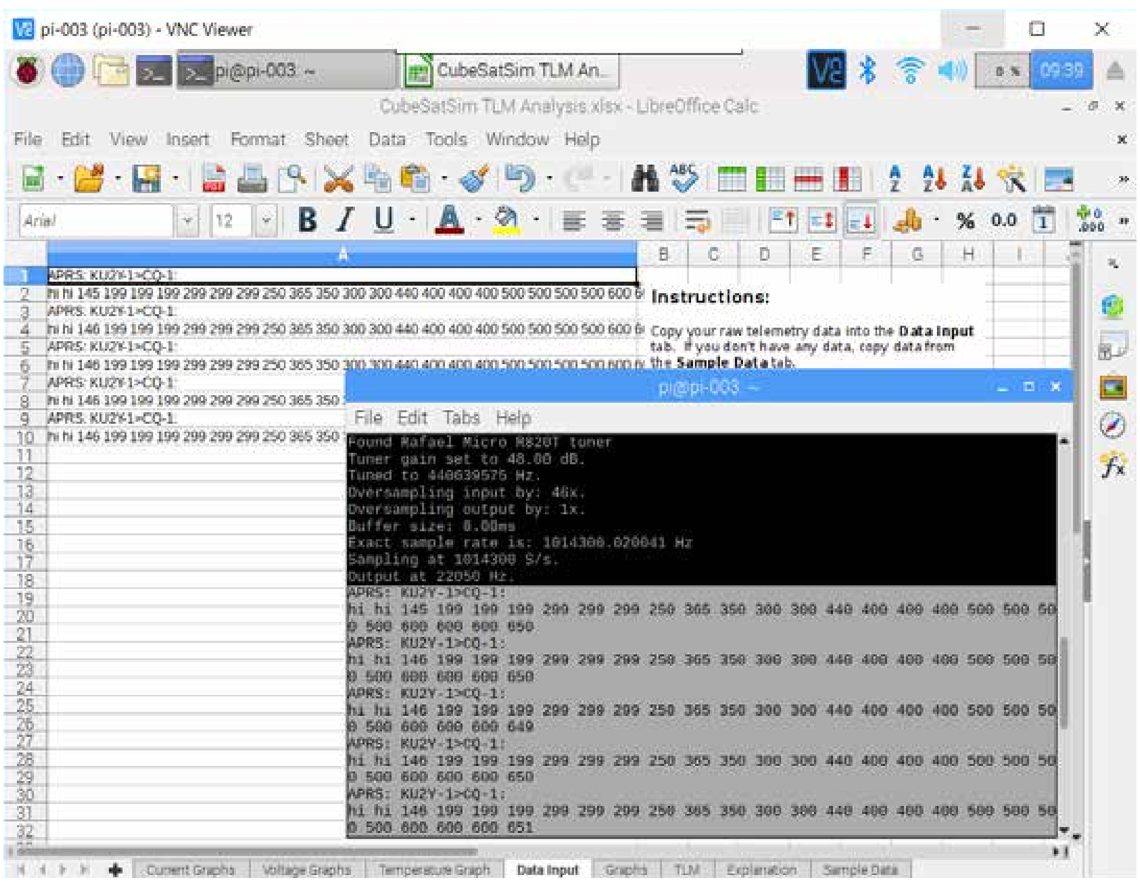

Figure 11 — Cut and paste on Raspberry Pi between decoder and spreadsheet.

Figure 12 — Raspberry Pi Ground Station running OpenWebRX with Touch LCD Display.

