The *AMSAT*® Journal

Volume 43, Number 2   **March/April 2020**

A New Member Portal Launches

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in this issue ...

AMSAT Announcements

AMSAT-NA Board of Directors Nomination Notice

AMSAT solicits nominations for the 2020 AMSAT Board of Directors election, to be held in the third quarter of the year. The seats of the following three incumbent Directors expire in 2020 and will be filled by this year's election: Tom Clark, K3IO; Mark Hammond, N8MH; and Bruce Paige, KK5DO. Further, up to two Alternate Directors may be elected for one-year terms.

A valid nomination for Director must be written and requires either one Member Society or five current individual members in good standing to nominate an AMSAT member. Written nominations, with the nominee's name, call sign, and contact information, as well as the nominators' names, call signs, and contact information, should be sent to the AMSAT Secretary:

Brennan Price, N4QX
300 Locust St SE, Unit E
Vienna VA 22180-4869
brennanprice@verizon.net

A copy should be sent to AMSAT Manager, Martha Saragovitz, at **martha@amsat.org**.

The AMSAT bylaws require that the nomination be written and in the form specified by the Secretary. **In light of the ongoing pandemic and the resulting closure of the physical office, the Secretary has elected to accept written nomination materials in electronic form, including e-mail or electronic image of a paper document.** Fax transmissions cannot be accepted due to the closure of the office.

No matter what means are used, petitions MUST be received by the Secretary no later than June 15th. **The Secretary will verify the qualifications of candidates and nominating members or Member Societies as petitions are received, and will notify candidates whether their nominations are in order by the end of June.**

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.

Apogee View

Clayton Coleman, W5PFG
President

I am humbled by the greetings and congratulatory messages received over the past month since becoming the President of AMSAT. Please join me in expressing gratitude to our immediate past president Joe Spier, K6WAO, for his dedication to AMSAT's mission of Keeping Amateur Radio in Space. Following Joe's resignation, Paul Stoetzer, N8HM, AMSAT's Executive Vice President stepped up to fulfill the role of our organization's chief executive. Paul, thank you.

It was a pleasure to speak with many of our members at the Orlando Hamcation. Attending Hamcation allowed me to meet with many of our volunteers and reach out to other organizations in amateur radio such as the ARRL and the Dayton Amateur Radio Association.

Little did I know at the time, Hamcation would be my last public appearance as AMSAT President due to the worldwide COVID-19 pandemic. While I would prefer to focus Apogee View on the exciting satellite projects ahead, instead my focus will be on the operational challenges that AMSAT will overcome in the immediate future.

Undoubtedly COVID-19 has left a mark on the radio amateur with impacts felt by event cancellations – the largest being the Dayton Hamvention. AMSAT typically has a large presence at Hamvention. Not only do we host forums, have a booth, do demos during the event, jointly host the AMSAT/TAPR Banquet, and run the AMSAT Academy, but Hamvention also offers a major revenue stream for us. Many members renew annually at Hamvention. Generous donors who care

about AMSAT's future make it a point to personally deliver their gifts. Through the sale of apparel, books, and other trinkets, we receive a healthy boost to our funds used to operate the corporation. Maintaining the level of funding required for the organization to achieve its goals is a key concern for our board of directors and senior officers. I am confident in our leadership team's ability to succeed in 2020.

The lack of in-person events may limit AMSAT's ability to demonstrate our capabilities live but will not preclude our ability to do so via online venues. Like many other organizations, AMSAT will seize this opportunity to produce new content online for its members and the broader community. While it is no substitute for the type of quality mentoring you'd find at an in-person AMSAT Academy event, those interested in growing their operating skill will be afforded the opportunity to do so online. In the next 60-90 days, we will begin to market new content via our social media presence, website, and the AMSAT News Service (ANS). If you are not following us on these channels, please consider following or subscribing.

Our membership is a key element to continued success. We must provide an experience to our members that represents that of a 21st-century organization. You will find a report from our V.P. of User Services, Robert Bankston, in this edition of *The AMSAT Journal*, giving a first glance at our new member management system. This new system brings forward AMSAT's capabilities for membership management by allowing more self-service functionality, broader communications capability, and increased functionality. To ensure we don't miss out on renewals and to make for easier onboarding new members in 2020, the shift to the Wild Apricot system is imperative. I thank our volunteers who are driving this initiative forward.

Over forty years ago, AMSAT established its first permanent office. 2020 marks a shift as to how the organization operates. Our Office Manager, Martha Saragovitz, has faithfully staffed the office for most of that time as the organization's sole, full-time employee. As AMSAT transitions to digital recordkeeping and online management systems, the need for a dedicated office will be reduced. Boards of directors, past and present, have expressed the desire to reduce the costs of performing corporate functions.

One of my top priorities is to transition AMSAT to a fully digital office. This process will be done in phases to ensure the continuity

of AMSAT operations and that Martha is adequately equipped. This will result in more efficient operations in areas of finance, corporate governance, member management, the store, and our future events. Ultimately, AMSAT will not have a dedicated office, with the physical attributes having been successfully migrated to their digital twin.

Our engineering team is continuing the GOLF (Greater Orbit, Larger Footprint) spacecraft development that will yield technologies to place our future satellites in higher orbits. Back in January of this year, the GOLF-TEE (Technology Evaluation Environment) prototypes saw their first lab transmissions. In addition to the GOLF project, the board of directors has committed to support amateur radio's inclusion on NASA's Lunar Gateway, a small spaceship in orbit around the Moon with living quarters for astronauts, a lab for science and research, ports for visiting spacecraft, and more. While some uncertainty exists about Gateway's future, AMSAT is following the project closely and will be prepared to commit resources when the time is appropriate. Our Fox program continues to manage both the AO-91 and AO-92 satellites in daily operation for amateur use. RadFxSat-2 (Fox-1E) is now scheduled to launch no earlier than the second quarter of 2020.

Lastly, I want to encourage your participation in AMSAT. The success of this organization rests on the tremendous dedication of volunteer and donor resources. Whether you are an engineer or a philosopher by trade, AMSAT has a position for you. We are in the unique situation of developing spacecraft with teams consisting of industry professionals alongside those coming from fields unrelated to space or RF technology. I've recently appointed Sean Kutzko, KX9X, to serve as our Volunteer Coordinator. With my full support, Sean will ensure that new volunteers are onboarded and integrated into teams at AMSAT.

Thank you for your membership, generosity, and support of AMSAT.

Engineering Update

Jerry Buxton, N0JY
Vice President, Engineering

AREx – Gateway Amateur Radio Exploration

Many of you have probably heard of NASA's Lunar Gateway, the "small spaceship" in orbit around the Moon as part of the Moon to Mars program. What is lesser-known until now, is the project by ARISS International that would put amateur radio on the Lunar Gateway in much the same way that ARISS put amateur radio on the ISS. AMSAT is a major support of ARISS of course and amateur radio on manned space missions goes back to the Space Shuttle (SAREX) and Mir Space Station (Mirex/SAREX).

Initial planning for this project has gone on for over a year as NASA was approached with the idea by early AREx teams. The plans and presentations for an installation that will suit NASA's strategic goals (primarily education) as well as providing backup communications for the astronauts and spaceship have brought us to the point where ARISS and the international AMSAT community including AMSAT-DL, AMSAT-UK, and JAMSAT are now moving forward to design and build the project that ARISS has presented to NASA.

There are two planned phases, called the Mark I and the Mark II. With some of the initial stages of the Gateway headed for launch soon and the available experiment slots (connections) filling quickly, the Mark I AREx is intended to be ready for delivery in early to mid-2022. As a "Minimally Capable Educational Outreach System" for NASA, the Mark I will provide an externally mounted "satellite" payload with fixed antennas & cameras attached (and an optional deployable boom for greater visibility) targeting simple ground stations that are built on COTS components. AREx embedded software, firmware, and data interfaces at the ground stations will allow for educational and classroom access to the Lunar Gateway cameras and experiments. For the amateur radio satellite operator, the Mark I will provide transponder and low-speed data exchanges. Nominal operating frequencies are C-Band 5.65-5.67 GHz uplink and X-band 10.45-10.5 GHz downlink, "five and dime."

AMSAT (-NA) has formalized support for the project and the intention to take on the roles providing Electrical and RF systems, software (primarily SDR/FPGA HDL code), and support for mechanical systems. In that, as Vice President of Engineering, I am issuing a call for volunteers for the AREx program, Mark I project, in those three areas. The exact structure of the volunteer workforce is not yet determined, however, AREx will have its own program management and systems engineering, not necessarily directly reporting to the Vice President of Engineering. AREx is an international undertaking that will involve teams from many countries, including possible teamwork across borders. I do not expect that there would be travel involved in the work done here although there may be some meetings of the systems and project leaders.

The scope of the project, made more stringent by the involvement in manned spaceflight, and the very tight timeline for delivery, will create the need for targeted and continuous work to be successful. That need can be met by volunteers who have more time as well as by more volunteers that contribute to spreading out the time and work, with the latter situation also providing redundancy that reduces the risk inherent in any all-volunteer project because of everything that comes first in "real life."

In any situation we have worked, whether our own satellites or beyond, another primary factor in success is the dedication to the job that you volunteer for. The entire team depends on each other for success. I encourage all volunteers to be honest in your consideration of how much time you can devote and your capability to commit to that for the project and your teammates, before joining in. It is a better contribution to be able to represent actual time available or if you are not sure, even waiting until a better time and another opportunity. I am not trying to dissuade anyone, certainly, as I said the more the merrier and better for reducing risk, I just ask that you be honest in your determination to join in. Simply, the impacts experienced when someone is incapable of making their commitment or did not let anyone know that they could no longer hold up their commitment can be detrimental and difficult to both the project schedule/success and their teammates.

This is a breakdown of the roles we intend to assume:
Electrical & RF Systems
Power Supply
Software Defined Radio/Signal Processor
Command and Data Handling
RF/Power Amplifier
Electrical Interfaces

Harnessing
Radiation/Effects
Test and Verification
Safety Hazards
Engineering Requirements
Software
Operating System
Command and Data Handling
FDIR
Mode Management
Pointing System
SDR/FPGA HDL Code
Test and Verification
Safety Hazards
Engineering Requirements

In the software role, we initially targeted the SDR/FPGA as it is part of the RF Systems. In our most recent AREx meeting it came out that we may be looked to for the rest of the software role items, so please do not limit yourself solely to the RF pieces. The RF pieces must be done in conjunction with the RF system so it is the primary need. However, we have seen some software volunteers coming forward during the GOLF projects, and we can certainly fill out more, if not all, of these needs:

Mechanical Systems
Mechanical Box Design
Antenna/Feed Design
Thermal Design
Camera System
Launch Mounts
Pointing System (electro-mechanical)
Procurement
Deployables
Materials
Drawings/Labeling/Configuration Control
Test and Verification
Safety Hazards
Engineering Requirements

The mechanical role, too, was not promised to be entirely part of our contribution. Certain elements such as Antenna/Feed Design, Thermal Design, and Camera System are either related to the Electrical & RF Systems role or items that we have opportunities to fill from the U.S. As with the software role, we can certainly take on more of the mechanical systems if we have the volunteers so please step forward if you can help with any of the rest of the items. We have worked many of these other items for ARISS so we can do these if we have the volunteers. Also of note, the Pointing System in this list refers to the deployable antenna/camera boom on the AREx Mark I. Actual antenna (dish) pointing is not on the table for Mark I but if that is your thing, you will have your chance with AREx Mark II. All three of these roles show three

common items at the end of each list. Test and Verification, Safety Hazards, and Engineering Requirements are driven not only by the needs of the system itself but also by the requirements of certification to fly on a manned mission. Beyond the function and environmental tests of the system, further testing and verification, as well as considerations of safety hazards and other engineering requirements, will be necessary. I expect that they will come from the team handling Space Agency Safety Certification and Space Agency Engineering Requirement Verification.

This is certainly an exciting opportunity, and it comes from the relationship that ARISS and AMSAT have established with NASA as well as those relationships between the other AMSAT organizations and their space agencies. It is also a very short timeline for this project, presenting a challenge for an all-volunteer workforce and further so by the need to qualify for human spaceflight requirements. Several of the hardware elements are expected to use commercially available components or systems to eliminate the need to design our own, as we are often used to doing, to be able to meet the timeline. Nonetheless, the design will require some forethought to make the AREx Mark II compatible with the hardware and electrical interfaces as well as the footprint on the spaceship.

ARISS International and our fellow AMSAT organizations look forward to this excitement and to counting on the volunteers from each country to step up and make the systems come together for our first cislunar orbiting "spaceship". I believe that the children involved in future ARISS classroom contacts will be very excited to be talking to an astronaut who is circling the Moon. And the opportunity for amateur radio operators worldwide to experiment with and experience microwaves and working with/through a lunar orbiting platform is undeniably part of what amateur radio is about.

If you are ready to help, please see the AMSAT web page for a link and instructions to apply. Please be sure to include a description of your qualifications and experience in the area for which you apply so the AREx team can put you together with the right team and get you into the stream as soon as possible. Thank you for your time! ⊕

Treasurer's Report

Robert Bankston, KE4AL
Treasurer

Now that I've had a few months to settle into my new position as AMSAT Treasurer and spend a little time digging through the numbers, I thought it was time to share what I have found and set the record straight about some of the misinformation that is being spread about AMSAT's financial position.

Despite rumors and misquotes of AMSAT being on an unsustainable path, let's look at where we really are and how we are doing.

Financial Performance
- Over the past ten years (2010-2019), AMSAT has averaged a $34,357 increase in net assets (what most people refer to as profits) per year.
- Our combined revenues over expenditures (profits) for the past 5 years (2015-2019) were $110,962, which includes launching 4 amateur satellites into space, readying RadFxSat (Fox-1E) and the ARISS InterOperable Radio System for flight, and getting started on GOLF and Lunar Gateway projects.
- In 2019, AMSAT generated $756,256 in revenues with just $617,425 in expenditures.

Note: Year to year fluctuations are generally a result of timing differences between project fundraising efforts and when AMSAT needs to spend money. In addition, AMSAT maintains its reserves in investment accounts, which are subject to market price fluctuations and must be included in our financial statements.

2018 is a perfect example:

- AMSAT authorized a $62,055 payment to NASA, which was not reimbursed until 2019.
- AMSAT spent $62,397 on the initial hardware development for GOLF.
- AMSAT launched two satellites in 2018, Fox-1D (AO-92) and Fox-1Cliff (AO-95).
- AMSAT had to report a $77,128 fair market value loss in investments (which was fully recovered in 2019).

Don't get me wrong; there is certainly room for improvement. I have already identified and started to implement cost-saving and budgetary control measures that can and will make us more efficient. As AMSAT
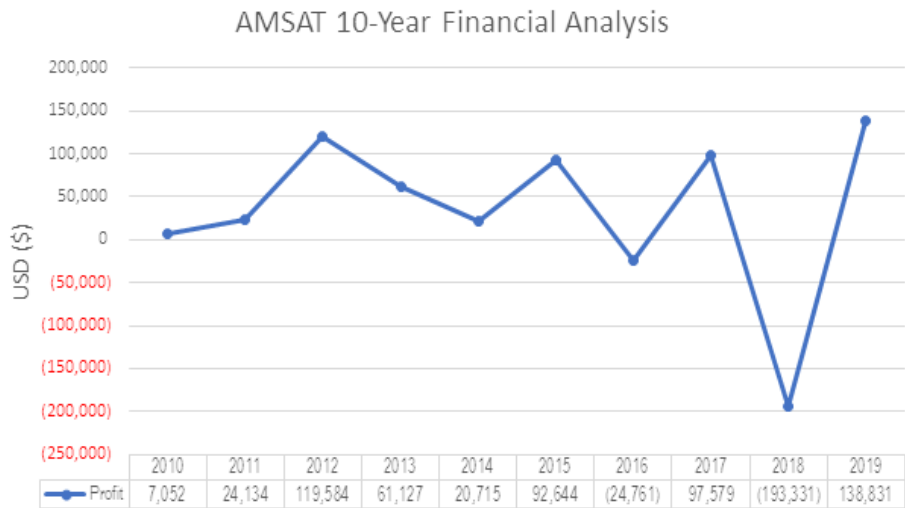
AMSAT 10-Year Financial Analysis

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Profit	7,052	24,134	119,584	61,127	20,715	92,644	(24,761)	97,579	(193,331)	138,831

Figure 1 — 10-year financial analysis.

AMSAT 10-Year Membership Revenues

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Membership	99,989	103,795	99,646	92,700	81,220	94,077	96,780	103,060	123,598	134,570
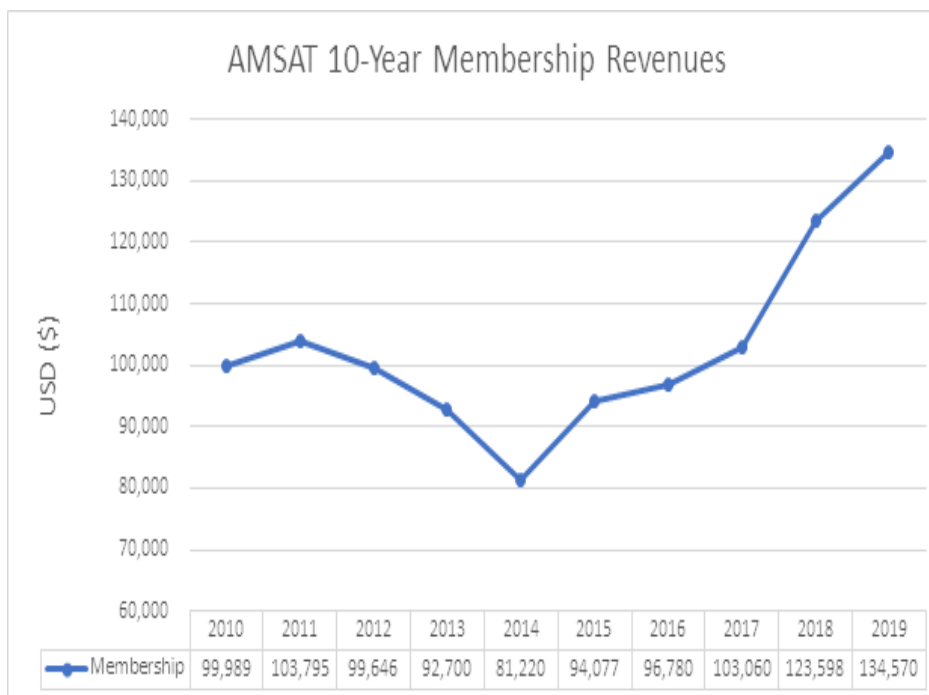
Figure 2 — 10-year membership revenues.