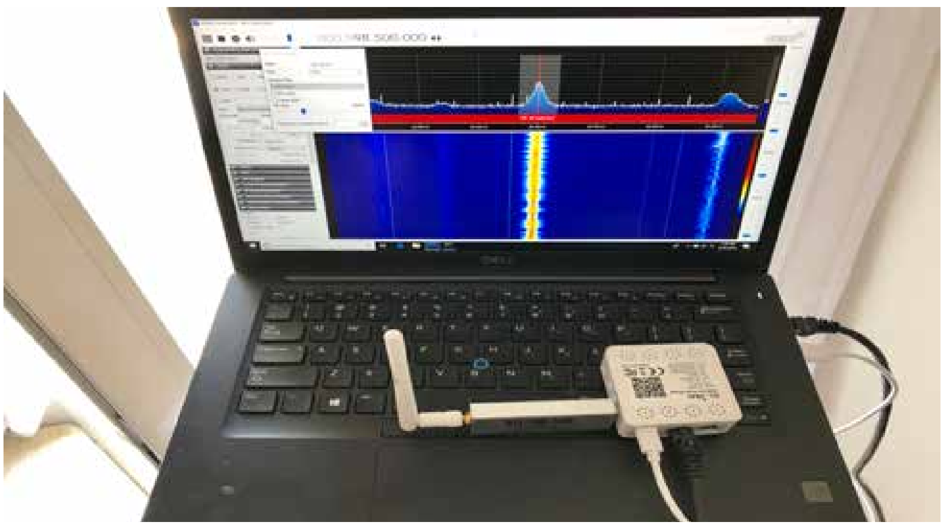

Figure 13 — No install RTL-SDR with Windows laptop.

Figure 14 — No-Install RTL-SDR with Android, running SDR touch application.

```
rtl_fm -f 440.386M -s 22050 -g 48 - |
    multimon-ng -a AFSK1200 -A -t raw -
```

The -f option sets the frequency, while the -s option sets the bandwidth. The | is the pipe command, which connects the output from the first program rtl_fm to the input to the next program multimon-ng. This completely avoids the audio porting issue of the previous approach. The -a option sets AFSK AX.25 1200 for decoding.

This one command then replaces the SDR, virtual audio cable, and AFSK 1200 decoder blocks in Figure 4, resulting in the blocks shown in Figure 7. An example output is shown in Figure 8. The Windows configuration for this Automatic Decoding is in the Wiki page[5]. This command could also be used on a Raspberry Pi. However, there are other significant advantages to a Raspberry Pi Ground Station that are discussed in the next section.

Raspberry Pi Ground Station

It is possible to configure a Raspberry Pi as a Manual or Automatic Ground Station, as described in the previous section. However, there are additional other benefits to using a Raspberry Pi, including:

1. All the software can be pre-installed on a microSD card, which can be shipped or downloaded to turn any Pi instantly into a CubeSat Simulator Ground Station. This saves about an hour of software download and installation and configuration, and is guaranteed to work.

2. The OpenWebRX application[6] can be used to share the RTL-SDR with other computers running just a web browser. Up to twenty users can then independently tune and decode the telemetry — very useful for a classroom exercise. See Figures 9 and 10.

3. Even the spreadsheet telemetry analysis can be done on the RPi using LibreOffice Calc. The LibreOffice suite is pre-installed in the standard "Raspbian OS with desktop and recommended software," as shown in Figure 11.

4. The Pi can be configured as a Wi-Fi Access Point (AP) using RaspAP[7] so that a dedicated Wi-Fi router is not needed.

5. A teacher without a computer or laptop can use the Pi if they have an HDMI monitor (display), USB mouse, and USB keyboard.
6. An inexpensive touch LCD and a USB power pack turn the CubeSat Simulator

Ground Station into a cool handheld device, although the text size on the screen is quite small.

The full instructions on how to configure a Raspberry Pi as a ground station are on our Wiki[8]. They have been tested with a Raspberry Pi 3B, 3B+ and 4B, as shown in Figure 12. We plan to include a Raspberry Pi Ground Station with the AMSAT CubeSat Simulator units available to loan for your classroom or event.