Treasurer, it is my job to safeguard AMSAT's resources from both fraud and waste, and I intend to do exactly that. I look forward to what more we can achieve.

Membership

• Membership revenues continue to rise and have increased 65.68% in just that past 5 years, all without any increase in dues rates for our members.

• New memberships, renewals, life memberships, and AMSAT Store purchases for the first three months of 2020 are on track to exceed the same revenue sources for 2019.

Transparency

AMSAT is fully committed to financial transparency. Our financial statements and regulatory informational reports (Form 990s) are and have always been publicly available (www.amsat.org/audit-and-other-financial-reports/). Furthermore, to add confidence, an independent certified public accounting firm reviews our financial statements and includes their report with our financials.

Solvency

AMSAT is on a solid financial footing and headed in the right direction. We started this year with over $134,000 in cash and over $591,000 in investments. The level of our reserves, ability to generate more revenues than expenses, and ability to continue to grow our members has AMSAT fiscally positioned to accept whatever challenges and opportunities tomorrow brings.

Conclusion

AMSAT does not expect to fully fund itself with membership dues. Member dues are meant to cover member services and benefits. Funding for everything else must come from other sources.

In 2019, member dues accounted for only $134,570 of AMSAT's total revenues. The remaining $621,686 came from the kind hearts of our donors and the incredible work of our volunteers – seeking out new revenue streams and securing grants to further support our mission.

We, at AMSAT, are keeping our promise to Keep Amateur Radio in Space and doing so in a fiscally responsible manner. To say otherwise is either a uniformed opinion or intentional misinformation – *the numbers don't lie.*

Robert Bankston (KE4AL), CPA
Treasurer
Radio Amateur Satellite Communication (AMSAT)

In addition to being a licensed amateur radio operator, Robert is a certified public accountant (CPA), business consultant, and principal with Bevis, Eberhart, Browning, Walker & Stewart, P.C., a public accounting firm in the Southeast United States. Robert serves in the lead corporate finance and accounting division, coordinating with area controllers, account managers, senior–level executives, investors, and lenders to provide business consulting, financial audit and review, and tax compliance services for midsize and multimillion–dollar companies and organizations.

AMSAT's New Member and Event Portal

Robert Bankston, KE4AL
Vice President, User Services

ALL MEMBERS MUST READ THIS ARTICLE AND FOLLOW THE INSTRUCTIONS TO ACCESS YOUR NEW AMSAT MEMBERSHIP ACCOUNT

I am excited to announce AMSAT has launched its new online member management system, the AMSAT Member and Event Portal. Effective immediately, we are discontinuing the use of the old database. In addition, we have removed all member applications/renewals from the AMSAT website store and will no longer accept paper-based applications/renewals through the mail or delivered in person.

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

• Simplified membership application and renewal process, with web-based, mobile-friendly forms and automatic email confirmations;
• Secure updating of your contact information, registering for events, and paying membership dues;
• Print membership cards; and
• Receive automatic email reminders when it's time to renew.

Accessing Your Account

Before We Get Started – Let's Talk about Email Addresses:

• AMSAT's new member management system uses your email address as your username, which accommodates one email address for each member and relies on the uniqueness of email addresses to differentiate among members.
• AMSAT's previous member database system does NOT include email addresses.
• We have extracted email addresses from AMSAT's website as a place marker in setting up the new member management system. This may or may not be your current email address. Therefore, one of three potential issues may exist, which we ask that you check:

1. Your email address may not be your preferred email address.
2. Your email address we have on file may not be valid.
3. You have never provided an email address to AMSAT.

If the email address we used is not your preferred email address, you can easily change it once you get logged in. If we do not have a current email address on file, there is an added step to get you signed up.

Let's Get Started

1. Visit AMSAT's new member and event portal website at **launch.amsat.org.**
2. Click on the LOG IN button in the upper right corner, just below the blue banner.
3. On the Log In page, click on Forgot password, to the right of the LOG IN button.
4. On the Reset Password page, enter your email address, enter the code (6 characters displayed in the picture, and click SUBMIT.

5. If all goes well and you see a message on the next screen, telling you "Password reset instructions emailed, jump ahead to Step 7. If, instead, you see a red box, with the message "ERROR WARNING – Email not found," proceed to Step 6.
6. If you are here, don't worry. All is not lost. Please send an email (from your desired email account) to members@amsat.org, with HELP in the subject line. In the body of the message, all we need is your full name, your call sign, and your AMSAT member number. Note, your AMSAT member number is in the upper-left corner of the mailing label on this issue of The AMSAT Journal. When we receive your email, we will update your account and send you an email reply that you are all set. Once you receive this email, go back to Step 1.
7. If you do not receive our email within a few minutes, please check your junk/spam filters and double-check the email address entered.
8. Open the email and click on the link to choose a new password (Figure 1). If the link does not open – please copy and paste the link into the address line of your browser.
9. On the new Reset Your Password page, enter your New password and confirm your new password, then click on the SET NEW PASSWORD button.
10. A new Reset Your Password page will appear, confirming that your password has been changed successfully and instructing you to log in with your new password. Click the member symbol in the blue box in the upper right-hand corner.
11. In the pop-up log-in window, enter your email address and your new password, then click the LOG IN button.
12. Once logged in, an "Accept Wild Apricot's Terms of Use" page will appear. You must agree to the terms of use before you will be able to log in.

Hello Buck Rogers,

A request was made to recover a lost password for this email address at https://amsat.wildapricot.org/

To choose a new password go to:
https://amsat.wildapricot.org/Sys/Password/Reset?id=eb0e8269-115b-41da-82b3-7dd84c7fcfc0
(if the link does not open - please copy-paste the link into the address line of your browser).

If you did not request a new password at https://amsat.wildapricot.org/, you may safely disregard this email.
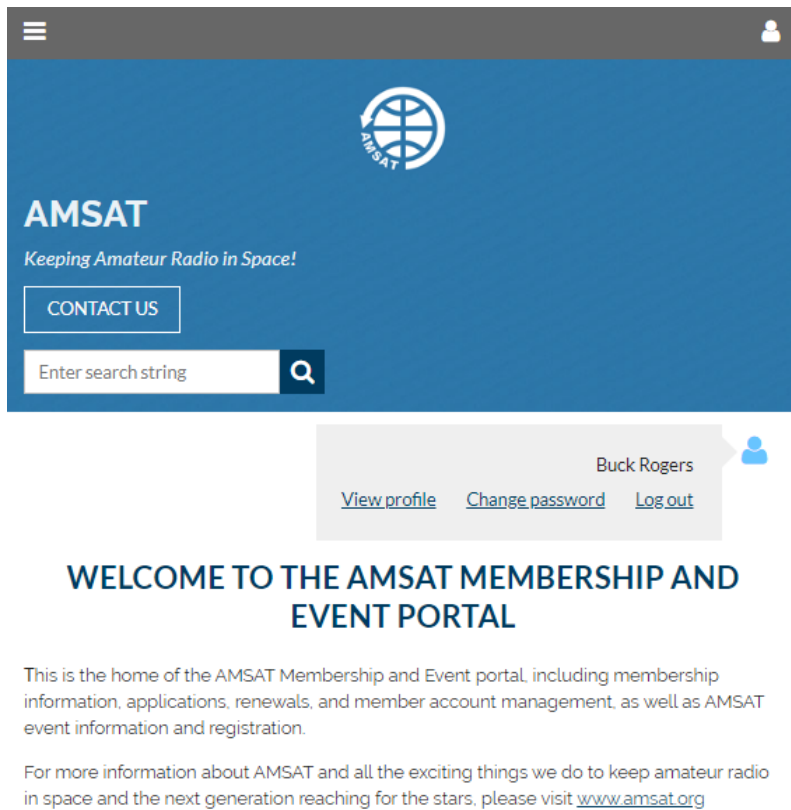
Many thanks,
AMSAT

Figure 1.

Figure 2.

Click the checkbox next to "I agree," and then click CONTINUE, which will take you to the AMSAT Membership and Event Portal home page.

13. On the home page, click on the blue member symbol in the upper right-hand corner, below the blue banner (Figure 3).

14. A pop-up window will appear, displaying your name and links to view your profile, change password, and log out. Click View profile.

15. On your My Profile page, you can view and edit your membership information, print your membership card, and renew your membership.

16. Click the EDIT PROFILE button.

17. On the My Profile edit page, review and update your personal information. This is also where you can change your email address if desired. Note, we have only entered in your name, call sign, member number, and email address. You must enter your mailing address to include your country. Once done, click the SAVE button.

While you're there, take a moment to explore and familiarize yourself with the site. If you have any questions, email us at **members@ amsat.org**.

Please note, for the time being, your member account on the AMSAT Member and Event Portal are separate and apart from AMSAT's main website and AMSAT Store login. Changing information on the AMSAT Member and Event Portal will not affect your account on **www.amsat.org** website.

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

This Is Only the Beginning

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

With our new Member and Event Portal, we are fulfilling our promise to you to provide a modern, interactive membership portal, capable of delivering the quality of customer service you deserve. We appreciate your support and hope you are as impressed as we are. ⊕

The proliferation of space debris has effectively placed all non-commercial, non-governmental CubeSat launches in a low Earth orbit (LEO) penalty box. Even with proven deorbit devices, non-essential missions are being heavily scrutinized.

While AMSAT has successfully operated low earth orbiting satellites carrying amateur radio since 1972; today's LEO birds, except for AO-7, limit communication distances to 4,000-5,000 kilometers. What if we could extend that range by linking two or more satellites together?

amsatLink

AmsatLink is a proposed three-phased program to ultimately establish a constellation of nanosatellites, linked in a peer-to-peer voice communications network for amateur satellite service. As a wireless ad hoc network, future satellites can be added to the network and ground stations, moving in and out of a nanosatellite node's footprint, can easily join and exit the network.

Features include:

- IEEE 802.11 wireless ad hoc network, operating within the FCC Part 97 amateur radio frequency allocation of the 2.4 GHz microwave band.
- Individual satellite and ground nodes connect directly, dynamically, and non-hierarchically to as many other nodes as possible and cooperate with one another to create one virtual network that can efficiently route data from/ to clients.
- If one endpoint cannot see its desired destination but can see nodes in between, the data will hop from one to the next until the final connection is made – completely and automatically.
- Small stack protocol to reduce overhead and ease communications between network nodes.
- Absolute timing obtained from GPS.

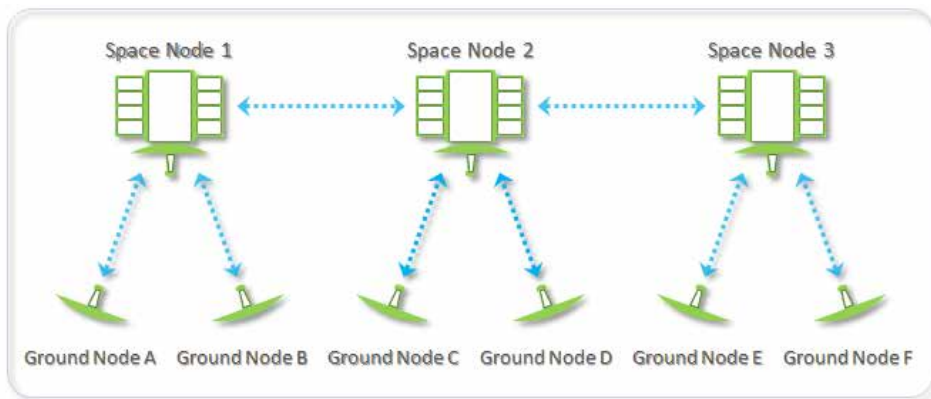In addition, as a constellation of nanosatellites

Together, We Are Stronger!

amsatLink

An Open Source CubeSat Constellation that Enables Cross-Link Communication and Multipoint Scientific Measurements

https://ke4al.github.io/amsatLink/

Typical Ground Station Node

orbiting the Earth, amsatLink allows for the multipoint collection of space weather measurements, which contribute a unique and invaluable set of scientific data for scientific and educational analysis.

While the idea of cross-link communication between satellites is not new, amsatLink hopes to continue the efforts of NASA's PhoneSat, EDSN constellation, and NODES missions, by:

• expanding the network to include ground-based nodes,
• demonstrating the use of voice over internet protocol communications, and
• organizing nodes into clusters, where each cluster consists of one nanosatellite node and any visible ground nodes.
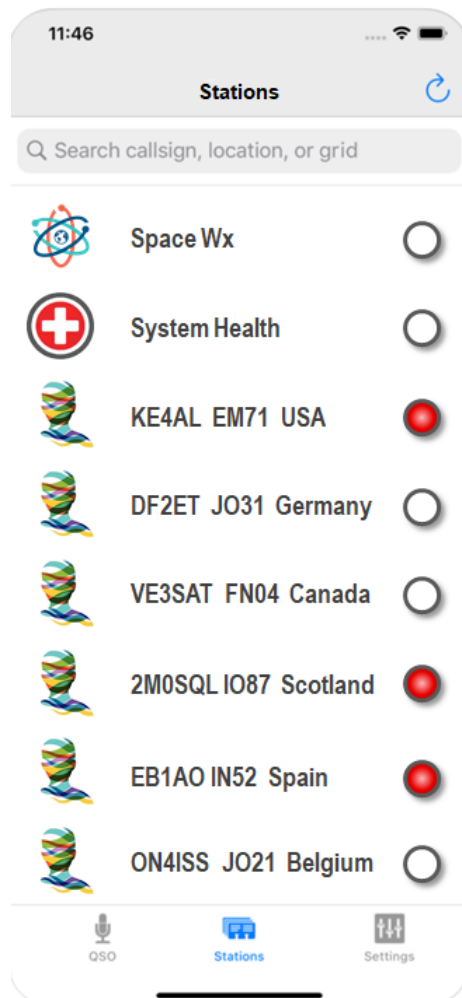
AmsatLink will continue NASA's design philosophy by utilizing commercial-off-the-shelf hardware and keeping the design and mission objectives as simple as possible. The estimated total hardware cost per satellite is less than $5,000. Proposed ground stations will also use off the shelf equipment with a total estimated cost of less than $150.

Phase 1

Design and build working prototypes of both nanosatellite and ground nodes as a proof of concept and test systems integration. Testing will include a terrestrial-based simulation and a high-altitude (60,000 – 105,000 feet ASL) simulation as a payload aboard high-altitude balloon launch.

Phase 2

Build two 1.5u nanosatellite nodes and launch them from the ISS as a technology demonstrator of a peer-to-peer communications network. Due to the typical ISS-launched orbits being only 400 km-450 km, we expect a short mission lifetime of only two weeks to a month.

Phase 3

Initial deployment of a three-1.5U nanosatellite formation at an optimal orbital altitude. Subsequent launches will add nodes to the network, greatly expanding the cross-link coverage area.

Let the Journey Begin

If we are going to be stuck at LEO for the foreseeable future, let's make the most of it – let's find a way to expand our footprint. AmsatLink is a solution worth pursuing.

Initial, Phase I development (proof of concept) has already begun and currently focused on identifying and modifying an open-source, UDP voice chat application to fit our needs. Progress is slow but steady, as I learn Java and how to use Android Studios, all at the same time.

Once a stable UDP voice chat application is up and running on the network, I can begin testing the effects of ± 60 kHz frequency change (Doppler shift at LEO) on network performance. Doppler effect for low-Earth-orbiting satellites at microwave frequencies is significant.

I have established a GitHub page to host, document, and share the project. Feel free to follow along as we explore the possibilities: **github.com/KE4AL/amsatLink**.

Educational Relations Update

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

As I write this column, the world of education is going through a sea change due to the novel coronavirus pandemic as in-person classes switch to online instruction. Some of us have more experience than others at distance learning, but I suspect that most of us in education will become experts over the next few months.

Instead of planning for our Education table at Hamvention, I am thinking about some online events and webinars to spread the word about AMSAT and the CubeSatSim – look for announcements on the AMSAT email list, and on social media including Twitter and Facebook. I also hope to share some videos of building and using the new CubeSatSim.

There is an article in this month's journal about the new hardware design of the CubeSat Simulator, which we are now calling the AMSAT CubeSatSim. It details the redesign by myself, Jim McLaughlin, KI6ZUM, and David White, WD6DRI. Perhaps you can build one at home over the next few months.

I want to thank Kevin Zari, KK4YEL, for volunteering to show the CubeSatSim at the AMSAT booth at Hamcation in Orlando, FL on February 12-14. He also showed off a prototype board stack of the new design and received lots of positive feedback.