Future

In addition to running their own ground station, many CubeSat operators can benefit from SatNOGS, the open-source global network of receive-only satellite ground stations[9]. To show how this works, we have been collaborating with SatNOGS to enable CubeSat Simulator data to be processed and stored in their databases. For example, you can see an experimental Dashboard for the CubeSat Simulator at this link[10]. You can also see all the other satellites telemetry dashboards displayed here[11]. A future article will describe how to use the CubeSat Simulator to explore SatNOGS.

The AMSAT CubeSat Simulator project is still a work in progress. We are continuing to improve and develop materials. We also wish to hear from you, with questions, comments, and ideas which may be reflected in a future article!

Conclusion

In this paper, we have explored the options for a CubeSat Simulator Ground Station. Some of the options are very low cost, such as the Windows RTL-SDR approach. Others have great flexibility and possibility in the classroom, such as the Raspberry Pi Ground Station. We strongly believe that CubeSat developers can benefit from setting up and using a CubeSat Simulator Ground Station. One's skills and techniques developed here will transfer directly to those required for the real flight model.

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Appendix - No-Install RTL-SDR

This appendix describes a no-install RTL-SDR approach that does not require driver installation, administrator rights on the computer, and works with Windows, Mac, Linux, Android, and iOS.

The approach is straightforward and requires a $20 OpenWrt Wi-Fi hub, an Ethernet cable, and the use of an SSH client such as PuTTY or ssh. The steps to configure and install the software on the hub are described in the Wiki here[12]. The RTL-SDR is plugged into the USB port of the hub, and the computer accesses it over Ethernet or Wi-Fi using the rtl_tcp application running on the hub.

On Windows, plug the USB power cable of the hub into a USB port on the laptop. Plug the Ethernet cable into the laptop and the LAN port on the hub. Run SDR# software as usual, but for the input, select RTL-SDR(TCP) instead of RTL-SDR(UDP) option. You will need to enter the IP address of the hub, which for the model I used was 192.168.8.1. Click the Play triangle, and you will have access to the RTL-SDR over the Ethernet cable, as shown in Figure 13.

This can also be used without the Ethernet cable by connecting to the Wi-Fi of the hub. The downside to this is that you will lose internet connectivity unless the Wi-Fi hub has an Ethernet connection on the WAN port.

This Wi-Fi approach also works for Android and iOS. If a power pack is used to power the hub, then you have a wireless solution, as shown in Figure 14.

Sometimes the RTL-TCP connection will stop working. To re-establish it, you will need to reset the hub by turning it off and on by unplugging it from the USB power source.

Support AMSAT

AMSAT is the North American distributor of SatPC32, a tracking program for ham satellite applications. Version 12.8d features enhanced support for tuning multiple radios. Features include:

1. The CAT commands of the IC-9100 have been extended again. The program now also controls the DV mode (DV for 'Digital Voice') of the radio. With the FT-817 the program now additionally supports the CWR mode.

2. All SatPC32 programs now process significantly larger Keplerian element source files. Especially because of the numerous new Cubesats, the number of data sets contained in the source files has increased significantly. For example the file Cubesat.txt currently contains data for nearly 400 satellites.

3. In all programs (SatPC32, SatPC32ISS, Wisat32, WinAOS and WinListen), the list of satellites contained in the source file ('Available' list in menu Satellites) is now displayed in alphabetical order to facilitate locating individual satellites.

4. The program SatPC32ISS now also allows the creation of up to 12 satellite groups. The new Cubesats have also increased the number of 'in-band' satellites. Originally, in-band operation in amateur radio was only available at the ISS.

5. In order to accelerate a change between the individual satellite groups, the 'Groups' window can now be called up by clicking on vacant areas of the main window, except in the Satellite menu. Such free positions are located on the right and left of the frequency window.

6. In the Satellites menu the data sets of the satellites contained in the active source file can now be displayed. When called, the data set of the currently selected satellite is displayed. The feature helps you to immediately know the identifier of the satellite.