Although events are canceled right now, feel free to get in touch with me as events get scheduled for the fall if you would like to borrow a loaner CubeSatSim. Contact me at ku2y@amsat.org to make arrangements if you would like one.

A New Design for the AMSAT CubeSat Simulator

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Introduction

The AMSAT CubeSat Simulator, also known as the CubeSatSim, has been under development for over 18 months. Initially shown at the 2018 AMSAT Space Symposium, it was officially launched at the 2019 Hamvention, and since then, loaner units have been shipped to events and classrooms around the country. At the 2019 AMSAT Space Symposium, some design updates were shared including a new Fox emulation mode. In this article, we describe a new hardware design for the AMSAT CubeSatSim. While backwards compatible with the old design, the new design has many new features and has a lower cost to build.

Background

The AMSAT CubeSatSim, shown in Figure 1, is a Raspberry Pi Zero W-based functional model of a "1U" CubeSat nanosatellite. It has a 3D-printed frame structure and is designed to act, as reasonably as possible, as one flying in Low Earth Orbit (LEO). Its purpose is to demystify to all how satellites work. Like typical LEO satellites, this simulator runs on rechargeable battery power and solar panels. The CubeSatSim transmits its authentic voltage, current, and temperature telemetry on the UHF Amateur

Radio band. For details on the design and construction, see our series of articles in the *AMSAT Journal* and in the 2018 and *2019 AMSAT Space Symposium Proceedings*, or the set of resources at **cubesatsim.org**.
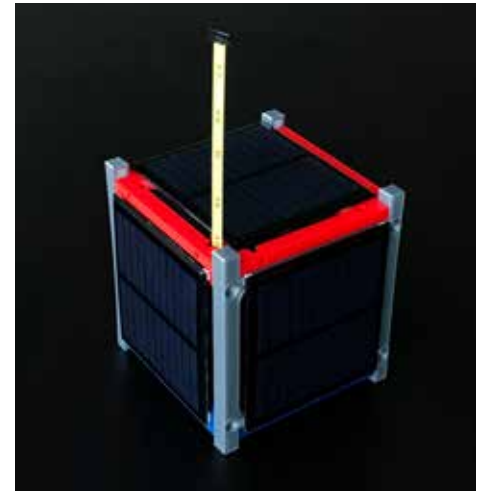

Figure 1 — The AMSAT CubeSatSim Satellite Simulator.

Alan, KU2Y, and Pat, N8PK, have been collaborating on the CubeSatSim since 2018. In 2019, Jim, KI6ZUM, and David, WD6DRI, became involved in the project. David was a very early Beta Builder and provided useful feedback on his build. He and Jim got together and offered their help in redesigning the board stack to reduce costs, using Jim's experience in manufacturing other amateur radio project boards. The latest collaboration started in the summer of 2019, resumed in the fall, and a number of versions and designs were proposed in late 2019 and early 2020 that resulted in the current new design.

Jim and David have been collaborating on STEM related projects since 2010 when they became mentors to the Mt. Carmel High School Amateur Radio Club, W6SUN, in San Diego, California. (Interesting side note: One graduate of that high school program is currently a college freshman engineering student of Alan's!) They, along with several other hams, continue to mentor at the high school where the students have launched several high-altitude balloon (HAB) flights with a variety of Amateur Radio equipped payloads. In addition to HAB payloads, students are currently working on an oceanographic buoy they plan to release in the Pacific Ocean and track via an on-board ham radio equipped tracking system. Jim and David have conducted a number of ARISS (Amateur Radio on the International Space Station) events from local elementary schools and from the Ruben

H. Fleet Science Center in San Diego's Balboa Park that have allowed students to talk directly with astronauts onboard the ISS via ham radio.

New Design Goals

At the 2019 Space Symposium, we described some design updates which replaced the Digital Transceiver for the Raspberry Pi board used in the original design. This reduced the cost of the CubeSatSim and also provided additional modulation schemes such as the FSK DUV (Frequency Shift Keying Data Under Voice) and BPSK (Binary Phase Shift Keying) Fox satellite emulation modes. This was accomplished by a new Transmitter/Filter Board (TFB) which replaced the old transceiver board. The redesign described in this article continues along this line, replacing the MoPower V2 UPS (Uninterruptible Power Supply) battery charging board, which is a Raspberry Pi HAT (Hardware Attached on Top). This new design also adds a new STEM Payload board for one's own experiments.

The MoPower V2 UPS battery charging Pi HAT (**www.allspectrum.com/mopower/**) was chosen for the original CubeSat Simulator design because it provided a number of needed functions, including:

- Charging of the Nickel Metal Hydride (NiMH) battery
- Regulation of the 5 V power supply to the Raspberry Pi
- Current and voltage monitoring of the 5 V power supply
- An on/off and reboot pushbutton
- Automatic shutdown when the battery voltage goes below a threshold level

While the MoPower board provided these features, after the replacement of the Digital Transceiver Board, it became the single largest cost item, at nearly $75. A goal of the redesign was to replace this board with components that cost substantially less.

At the same time, a goal was also to improve some of the specifications, including to decrease the "flight" battery charging time. Because of its design as a UPS backup, the MoPower V2 UPS board supported only trickle charging. This meant that a fully discharged battery would require up to six hours to be fully recharged. NiMH batteries can support faster charging modes.

Battery Charging

Jim and David suggested to replace the MoPower V2 UPS board with an integrated circuit NiMH charging module, and to

switch from the 9 V NiMH battery to a set of individual cells. At the same time, Alan investigated a higher voltage and current power solar cell, one that has a specified Voc (open circuit voltage) of 5.5 V and an Isc (short circuit current) rating of 160 mA. The new method utilizes the lower battery voltage and higher solar panel output voltage resulting in a design that is both inexpensive and has good performance. The MoPower UPS board required an input voltage of at least 12 V to charge the 9 V NiMH battery. With the original 4 V solar panels, this required a boost regulator to increase the 4 V to 15 V to charge the battery. The new design uses three cells in series for a 4.5 V battery pack, which can be either AA or AAA size. With the new 5.5 V solar panels, this eliminated the need and cost for a battery-charging boost circuit.

After testing a number of different NiMH charger boards, we standardized on the CN3058 NiMH charging board. We chose the "3S" version which uses three cells. This charger can provide up to 1 A in constant current mode, and automatically shuts off when the charging is complete.

The MoPower v2 UPS board used a 12 V DC powerpack with a barrel connector for external charging. This was an expensive powerpack, and the barrel connector is a poorly standardized connector, with diameter differences that can be seen by the eye, causing incompatibility. We took the opportunity of the redesign to switch to a micro-USB connector for a 5 V charging input. This allows for a Raspberry Pi power supply or any mobile phone micro-USB charging cable to be used. We supply the 5 V from the micro-USB through a diode for polarity protection and a 5.2 V Zener diode for overvoltage protection. In the future, we may switch to a USB-C charging input after these cables become more common and cheaper.

5 V Supply for Raspberry Pi

The MoPower V2 UPS board supplied power from the 9 V NiMH battery using a buck converter to reduce it to 5 V to power the Raspberry Pi. In our new design, we power the Pi using a boost converter regulator module to generate the 5 V for the Pi. For the boost regulator, we chose a board with 1 V - 5 V input voltage and 5 V output voltage capable of supplying up to 500 mA. We tested a number of other boost regulators which claimed similar specifications, but they did not perform well at input voltages below 4 V. Since we wanted to operate our battery in the range 4.5 V to 3.0 V to allow direct charging from the solar panels,

this ruled them out. The input to the 5 V regulator from the battery and the battery charger goes through a polyfuse resettable fuse (also known as a PTC or polymeric Positive Temperature Coefficient device) rated at 1.5 A for overcurrent protection.

To replicate the 5 V bus current and voltage monitoring, we just added additional INA219 current and voltage sense boards. With one for the battery, one for the 5 V bus, and one for each of the six solar panels, this means that there are eight INA219s in use. We exclusively use the purple board type because it has a smaller footprint than the original blue boards. Four INA219s are on the Raspberry Pi i2c-1 I2C bus, and the other four are on the i2c-3 I2C bus. The i2c-0 bus is no longer used in this design, as it should only be used for Pi HAT sensing, something we may implement in a future design consideration.

Pushbutton

Once we had the basic battery charging and 5 V regulation functionality working, we then needed to replicate the other functionality that the MoPower board was providing. For the on/off reboot pushbutton, we used a DPDT (Double Pole, Double Throw) momentary pushbutton switch. To start up the Pi, we use one of the poles of the switch to briefly short GPIO Pin 5 and Pin 6 (GPIO3 and GND, respectively) which automatically wakes the Pi from a halt state and boots it up. To shutdown the Pi, we use a small Python program, the Howchoo pi-power-button (**howchoo. com/g/mwnlytk3zmm/how-to-add-a-power-button-to-your-raspberry-pi**), which runs on boot and monitors GPIO Pin 27 which is wired to the other pole of the switch. When the Pi is running, if this GPIO pin is shorted to ground for less than 1 second, the Python code performs a reboot (executing the command sudo reboot -h now). If the GPIO pin is shorted for over 3 seconds, the Python code performs a shutdown to the halt state (executing the command "sudo shutdown -h now"). To simplify construction, we chose a right angle switch that mounts directly on the PCB so that no wiring is needed and no frame mounting is required for the switch.

Remove Before Flight Switch

During the redesign, we also changed the Remove Before Flight (RBF) switch to be more like a typical flight CubeSat RBF switch. In the old design, the RBF switched between DC power input and solar power input. This meant that the Simulator could still be run with the RBF plug inserted.
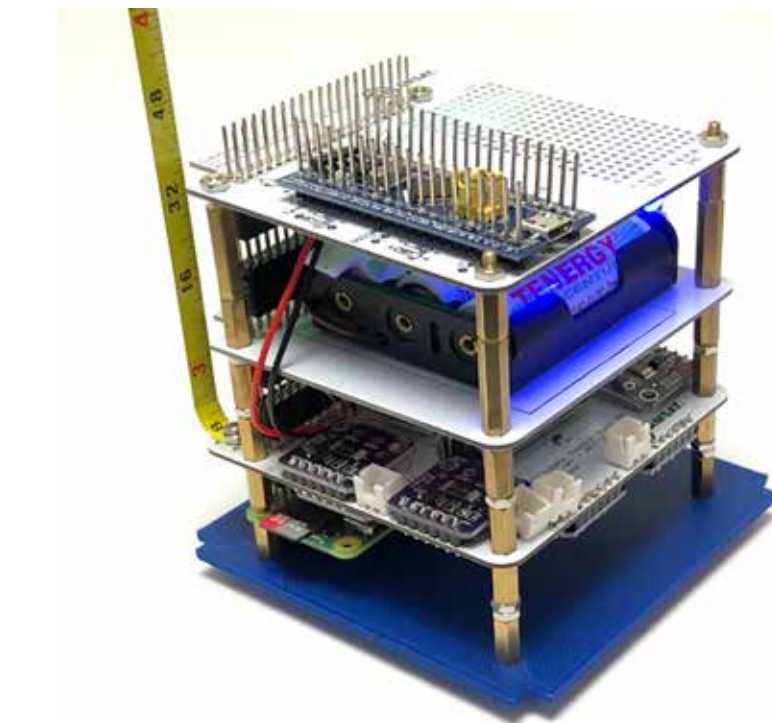

Figure 2 — The AMSAT CubeSatSim board stack: from the bottom, Raspberry Pi Zero WH, Main PCB, Battery Board, STEM Payload Board.

It also meant that the only way to fully disconnect power to the Simulator was to physically unplug the battery. In this new CubeSatSim design, the RBF switch disconnects all power when the plug is inserted. However, the battery can still be charged via DC input or the solar panels. The RBF switch in the old and new design utilizes two micro switches built into a TRS 3.5mm audio jack. The old design also used a jumper in the RBF 3.5 mm plug to route power. In the new design, there is no jumper, so it is possible to use any 3.5 mm plug or even a 3D printed plastic plug in the shape of a 3.5 mm plug as the switch.

Automatic Shutdown

The automatic shutdown that is based on battery voltage level on the MoPower v2 UPS board is done using a microcontroller. We considered implementing some kind of hardware based detection and shutdown. Ultimately, we decided to just implement the function in software. Since we are already monitoring the battery voltage using an INA219 in the CubeSatSim software, it is easy to periodically check the voltage and perform shutdown if it drops below a threshold, such as 3.0 V.

Band Pass Filter

We also chose to integrate the 433 MHz Band Pass Filter (BPF) into the PCB, eliminating the need to buy a discrete BPF. We tried to design the BPF so that

we didn't use surface mount device (SMD) components, but we were not able to easily. Instead, we implemented a select few surface mount components for this filter. If a builder is unable to obtain access to a reflow oven to solder these surface mount components, a discrete external BPF could still be used, such as the one used with the retired TFB. By shifting the antenna mounting position to the corner of the board, we are also able to have the option to incorporate a tape measure monopole antenna, as shown in Figure 1. A small screw through the center hole of the SMA connector holds the ¼" tape measure length in place. A small "rubber duck" external antenna, as was featured in the original design, can still be used by installing the SMA connector and running a short length of coax.

Stacking

In the original design, three boards were stacked to provide the transmitter, battery charging, and solar power functionality bundle. We required a stacking header on the Raspberry Pi Zero W so that we could plug in the solar power board below it, and the charging board and transmitter board above it. In the new design, we integrated all these functions into a single board, and then had the board plug on top of the Pi, as shown in Figure 2.

We continued to use stacking GPIO headers on the board so that we could stack a battery board and the new STEM Payload board

Figure 3 — The Main PCB Showing components mounted on top and bottom of PCB.

above it. To give space between the boards, we double up on the stacking GPIO headers. In this design, we no longer require a stacking header on the Pi, so a standard Pi Zero WH can be used, or a Pi Zero W with a male header added. This means our new board is a Pi HAT, unlike the previous design where boards plugged on top and under the Pi. To fit everything on the one board, we mount components on both the top and bottom of the Main PCB, and mount all the switches and connectors as shown in Figure 3. This shows the RBF, pushbutton, and charging connectors on the left side, and the antenna connector and BPF on the right side.

Frame

We had not planned to change the 3D printed frame for the CubeSatSim, but when we learned about a new 1U CubeSat frame by Juliano85 posted on Thingiverse in January 2020 (**www.thingiverse.com/thing:4096437**), we were eager to print one and give it a try. It turns out to be a more sturdy, easy-to-print and assemble frame,

Figure 4 — New 3D Printed CubeSatSim Frame by Juliano85 on Thingiverse.com.

as shown in Figure 4. Also, with the larger 5.5 V 90 mm x 80 mm solar panels we incorporated, the panels cover almost the entire side, as seen in Figure 1, so we need only a minimal frame exo-structure such as this one. By locating all the switches, connectors, and LEDs on the +X side of the board, we have the luxury of a full-sized solar panel on that side as well.

STEM Payload Board

The original CubeSat Simulator design imagined a payload subsystem, where additional sensors would be read by an Arduino which would then communicate with the Raspberry Pi over the I2C bus. While some students did implement this, not having a physically mounted board was a real problem.

Jim and David originally developed the STEM Payload Board as a STEM board in partnership with Bob Twiggs, KE6QMD, the co-inventor of the flight CubeSat standard. Bob wanted a way to draw K-12 education back into the CubeSat world and to have a model that was inexpensive

enough that a whole classroom of students could afford a kit to explore and in which to be engaged.

The STEM Payload Board is built around an inexpensive STM32F103C8T6 board, sometimes called a "blue pill" board due to its shape and color. This STMicroelectronics microcontroller incorporates a 32-bit ARM processor which allows for software to be easily written using the common Arduino development environment. The board also has a BME280 temperature/pressure/humidity sensor, as well as a GY-521 module IMU (Inertial Measurement Unit) made up of a magnetometer, an accelerometer and a gyroscope. A big bang for the buck indeed!

In the new design, the STM32 communicates with the Raspberry Pi over a serial connection on the Pi Zero GPIO bus. This makes it easy to develop and debug software. We hope to share the experiments using the new STEM Payload Board in a future article.

Testing the New Design

We built a number of prototypes of the new design CubeSatSim and have run tests, and so far the results look very promising. The charging curve shown in Figure 5 shows the charging current over about Time t = 140 minutes (X-axis) for an initially nearly-discharged AAA battery. Note that the charging current is shown as negative (Y-axis) since the current is entering the battery. The charging current begins at over 300 mA. As the battery reaches capacity, the charge current drops back to about 90 mA. However, this current is too large for a trickle charge, which should be more like 15 mA for a AAA NiMH battery and 30 mA for a AA battery. Also, with the RBF switch removed, the load is such that the charger circuit never turns off. However, if the Pi is off and the
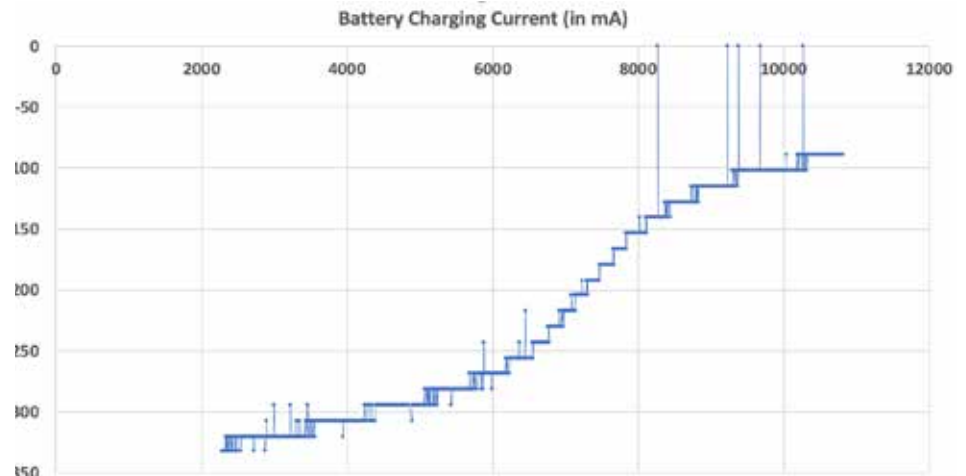

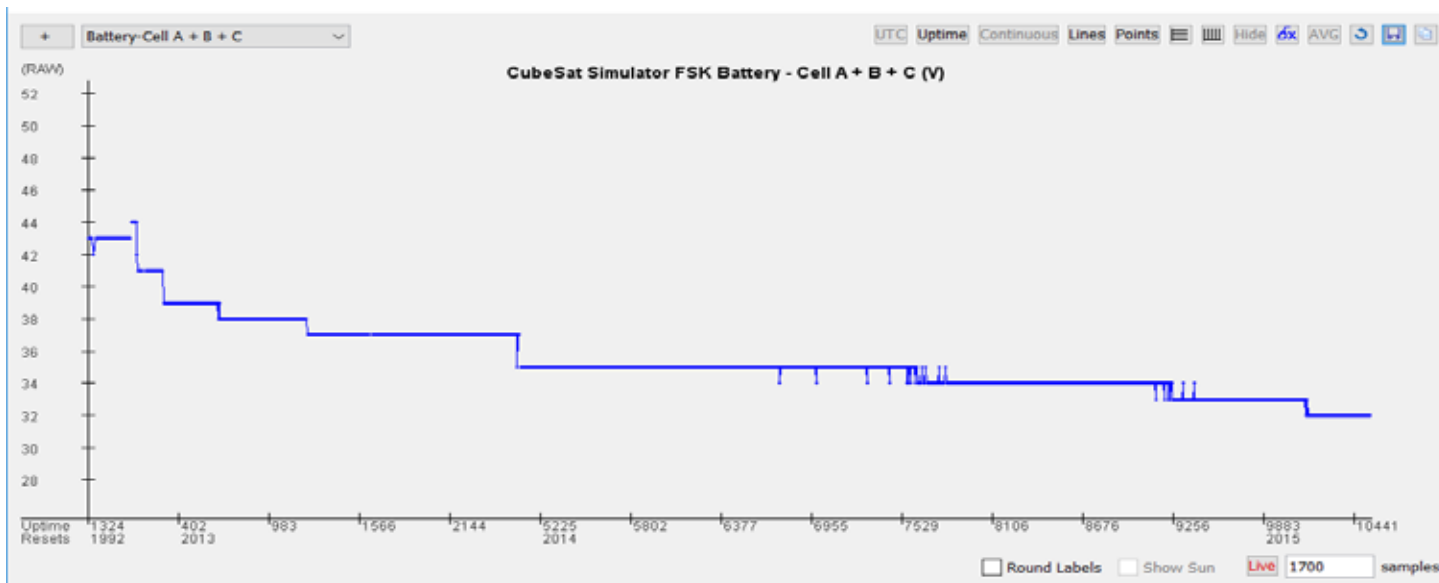**Figure 5 — Battery Charging Curve Test.**

Figure 6 — Battery Discharging Voltage Curve showing Volts x 10 (i.e., 40 is 4.0 V).
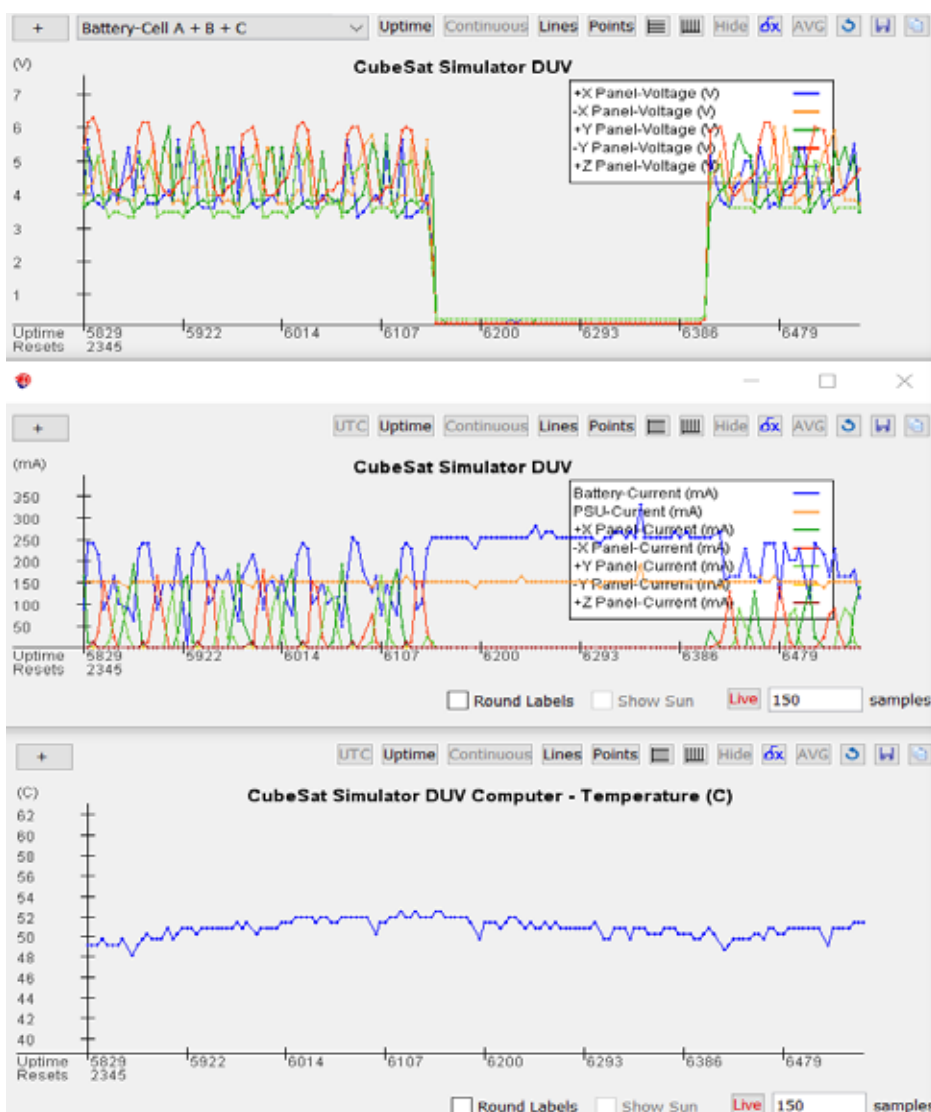
Figure 7 — CubeSatSim Telemetry Decoding in FoxTelem with Real-Time Graphing.

RBF switch plugged in, the charger does shut off. This means that the charger should not be left plugged in for long periods of time unless the RBF switch is in.

The discharging curve for AA batteries in Figure 6 shows that the CubeSatSim can easily run for three hours. Using AAA batteries it can run for about an hour. When the CubeSatSim is displayed at events that last for multiple hours, the AA batteries provide good longevity.

The new Electrical Power Subsystem (EPS) design is not necessarily considered "power positive." That is, the CubeSatSim will not run without batteries. This capability was a nice feature of the old design in that it could run without a battery, but with the board mounted cells in the new design, we don't think this will be a problem.

One quirk we discovered is that if the CubeSatSim runs low on batteries and shuts down, plugging in the micro-USB charging cable does not make the Pi startup. Pressing the pushbutton also does not seem to start it up. Instead, after about 30 seconds of charging, inserting and removing the RBF switch seems to wake up the Pi and turn on the system.

The new RBF switch works as expected. One benefit is that the Pi starts up automatically when the RBF switch is removed. With a suitable delay in the demo script, this makes for a good launching demo sequence, where the CubeSatSim wakes up and starts transmitting after "launch."

Chris Thompson, G0KLA/AC2CZ, the author of AMSAT's excellent FoxTelem satellite decoding software (**www.amsat.**

org/foxtelem-software-for-windows-mac-linux/), continued to assist us. Chris released the new test version of FoxTelem Version 1.09 with support for the FSK and BPSK modes of the CubeSatSim. See Figure 7 for a graph showing solar panel voltages, currents, and temperature under illumination and eclipse (darkness). We are greatly enjoying the real-time telemetry graphs generated by FoxTelem! We will discuss experiments and tests which can be performed with the CubeSatSim and FoxTelem in a future article.

We have also been experimenting with the AMSAT CubeSat Simulator on a turntable in front of an LED lamp as a substitute for the fuller radiant spectrum delivered by the halogen lamp. While the LED lamp does not activate the solar panels to produce sufficient current, you can see the periodic peaks on the voltage plots. This provides an alternate demo that does not involve the extremely hot 250 W halogen lamp. For many demos, we believe this will be good enough. For others, placing the CubeSatSim model in the natural sunlight does indeed generate currents.

In particular, at high noon at our latitude, even in early spring, it is possible to generate a small charging current to the battery, something we were never able to do with the old design. In mid-summer or at lower latitudes, it should be possible to generate a decent charging current for the battery to run the Simulator in the sunlight for very long periods!

In a future article, we will show how to use FoxTelem to analyze the Simulator telemetry and to calculate the efficiency of the electrical power subsystem. We have some initial results that suggest that our efficiencies are as good if not perhaps a little better than the old design.

Conclusion

This article has described our redesign and upgrade of the AMSAT CubeSat Simulator. We are very happy with the results. The new CubeSatSim design is available on a GitHub link from **CubeSatSim.org** including full schematics, board CAD files and Gerber files, and open source software. You can explore the site at **CubeSatSim.org**.

Have you built a CubeSatSim using this new design? If so, we'd love to hear from you. Feel free to share on Twitter with the #CubeSatSim hashtag or on the AMSAT Facebook page. Also, we'd love to hear from you via email at **ku2y@amsat.org** and **n8pk@amsat.org**.

For Beginners - Amateur Radio Satellite Primer (Part IV)

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[Portions of this article were first published as: "Working Your First Amateur Radio Satellite (Part IV)" in the August 2010 issue of Monitoring Times Magazine, *Brasstown, NC. Thank you MT!]*

Wow! It's been a busy year on the satellite bands here in North America! Many new satellite operators are putting new Maidenhead Grid Square roving contacts into our logs, with lots more "Satellite DXpeditions" planned for the summer months ahead.

However, now that spring has arrived for those of us in the Northern Hemisphere, it's probably time to begin thinking about how you can maximize your satellite ground station once the warmer weather arrives. In this installment of my satellite primer, I'll discuss some of the various types of feed lines and connectors that are particularly suited for satellite operation.

Feed Lines for Satellite Work

Most veteran satellite operators know that otherwise excellent antennas can be rendered quite useless if they are linked to your station equipment with poor quality feed line. The feed line is what connects your antenna to your radio. And, while the proverbial "wet noodle" feed line might work well for local VHF/ UHF repeater or scanner activity, again, because satellite work is weak signal work, many types of feed lines used in the former activity are not at all suited for the latter.

The principal concern with feedlines is loss, and every feedline has it to some degree. That is, if you insert 50 W into a feedline at your station, you'll have less than 50 W once your signal gets to your antenna. The rest of the power is lost somewhere in the feedline, usually in the form of heat.

Unfortunately, these characteristics are also at work when you receive signals as well. And because the signal from one of our satellites is already weak when it strikes your antenna, it follows that you can ill afford to waste any of that precious downlink RF heating up your feedline! What's more, those losses usually increase as the line length and

operating frequencies being transmitted or received increase.

So, most of us working the birds these days are using some form of coaxial cable (or simply "coax") for feedline. There are about as many varieties of coax cables as companies manufacturing them. However, most of us use some form of low-loss coaxial cable such as Belden 9913 or Times LMR 400 as opposed to lengths of RG-58, RG-8X. RG-213 or RG-8 that are used in most other amateur radio work.

Veteran satellite operators use low loss coax cable in their Earth stations because, as the name implies, this coax exhibits much lower losses (particularly at VHF and UHF frequencies) than those used for other (primarily HF) amateur activities. For many years, I've used a variety of Belden 9913 coax for my various satellite stations. It exhibits a relatively low loss (on the order of about 2.6 dB at 400 MHz) per 100 feet, which is roughly half that of a similar length of RG-8 coax (about 4.1 dB).

The magic number to always keep in mind when comparing feed lines is 3 dB. That's because, for every 3 dB of loss, roughly half of your signal is being wasted in the feed line. So, in the example above, at frequencies close to one of our popular satellite uplink or downlink frequencies (400 MHz), using a 100-foot length of RG-8 means that well over half of your uplink power (or downlink signal) will be lost in the coax. Ouch!

Unfortunately, for all of its low-loss attributes, Belden 9913 also has a dark side. Because the dielectric in this coax is largely made up of air, it tends to attract moisture. And even though you can try your best to completely seal connection points from the elements, over time the normal heating and cooling of the atmosphere will result in moist air working its way inside the cable and eventually condensing there. The fancy name for this effect is called diurnal pumping. For this reason, veteran satellite operators sometimes (derisively) refer to 9913 and its variants as "garden hose".

Fortunately, a newer brand of cable on the market, called Times LMR 400, offers about the same loss characteristics as Belden 9913 at about the same price, but without the "garden hose" issue. An excellent source for information about the various types of transmission lines (including their loss characteristics) can be found at **www.rfcafe.com/references/electrical/coax-chart.htm**.

Preamps

As I've noted, the downlink signal from these satellites is already weak when it strikes your antenna. So, another "nice to have" (but not necessary) addition to your base station setup is a receive preamplifier to boost the satellite's downlink signal. These preamplifiers (or "preamps" as we call them) come in many shapes and forms. Some are integrated into the radio itself (or into external, so-called "brick" amplifiers") while others are designed to be mast-mounted nearer to your antenna.

Over the years, I've found the mast-mounted variety work best because they boost the satellite's weak downlink signal where it is strongest, that is, before any of that weak satellite downlink signal is lost in the feed line to your station. However, unless the preamp is specifically equipped with internal switching relays, it is VERY important to remember that transmitting a signal back through one of them will often prove fatal to the device. I've "smoked" more than one of these in my time this way!

A Word About Connectors

While I have already discussed the importance of using a high quality, low-loss feed line to and from your satellite antenna (and keeping that feed line length as short as practicable) it is also important to use the very best connectors you can afford. Just as with choosing your feed line, if you try to skimp on the connectors for the feed line connecting your antenna to your radio, you could lose a significant portion of your signal through those connectors as well.

Remember, every dB of attenuation that weak satellite signals encounter while traveling from your antenna to your radio is a bit of the downlink you won't hear. A 3-6 dB loss from using cheap, HF-only rated coax and poor quality connectors can turn a marginal VHF or UHF downlink signal into one that simply isn't there.

Connectors add to line losses by creating impedance "bumps" that act like little resistors in the line. At HF (and to some extent at 6 m and 2 m) you can usually get by with using the common SO-239/PL-259 connector combination. However, at higher frequencies (such as at 70 cm and above where many of our amateur radio satellites operate) most satellite-capable equipment now comes equipped with a Type-N connector. The type-N connector, when properly installed, will help minimize these small mismatches in the feed line which, in turn, will allow a greater portion of that (already weak) satellite downlink signal to make its way to your operating position from your satellite antenna.

As I've also noted, it is also critically important to make sure that these connectors are well seated — and well sealed! — when installed at your antenna. Otherwise, your coax will very quickly become waterlogged and then you'll really have line losses to contend with! One popular method I've successfully used over the years is to wrap electrical tape tightly around the connectors and/or feed line where they join, or use one of the many available hand-moldable compounds sold just for this purpose.

Finally, A Type-N Connector For The Masses!

PL-259 connectors are usually easy to assemble and solder. However, if you are like me, working with so-called "regular" N connectors has always been a problem. The typical Type-N connector consists of up to 6 components, all of which must be carefully seated and soldered to seal out moisture properly. However, no matter how carefully I assembled and installed feed lines using these traditional Type-N connectors, I often found that (particularly in outdoor applications) the slightest pull on the coax usually resulted in a detached (or shorted!) N connector.

Thankfully, innovation has now come to the rescue! The two-piece N connector shown in the accompanying photo is a silver-plated,

Mast-mounted preamps, such as this one from SSB electronics, boost weak satellite downlink signals at the antenna feed point

gold-tipped connector of excellent quality that solders and assembles much like a PL-259. Yet, this version maintains most of the "bumpless" impedance and weatherized qualities of the classic Type-N. Even the same UG175 and UG176 reducers for PL-259s can also be used for smaller cable types. Those of us who are "all thumbs" (like me!) when it comes to working with coax connectors need never again struggle with a Type-N!

A good source for this modern, PL-259-like version of the classic Type-N connector is Part Number "#1273" from Universal Radio in Reynoldsburg, Ohio or Part Number "OPEK AT7302STG" from R&L Electronics in Hamilton, Ohio.

Looking Ahead

Back in the "Dark Ages" (when I was the President of AMSAT in the late 1990s) I often remarked that the majority of our supporting members back then (and perhaps still today) have never actually communicated through one of our satellites! So, if you are one of those folks who have, as they say, "Always wanted to do that but never got around to it", this series of satellite primers are all designed to help you (finally?) get up and running on one (or more) of the amateur radio satellites we now have in orbit.

So, with that thought in mind, in future columns, I'll be exploring some of the features of our current fleet of satellites in orbit plus some currently on the drawing boards or now being prepared for launch. I'll also be sharing some information on how our amateur radio satellites (along with the AMSAT organization and its predecessors) came to be. See you then.