7. The program has improved control of the sub-audible tone required by some satellites. The program can now automatically switch the sub tone on/off when switching between PL tone satellites and others, changing between u/v and v/u satellites, changing the group, closing the program, etc.

A registration password for the demo version may be obtained for a minimum donation of $40 for members and $45 for non-members. Order by calling 1-888-322-6728. The author DK1TB donated SatPC32 to AMSAT. All proceeds support AMSAT.

AMSAT GOLF $125,000 Development and Launch Initiative Goal

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
Gold Donors contribute at least US $100 per month	❐ $100 / month ❐ $1200 one time
Silver Donors contribute at least US $50 per month	❐ $50 / month ❐ $600 one time
Bronze Donors contribute at least US $25 per month	❐ $25 / month ❐ $300 one time
Core Donors contribute at least US $10 per month	❐ $10 / month ❐ $120 one time

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.

AMSAT is Amateur Radio in Space
... and YOU are AMSAT!

Seize opportunities to launch your amateur radio experience to new heights!

AMSAT Ambassadors - NEW

AMSAT Ambassadors program is looking for satellite operators to share enthusiasm for Amateur Radio in Space with others by:

- Promoting AMSAT at in-person events, practical demonstrations, online, or in written communications
- Offering personal mentoring and coaching to new enthusiasts either in-person or via online means
- Connecting members and potential enthusiasts with proper resources at AMSAT.

To volunteer, send an e-mail to Robert Bankston, KE4AL at: **ke4al@yahoo.com**. Robert

AMSAT Internet Presence

AMSAT's information technology team has immediate needs for volunteers to help with development and on-going support of our internet presence:

- Satellite status updating and reporting.
- Add/delete satellites to ANS and the web as needed.
- Research and report satellite details including frequencies, beacons, operating modes.
- Manage AMSAT's Facebook and Twitter presence.

To volunteer, send an e-mail to Robert Bankston, KE4AL at: **ke4al@yahoo.com**.

AMSAT Engineering Team

AMSAT Engineering is looking for hams with experience in the following areas:

- Attitude Determination and Control, and Thermal Engineering, to help in the design of high orbit CubeSats.
- Power systems, for CubeSats from 1U through 6U and LEO to HEO.
- Help with solar, power supply, and battery design for both LEO and HEO missions.
- Logistics, for parts procurement, inventory, and distribution.
- Documentation, for designs, tests, and public relations.

To volunteer, please describe your expertise using the form at **www.amsat.org/contact-amsat-engineering/.**

AMSAT User Services

AMSAT is looking for an on-line store co-manager with WooCommerce experience to update and refresh the AMSAT Store web page when new merchandise becomes available or prices and shipping costs change.

- Add new merchandise offerings
- Delete merchandise no longer available
- Update shipping costs as needed
- Add periodic updates for event registrations
- Interface with the AMSAT Office.

To volunteer, send an e-mail to Robert Bankston, KE4AL at: **ke4al@yahoo.com.**

AMSAT Educational Relations Team

AMSAT's Educational Relations Team needs volunteers with a background in education and classroom lesson development ...

- Engage the educational community through presentations of how we can assist teaching about space in the classroom.
- Create scientific and engineering experiments packaged for the classroom.
- Create methods to display and analyze experimental data received from Fox-1.

To volunteer send an e-mail describing your area of expertise to Alan Johnston, KU2Y at: **ku2y@amsat.org**.

ARISS Development and Support

AMSAT's Human Space Flight Team is looking for volunteers to help with development and support of the ARISS program:

- Mentors for school contacts
- Support for the ARISS web
- Hardware development for spaceflight and ground stations
- Help with QSL and awards certificate mailing.

To volunteer send an e-mail describing your area of expertise to Frank Bauer at: **ka3hdo@amsat.org.**

Find more information at amsat.org. Click Get Involved, then Volunteer for AMSAT.