This two-piece Type- N connector assembles like a PL-259 but still exhibits all the RF characteristics of the original N connector design. (Courtesy: Author)

PSAT 1U — A Low-Cost, Easy-Build 1U CubeSat for Hands-On Lab and Space Applications

George Downey, University of Maryland
Bob Bruninga, WB4APR, U.S. Naval Academy

Abstract

The majority of US Naval Academy student amateur satellite projects evolved with a primary communications payload based on AX.25 packet radio. The original 10" cube satellite PCSAT (NO44), launched in 2001 (still semi-operational), used discrete components, chips and hardware TNC's (Terminal Node Controllers). Through eight other missions, the design was condensed down to fit the entire AX.25 comms payload on just half of a single 3.5" square CubeSat card and flew on the successful PSAT (2015) and PSAT2 1.5U CubeSat in June 2019. This paper summarizes the final condensation of this basic comms architecture down from 1.5U to a single 1U CubeSat frame while retaining plenty of mission power for communications users worldwide and to support at least 1/3U of additional payload volume. The PSAT1U design is so low cost that it is possible for undergraduate students to not only build them for flight, but also to build them as engineering models for use in hands-on lab demonstrations and attitude control experiments. Two such attitude control tests that can be done in the lab are also described.

Structure

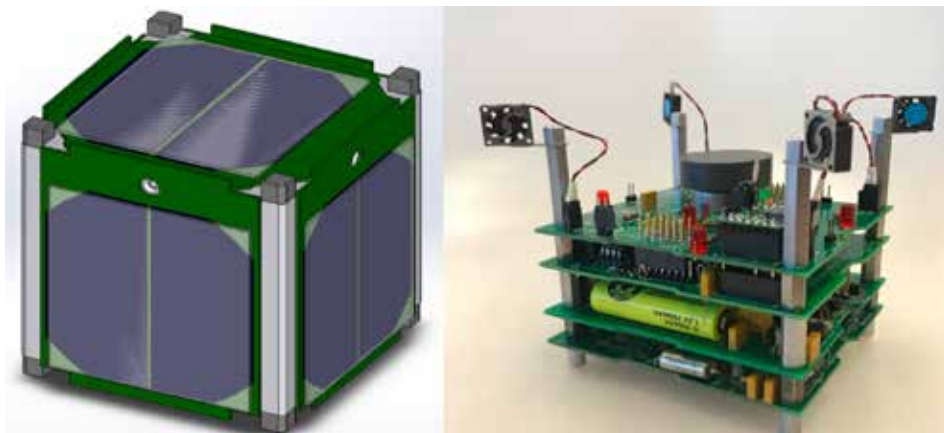PSAT1U's satellite flight and lab units are

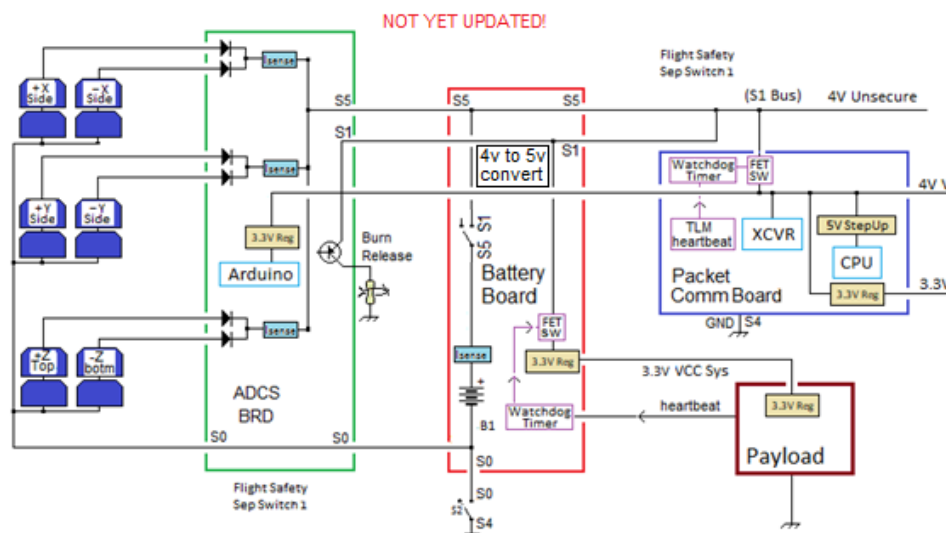Figure 1 — Flight Unit (Left) and Lab Unit (Right).

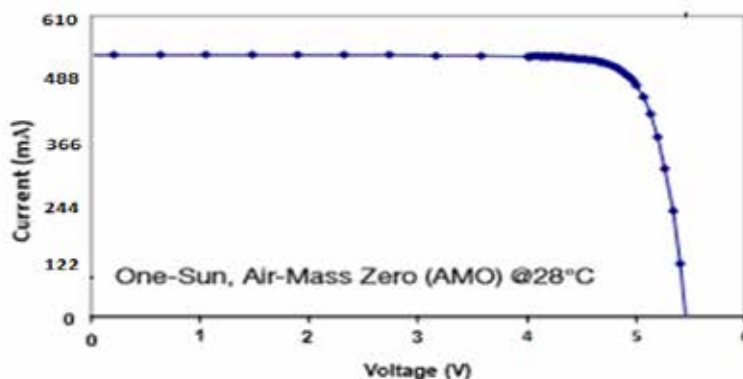Figure 2 — PSAT1U Electrical Power Distribution design diagram.

Figure 3 — I-V Curve for Two ZTJ Cell Side Panel.

shown in Figure 1. The satellite was designed for a maximum mass of 1500 g within the 1U frame, and the ability to host additional payloads within about 1.5" in the board stack. The Electrical Power System (EPS) and physical layout of the satellite were designed to be flexible and provide power for the comms mission and additional payloads.

Electrical Power System (EPS)

Since the size of PSAT1U is reduced by 33% compared to previous 1.5U satellites, the biggest impact is in the solar panel collection area. In this case, only two ZTJ solar cells fit per side, instead of the three cells used in past designs.

Solar Cells

For flight, PSAT1U uses factory second ZTJ solar cells, rather than the very expensive UTJ solar cells, offer similar performance at one-tenth of the cost. The ZTJ cells do not include cover glass because of the low cost. Inexpensive thicker microscope cover glass is used as it is 1% of the cost and any added mass increase is insignificant.

ZTJ Solar Cell power output. The ZTJ cells output a maximum current of 503 mA, at a max power voltage (V¬mp) of 2.41V, giving a power output of 1.21 Watts per cell. In Figure 3, the IV curve has been redrawn
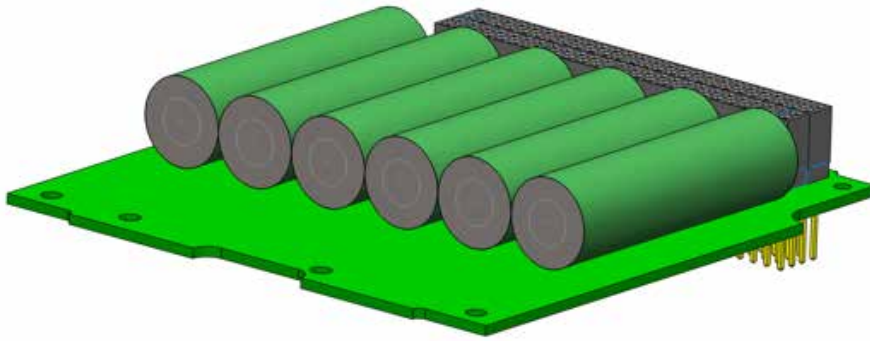
Figure 4 — PSAT1U Battery Board Design.

to show the actual values for a two-cell side panel, summing to only 4.8 volts compared to the 7 volts on 1.5U CubeSats, offering a peak solar power of 2.42 W.

Whole orbit power. For a cube satellite, the average total illumination of all six faces, all twelve edges, and all eight corner geometries works out to about 1.4 times the power of a single side. This gives about 3.5 W total average sun power while in the Sun. Reducing that by worst-case eclipse times for a typical LEO orbit and battery storage inefficiencies results in a whole orbit average power of about 1.5 Watts average mission power. This does not include additional solar power due to Earth solar albedo, which is kept as a design margin.

Battery Board

Chemistry. NiCd batteries have over 50 years of space heritage and survivability and offer excellent lifetime survivability. While lithium cells offer higher energy density, they are much less forgiving of abuse and require complex battery management systems on each cell to prevent hazards and failures. Single errors in charging or discharging can destroy the cell permanently. Alternatively, NiCd cells can survive occasional overcharge and complete discharge with negligible damage, making them an ideal low-risk solution for student projects.

Since all past USNA CubeSats have used additional mass ballast to maximize orbit life, there is no need to reduce battery mass in PSAT1U, making NiCd cells a better choice for this application.

To meet peak power demands and provide power in eclipse, PSAT1U's batteries need a capacity of 3.5 W for a 30-minute eclipse, or about 1.7 W-hrs. Commercial CubeSat lithium batteries cost $1900 and require additional components that add complexity. A ready-made 10 W-h lithium CubeSat EPS board costs $5600. Using NiCd cells, 5.6 W-hrs can be achieved using six 1400 mAh cells at 4 volts and only cost about $100.

While the use of NiCd cells compared to lithium is an increase in volume by three times and an increase in mass by nearly four times, the benefit is a 95% reduction in cost while still meeting the power budget and mass limitations. The NiCd cells are 1.898" x 0.543". PSAT1U's battery board design is shown in Figure 4.

Boost Regulator. Two ZTJ solar cells, summing to a 4.8 V maximum power point, are an excellent charge source for the NiCd battery, but need a DC/DC converter to boost the unregulated 3.6 V to 4.2 V battery voltage to a regulated 5 volts. The board uses three pairs of parallel 700 mA-h 1.2 V AA NiCd cells connected in series to achieve the 3.6 V to 4.2 V battery bus voltage.

The 5 V boost inverter, the Pololu U3V12F5, is shown in Figure 5 with its efficiency and a 3.3 V input. When powering only the SATT4 CPU at about 30 mA, the efficiency is around 85%, which then would effectively be drawing 37.5 mA.
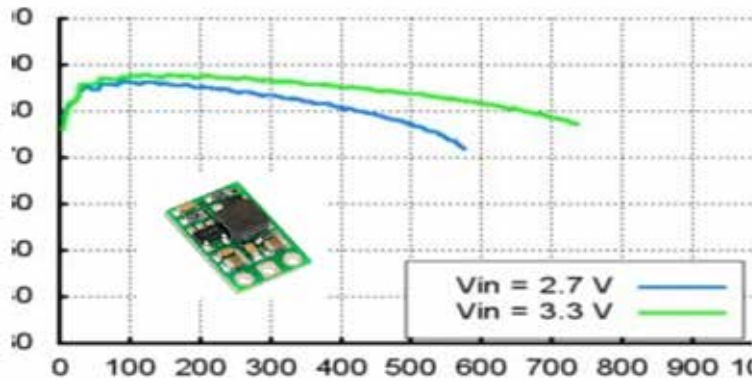
Attitude Dynamics and Control Systems (ADCS) Board

Centralized connection board. Because the ADCS depends on sun vector inputs from all solar panels and the ADCS CPU is also used to read solar panel current from each panel, and house the connections to all the torque panels, the ADCS board serves as the central connection point for the solar side panel connectors which contain all these signals and power. This makes it the top board in the stack so that the connections to all the side panels can be made last during assembly.

Diodes and current sensors. When summing current from multiple solar panels, each panel needs an isolation diode. The diode voltage drop for the 1N5819 Shottky diode is given by the specification sheet as 0.5-0.7 V at 500 mA.

In-house experimental testing of the 1N5819 Diode showed performance that was dropping only 0.4 V at 500 mA. Another 0.16 volts can be obtained if 1N5817 diodes are used.

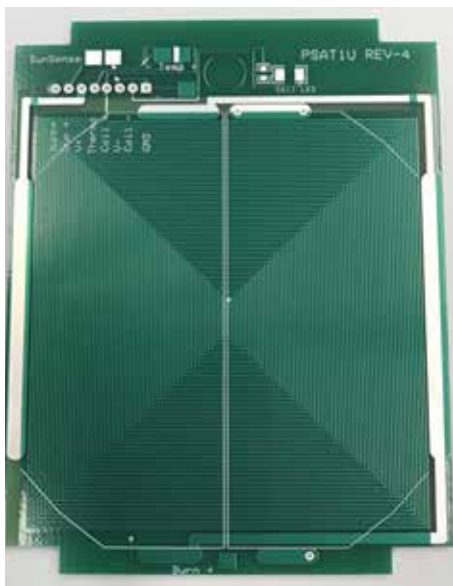One current sensor for each axis on the ADCS board measures the solar cell current

Figure 5 — Pololu 3 V to 5 V DC/DC Regulator Efficiency.

Figure 6 — PSAT1U Battery Board.

Figure 7 — PSAT1U Side Panel (No Solar Cells).

for lifetime performance tracking as the cells age. To save A/D telemetry demands, only three current sensors are needed, one for each axis of opposite facing solar panels which are connected in parallel. The ambiguity between whether the positive or negative axis panel is providing power is resolved by looking at the polarity of the sun vector from the sun sensors in that axis.

Arduino Pro Mini microcontroller. The Arduino programming environment is used for all ADCS and Communication and Data Handling (C&DH) functions. The Arduino Pro Mini can hold up to 30 KB programs, which is more than adequate since the initial test program for telemetry is only 4.5 KB.

Torque coil side panels. Figure 7 shows the side panel for PSAT-1U and highlight the embedded torque coils. The coils are present on both sides of the panel, and each face of the satellite is populated with a panel.

The torque provided by the coil is generated by the equation:

$$T = nIABsin(\theta).$$

The total area is found simply by summing the area of each turn in the coil, which results in an average area per coil turn of about 34% of the outer turn (58 Ohcm2). This ratio is useful in the torque equations because the average area can be found for any size coil, just by multiplying the area of the largest turn by 34%.

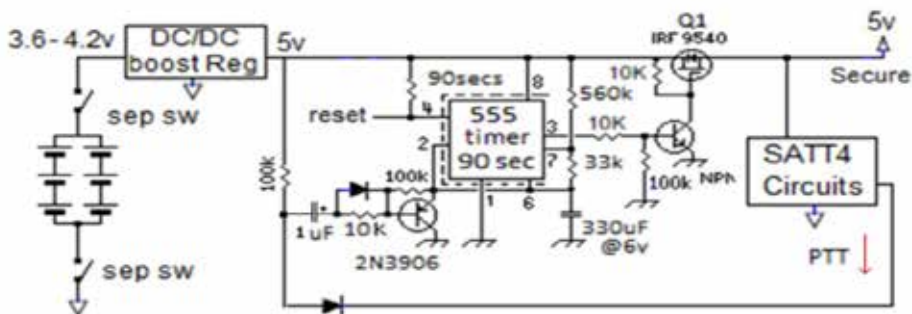For max torque, the angle is at a maximum of 90°. The Arduino can supply a maximum

of 40 mA to the coil. The Earth's magnetic field is assumed to be 3.09x10-5 T. Therefore, using equation 1, each torque coil can provide a maximum torque of 1.43x10-7 Nm. With four on each axis (front and back of both panels), the maximum torque provided will be 5.74x10-7 Nm. This is comparable to the other disturbance forces on the spacecraft in space.

Watchdog timer reset circuit. Radiation-induced upsets and transients can glitch spacecraft processors. To mitigate this, PSAT1U has two secure power circuits and watchdog timers, shown in Figure 8. One is on the SATT4 communications board that will reset the comms CPU and cycle power in the event of any lockup that stops its routine as shown below. The other is on the ADCS board in the Aux Payload.

The 90-second watchdog timer resets the CPU if it fails to transmit its one-minute telemetry. The FET switch is held on by the 555 watchdog timer and NPN transistor during the timing cycle. If the timing capacitor fully charges (90 secs) then the 555 will trigger a reset which will output low and let the NPN turn off and FET switch to open. This will interrupt the 5 V bus on

Figure 8 — Watchdog Timer Schematic.

the SATT4 board for about a two-second power-cycle if ever the one-minute SATT4 telemetry does not key the transmitter PTT line. Normally, however, the PTT circuit dumps the charge on the 555 timing capacitor so that it never reaches full charge as long as PTT occurs at least once a minute. Notice also that there is a 1 uF capacitor in series with the PTT line so it is only a transition of the PTT line that keeps the capacitor discharged. If the PTT happens to latch on, then because of the 1 uF cap, the timing capacitor is not dumped and the system will reset.

This circuit has been used on most USNA PSAT style satellites in the past two decades and is still working after 18 years in space on PCSAT. But, all of those designs used 6 volt or higher voltage power supplies which were adequate to assure the FET could be fully turned on. For PSAT1U, operating at a bus voltage of only 5 volts, there is little margin when the gate of the FET needs at least 4.5 V to turn on. According to the specification sheet, the FET can provide 500 mA with about 0.3-volt drop with a gate voltage of 4.5 V and maybe 0.2 V at 5 V on the gate.

Testing. To assume good turn on, each FET

Load	Voltage	Ipk	Duty Cycle	Normal (mA)	Stdby (mA)	ALL ON (mA)
SATT4 RX (StdBy)	5	60	90%	54	54	OFF
SATT4 RX	3.3	120	10%	12	OFF	120
SATT4 TX Tlm	4	750	2%	15	15	750
SATT4 TX users	4	750	4%	30	OFF	OFF
Arduino CPU On	3.3	5	10%	1	OFF	5
Arduino CPU sleep	3.3	2	90%	2	2	OFF
Payload Stdby	3.3	.	.	.	.	.
Payload Off	3.3	.	.	.	.	.
Totals				113	71	946

Solar Current per Panel=	503.085 mA		Avg Capacity Produced Per Orbit	599.55 mAh
Average Current from geometry=	712.55 mA		Avg Capacity Consumed Per Orbit	56.5 mAh
Current Margin (Stdby)*	432.085 mA		Capacity Margin	543.05 mAh
Current Margin (Normal)*	390.085 mA			

* Margin Calculated Assuming Single Panel Power Production (minimum)

Figure 9 — PSAT1U Power Budget.

Time (min)
Eclipse: 30
Daylight: 60

is tested to be sure that it has a low voltage drop across it when used in this circuit. No more than 0.3 V is acceptable when providing up to 800 mA to the load.

One batch of 26 FETs was tested with a 5.2 Ohm load. The average voltage drop at a 5 V supply was 0.27 V, with a standard deviation of 0.011 V. Another batch of FETs was tested with an average voltage drop of 0.363 V and was not used.

Power Budget

PSAT1U's power budget is shown in Figure 9. An orbit eclipse time of 30 minutes was assumed in the power budget calculations. The power budget accounts for three different mission modes. These include normal operations mode, standby mode, and safe mode. The budget also accounts for four different loads, the SATT4 communications board Receiver, SATT4 communications board Transmitter, the CPU, and a potential payload.

Attitude Dynamics and Control System (ADCS)

Magnetometers and sun sensors provide the attitude determination roles on PSAT1U. The ADCS board is shown below in Figure 10. Several mission modes can be programmed into the board, including free float, Bdot, constant spin, and an experimental sun-pointing mode. The experimental sun-pointing mode is not

actually required in PSAT1U because each side provides equal power and can operate well in any attitude, but it does provide academic experience.

Attitude control for flight uses magnetorquer coils. These coils are built into the solar cell side panels. Each coil has a dipole moment of 0.0046 Am2. There are four coils on each axis which provides 0.0184 total dipole moment, and at a magnetic field of 3.09×10^{-5} T, the maximum torque provided will be around 5.74×10^{-7} Nm. The torque coil design is shown previously in Figure 7 of section 3.3.4.

Communications System

Communications Board

PSAT2's communications board is a 1.5-Watt APRS transceiver operating in the 2-meter amateur radio band. Its processor supports these capabilities:

- A Digipeater function to relay user packets from uplink to downlink
- Five external analog inputs compatible with most TNC analog telemetry.
- 8 digital output bits that can be toggled under-ground control for spacecraft functions.
- A serial port for uplink and downlink between other boards and the ground
- A transistor on/off power control line (originally used as a GPS power control in terrestrial applications) that can be used for possible other satellite functions.

SATT4 Dual Bank Switching. The SATT4 can be programmed with two separate operating configurations or banks. The main use of this feature on most of our CubeSats is to enable and disable user digipeating (packet relay) and to switch the uplink receiver to a separate frequency if needed for the payload experiment. The configurations in Bank0 and Bank1 are switched on the condition of the JP1 bit. Unfortunately, this is also the 5th Telemetry channel input. See the telemetry section to see how this bit is shared between commanding and Temperature sensing.

SATT4 Communications Board. The SATT4 communications board block diagram is shown in Figure 11. The physical USNA SATT4 board is shown in Figure 12.

SATT4 Bus Voltage Considerations. The SATT4 board's watchdog timer runs on the 5V bus and powers everything on the SATT4 board as long as the watchdog timer does not time-out due to lockup of the SATT4 one-minute telemetry.

The board's transceiver will operate on the 4V Vbatt secure line to provide the maximum RF power directly to the transmitter without loading down the DC/DC boost regulator. This voltage does not need to be regulated because the RF transmitter is the highest load on the satellite and only varies output power slightly on unregulated power.

The current required has been measured to be about 30 mA at 5 V. Considering the 85% efficiency of the converter, this equates to about 40 mA on the 4 V bus.

SATT4 Inputs and Outputs. The SATT4 has five analog channel inputs for as shown
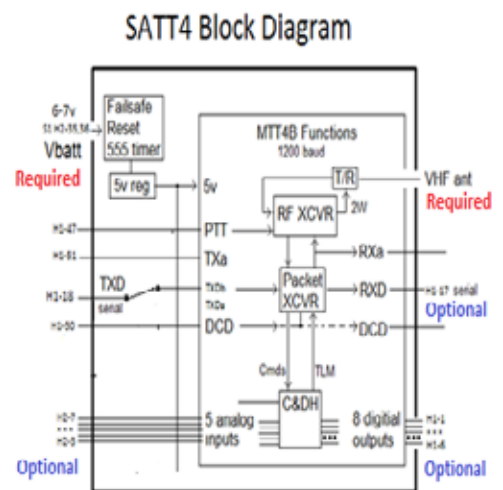

Figure 10 — ADCS Board Model.

Figure 11 — SATT4 Communications Board Block Diagram.

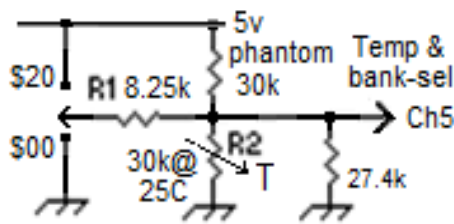**Figure 12 — USNA SATT4 Communications Board.**

Figure 13 — Thermistor Schematic.

here. These five channels are transmitted to the ground in the once a minute telemetry packet:

PSAT2>APRSAT,ARISS:T#SSS,111,222,333,444,555,10101010

The telemetry packet begins with the SSS serial number (one per minute), then the five channels, and ends with eight 1/0 bits on the end of the telemetry indicate the state of the eight discrete command bits. Two of these are used internally, but six are available for hardware command purposes. They can be commanded high or low (see Table A.)

The Vin voltage telemetry on CH1 is wired to the S1 bus connection H2-35/36 so that it can read the battery voltage directly.

Configuration Bank Select: First, notice that the logic of the Bank Select is reversed. When the bit is pulled to ground with the $00 command the bank is switched to Bank1. When it is left floating or high with the $20 command then the default Bank0 is selected. For command purposes, we want to invert this, to have the default bank be SAFE (with user digipeating off) and have it asserted with the $20 command to turn it on. To do this we bias the bit low with the

XCVR thermistor in parallel with a 27.4k resistor by default to keep it in Bank1 (active-low) which is now configured for safe mode and no digipeating. Then we strap the $20 bit to this pin via an 8.25k ohm R1 pull-up resistor so when $20 goes high it switches to Bank0 (the default) and the thermistor works as a normal R1/R2 divider. This makes the operational shift to DIGI-ON mode be $20 TRUE logic. This matches all other $XX command bits. The two states are shown in Table B.

The 27.4 k and series 8.25 k resistor are used to bias the thermistor so that it can still give temperature telemetry even when the bit is also used for Bank-select. Note, that the thermistor is in the ground leg (saves having 5 V to all thermistors) and this inverts the sense of the A/D values and high temps give low counts and low temps give high counts.

SATT4 Telemetry Formats. Payload data formats can be anything defined by the payload and sent to the SATT4 on the serial input for transmission. The telemetry packet format for the SATT4 has already been defined above. But two other fixed formatted beacon packets can be programmed into the SATT4. The BText and LText are shown in Table C.

SATT4 Serial Communication Ports for AUX payloads. The SATT4 has two serial ports for auxiliary processors, both transmitted in the same format. The receive or uplink packets appear on the RXD lines and contain all raw packets heard on the channel so that individual payload CPU's monitoring that line can listen for unique commands sent from their ground stations. The RXD data line idles high and it is pulled low at TTL levels at 9600 baud when packets are received. It can drive several TTL loads for any CPU monitoring for data. Remember, the actual data RF channel, though, is only at 1200 baud AX.25. Similarly, the TXD data line of these ports will accept 9600 baud serial ASCII formatted data from any auxiliary payload CPU and transmit it to the ground using the SATT4's existing header: [e.g., PSAT2>APRS,ARISS:] In this case, to share the line from multiple sources, the SATT4 input is TTL and is idling high.

Any CPU with data then sends the data in TTL levels via an NPN Pulldown Transistor. There is no handshaking so these CPUs should not hog the line and should keep all transmissions brief. Again, anything over about once a minute is excessive unless it is in response to immediate ground command. The CPU must format the data so that it is recognized by its intended recipient distinct

Analog Telemetry Port SATT4

1. GND
2. VCC
3. PA3 Ch 5   Tbatt (and bank SW)
4. PA4 Ch 4   Temp Z-
5. PA5 Ch 3   Temp Z+
6. PA6 Ch 2   System Load Current
7. PA7 Ch 1   7v bus Voltage
8. +5 Volts

I/O Port C bits:

1. GND
2. PC0
3. PC1
4. PC2
5. PC3
6. PC4
7. PC5 $20 bit to bank/sw PA3(JP1)
8. +7 volts VCC

Table A.

Default: Bank1 - PSAT2-1>APSAFE: Uplink on 145.980, SAFE or DTMF ops and no BTemp

$20 cnd: Bank0 - PSAT2 >APDIGI: Uplink on 145.825, digi ON, TLM Ch5 is good

Table B.

SATT4 telemetry:	PSAT2>APRSAT,ARISS:T#SSS,111,222,333,444,555,10101010
SATT4 Beacon:	PSAT2>APRSAT,ARISS:US Naval Academy, W3ADO
SATT4 Ltext:	PSAT2>APRSAT,ARISS: whatever you want goes here…

Table C.
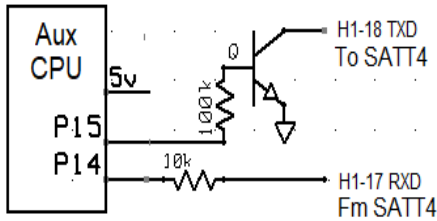
Figure 14 — Serial Port Schematic.

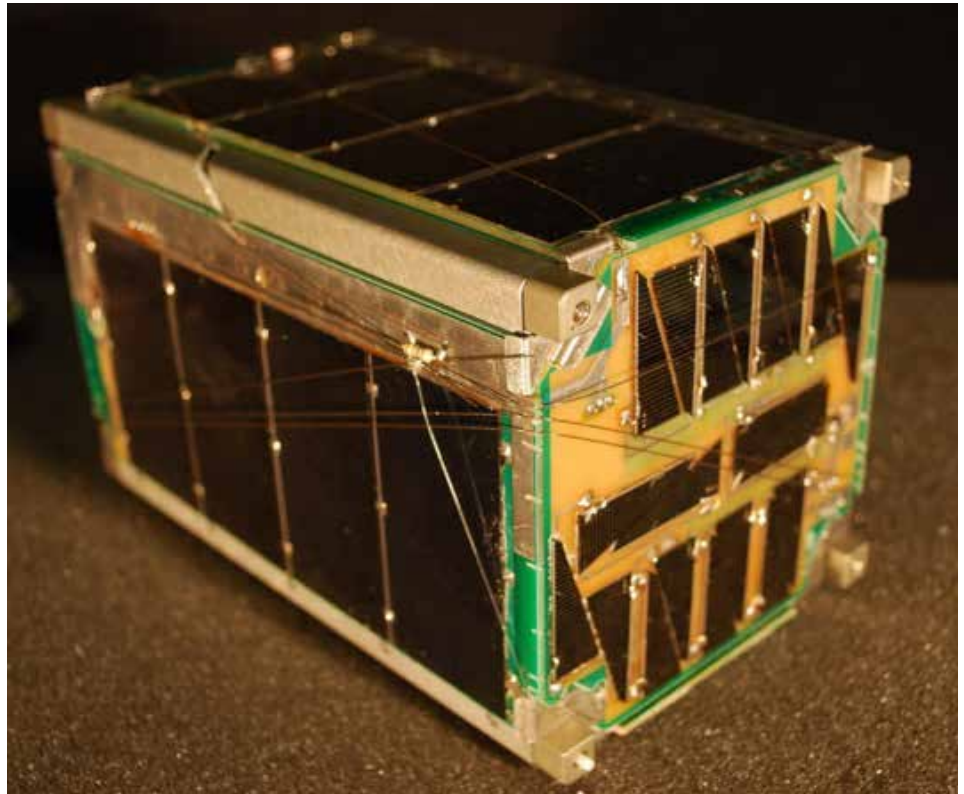Figure 16 — Burn resistor antennas on PSAT.

Figure 15 — Body Wrapping Concept for Antenna.

➤ Volume: 273.6 cm³
  ◦ Max H: 3.8 cm
  ◦ Max W: 8.0 cm
  ◦ Max D: 9.0 cm

➤ Power: 1.92W
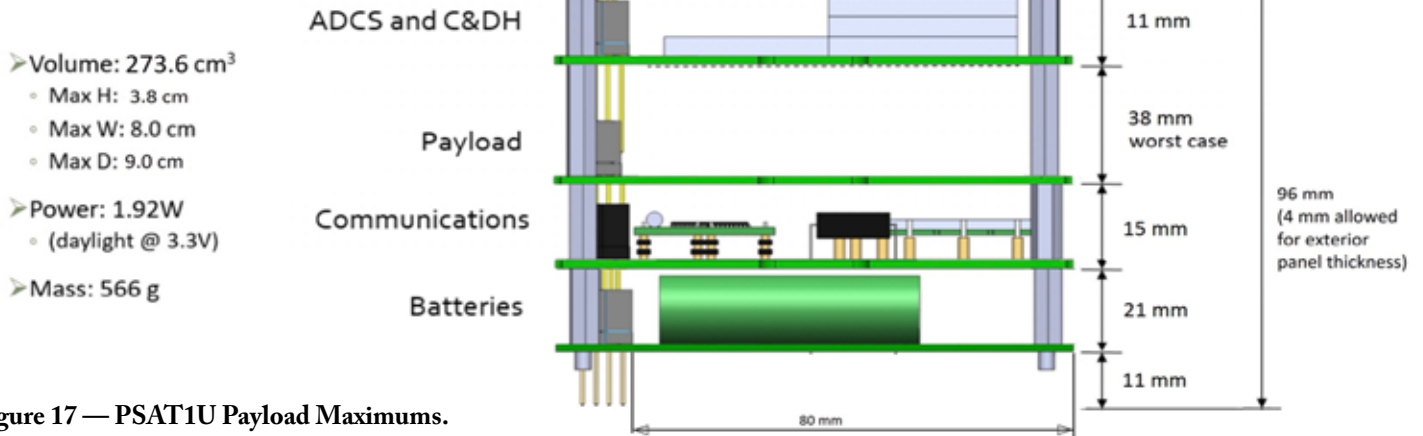 ◦ (daylight @ 3.3V)

➤ Mass: 566 g

Figure 17 — PSAT1U Payload Maximums.

from any other traffic. All ASCII text ending in a CR will be transmitted in one packet. Typical data lengths should be kept to about 72 characters or less and the format should use only PRINTABLE ASCII characters, for compatibility with the worldwide APRS ground station network. It is possible to transmit multiple short lines in one packet if the "pass" byte is used before each CR (except the last).

Antenna Design

PSAT1U uses VHF packet radio communications for both telemetry and command and control on 145.825 MHz. A VHF monopole wire antenna about 724 mm in length appears to give the lowest SWR in the EZNEC model. This is longer than a typical ¼ monopole because the CubeSat frame counterpoise is so small. Our designs typically use a pair of orthogonal whips for cross-polarization.

The multiple CubeSat antennas are wrapped around PSAT1U's body from their various drive points to all arrive at a single point where the burn resistor can be located. A nylon fishing line holds the antenna whips in place until the burn resistor burns through the nylon string, releasing the antenna. The body wrapping and burn resistor design concepts are shown in Figures 15 and 16, as incorporated on a previous USNA small satellite.

Payload

PSAT1U can host a variety of different payload experiments in the allowed volume as displayed in Figure 17.
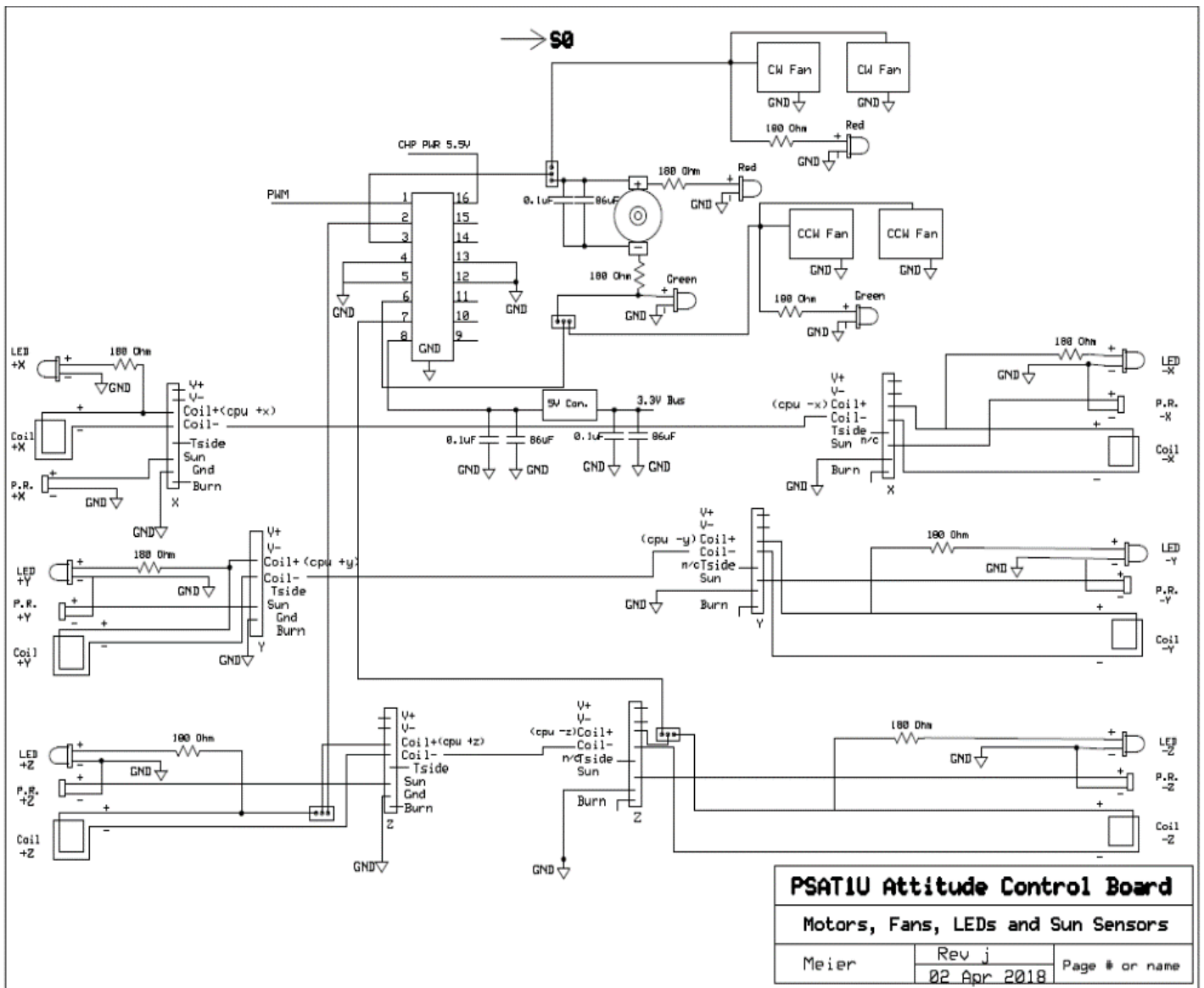
Auxiliary payloads must have a mass less

Figure 18 — PSAT1 ADCS LabSat Board Schematic.

than 560 g and a maximum volume of 240 cm3. Specifically, payloads are allowed a maximum height of 3.8 cm, a maximum width of 8.0 cm, and a maximum depth of 7.7 cm. Payloads should operate within the available on-orbit average power of 1.9 W, operating at a voltage of 5 V. The bottom height measurement can be reduced if needed by cutting the ends of the headers on the bottom board flush and finding alternate placements for separation switches. This could allow up to 9 mm of extra height for the payload, totaling to 4.7 cm and a volume of 340 cm3.

LabSat Attitude Control Board

For operations in the lab, and more importantly, to be able to demonstrate attitude control, a special Attitude Control Board (ACB) can be built. The ACB sits as the top board on the PSAT1U structure in place of the top solar panel. The ACB includes two thruster fans, a reaction wheel on one axis, and the existing magnetic torque coils, controlled by the Arduino on the ADCS board.

Design

The overall schematic for the ADCS LabSat board is included below in Figure 18. As seen in the schematic, the classroom ACB includes an "H" bridge driver chip, a reaction wheel motor, fans, LEDs, sun sensors, and photoresistors. Incorporating all of these components on a small LabSat board allows students to learn about ADCS while working with a satellite of accurate form factor for flight-ready CubeSats.

Assembled Structure
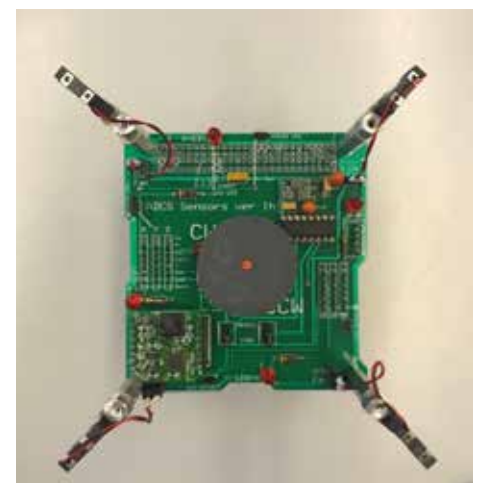
Figures 19 and 20 show the final product
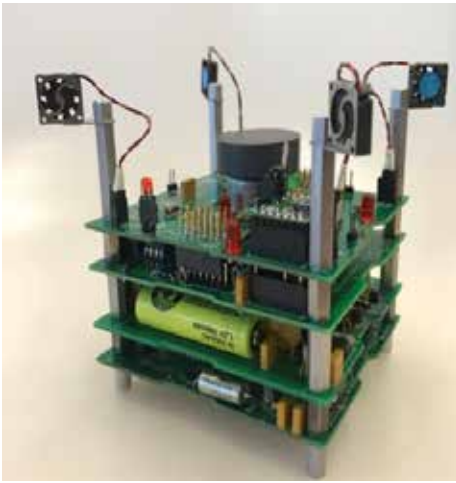

Figure 19 — Completed LABSAT Module.

Figure 20 — Completed PSAT1U with LABSAT module installed.

of PSAT1U with the LabSat payload board atop it.

Attitude Control Testing

Dynamic ADCS testing. A simple test/demo system for a model CubeSat is shown in Figure 21. First, on the shelf below the satellite, (not visible) magnets were placed in specific locations to cancel out the Earth's magnetic field as reported by the satellite. Then, a magnet was suspended by a strip of paper (visible on the right) hanging on an arm balanced on the rotating knob of a darkroom timer. The length of the arm was adjusted to simulate the Earth's magnetic field at the satellite.

To test the dynamic response of the CubeSat, the timer rotates the magnet at 1 RPM, simulating the spacecraft rotating in the opposite direction. For this demonstration, each of the torque coils on the side panel had an LED illuminated when the torque coil is energized. This made it possible to visually interpret the reaction of the satellite in its various ADCS command modes. This simple test setup 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 torque coil response.

In the same Figure 21, you can see the 6-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. The umbilical wires all have ferrite beads and chokes on them to prevent RF from getting into the control lines. As each axis has four separate torque coils, this test was important in making sure that they were all working together in
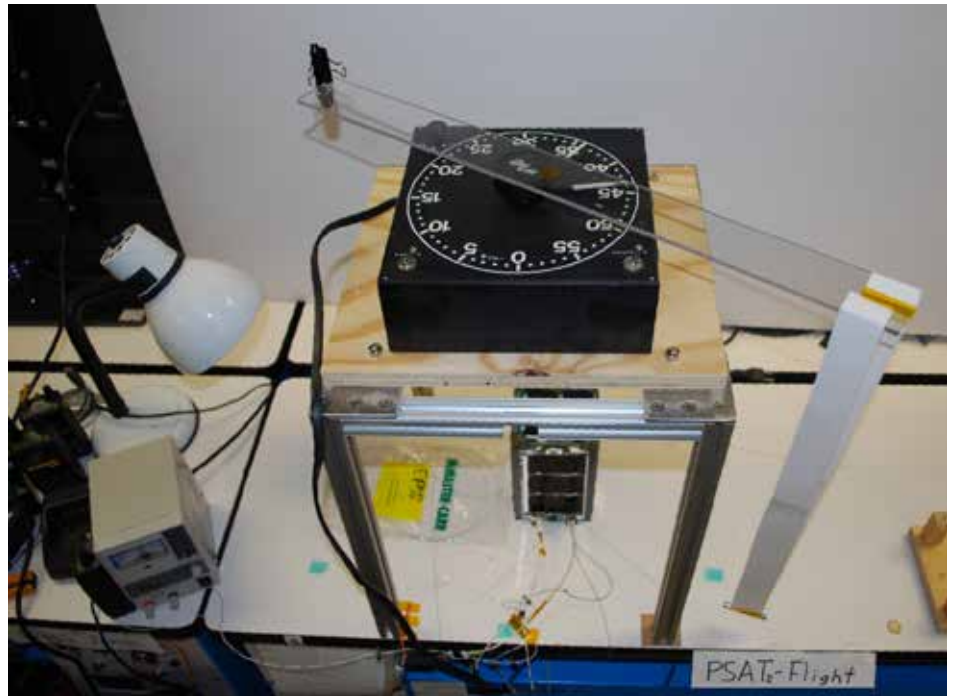

Figure 21 — Poor man's ADCS Test set. Notice the magnet on the right suspended from an arm rotating at 1 RPM by the dark-room timer motor.

the right direction. This is done by holding a compass near the coils as the magnet swung around the CubeSat and activated the various attitude control modes.

Another lab test setup that gives even better flight simulation is the Frictionless Suspension Test System.

Frictionless Suspension Test System (FSTS)

The Frictionless Suspension Test System can test satellites in an isolated rotational degree of freedom in the Z-axis. By hanging a satellite from the string connected to a stepper motor, the motor can closely mimic the position transmitted from a sensor onboard the satellite. In this way, the stepper motor can follow the satellite's position so that there is minimal external torque applied from any small errors between the suspension hook and the satellite due to the long support string. By hanging the satellite about a desired axis and "shadowing" its position with the support string, its dynamics can be tested in that rotational degree of freedom.

Any disturbance torques in the FSTS can be an order of magnitude less than any air bearings or other apparatus and are down on the order of those that might be experienced in space. Even at low speeds, air bearing systems still introduce non-negligible amounts of friction and disturbance torques due to the turbulence of

the airflow through the bearing, no matter how well it is machined. However, FSTS has the advantages of low cost and simplicity.

Description

For the communication link between the satellite under test and the FSTS suspension stepper motor controller, either the satellite's existing telemetry and ground station can be used, or an XBee transmitter and magnetometer on a sensor board can be used. The Satellite or sensor board sends azimuth data every half-second. The initial alignments must be correctly calibrated before use. Recalibration is required any time the FSTS is moved due to the Earth's varying magnetic field and the influence of surrounding structures and objects. The user should also be conscious that large current-carrying electronics and ferromagnetic objects can create near-field disturbances to the calibrated magnetic field, causing a faulty determination of azimuth by the Sensor Board.

When the FSTS Electronics Board receives the azimuth data from the Satellite or Sensor Board, it determines the error between its current position and the new position of the satellite being tested and commands the stepper motor to turn to the updated position in the correct direction.

The Liquid Crystal Display (LCD) displays the position of the satellite and the motor during testing, as well as a numerical

Figure 22 — FSTS structure.

determination of the satellite's rotation rate.

Display. Once the system is aligned in the desired direction and the start button is pressed, the LCD begins to output the satellite's azimuth, the motor's azimuth, the satellite's rotation rate, and the average rotation rate. The rotation rate is measured as: $\omega_{avg} = 0.9\omega_{avg} + 0.1\omega$.

Initialization

The user must first align the satellite pointer with the stepper motor pointer by manually adjusting the swivel joint just above the satellite hook. Then the program is started, and the user is prompted to press a button once the pointer on top of the FSTS and the satellite are aligned. Upon the press of the button, the motor's position is initialized to equal the satellite's azimuth. The long support string ensures that the error between the motor azimuth and the test satellite's

azimuth will impart negligible torque on the test satellite.

Motor control. The 12 V Airpax stepper motor can be stepped in ½ steps to achieve 3.75° precision rather than whole step 7.5° precision. This allows better precision to shadow or mirror the test satellite's azimuth.

Characterizing the friction in the system. A detailed analysis of disturbance torques on a CubeSat is covered in [4]. The total worst-case disturbance torque was estimated to be 1.1x10-6 Nm. To find the maximum allowable offset error between the support motor and the satellite, the torsional spring constant of the 53" (1.36 m) long string, measured by comparison to the half period of a cylinder of known inertia (see equation below), where:

$$I = \tfrac{1}{2}mr^2 = 0.0011123 \ kg \cdot m^2 \qquad\qquad 2.$$

Next, we wound the string up 3 turns and released it, noting the time for period as $T = 100.12 \ s$.

Then, the angular frequency for the system was found by

$$\omega_n = \tfrac{2\pi}{T} = 0.06283 \ rad/s \qquad\qquad 3.$$

Finally, the spring constant, K, was found by

$$K = I\omega_n^2 = 1.532 \times 10^{-7} \ \tfrac{N \cdot m}{dea} \qquad\qquad 4.$$
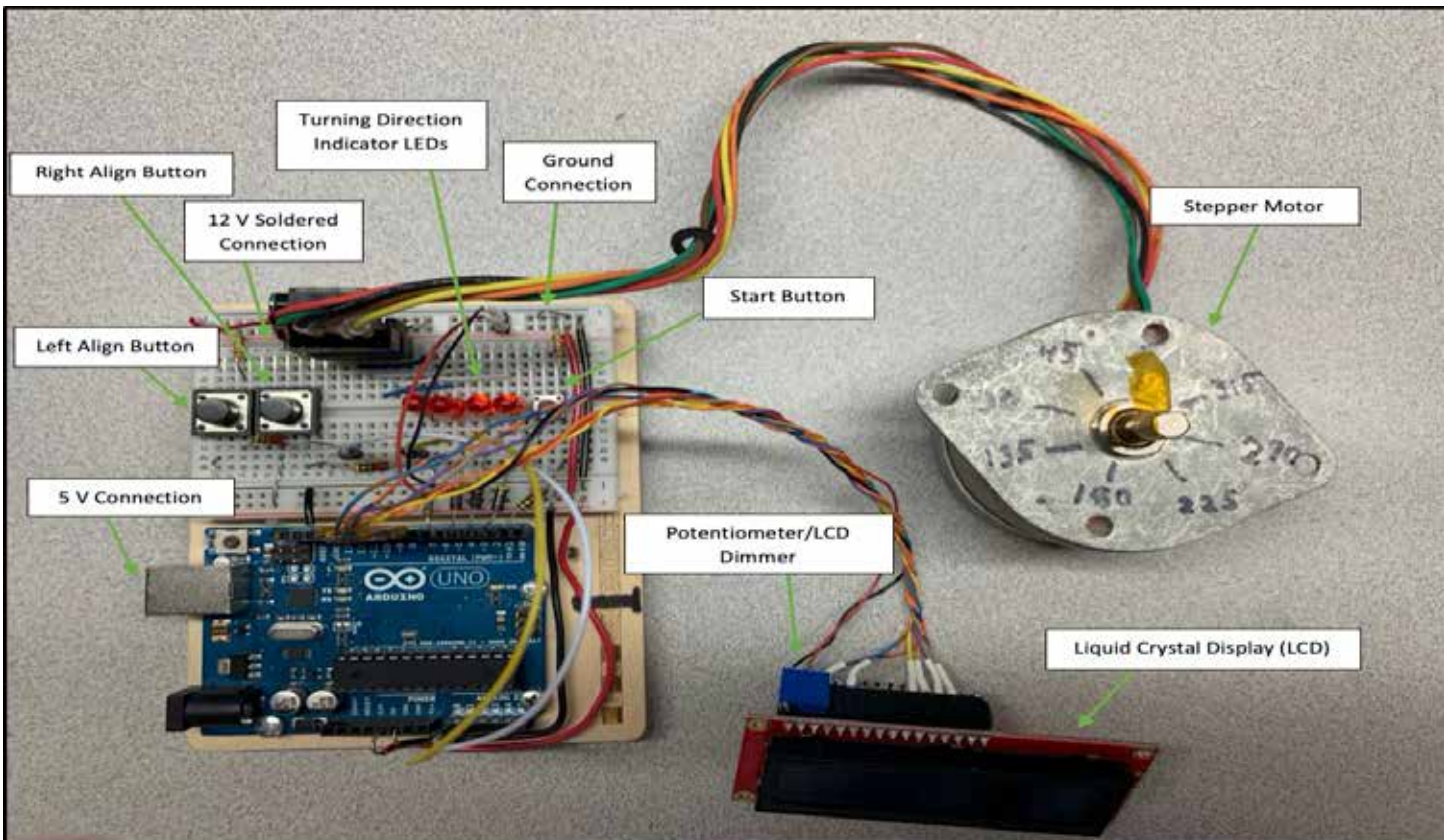

Figure 23 — FSTS Motor Electronics Board, display, and motor.
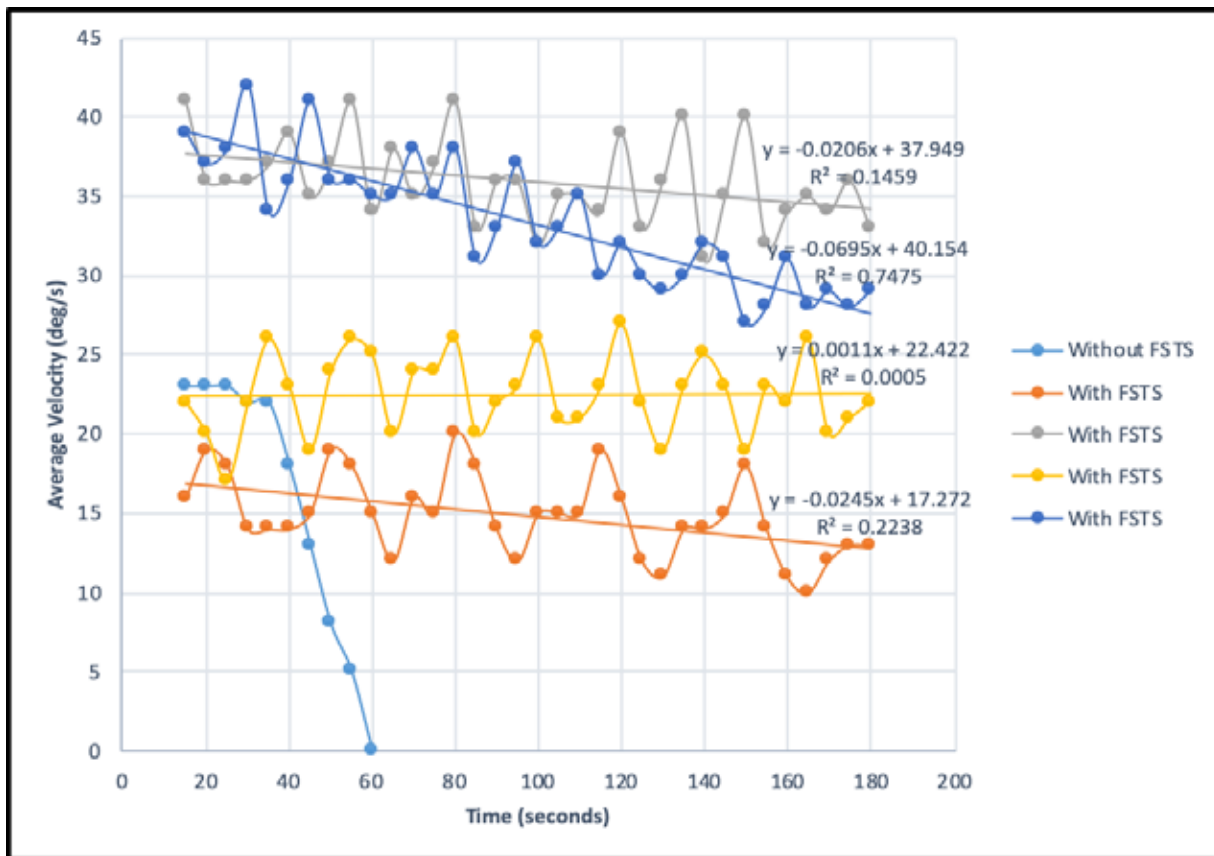
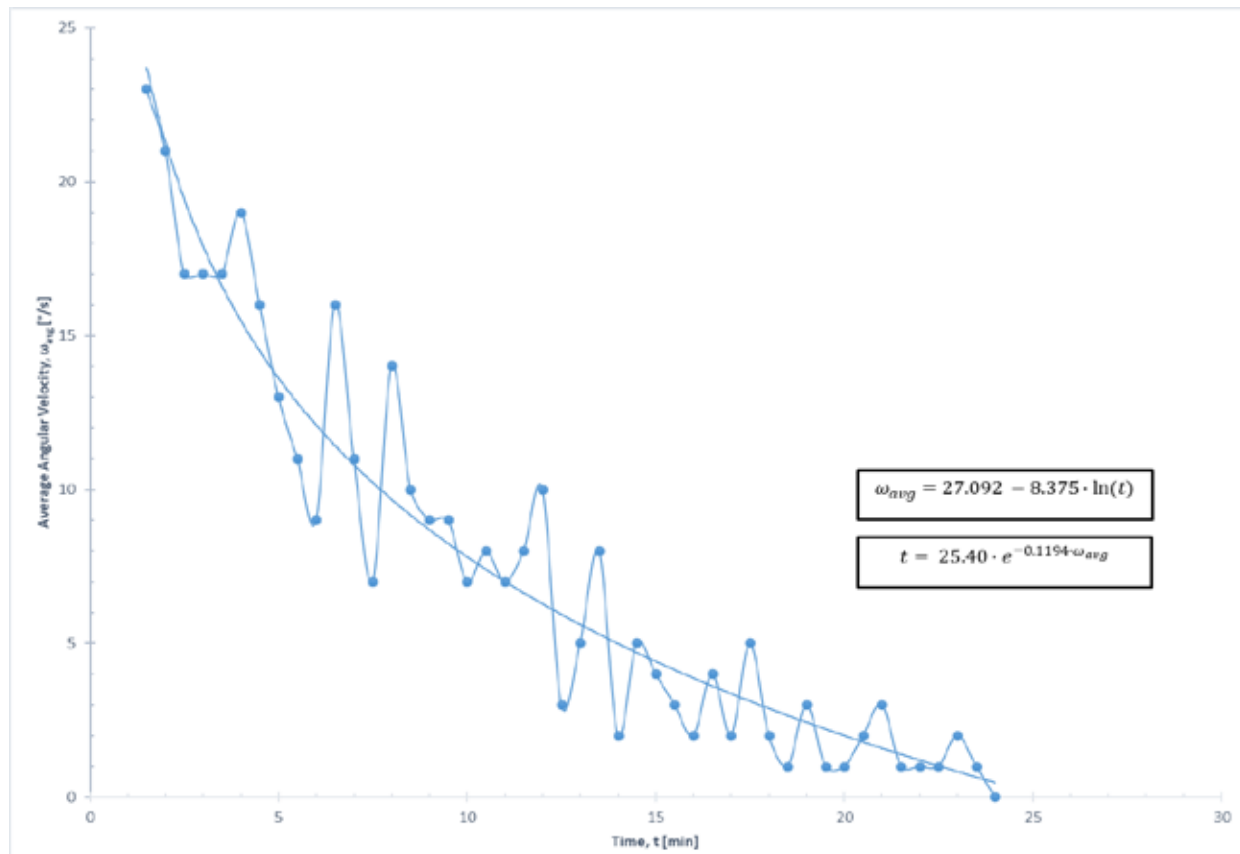**Figure 24 — Testing the effectiveness of the FSTS.**

Figure 25 — Angular deceleration during testing.

motor azimuth) and still apply less torque than the worst-case in-space disturbance torque, of 1.1x10-6 Nm. Furthermore, since the side torque coils on the Naval Academy's PSAT2 can generate between 1.3x10-6 and 3.1x10-6 Nm of torque, or up to three times the worst-case disturbance torque, then this error can be offset. Thus, the FSTS can allow near zero-gravity environment simulation.

Testing

To verify the FSTS' successful reduction of friction, a satellite with a measured MOI of 0.00616 kg m2 was used.

The first test was conducted without the FSTS system activated. The satellite was given an initial push at a rate of about 30°/s. The satellite's average rotation rate, as seen on the LCD, was recorded every five seconds until the rate slowed to zero and the board began to spin in the other direction. This test established the baseline without the FSTS. Next, tests were done at multiple initial rotation rates for three minutes. Again, the average rotation rate was recorded every five seconds. The results for all five tests can be seen in Figure 24.

As is seen in Figure 24, activation of the FSTS drastically reduces rotation decay and allows for continuous rotation. To determine how long the system could operate, a longer test was done over 25 minutes. The plot of the average angular velocity is seen below in Figure 25. The steady decay is an indication of the decelerating satellite. Next, the question was how much of the deceleration was due to FSTS friction, and how much was due to aerodynamic drag.

In this test, the pointer at the bottom of the string was allowed to settle once the satellite was hanging. Once the satellite was completely still, the starting azimuths of the motor and the Sensor Board with the metal plate were recorded. In the test, the motor started at 000°, while the Sensor Board was pointing at 285°. After recording the azimuths, the FSTS Electronics Board was commanded to spin the satellite at a constant rate of 30°/s. After about 15 minutes, when the string torque and aerodynamic torque were given ample time to reach steady-state, the data collection began. Recordings of the satellite position were taken every time the motor passed north. The average azimuth of the satellite after 123 passes was 299°. This corresponds to a 14° average drag offset. Using the string's torsional spring constant, we estimate the aerodynamic torque to be 6.15x10-5 Nm. Since this is an order of magnitude larger than any torque on the satellite expected from the error between

the motor and satellite position, then the limiting factor for friction in the FSTS is aerodynamic drag and not the error in the system itself.

Using the Sensor Board and metal plate's combined MOI, an estimate for the aerodynamic deceleration of the satellite is made as

$$t = \frac{\tau}{I} = \frac{-6.15 \times 10^{-5} \, Nm}{0.00616 \, kg \cdot m^2} = -1.0 \times 10^{-4} \frac{rad}{s^2} = -0.0572 \,°/s^2$$

Since this value is on the same order of magnitude as the linear fits in Figure 24, we know that this deceleration estimate for a satellite spinning at 30°/s is reasonable.

Since the FSTS imparts less torque on the system than the typical disturbance torque of 1.106x10-6 Nm experienced on-orbit, then it is a viable test environment. Satellite dynamics can be tested for tens of minutes, simulating a low-altitude orbital environment. Finally, since the error torque due to the lagging stepper motor is less than the aerodynamic drag torque of 6.15x10-5 Nm, then the FSTS effectively minimizes the external torque applied to the satellite

during testing. Therefore, this system is a very low-cost way to simulate an orbital environment in one rotational degree of freedom (see Table 1).

References

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O:\EA469-470\2017-2018\PSAT1U\EPS\Documentation\PSAT1U-EPS-DESIGN-a9.docx

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Cost Budget

Item	Description	Vendor	Qty	Unit Price	Extended Price
1U CubeSat Chassis	Skeleton Chassis	Pumpkin	1	$1,400	$1,400
Solar Cell	ZTJ Bare Solar Cells	SolAero Tech, Inc	12	$50	$600
Cover Glass	36/pkg	Ted Pella, Inc	1	$165	$165
ADCS Board	Magnetorquer boards	Student Built	1	$200	$200
Battery Cells	1.2V 700mAh NiCd	Digi-Key Electronic	6	$2	$13
Comms Board	SATT4	Tiny Trak	1	$400	$400
Battery Board	Battery Board	-	1	$50	$50
Antenna	Wire Monopole Antenna	-	1	$10	$10
3V DC Motor	RF-300FA-12350	FastTech	1	$4	$4
				Total:	$2,842

Table 1. Cost Budget

Gridmaster Heat Map

Paul Overn, KE0PBR

One of the questions that I have had while activating grids was: What grids should I activate? Seems like a simple question, go somewhere besides your QTH grid, and start calling people. Even though this method is great, it leaves a little to be desired. Some grids will be activated numerous times while others will be left alone.

One night Mitch (@AD0HJ), Ron (@ad0dx) and RJ (@WY7AA) were on one of our normal BS sessions, and the thought of a "Heat Map" came up and was talked about how great it would be to have a map of the 488 grids that shows which ones have been activated, and which ones haven't. After some conversation, we quickly moved on to another completely unrelated topic. But I couldn't let it go. I have done some database development so I thought I would give it a try.

So the @GridmasteHeatMap project was born. The way it works is anyone can submit their data to me, and I add it to the data from all other ops. Then I post on twitter a map that is based on the Gridmaster Excel sheet that Robert (@KE4AL) has created. The map we created shows all of the grids, and the percent of operators that have submitted data, that have that grid confirmed. The data is color-coded (red = low percentage of the ops have it, yellow around 50%, and green around 100%). See example in Figure 1.

As of today, the Heat Map is only available on twitter (follow @gridmasterheatmap), about once every 2-4 weeks we take all the data, enter it into the database and post the latest HeatMap. The first public map (25 operators submitting data) that I posted showed some interesting data points.

- The rarest grids were not the DM02 (24%) or CM79 (20%). They were interior grids like DN56 (12%), DN96 (12%) and FN45 (26%).
- The most activated grids were not in populated areas. EN26 (92%), DM14 (96%) and DM43 (96%) were the most activated.
- There were somewhat rare grids that were surrounded by common grids. DN50 (32%), EN02 (36%) and FM16 (36%).

This initial map really boosted some interest. Since then, we have had 84 operators submit data. This data has now expanded into Alaska, Hawaii, and Europe. I would also like to take the time to thank one of the most instrumental people on the project K7TAB, Chris Tabor, who created a much easier to use interface that now shows all the grids on different maps — a very helpful addition! Thanks, Chris!

There have been some unintended benefits from the Heat Map project:

- Friendly competition to get your home grid to 100%.
- Unknown "rare" grids have been activated. People are looking at the map to determine which grids to go to. In addition to operators using it to plan

an extended rove, people have realized that their neighboring grid is needed by many people, so they head out there for a few passes
- If someone is roving, we have been able to post a list of ops that need those grids and tag them on twitter. This notifies them of a needed grid being activated.
- We can create a list of who is activating what grids. You can mine that data to find some less active operators, and maybe schedule with them for a QSO.

As you can see this project has taken on a life of its own. But without the operators that have submitted data, this never would have been possible. I would like to thank each of them for all their help and ideas.

FAQ:

Where can I see the HeatMap?
You need to be on Twitter and follow @GridmasterHeatMap. There currently isn't any other efficient way to distribute the map.

How do I submit data?
The easiest way is to just send me your Gridmaster Excel sheet. If that isn't your style, you can go to ke0pbr.wordpress.com and review the article on the many ways you can send in data.

How can I participate and help?
Just send me your confirmed grids. I take the data in any way you can provide it. But I do have some preferred methods:

- Just email me your Gridmaster Excel sheet. If you don't want to send me the full sheet, you can just send me the "Confirmed In LOTW" tab.
- Don't have the Excel sheet? Log into LOTW, then just go to your VUCC page, click on "All Credits," "Select VUCC Award to View," then cut and paste the Grid Square table into an email to me.
- Don't forget to let me know your call!

When should I send you updates?
Anytime. Whenever you send me your data, I only import the new data. So you can send me your full list or just the new data.

I'm amazed at how this simple idea has taken off, and the effect it has had on the satellite community. I hope this success continues to grow! 🌐
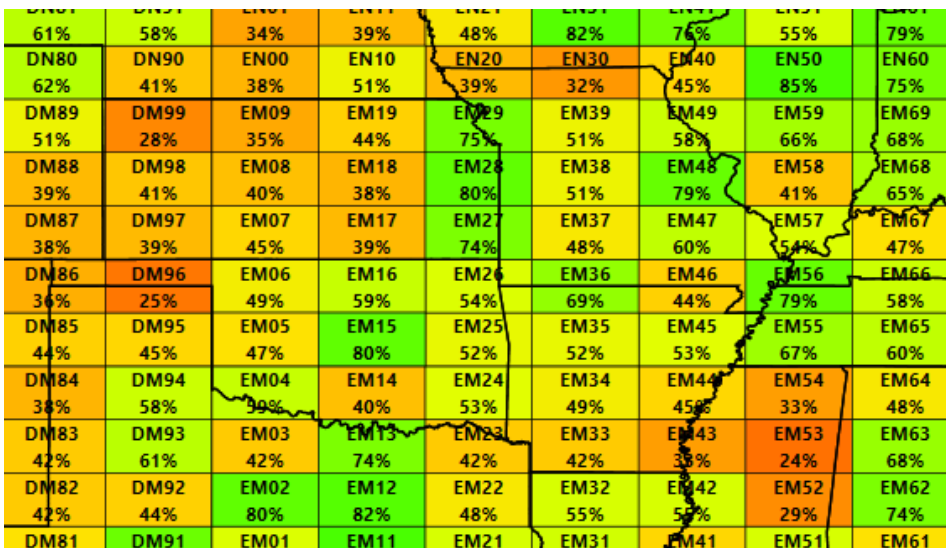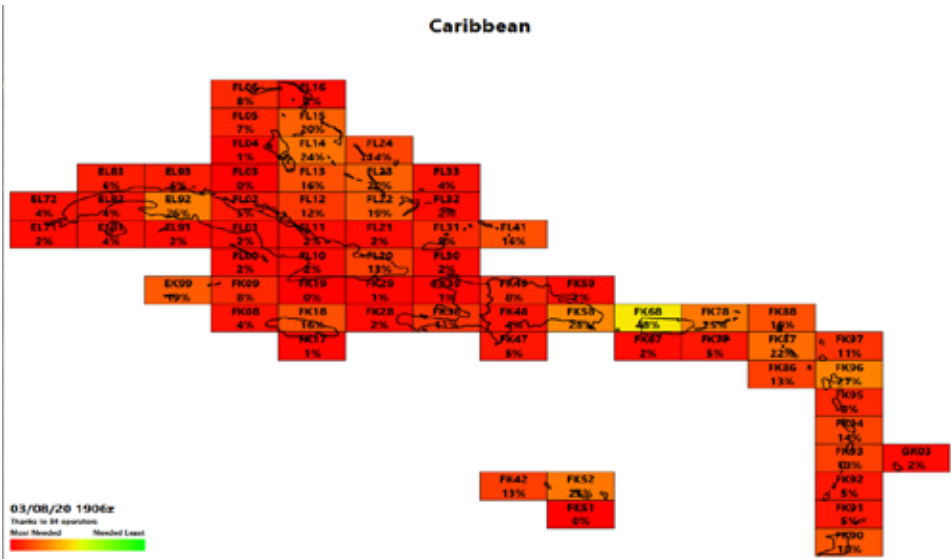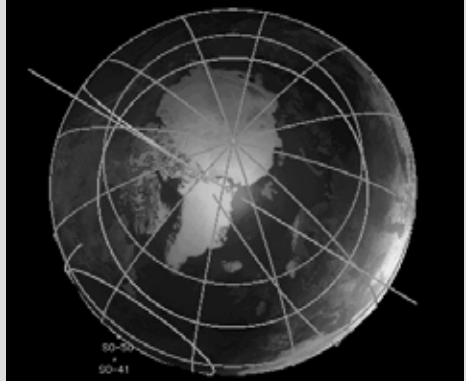

Figure 1.

Gridmaster Heat Map of U.S. (488) as of 3/20/20 (red indicates most needed).

Gridmaster Heat Map of Caribbean. as of 3/8/20 (red indicates most needed).

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

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**.

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.

Donor Level		Option	
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	

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